Spezialforschungsbereich
(SFB)

Numerical and Symbolic Scientific Computing

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Linz, June 11, 1997 ....
(Speaker of the SFB)

Linz, June 11, 1997 ....
(Rector, University of Linz)

Contents

1 Initial Situation of the SFB

The initial situation regarding personnel, funds, and equipment of the proposed *Spezialforschungsbereich (SFB)* "Numerical and Symbolic Scientific Computing" is given as follows:

Participating Personnel

The total number of participants in "Numerical and Symbolic Scientific Computing" *before* the start of the project *(Grundausstattung Personal)* is 21, including 21 scientists and 0 non-scientists. All participants are affiliated with the Johannes Kepler University Linz.

Note that Project 11 (see Section 3.3.2) is reserved for a later application by the successor to the chair for mathematics with emphasis on analysis (Institute for Mathematics). **Herewith the SFB applies for the possibility that the successor to the chair for mathematics can apply for this project immediately after accepting the call.**

Funds (1996)

The funds provided by the University of Linz to the research groups participating in the SFB in 1996 amounted to 1204 KATS *oDot* and 1062 KATS *aoDot*, resulting in a total of 1266 KATS. This corresponds to 7 % of the total budget for these two cost categories at the Faculty of Technical and Natural Sciences (TNF). This figure reflects the share of SFB participants in the total number of personnel. The equipment capacity used for the SFB amounts to about 20 %.

2 Summary of Requested Funds from the SFB Memorandum (Funds Requested from Agencies other than the FWF)

Beyond the funding provided by the TNF in 1996, the following additional funds requested by the SFB from "Stadt", "Land", and "BMWV" (see also "Special Memorandum" in Section 7):

1. Annual funds for renting the offices (ca. $300m^2$): **500.000,– ATS**.
2. Initial equipment (Erstausstattung) for the offices (without computers): **500.000,– ATS**.
3. Running costs for the offices: **500.000,– ATS**.
4. Depending on the funding level for the scientific equipment, additional funding will be necessary in order to provide the adequate technical infrastructure for SFB (cf. also Table 14).

Thus, in total, annual funds of **1.000,000,– ATS**, and additionally **500.000,– ATS** in the first year as well as additional funds for the scientific equipment are requested from "Stadt Linz", "Land Oberösterreich", and "BMWV".

3 General Information about the SFB

3.1 Survey of Participating Scientists

3.1.1 Alphabetical List

The list of participants is given in Table 1.

3.1.2 Personal Records (CVs) and Publication Lists

CVs and publication lists of all participating scientists are summarized in alphabetical order in Appendix A.

3.2 Administrative Bodies

There will be two administrative bodies, the executive board and the member council (see Section 6 "Ordnung des SFB").

The **executive board** (Vorstand) consists of 5 members, including the Speaker and the Co-Speaker. The Speaker of the SFB will be Ulrich Langer, the Co-Speaker of the SFB will be Bruno Buchberger.

The **member council** (Mitgliederversammlung) consists of all SFB members.

3.3 Research Program

3.3.1 Scientific Concept and Long-Term Goals

The long-term scientific goal of the SFB is the design, verification, implementation, and analysis of

- numerical,
- symbolic, and
- graphical

methods for solving

large-scale direct and inverse problems with constraints

and their synergetical use in scientific computing for real-life problems of high complexity. We have in mind so-called field problems (usually described by Partial Differential Equations (PDEs)) and algebraic problems (e.g. involving constraints in algebraic formulation).

The particular emphasis of this SFB is put on the *integration* of graphical, numerical, and symbolic methods on different levels:

Numerical and symbolic methods have been developed so far by two fairly disjoint research communities. The University of Linz is one of the few places with strong groups both in numerical and symbolic computing. Thus, we intend to make the joint work on numerical and symbolic methods one of the main focuses of the SFB. For the first time, this will also encompass the phase in which new mathematical results - as the basic of new numerical and symbolic algorithms - are derived: The SFB also incorporates a subproject aiming at computer-support for proving new mathematical theorems using advanced symbolic techniques. The integration of numerical and symbolic methods is also in the center of our study of the partial differential equations that form the benchmark problems in the SFB: For the first time, numerical methods will be brought together with algebraic methods (e.g. generalized Groebner bases and quantifier elimination) for handling PDEs with complex constraints. And, more traditionally, symbolic methods will be used in the preprocessing and postprocessing phases of the numerical methods.

The *interaction of numerical and symbolic methods with graphical methods* is another focus of the SFB. Of course, visualization by advanced graphics and animation is indispensable both in understanding and presenting the results of numerical and symbolic computations. However, we will put an emphasis also into the reverse direction: Refined numerical and, in particular, symbolic methods (e.g. algebraic parameterization of curves and surfaces, topology analysis by algebraic decomposition) must be developed for improving the topological correctness and reliability of graphics for advanced applications.

The methodological coherence of the SFB can be summarized as follows: In the first four subprojects, new symbolic proving and solving algorithms for various domains of mathematics (integers, real numbers, complex numbers, general domains defined by functors) are developed that can be used in connection with numerical methods for treating a benchmark class of direct and inverse problems described by partial differential equations with constraints, which is the subject of a second group of subprojects. Refined graphical tools are used for the visualization and presentation of the results, which is one of the main subjects of the graphical subprojects.

The integration of symbolic and numerical methods in the comprehensive view described above must be seen as a long-term goal. In the first period of the project, we will have to concentrate

- on the interaction of the methods where this is relatively immediate (e.g. in the preprocessing and postprocessing phase of the application of numerical methods)
- on training the co-workers of the project coming from the symbolic and the numerical side to work closely together and build up a common language and expertise,
- on preparing the methods from symbolic computation (e.g. computer-support in formal proofs, algebraic constraint solving, algebraic analysis of PDE solvability) that should later be seamlessly integrated with the numerical work.

Only in the second stage of the project it is realistic to expect that the problem solving cycle for solving the problems tackled in this project will be a smooth combination of symbolic and numerical methods and the software built in the frame of the project will fully integrate the symbolic and numerical parts.

The class of field problems considered involves applications where one or more (interacting) physical field quantities (varying in space and/or time) appear, e.g., velocities, displacements, magnetic vector potential, temperatures, concentrations, voltages. They are usually described by (a combination of) partial differential equations and/or integral-/integro-differential equations containing parameters (constants or, more frequently, functions depending e.g. on space or on the fields themselves, thus naturally leading to nonlinear problems) in three-dimensional domains with a potentially complicated geometry.

Already deriving such mathematical models from "real-world" descriptions of the systems to be modelled is at least very time-consuming and can benefit from the systematic use of symbolic methods. If the models contain quantities on different scales, asymptotic methods based on symbolic algorithms will be used to derive a simplified model which is then treated numerically (these two steps might also have to be iterated).

Even if the geometry and all parameters are completely known (which is often unrealistic to assume), the efficient numerical treatment of such models (=: the treatment of direct problems) is a very challenging task. This becomes even more complicated if there are constraints like they appear e.g. in contact problems of continuum mechanics. These constraints, in the most general case, are arbitrary predicate logic formulae involving free variables, propositional connectives and quantifiers. Much progress has been made in recent years in the simplification (quantifier-elimination) and exact solution of such constraints using symbolic algorithms. The integration of these and improved symbolic methods for constraint solving into the context of the benchmark problems will be one of the major tasks of the SFB. Similar problems also occur in multi-body dynamic problems, where the constraints are formed either by kinematic relations characterizing joints between single bodies, or by conditions modelling inter- or intra-body collisions and impacts. Simplifying such constraints (either in continuous or in discretized form) in a way that can be used to accelerate the numerical solution process would be very useful and requires (if automated) tools from and research in symbolic computation.

The complexity is further increased if one drops the assumption that all problem data are known, which leads to the treatment of various "inverse problems". E.g., one might want to determine some material parameters from (noisy) measurements of field quantities, either distributed over the domain or at the boundary only (which leads to problems related to impedance tomography). A similar situation may arise in physically non-linear problems of continuum mechanics, e.g. in elasto-viscoplasticity, where the field equations can be formulated in a linear elastic background medium subject to additional sources. These sources represent the viscoplastic parts of strain, and the inverse problem arises to determine these sources such that the deformation of the linear background medium coincides with the elasto-viscoplastic one. Such problems are nonlinear even if the underlying direct problem is linear, and, which is crucial, usually ill-posed in the sense of

1. lack of uniqueness, and/or
2. unstable dependence on the (noisy !) measurements.

Uniqueness can frequently be enforced by bringing additional information (like positivity, monotonicity, convexity) into the problem; such information can again be viewed as constraints. To deal with the instability issue, one has to employ and design "regularization methods", where we plan to concentrate on iterative regularization methods. There, even for small-scale model problems, most mathematical questions involving convergence (rates) and optimal parameter choice rules are still unsolved (in a mathematical sense, although such algorithms are used in practical situations with varying success). Computer-support in symbolically proving new mathematical results in this area and computer algebra methods (generalized Groebner bases and other classes of bases, constraint simplification and algebraic constraint solving) for studying these questions will be integrated with the numerical methods. For large-scale problems, such questions cannot be seen isolated from the solution of the various direct problems involved in the iterative solution of the inverse problems, which might again be done iteratively, thus leading to nested iterations (of a non-standard nature, since well-posed and ill-posed problems are combined there). Finally, for Newton-like iterative methods (both for solving inverse and nonlinear direct problems), derivatives of complicated operators have to be computed efficiently. Such operators to be differentiated can e.g. be

1. the operator mapping a parameter function into boundary values of the solution of a partial differential equation involving this parameter, if the inverse problem is a parameter identification from boundary measurements,
2. the operator mapping a domain onto the far-field pattern of a wave scattered by this domain, if we look at inverse obstacle scattering,
3. the operator mapping the shape of a domain onto some objective function to be minimized, which again involves the solution of the direct field problem (e.g., an expression involving a stress field), if the inverse problem involves shape optimization.

The last two problems discussed are not identical mathematically, but closely related, at least with respect to the efficiency questions outlined above, so that it makes sense to look at them from a common perspective for our purposes. An additional difficulty in shape optimization is that they typically contain constraints both on the geometry of the admissible domains and on the fields (like maximal admissible stresses).

In all these examples, an efficient calculation of such derivates of implicitly defined operators might benefit from symbolic methods or from automatic differentiation (which is currently out of the scope of the project). In some cases, it involves the computation of adjoint equations, which is again a symbolic task. New and known algebraic and symbolic methods (manipulation of formal identities by the Zeilberger approach, computer-supported proof of operator properties, symbolic derivation and simplification) should be applied in order to increase the depth and reliability of the analysis and the numerical tractability of the resulting formulae.

Thus, in all phases of treating the (direct and inverse) benchmark problems studied in this SFB (the modelling phase, the phase of deriving new mathematical knowledge for the solution of the problems, the phase of analyzing the operators involved, the phase of actually solving the partial differential equations involved, the handling of inverse problems and parameter optimization problems, and the phase of graphical representation of the results), a close interaction and merge of graphical, numerical and symbolic methods is the essential source of a new level of theoretical and practical sophistication and performance and will be the main focus of the SFB.

Finally, one long-term goal of the SFB consists in the development of a research software package for solving large-scale direct and inverse field problems with constraints on powerful workstations including multiprocessor workstations as well as on workstation clusters and parallel machines with distributed memory (e.g., under MPI). The main problems with the parallelization of such a code are connected with the parallelization of the PDE solvers, i.e. of the solver for the direct field problems. Domain decomposition methods have turned out to be the basic technique for parallelizing PDE solvers and for constructing new parallel solvers, especially preconditioners. On the other hand, domain decomposition techniques can be use for describing complex geometries, for coupling physically different fields, and for coupling different discretization techniques. The research package will provide advanced preprocessor facilities (including graphical, symbolic,and parallelization tools), algorithms for solving different direct and inverse field problems, and postprocessing tools.

3.3.2 Project Structure and Participating Institutions

The projects can be classified into four categories, namely into one management and three scientific categories.

0. Coordination and Service: Project 0

I. Symbolic Scientific Computing: Projects 1, 2, 3, 4

II. Numerical Scientific Computing and Applications: Projects 5 to 11

III. Graphical Scientific Computing: Projects 12, 13

Below we give a list of all projects, together with their titles as well as the name and affiliation of the Principle Investigator:

- *Project 0: Coordination and Service Project*
  U. Langer, Institut für Mathematik, JKU Linz

- *Project 1: Solving and Proving in General Domains*
  B. Buchberger, Institut für Symbolisches Rechnen, JKU Linz

- *Project 2: Proving and Solving Over Reals*
  H. Hong, Institut für Symbolisches Rechnen, JKU Linz

- *Project 3: Symbolic-Numerical Computation on Algebraic Curves and Surfaces*
  F. Winkler, Institut für Symbolisches Rechnen, JKU Linz

- *Project 4: Symbolic Summation and Combinatorial Identities*
  P. Paule, Institut für Symbolisches Rechnen, JKU Linz

- *Project 5: Coupled Field Problems: Advanced Numerical Methods and Applications to Nonlinear Magnetomechanical Systems*
  U. Langer, Institut für Mathematik, JKU Linz

- *Project 6: Navier-Stokes Solver*
  W. Zulehner, Institut für Mathematik, JKU Linz

- *Project 7: Large Scale Inverse Problems*
  H. Engl, Institut für Industriemathematik, JKU Linz
- *Project 8: Hierarchical Methods for Simulation and Optimal Design with Applications to Magnetic Field Problems*
  U. Langer, Institut für Mathematik, JKU Linz
- *Project 9: Estimation of Discontinuous Parameters in Differential Equations*
  O. Scherzer, Institut für Industriemathematik, JKU Linz
- *Project 10: Structural Dynamics of Elasto-Plastic Multi-Body Systems: Integrated Symbolic and Numerical Computations*
  H. Irschik, Institut für Mechanik und Maschinenlehre, JKU Linz
- *Project 11: This project is reserved for a later application by the successor to the chair for mathematics with emphasis on analysis. Herewith the SFB applies for the possibility that the successor to the chair for mathematics can apply for this project immediately after accepting the call.*
  N.N., Institut für Mathematik, JKU Linz

  Hier ist vorgesehen, daß der zu berufende Professor für Mathematik (Schwerpunkt: Analysis) ein Projekt zur Analysis und numerischen Analysis nichtlinearer partieller Differentialgleichungen einbringt ! **Der SFB beantragt hiermit, den neu zu berufenden Professor für Mathematik die Möglichkeit zu geben, sofort nach Annahme des Rufes ein Projekt im Rahmen des SFB nachzureichen**.
- *Project 12: Sophisticated Data Distribution Systems*
  J. Volkert, Institut für Systemprogrammierung, JKU Linz
- *Project 13: High Performance Visualization for High-Dimensional Data*
  J. Volkert, Institut für Systemprogrammierung, JKU Linz

3.3.3 Cooperation and Overlap of the Participating Groups

Naturally, there is strong cooperation and overlap of the projects within one category. Let us first describe the aspects of this cooperation:

Symbolic Scientific Computing:

Projects 1-4, in addition to providing advanced symbolic tools for the other projects, have an intensive inner coherence: These projects investigate and are based on the interplay between "solving" and "proving" in four different ranges. Project 1 considers solving and proving in general domains defined by functors, Projects 2 and 3 consider solving and proving over the real and the complex numbers, respectively, and Project 4 can be viewed as studying, solving and proving over the natural numbers.

Numerical Scientific Computing and Applications:

Project 7 deals with large scale inverse and optimal design problems, the main emphasis being laid upon the efficient coupling between regularization methods for dealing with inverse problems and direct solvers, especially multilevel methods. Similarly, Project 8 is devoted to the hierarchical coupling of simulation and optimal design of electromagnetical devices. In Project 9, the specific inverse problem of identifying discontinuous parameters in partial differential equations is to be studied; also here, an efficient coupling of regularization and direct solvers, especially domain decomposition methods, is crucial. Thus, in addition to very close cooperation between the Projects 7, 8 and 9 dealing with inverse problems on two different levels of abstraction, intensive cooperation between these projects on the one hand and those where efficient direct solvers are to be studied (especially Projects 5 and 6) is crucial for success. On the other hand, parameter identification can also be thought of as a preprocessing step for solving direct field problems, so that Projects 7 and 9 should later also be able to provide input for Projects 5, 8, and 10. Project 10 deals with the development of efficient computer aided methods for the simulation of elasto-plastic multi-body dynamic problems. In both, the low and the high frequency domain of vibrations of such structures, efficient direct solution procedures are required together with the solution of inverse problems. The latter occur by formulating non-linear effects as sources of deformation in linear elastic background bodies, a formulation reflecting the dislocation type nature of inelastic deformation. Seeking for the distribution of this distributed dislocations leads to inverse problems to be solved properly . Direct methods developed in Project 5 as well as methods for large scale inverse problems provided in Project 7 should therefore be crucial for Project 10, and an intensive co-operation should take place between these projects. The hard core of the planed research software package consists of the solver routines for direct and inverse field problems with constraints and the parallelization of solvers for the direct field problems. All projects of the project category II will contribute to this code. Beside the basic algorithms for solving direct and inverse field problems, there will be also specific contributions arizing from the specific applications. In particular, this concerns the contribution to the preprocessor.

Graphical Scientific Computing:

Project 12 and 13 share several issues, both from the conceptual and the technical point of view. Concerning the conceptual side, both environments will exhibit a uniform look-and-feel in order to let users think of a single environment. On the one hand this affects basic graphical user interface elements, where we will use one of the existing user interface standards. On the other hand both environments must provide additional elements for the purpose of multi-dimensional data and data structure visualization. Such elements are more specialized, and their design will have to be flexible in order to match the related requirements of both environments. Concerning the technical side, Project 12 and 13 will share a common high-performance facility for data exchange with parallel applications. Although the data exchanged with both environments differ with respect to their semantics, they will be transmitted via a common, preferably client-server-based, infrastructure.

Cooperation and Overlap of the Project Categories:

As emphasized in Section 3.1.1, the long-term goal consists in the synergetical use of graphical, numerical, and symbolic methods for solving large-scale direct and inverse problems with constraints including pilot applications to real-life benchmark problems of high complexity. The groups cooperating in this SFB establish a potential in graphical, numerical and symbolic computation that is unique in Austria. The SFB aims at developing new tools for the solution of a class of computational problems in engineering applications that make full use of and crucially depend on this combined expertise. Also, for the first time, the two basic aspects of "solving" and "proving" are combined and viewed together in one project. The basic philosophy of this SFB is as follows:

- The SFB is driven by the desire to make significant progress in the computational treatment of demanding problems in practically interesting high-tech applications, e.g. magnetomechanical systems (Project 5), fluid dynamics (Project 6), magnetic field problems (Project 8), elasto-plastic multi-body systems (Project 10).

- Typically, the solution of these problems (by approximation, simulation, optimization) involves the solution of direct and inverse problems for various classes of partial differential equations (Projects 5, 6, 7, 8, 9, 10).

- Handling these systems in an efficient way needs

  - a new level of computer-support in the phase in which new mathematical knowledge is invented and proved (Projects 1-4),

– symbolic tools for solving algebraic systems of equations, inequalities and constraints involving quantifiers to which subproblems in the treatment of partial differential equations are often reduced (Projects 1-4),

– the simplification and transformation of symbolic expression involving quantifiers (Projects 1-4),

– partly new mathematical studies in partial differential equations (e.g. alternate iteration schemes: Project 5, adaptive grid refinement strategies: Project 6, iterative regularization methods: Project 7, hierarchical coupling of direct simulation and optimization: Project 8,),

– automation in the preprocessing steps of solving partial differential equations (e.g. geometrical representations and automatic mesh generation in the finite element approach: Project 5 - 10, estimation of discontinuous parameters in the equations: Project 9, integrated hierarchical approach to simulation and optimization: Project 8, hierarchical objects: Project 10),

– fast, DD-based data distribution for the parallelization of solution methods (Project 12),

– improvements in the visual representation of solutions, especially in the case, when the solution is distributed over various processors (Project 13).

The solving tools of Projects 1-4 are the basis for subproblems in the mathematical treatment of partial differential equations and in the preprocessing phase of numerical methods for partial differential equations. The proving tools of Projects 1-4, in particular the Projects 1 and 2, will be used in establishing the proof of new formulae that appear in the course of the studies in the Projects 5-9.

For instance, in Project 10, symbolic methods of computation provided in Projects 1-4 should be utilized for setting up the equations of constraints assembling the elasto-plastic single bodies to a multi-body system. Since advanced visualization problems occur with respect to the motions performed by multi-body systems under conditions of impact and collision or in the high frequency domain, Project 10 also may form an appealing field of application for the methods of graphical scientific computations derived in graphical projects, especially, in Project 13.

Therefore, the symbolic Projects 1 - 4 and the graphical Projects 12 - 13 will massively contribute to the preprocessing and postprocessing facilities of the planed research software package.

3.3.4 Individual Contributions of the Projects to the Overall Objective

Project 1

Project 1, Project 2, Project 3, and Project 4 are intimately connected by the following basic philosophy: All four projects consider proving and (exact) solving but in different domains: **P1** in general domains defined by functors, **P2** over the reals, **P3** over the complex numbers, **P4** over the natural numbers. Project 1, in addition, will strive for providing a uniform logic and software front-end (based on Mathematica) from which the user can call and use the various provers and solvers developed in all four projects P1, P2, P3, P4. The interaction with Projects 5 - 10 is two-fold:

- The provers developed in P1, in particular the special provers for proving properties of (real) functions can be used in establishing the theory behind the solvers to be developed in the frame of the projects P5 - P10. Also, as the project advances, prototype systems will be available to the researchers in the other projects to support them in their mathematical work.

- The software developed in the other projects will implement solving and computing in particular mathematical domains, hence it can be used as “black-boxes” in a logical framework for proving in these domains.

Project 2

Project 2 deals with efficiently proving/solving constraints arising from problems over the reals. This is a booming branch of modern scientific computing whose foundations go back to the beginning of the systematic usage of computers in problem solving and beyond.

Traditionally problems over the reals occur in various areas of economics, natural sciences and computer science. They cover a broad range from problems, for instance, in cost optimization and production planning in economics to problems in automatic complexity analysis in computer science.

Therefore project 2 heavily contributes to the main goal of this proposal, namely to strengthen the capabilities of contemporary scientific computing. It also supports the desired synergy effect between symbolic and numeric computing essentially. It is planned to solve these problems over the reals by combining methods from computer algebra, numerical analysis and interval mathematics. This is a unique approach which has been developed just in the course of the last few years. In this area much expertise can be found at Linz, in particular at RISC.

Apart from this project 2 is a valuable supplement to the other projects within the SFB proposal. On the one hand it will use tools from various other ones, like project 3, 4 and 12. On the other hand it will supply tools for many other projects, take projects 1 and 7 for example. Thus we expect that several cooperations with members from other project groups will be formed. In particular this concerns projects that are related to the second one by generalization as well as specialization. Take projects 1 and 4, for instance.

Project 3

Geometric information is important for many of the individual projects. Geometric objects, such a algebraic curves and surfaces, can be represented in different ways, e.g. by their algebraic equations, by parameterizations, by birational projection to a hypersurface, by local parameterizations around the singularities. These different representations have their advantages and disadvantages for particular applications. So we need to be able to efficiently transform representations. In particular, this plays an important rôle in Project 5, 8, 9, and 12. The contribution of Project 3 to the overall goal will be the development of efficient representations and transformations between these representations. We intend to make use of both symbolic and numerical methods for achieving this goal.

Project 4

Project 4 (P4) is intimately related to P1, P2, and P3 via the common theme of simplification and transformation of symbolic expressions involving quantifiers. Crucial tasks in P4 are symbolic summation, i.e., elimination of sum-quantifier, and automated treatment of holonomic functions, i.e., special functions described as solutions of systems of (linear) difference-differential equations. This implies that, besides its role within symbolic scientific computation, project P4 is relevant also to the overall objective; two major aspects are: The first one, of global combinatorial nature, consists in the fact that techniques for summation and for solving difference equations are fundamental to any kind of algorithm analysis (e.g., efficiency analysis of algorithms developed in P5-P12); the second application aspect concerns the potential of automatic treatment (e.g., simplification or proving) of identities that involve holonomic functions. The latter might arise as solutions of standard differential equations such as elementary transcendental functions or higher functions (e.g., Bessel functions), but also as certain families of orthogonal polynomials (e.g., Chebyshev polynomials in approximation).

Project 5

One task of the project consists in developing a preprocessing tool for the description of a class of coupled field problems and its preparation for the parallel solution. Although this project aims at a specific class of coupled field problems (namely, magneto-mechanical fields), the principles and tools developed here will be usable in Projects 6 - 10 dealing also with direct and inverse field problems. One common problem in this context consists in the input, the internal representation, the changing (e.g. for the optimization, or in the case of the presence of moving parts) and the control of complex 3D geometries as well as the generation of the corresponding meshes. In addition to the projects mentioned above, different aspects of these problems play a major role in Projects 3, 12, and 13. Similarly, the input of the data of PDE as well as the initial and boundary conditions and the preparation of the input data for the numerical simulation, including the simulation on parallel computers, will be handled on the basis of same principles in all projects dealing with field problems. The second contribution to the overall objective consists in the construction, analysis and implementation of fast (parallel) solvers for coupled mechanical and magnetic fields in 3D.

Project 6

This project will primarily contribute to the objective of designing, analyzing and implementing of advanced numerical methods for solving direct problems, namely, for industrial flow problems. This opens up the possibility in an advanced stage of the SFB to integrate these methods for solving coupled field problems and to tackle inverse problems (design problems) related to industrial fluid flow, which, generally speaking, is quite often the original task of design engineers.

In addition to bring in an efficient solver for a particular class of field problems it is intended to also contribute to preprocessing and solving for more general classes of problems, namely:

- Special preprocessing tools will be developed to efficiently handle near-wall regions described by some sort of constraints which can be also relevant to other types of field problems to deal with separate adjustable geometrical regions.
- Algebraic multi grid solvers will be developed in this project which can deal with non-symmetric problems and/or different types of variables corresponding to different fields. This could lead to similar techniques for other field problems, see, in particular, Project 5 for an electro-mechanical field problem, similar in structure to the Navier-Stokes equations.

Project 7

Many problems in applications are inverse problems in the sense that causes for desired or observed effects have to be determined, i.e., computed. Inverse problems may either appear as sort of a preprocessing step for direct field problems, e.g., when unknown parameters in partial differential equations have to be determined numerically from (noisy) measurements of the solution, or they may themselves be the problem to be really solved in the end like in nondestructive testing or inverse scattering. Related problems appear in optimum design where, e.g., the shape of a body has to determined in such a way that, under various constraints e.g. on shape and stresses, the total weight is minimized. Nearly any realistic modeling problem involves (at least in one of these forms) an inverse problem. Thus, an efficient handling of inverse problems in a two-way cooperation with projects dealing with direct problems contributes to the overall goal of the SFB in a major way.

Project 8

The subject of this project is the development of numerically efficient algorithms for solving optimal design problems with applications in magnetostatics. These new algorithms are to be based on the hierarchical coupling of direct simulation and optimization.

Efficient algorithms which have been proposed recently for the direct simulation of 2D magnetostatic problems will be modified and adapted. In particular geometrical constraints and parameter-dependent geometries, which require more flexible data structures, have to be considered. The project will directly benefit from the results of Project 2 (handling of constraints over reals), Project 3 (checking of geometrical constraints) and Projects 12–13 (pre- and postprocessing).

Furthermore, this project is concerned with the design of algorithms for the direct simulation of 3D problems in order to solve 3D optimization problems in a further stage.

Similar classes of problems are considered here and in Project 5. Besides other projects, the latter will benefit from the direct solvers in 3D developed here.

Project 9

Physical models frequently contain discontinuous (or singular) model parameters. Examples of such parameters include spatially varying heat sources in heat conduction problems, spatially varying material parameters describing different material properties, to name just a few. In many physical models one in principle is aware of the type of model parameters and of the fact that they might be discontinuous (or singular), while the actual values of the parameters and the locations of discontinuity are unknown. The project aims at developing fast and accurate methods for estimating parameters with discontinuities (or singularities) and therefore contributes to the modelling step for field problems as treated in other projects.

Project 10

From the proposed work, it is quite clear that the elasto-plastic multi-body systems studied in Project 10 have to and will serve as a field of application for various developments performed in the other projects of the SFB, which mostly deal with more fundamental aspects of symbolic, numerical and graphical scientific computation. A close cooperation therefore is planned with the group of Prof.Langer (Projects 5 and 8) in all aspects involving the coupling of direct solvers with methods for solving inverse dynamic problems in elasto-viscoplasticity. Of course, also the cooperation with Project 7 (Prof. Engl) will be crucial for the success of Project 10. Regularization methods developed in Project 7 should find advanced large scale applications in the elasto-plastic multi-body systems treated in Project 10, especially with emphasis laid on the efficient coupling of inverse and direct solvers. Moreover, computational experience will be developed and provided in Project 10 with respect to an object-oriented programming of large-scale problems, a topic of increasing importance within the engineering community. Our group will also provide experience with respect to the principles of mechanics in general and concerning coupled field problems; therefore a consulting type of co-operation should take place with Project 6 (Navier-Stokes equations) and Project 5 (magnetomechanical systems). Project 10 furthermore will serve as a field of application for the projects concerning symbolic computations in various ways: First, methods from symbolic computation for computing derivatives and convolution integrals will be needed in Project 10 in both, low and high frequency computations. It will be furthermore investigated if the methods to be developed in Project 2 will help to simplify kinematic constraints to be considered in the stage of assembling the multi-body systems. It is also obvious that the graphical tools to be developed in Project 12 and 13 should find stimulating and practically important applications in the field of multi-body dynamics.

Project 11

This project is reserved for a later application by the successor to the chair for mathematics with emphasis on analysis.

Hier ist vorgesehen, daß der zu berufende Professor für Mathematik (Schwerpunkt: Analysis) ein Projekt zur Analysis und numerischen Analysis nichtlinearer partieller Differentialgleichungen einbringt !

Project 12

The facilities provided by the software environment, which we will develop in P12, can be utilized in several other projects, particularly in project 5 and 8. We regard the use of our environment as a crucial part within the overall solution process of partial differential equations. If numerical algorithms are to be performed in parallel, their performance heavily depends on the balance of computational load and the involved communication overhead. Both factors are primarily determined by the way how the problem is decomposed into subdomains and how subdomains are mapped to processors. Thus successful application for DD methods for parallel processing requires graphical exploration and evaluation facilities in order to obtain sufficient estimates about parallel efficiency before the program run. The integrated and modular character of our environment facilitates and speeds up exploration and estimation. It also provides important "hooks" where project-specific adaptions can be applied. For example, in connection with project 5 adaptions will be made with respect to mesh or geometry describing formats and mesh partitioning algorithms. On the other hand, the environment's graphical and numerical evaluation facilities are general enough to be applicable with various computation schemes such as schemes based on DD methods or explicit time integration schemes.

Project 13

Numerical approaches to solve large scale field problems generate huge datasets. In order to interpret the results, the scientist needs visualization tools, which will produce the desired output within an acceptable time period. The methods, which will be developed in project 13 will considerably reduce the time of visualization. The consequences are that the scientist has more time for his research and/or is able to use improved methods for visualization. Therefore he can get better insight into the datasets under investigation. Thus, the supply of other projects with efficient visualization tools will indirectly but essentially contribute to the overall goal of the SFB.

3.3.5 Financial Requirements during the Entire Duration of the SFB (10 years)

We expect that the financial requirements for the continuation of the SFB beyond the first three years will be similar to those in the first phase. That is, the cost (Ergänzungsausstattung) for years 4 through 10 is expected to be on the order of **16 to 19 MATS** per year. Funding by the university is supposed to stay at about the current level. We also expect that the "Stadt Linz", the "Land Oberösterreich", and the "BMWV" will continue to provide annual financial support for renting the offices and for running cost for the infrastructure. Furthermore, we hope that we can increase the funding from sources outside Austria, due to the enhanced international competitiveness of the partners involved.

3.4 Project Survey

3.4.1 Verbal Summary

Project 0

This project provides the management, the administration, the hard- and software services, the documentation and the scientific service for the SFB.

Project 1

The goal of this subproject is to design and implement an automatic theorem prover in natural deduction style, for the use of the working mathematician. This prover will be an interactive tool both for

- presentation of mathematical knowledge and
- developing mathematical knowledge

in the form of

- theorems and their (interactive) proofs and
- algorithms and their behavior.

The prover will integrate, for the first time, the three essential ingredients of mathematics: proving, solving and computing. It will build upon the intimate relationship between mathematical theories and mathematical algorithms.

This goal will be achieved by further developing the existing techniques for automatic proving, but shifting the focus from the built-in "black-box" engine style to a "white-box" open style, in which the user can easily visualize and understand the proof at the desired level of detail, can locate reasons of failure, can interact and guide the proof steps - and finally can obtain the proofs exactly in the form in which they can be included into papers, lecture notes, etc.

Moreover, by using a particular functor based approach, the new system will be able to assist the user in the routine parts of building new mathematical theories and algorithms, in the same natural style in which human mathematicians work. This functor based approach will allow the prover to incorporate and use proving techniques which are specific to each mathematical domain.

Also, the system will be able to use advanced algorithms from specific areas of mathematics (e.g. algebraic algorithms, numerical algorithms, etc.) for solving queries related to those particular domains, hence it will also act as a front-end for the interface between the mathematician and various solving and computing software tools developed in the frame of the other subprojects.

Project 2

OBJECTIVE: We will develop mathematical theories, algorithms, and software libraries/packages for efficiently proving/solving real algebraic constraints (quantified boolean expressions of polynomial equations/inequalities over real numbers) of moderate sizes.

MOTIVATION: Many important and difficult problems in mathematics, scientific, engineering and industrial computations can be reduced to that of proving/solving real algebraic constraints. Thus the availability of efficient algorithms/softwares for real algebraic constraint proving/solving will significantly increase the problem solving power in science and industry.

STATE OF THE ART: We already have algorithms/softwares that can *in principle* prove/solve *all* the real algebraic constraints. We also have algorithms/software that are *fast enough* for *small* inputs (up to 4 variables) or inputs from certain *sub*-classes. These are already used by scientists and engineers for solving small problems. But we do *not yet* have fast algorithms/softwares for *moderate* size inputs. There are numerous important *real-life* problems of moderate size (with about 10 variables).

MAIN THRUST: Thus, the main thrust of of this project will be focused on devising methods/software for *moderate* size inputs. We expect that this will require combining methods from computer algebra, numerical analysis, interval analysis, and developing new mathematical theories and software techniques.

METHODS: Through the experience/experiments with the existing methods/tools, we have identified several sources of inefficiency and also conjectures for possible improvements and new methods. Based on these we formulated 9 research ideas to pursue: pruning projection by box approximation, using intermediate results of projection, using convexity for bounded quantifiers, multivariate tightening, integrated combinatorics, approximate quantification, exact division, use of chain rule, and approximate simplification. Each research idea is rich/heavy enough to be pursued by one person throughout one year (working 2/3 time).

DELIVERABLES: We will deliver for each of the 9 tasks (based on the 9 ideas listed above) the followings: one scientific report (in LaTeX), one software package (in C++ or Java), one software documentation (in HTML), one graphical user interface to the software (in Java).

Project 3

In computer aided geometric design (cagd) algebraic curves and surfaces play an essential rôle in modelling physical and virtual objects. The main goal of the project is the improvement and/or perfection of existing methods and the derivation of new methods for designing, manipulating, and visualizing algebraic curves and surfaces. Algebraic curves and surfaces can be represented in different ways, e.g. implicitly by a defining polynomial equation, parametrically by rational functions, or locally by Puiseux series or places. Every one of these representations has its own particular advantages, and so we need to have efficient algorithms for changing representations.

In the past few years our research group has been working on symbolic methods for efficient computation of parameterizations of algebraic curves. This involves genus computation, complete analysis of the singularities, and determination of a system of adjoints. For instance, we have been able to derive an algorithm for determining an "optimal" parameterization, i.e. a parameterization having coefficients in the simplest possible ground field. However, there is still much room for improvement. Currently we are using blow-ups and quadratic transformations in the computation of genus and adjoints. This can probably be done much more efficiently by using local Puiseux expansions. There are hints in the literature on using series for genus computation, but for determining the adjoints we need more research. One problem that has ultimately to be solved in the parameterization process is the determination of simple points on the curve, of course with coordinates in a simplest possible ground field. We are working on solving this problem for various practically interesting ground fields, such as $\mathbf{Q}$, rational functions over $\mathbf{Q}$, or finite fields.

This parameterization of algebraic curves is particularly interesting in computer aided geometric design (cagd), where one usually models the boundaries of objects by algebraic curves or surfaces in parametric form. The classical approach to cagd is numerical in nature, i.e. the boundary patches are approximated to high enough accuracy. In such a numerical approach it can be a problem to trace along a curve, in particular near a singularity. The Jacobian matrix vanishes at a singularity, creating problems with Newton approximation. We want to use fast numerical methods when possible, and symbolic algebraic methods when necessary for topological correctness. This combination of symbolic and numerical tools is particularly important in visualization of geometric objects. Recently successful hybrid symbolic/numerical algorithms have been developed in a Ph.D. thesis. We intend to continue this promising work.

One important problem in cagd is the computation and investigation of offset curves and surfaces, i.e. curves or surfaces which keep a certain distance from some base curve or surface. In our group we are currently implementing and testing new algorithms for offset curves. Also the above mentioned problem of finding simple points over certain ground fields could probably lead to automatic determination of offset surfaces to interesting classes of curves and surfaces in cagd, such as pipe and canal surfaces.

In the last decade various new approaches have been presented for automatically proving or disproving geometrical hypotheses. Here both the hypotheses and the conclusions are expressed in terms of algebraic curves, surfaces, or higher dimensional objects. Elimination methods such as resultants, characteristic sets, and Gröbner bases play a crucial rôle in all these methods for geometric theorem proving (gtp). Dixon resultants could bring a decisive improvement in complexity of the gtp algorithms. Our group has some very promising results in this direction and we intend to continue our investigation in gtp.

Over the years we have been collecting our algorithmic developments, and we have implemented them, together with the work of other groups, in our program system CASA. This system CASA is a tool for describing, constructing, investigating, and visualizing curves, surfaces, and higher dimensional varieties in constructive algebraic geometry over an algebraically closed field, such as the complex numbers. CASA has been presented at several conferences, and it is also used by researchers at other universities. We plan to keep developing and improving this program system CASA.

Project 4

The algorithmic problem of symbolic summation can be viewed as the discrete analogue of the well-known problem of "symbolic integration" or "integration in finite terms".

Typical applications for symbolic summation algorithms are to find in the context of algorithm analysis or, more general, in the area of combinatorial identities. A simple example is the binomial theorem $\sum_{k=0}^{n}\binom{n}{k}x^k = (1+x)^n$, which again finds generalizations in certain other combinatorial contexts (e.g., so-called "q-analogues").

Examples for automatic treatment of summation problems range from closed-form evaluations of elementary type as the binomial theorem to number-theoretic results as the celebrated Rogers-Ramanujan identities in additive number theory. But even for very simple situations as, for instance, the subset-count leading to the above binomial theorem for $x = 1$, automated proving or closed-form evaluation has for a long time been considered as algorithmically infeasible; see, for instance, Knuth's "Art of Computer Programming" (Vol. I, 1968).

Only a few years ago this situation has changed due to Zeilberger's "holonomic systems approach". Exciting applications, e.g., "one-line" proofs of the Rogers-Ramanujan identities (Paule, 1994) or in the context of Apery's irrationality proof for $\zeta(3)$, has led to renewed intensified research in the classical symbolic summation problem.

Since the beginnings of these new developments in the early 90's, the combinatorics group at RISC has contributed to the field in various significant ways. For instance, the standard reference in the area, i.e., the book "$A = B$" by Petkovšek, Wilf and Zeilberger, points to the Paule/Schorn package as *the* Mathematica implementation of Zeilberger's "fast" algorithm. Another software that is going to become standard, is Riese's implementation of a q-analogue of this algorithm. It is based on the concept of "greatest factorial factorization" of a polynomial (Paule, 1995), which can be seen as a difference operator analogue to square-free factorization, the latter being related to differentiation.

In spite of its historical roots and the exciting and promising achievements made over the last years, one really has to emphasize that symbolic summation became a promising and well-recognized subbranch of computer algebra only recently. And in view of the novelty of these developments it is evident that still much more needs to be done, in theory as well as concerning implementation.

The main objective of this sub-project is research in algorithms design for symbolic summation and holonomic functions. The theoretical work is guided and motivated by concrete problems arising within the frame of this SFB project and from the area of combinatorial identities in general. Vice versa, the proposed research in algorithms will stimulate research in the application areas, because the newly designed algorithms will significantly enhance the number of situations where nontrivial parts of research in combinatorics and in related fields can be left to the computer.

Summarizing, the general project goal is the development of computer algebra algorithms for automated proving or closed-form evaluation of summation identities arising in combinatorial context. In order to accomplish this goal, the problem of *proving* or closed-form evaluation will be transformed into problems of *solving*. This, for instance, means: solving linear systems of equations with rational function coefficients, finding (symbolic) solutions of difference equations, or finding (e.g., by applying Gröbner bases theory) certain operators in annihilating ideals that arise in the context of certain noncommutative difference operator algebras and corresponding (left-)modules. It is a fundamental aspect of the proposed research that its goals can only be achieved by effective interaction of mathematical theory and practical implementation of efficient algorithms.

Project 5

The modelling of complex electromechanical systems often leads to coupled field problems involving the interaction of different systems of non-linear Partial Differential Equations (PDEs) in complicated 3D geometries. The complexity of these systems requires the development of efficient simulation tools working on powerful workstations as well as on workstation clusters and parallel computers. Roughly speaking, these simulation tools consist in

- preprocessing tools,
- the PDE solver, and
- postprocessing tools.

The subject of this project is the development, the analysis, the implementation and the application of advanced numerical methods for the solution of 3D non-linear, stationary and instationary (dynamic) coupled magnetomechanical field problems described by Maxwell's and Navier's systems of PDEs as well as the development of an advanced user surface including the handling of parallel processing. In the time-dependent case, this problem leads to the coupling of parabolic and hyperbolic PDE systems for defining the magnetic vector potential $\vec{A}$ and the displacement field $\vec{u}$ under suitable initial and boundary conditions as well as gauging condition for $\vec{A}$. In the recent years, advanced numerical methods have been developed for 3D Maxwell's as well as for Lamè - Navier's equations separately, whereas the development and, especially, the analysis of similar methods for the coupled problems are at the very beginning. The usual approach to the solution of such problems consists in decoupling the field problems by an alternate iteration scheme. However, this decoupling can lead to a loss in efficiency of the corresponding numerical schemes, especially, in the presence of non-linearities and strong coupling terms. Therefore, new numerical schemes should avoid these losses in efficiency and should be based on hierarchical adaptive approximation and solver techniques including algebraic and hybrid multilevel solvers. The numerical solver together with appropriate pre- and postprocessing tools including automatic 3D mesh generators should enable us to simulate more and more complicated problems in advanced electromechanical applications.

Project 6

Computational fluid dynamics is an important tool for engineers for designing products or analyzing and improving processes. Real life applications, in particular in engine development and steel production, are the motivating background of this proposal.

The standard governing equations for flow problems are the Navier-Stokes equations. Industrial flow is often turbulent, which, in principle, is believed to be incorporated in the standard Navier-Stokes equations. This, however, would imply extremely fine grids with prohibitively high cpu times and memory capacity for complex geometry.

A more realistic alternative are statistical turbulence models, which are based on the Reynolds-averaged Navier-Stokes equations. Several approaches of different complexity and different range of applicability have been suggested in literature. All these statistical models have in common that a special treatment of near wall regions are necessary.

Therefore special techniques in the grid generation are required for allowing to shift the boundaries in order to describe these near wall regions with the capability of a posteriori adaption.

The discretization of the governing system will be basically done by a finite element technique whose stability for low Reynolds number flow is well established.

For high Reynolds number flow special stabilization techniques are to be included. One approach relies on stable finite volume schemes for the convective term as they are well known for general conservation laws. The project will focus on possible combinations of mixed finite element and finite volume methods, or more generally speaking, of flux oriented discretizations which both work on the same grid.

Adaptive grid refinement strategies based on an a posteriori error estimator have to be included in order to improve the efficiency. Classical estimators are based on the residuals of the discretized equations and lead to norm estimates of the error. In connection with a turbulence model this could lead to a refinement strategy which prefers the near wall regions. For some interesting quantity which does not heavily depend on the behaviour of the flow near a wall this might lead to an inefficient refinement strategy. A more promising technique for a class of problems including the laminar Navier-Stokes equations has been developed on the basis of a dual problem. This technique should be extended to turbulence models.

Adaptivity introduces several levels of grids. Therefore, solution strategies for the resulting large scale system of discretized equations should be based on a multi-level approach. Solution techniques based on a partial decoupling of momentum and continuity equations has been used for quite a while. New theoretical investigations make clear how to construct such a method which is also suitable for a smoother in a multi-grid method. In the symmetric case (the Stokes problem) the success of the method rely on the property that the method is not expansive. In recent papers it was shown how this could be carried over to the general non-symmetric case which includes the Navier-Stokes equations provided one can keep the non-expansivity of the smoother.

Since the starting grid in a real life application usually is already rather fine, solvers on this grid level are to be constructed on the basis of an algebraic multigrid approach.

Project 7

Inverse Problems are concerned with determining causes for a desired or an observed effect. Their importance in many application fields is growing. The mathematical formulation of inverse problems usually leads to ill-posed problems whose solution does not depend continuously on the data. This instability has to be treated by so-called regularization methods. The proposer and his group have contributed over the last years to the convergence theory of regularization methods for solving linear and especially nonlinear ill-posed problems. These rigorous theoretical results have been applied so far only to "toy problems". On the other hand, large scale inverse problems have been solved in many applications in science and industry, also in the proposer's group. In solving large-scale inverse problems, e.g., by iterative regularization methods, the cost of solving the direct problem and computing its gradient cannot be neglected. Therefore, it is the major aim of this project to develop theory-based methods for the optimal coupling between regularization methods and direct solvers for (mainly nonlinear) inverse problems where the corresponding direct problem involves partial differential equations. Related questions appear in shape optimization and will also be studied in this project.

Project 8

The subject of this project is the development, analysis and implementation of numerically efficient algorithms for solving optimal design problems arising, e. g., in magnetostatics. The project aims at a unified treatment of direct simulation and optimization based on hierarchical methods.

The development of both, numerical algorithms and the power of hardware components during the last few years enables us today to solve direct simulation problems with some 100.000 unknowns in seconds. However, most of the practical problems are inverse or are given implicitly by a functional which is to be optimized. Here, we are concerned with the later case, for which until now no efficient numerical methodology exists.

Our approach aims at a uniform algorithm involving both, direct simulation and optimization, instead of just using some direct simulation within an optimization algorithm. The application of hierarchical methods seems to be the right approach if optimal algorithms are sought. Here, nested algorithms similar to nested Newton iterations in the nonlinear case allow only a few iterations on finer grids whereas most of the iterations are realized on coarser grids where the solution of the direct problem is cheap.

Nevertheless, the development of such unified algorithms requires the experience in the field of direct simulation. In the 2D case, the Project concentrates on the adaptation of existing algorithms to hierarchical optimization methods, whereas in the 3D case, direct solvers and their components as, e.g., preconditioners, have to be developed and analyzed.

Parallel computers offer the opportunity to speed up the solution of direct problems which is indespensible with respect to optimization. 2D applications have shown that Domain Decomposition (DD) methods or methods based on DD partitions are well suited for this purpose in the field of magnetostatics. That is why a DD data decomposition has to be seen as part of the overall solution process.

Computer aided optimal design of electromagnetic machines (e.g. electric motors) is ultimate aim of practical applications. There is a great variety of design parameters affecting the machine, and each evaluation of the model of the electromagnetic machine results in solving a nonlinear problem on its magnetic field, i.e., numerically solving a nonlinear partial differential equation. So there is a high complexity of this task for all cases relevant in real applications. The project aims at an efficient coupling of optimal direct simulation algorithms and optimization.

The first step lying at hand will be the combining of an optimization code **OPTI** with the fast simulation code **FEPP** (Schöberl, 1996) aiming at the development of an efficient package for optimal design of parameters in models for electromagnetic machines.

However, the crucial goal of this proposal is the development of new and much faster methods based on

- the hierarchical coupling of simulation and optimization by a "Multilevel–Nested–Iteration" and
- the parallelization of the coupled method.

The development of parallel algorithms for solving nonlinear problems for magnetic fields and their implementation on massively parallel computers is currently supported by the Austrian Research Fund FWF under a grant given to the principal investigator. The results of that project may be harnessed for parallelizing the hierarchically coupled methods to be newly developed in this proposal.

Project 9

In many practical problems governed by differential equations one in principle knows the type of equation but not the explicit values or forms of the parameters. E.g., if one considers heat conduction in a material occupying a three-dimensional domain Ω whose temperature is frozen at the boundary, the temperature distribution u after sufficiently long time can be modelled by

$$\begin{array}{rcll} -\nabla.(a(x,y,z)\nabla u) & = & f(x,y,z)\,, & (x,y,z)\in\Omega\,, \\ u & = & 0\,, & \text{on } \partial\Omega\,, \end{array} \tag{1}$$

where f denotes internal heat sources and a is the (spatially varying) heat conductivity. One can try to identify the parameter a from internal measurements of the temperature u or from overdetermined boundary measurements.

Of particular interest are problems, where the parameter a is discontinuous, e.g., if materials with different conductivity occur in the problem above. Another interesting parameter identification problem is the estimation of locally varying source terms (a known and a possibly discontinuous function f is to be determined in (1)).

Parameter identification problems belong to the class of *nonlinear inverse problems* and they are ill-posed, i.e., the solution does not depend continuously on the data. Therefore, some *regularization techniques* have to be applied to solve such problems in a stable way numerically.

In the literature, Tikhonov regularization is a well known method for solving parameter identification problems in a stable manner. Recently iterative methods such as Landweber iteration and Gauss-Newton method were shown to stabilize ill-posed problems if they are combined with an appropriate stopping rule. For all these methods good results (reasonable convergence rate) are obtainable if the exact solution a (of (1)) is smooth.

It is the aim of this project, to develop new regularization methods and their efficient numerical realizations in the case of parameters with singularities (e.g. discontinuous functions).

Project 10

The main intent of the present proposal is the extension of the existing computational experience to elasto-plastic multi-body systems. The main idea is to create such "smart" programs which can perform a preliminary analysis of the multi-body system in question, so called object-oriented programs. That means that the mechanical behaviour of the component bodies should be characterized by hierarchical classes of objects. Standard mechanical bodies as rods, plates etc. should be implemented in connection with various inelastic strain-stress relations. The program should be "intelligent" enough to choose the suitable computational strategy for solving the elasto-plastic problem of the whole multi-body system. Inelastic part of the strain is treated as a source of eigenstrains in linear elastic bodies, so that an analytical formulation of the elastic solids can be applied to the physically non-linear problems. Special attention will be paid to the use of finite element method with exact stiffness matrix. The efficiency of the approach will be increased by means of the linear concept of the influence numbers and modal matrix, since they will be computed before the main calculation. These concepts of the linear analysis are to be consistently applied to dynamics of elasto-plastic multi-body dynamics. Another challenging problem is the prevention of uncontrolled high frequency vibrations in engineering structures which affect small sensitive elements of the complex structures, e.g. microprocessors, controllers etc. Special approaches will be proposed for the prediction of high-frequency vibrations in complex structures since the conventional well-established methods of structural analysis, such as finite element method, substructure synthesis method etc. are not suitable because of high computing cost.

The local principle in structural dynamics which is obtained by the group and is a sophisticated generalization of multi-body dynamics, allows one to decompose engineering structures into substructures and provides one with the governing equation for each substructure and the imposed constraints. Various methods, among them symbolic computation, FE-, BE-, integral approaches, are applied for modelling the dynamics of each structural member. Structural members of conventional geometry and classical mechanical objects like rods and plates, will be handled by applying symbolic computation. Nonlinear effects, internal material damping and local low contact rigidity can be taken into account by means of the eigenstrains or self-stresses. Dynamics of structural members of the complicated form will be settled down by means of FE-analysis or another numerical methods. Consequently, integral methods will be applied in the high frequency domain and the results obtained will be matched to the those at low frequencies. In this case the global description of the engineering structures will be obtained for any broad band dynamic loading. The proposed project is expected to provide the user with a very flexible, mighty, object-oriented and multi-purpose software which results in considerable reduction of the computing cost.

Project 11

This project is reserved for a later application by the successor to the chair for mathematics with emphasis on analysis.

Hier ist vorgesehen, daß der zu berufende Professor für Mathematik (Schwerpunkt: Analysis) ein Project zur Analysis und numerischen Analysis nichtlinearer partieller Differentialgleichungen einbringt !

Project 12

The subject of this project is the development of a sophisticated data distribution system for parallel unstructured mesh computations and, in particular, for Domain Decomposition (DD) solvers which put additional requirements onto the decomposition. In this sense, the subject is part of an overall solution process of partial differential equations continuing with the topics discussed in projects 5 and 8.

Nowadays computations with large unstructured meshes are performed on parallel computers because of size considerations and computational requirements. Using distributed memory machines the user is faced with the non-trivial problem of data distribution. Meshes must be partitioned across the local memories of the processors in such a way that a good load balancing is achieved and interprocessor communication is kept minimal. The situation is even more complicated if DD solvers are to be applied, since the definition of "well shaped" subdomains is required additionally.

It is known that optimization of these issues involves the solution of NP-complete problems (Garey, 1979), so up to now researchers have developed heuristics that yield reasonable, yet suboptimal results (Hendrickson, 1995; Karypis, 1995; Pellegrini, 1996; Walshaw, 1994). Using virtual shared memory machines data distribution is also relevant since a good distribution promotes data locality and so improves overall performance. The decision about the efficiency of a distribution is hard to find because it depends on several factors, including the suitability of a distribution algorithm for the given mesh, the problem to be solved, and the target computer. Thus the data distribution procedure is not a fully automatic, but an interactive process, which should be supported by appropriate tools. With such a tool the application user can create and evaluate several distributions and determine the best one for his or her purpose.

The result of our research is a software environment that allows the user to create efficient distributions of graph-based data structures (including unstructured 2D and 3D meshes) easily and quickly. Based on such a distribution, a DD-data structure, which serves later on as input for parallel computations, can be generated. Furthermore the environment offers enough flexibility in order to provide seamless combination with problem solving environments for parallel scientific computations, such as with those developed in projects 5 and 8.

The key to efficient data distributions is the integration of state-of-the-art distribution algorithms into the environment. On the one hand we will integrate some efficient algorithms developed by other researchers, on the other hand we have located deficiencies in some of today's best algorithms and we will develop alternative algorithms which give better results for certain classes of graphs.

The most important contributions to simplicity of the data distribution process are a user-friendly graphical user interface and a flexible and extensible input/output interface. Graphical front-ends for the best available distribution algorithms allow easy and fast creation of distributions, which is essential for experiments. Results will be stored in a distribution workspace where they can be evaluated by means of graphical displays. The displays are based on distribution quality metrics and use colored 3D charts in order to give the user a first estimation on how efficient a given parallel application will behave with a given distribution. Furthermore all distributions in the workspace can be compared graphically in order to find the best one at a glance. The graphical displays are based on distribution quality metrics. Since the variety of unstructured mesh computations and parallel computer architectures makes the definition of universal quality metrics impossible, we will examine the applicability of known metrics for different applications and parallel computers, and investigate new metrics that consider characteristics of recent parallel numerical codes and so yield more accurate estimations.

In particular, numerical algorithms based on DD methods require a decomposition into "well shaped" subdomains rather than a simple distribution of the mesh. The generation of reasonable decompositions of domains into subdomains, especially in the case of complicated, i. e., non-convex, geometries, requires new ideas. The visualization and evaluation of the decompositions generated automatically are of major importance. A new kind of DD preprocessing which defines subdomains based on the partition of the mesh will be necessary. Hereby, the requirements originating from the numerical point of view may influence considerably the criteria for evaluating a decomposition. The availability of a 3D Domain Decomposition preprocessor would allow us to choose from a wide range of numerical algorithms including global parallelized solvers, DD solvers or even solvers applying coupled finite element - boundary element discretizations.

In order to provide seamless combination with problem solving environments the data distribution system requires a modular software architecture with maximum flexibility. We plan to exploit the facilities of dynamic linking in today's operating systems in order to allow the user to configure the system with selected components that are composed to a running system at program startup. User-specific components will be built upon pre-defined components that offer object-oriented programming interfaces and so provide customization with minimum effort.

In a case study we will combine the environment with *NETGEN* (Schöberl, 1996) and *FEPP* (Schöberl, 1996), a problem solving environment developed in projects 5 and 8. Since the numerical algorithms benefit from services provided by a data distribution system at several stages, they represent an ideal experimental platform. During this case study we will develop several special-purpose functions for *NETGEN* and *FEPP*. The result will be a user-friendly environment for generating DD-data for complex geometries which are the input for DD solvers for partial differential equations in two and especially in **three** dimensions running on massively parallel computers. Experiences gained through this case study will be brought back into our environment and so promote its flexibility for further applications.

Project 13

Three goals are addressed in the scope of this project: speeding up the visualization process, new tools for the development and debugging of scientific applications, and new visualization techniques.

Scientific simulations generate a multitude of data values. Visualization aids the understanding of the results by depicting the data in a graphical form. This allows the user to *explore and analyze* the computed data. For time dependent data animations are used to visualize how the data changes over time. Several projects in the scope of this SFB compute meshes with several million nodes for multiple time steps. Conventional visualization packages are not efficient or powerful enough to generate visualizations and/or animations of such data volumes within a reasonable time frame. Therefore this project uses novel results from computer graphics research (image based rendering) to accelerate the visualization of data. Also combining image based rendering techniques with suitable compression techniques allows to avoid most of the communication bottleneck of parallel and distributed visualization systems. Additionally research in the use of methods which generate the best possible image given constraints on time and communication bandwidth will be conducted. Such systems can then be used in the combination with virtual reality environments which allow the interactive display of scientific data.

The second goal is to realize a system which aids the development and debugging of scientific simulations. By running visualization and application in parallel the user is able to monitor the simulation. This is an invaluable aid in *solving* scientific problems because it allows to detect problems quite early in the development phase. Conventional debugging methods cannot handle the large data sets generated. Therefore a goal is a system which allows the user to control and monitor the simulation and show data values in a meaningful (graphical) form. Even more powerful is the concept of 'steering': The possibility for the user to influence the running simulation by tuning parameters interactively. Most large scientific simulations utilize the power of parallel computing to compute results. Therefore a key requirement for the system is the support for parallel and distributed environments. Moreover the system includes support for the development of parallel simulations. Here two main issues are the support for performance evaluation and the detection of (communication) errors. Performance evaluation is achieved by looking at the results gathered from monitoring a running simulation. But the monitoring also generates data about the communication behaviour of the program. This allows to detect communication errors and allows to analyze communication patterns for performance issues.

The third part aims at new visualization methods for high dimensional data with the emphasis on three dimensional vector fields. Such vector data is generated by simulations computing field or fluid behaviour. Recent progress in visualization methods for two dimensional vector fields with streamlines using enhanced optimization techniques will be used as a basis to develop new visualization techniques for three dimensional vector fields. Furthermore research on a new visualization methods with respect to time dependent data is conducted. Analyzing the data beforehand allows to decide which parts have changed significantly. This can be used to speed the rendering as only changed parts need to be rerendered for the next image. To avoid visual clutter in images a new method is proposed which analyzes the data beforehand and displays details only where the data is "interesting". Uniform regions are displayed in a coarse representation whereas "complicated" regions are displayed with a finer resolution.

3.5 Importance of the SFB for the Participating Institutions

The research groups participating in the SFB have separately made considerable contribution to the design, verification, implementation and analysis of quite different techniques in advanced scientific computing. These techniques include numerical methods for field problems described by partial differential equations, numerical methods for inverse problems, analytical methods, methods of symbolic computation, and, last but not least, graphical techniques. Thus, in Linz there is the rare chance for developing graphical, numerical, and symbolic scientific computing not only side by side, but for significantly contributing to innovation on international level on a long term basis by combining these components and by applying the developed instruments to complex problems in Mechatronics. Therefore, the SFB will provide the framework for the close cooperation of the participating research groups belonging to Research Institute for Symbolic Computation (RISC), Institute for Mathematics, Institute for Industrial Mathematics, System Programming Institute, Institute for Electrical Measurement Technology, and Institute for Mechanics.

3.6 Integration of Young Scientists

3.6.1 List of Current Diploma and Ph.D. Theses Related to the Projects

See Table 4.

3.6.2 Special Programmes for Young Scientists in Connection with the SFB

Young scientists are represented in two ways in the SFB "Numerical and Symbolic Scientific Computing". First, the SFB will provide funding for a relatively large number of Ph.D. and diploma students. Second, students at all levels will have the opportunity to participate in the SFB–Colloquium as well as in the internal lecture series and the annual International SFB–Workshop. After a successful first period of SFB, we plan to apply for a "Science College" (Wissenschaftskolleg) in order to strengthen the Ph.D. education.

3.7 FWF Funded Research Projects of the SFB Participants Outside of the SFB

See Table 5.

3.8 Research Projects of the SFB Participants Outside of the SFB Funded by other Institutions

See Table 6.

3.9 Survey of National and International Cooperations

All participating groups are strongly embedded in the international research scene. Details are given in the context of the individual projects and in the CVs.
Since the Parallel Scientific Computing also plays an important rule in this SFB, there will be some cooperation with the SFB *"Advanced Models, Applications and Software Systems for High Performance Computing" (AURORA)* located at the University of Vienna.

3.10 Tables 1 - 6

Tabelle 1. Übersicht über die am SFB Beteiligten.
Mitglieder im Sinn der Ordnung des SFB sind mit einem * vor dem Namen gekennzeichnet

Name, Vorname, akad. Grad	Fachrichtung	Forschungsstätte	Code	finanziert aus GA/EA/ST	Mitarbeit Projektteil
1	2	3	3a	4	5
Baldinger Martin, Dipl.-Ing.	Technische Mechanik	JKU Linz	0/21	GA	10
Blaschke Barbara, Dipl.-Ing. Dr.	Industriemathematik	JKU Linz	0/21	EA	7
Brunner Walter, Dipl.-Ing. Dr.	Technische Mechanik	JKU Linz	0/21	EA	10
*Buchberger Bruno, DDr. Univ.-Prof.	RISC	JKU Linz	0/21	GA	1
Bürbaumer Harald, Dipl.-Ing.	Technische Mechanik	JKU Linz	0/21	EA	10
*Engl Heinz, Dipl.-Ing. Dr. Univ.-Prof.	Industriemathematik	JKU Linz	0/21	GA	7, 9
Grabner Siegfried, Dipl.-Ing.	Informatik	JKU Linz	0/21	EA	12
Haase Gundolf, Dipl.-Ing. Dr.	Mathematik	JKU Linz	0/21	GA	5, 8
Hillgarter Erik, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	3
Hirnschrodt Michael, Dipl.-Ing.	Elektrische Meßtechnik	JKU Linz	0/21	EA	5
Hochrainer Markus, Dipl.-Ing.	Technische Mechanik	JKU Linz	0/21	EA	10
Hohage Thorsten, Dipl.-Math.	Industriemathematik	JKU Linz	0/21	EA	7
Holl Helmut, Dipl.-Ing. Dr.	Technische Mechanik	JKU Linz	0/21	GA	10
*Hong Hoon, Dr. Univ.-Doz.	RISC	JKU Linz	0/21	GA	2
*Irschik Hans, Dipl.-Ing. Dr. Univ.-Prof.	Technische Mechanik	JKU Linz	0/21	GA	10
Jebelean Tudor, Dr.	RISC	JKU Linz	0/21	EA	1
Kaltenbacher Manfred, Dipl.-Ing. Dr.	Elektrische Meßtechnik	JKU Linz	0/21	GA	5
Kickinger Ferdinand, Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	6
Kindermann Stefan, Dipl.-Ing.	Industriemathematik	JKU Linz	0/21	EA	9
Koppler Rainer, Dipl.-Ing.	Informatik	JKU Linz	0/21	GA	12
Kranzlmüller Dieter, Dipl.-Ing.	Informatik	JKU Linz	0/21	GA	13
Kuhn Michael, Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	8, 12
Landl Gerhard, Dipl.-Ing. Dr.	Industriemathematik	JKU Linz	0/21	GA	7

Tabelle 1.
Fortsetzung

Name, Vorname, akad. Grad	Fachrichtung	Forschungsstätte	Code	finanziert aus GA/EA/ST	Mitarbeit Projektteil
1	2	3	3a	4	5
*Langer Ulrich, Dipl.-Ing. Dr. Univ.-Prof.	Mathematik	JKU Linz	0/21	GA	5, 6, 8, 12 Sprecher
*Lerch Reinhard, Dipl.-Ing. Dr. Univ.-Prof.	Elektrische Meßtechnik	JKU Linz	0/21	GA	5
*Lindner Ewald, Dipl.-Ing. Dr.	Mathematik	JKU Linz	0/21	GA	8
Minimair Manfred, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	2
N.N., Dr.	Mathematik	JKU Linz	0/21	EA	0
N.N., Dr.	Mathematik	JKU Linz	0/21	EA	0
N.N.	Mathematik	JKU Linz	0/21	EA	0
N.N., Dipl.-Ing.	RISC	JKU Linz	0/21	EA	2
N.N., Dipl.-Ing.	Elektrische Meßtechnik	JKU Linz	0/21	EA	5
N.N. (Diplomand)	Elektrische Meßtechnik	JKU Linz	0/21	EA	5
N.N. (Diplomand)	Mathematik	JKU Linz	0/21	EA	5
N.N., Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	6
N.N., Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	6
N.N. (Diplomand)	Industriemathematik	JKU Linz	0/21	EA	7
N.N. (Diplomand)	Industriemathematik	JKU Linz	0/21	EA	7
N.N., Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	8
N.N., Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	8
N.N. (Diplomand)	Mathematik	JKU Linz	0/21	EA	8
N.N. (Diplomand)	Mathematik	JKU Linz	0/21	EA	8
N.N., Dr.	Industriemathematik	JKU Linz	0/21	EA	9
N.N., Dipl.-Ing.	Mathematik/Informatik	JKU Linz	0/21	EA	12
N.N., Dipl.-Ing.	Informatik	JKU Linz	0/21	EA	13
N.N., Dipl.-Ing.	Informatik	JKU Linz	0/21	EA	13
*Paule Peter, Dr. Univ.-Doz.	RISC	JKU Linz	0/21	GA	4

Tabelle 1.
Fortsetzung

Name, Vorname, akad. Grad	Fachrichtung	Forschungsstätte	Code	finanziert aus GA/EA/ST	Mitarbeit Projektteil
1	2	3	3a	4	5
Pfau Ralf Uwe, Dipl.-Math.	Industriemathematik	JKU Linz	0/21	EA	7
Radmoser Esther, Dipl.-Ing.	Industriemathematik	JKU Linz	0/21	EA	9
Riese Axel, Dipl.-Ing. Dr.	RISC	JKU Linz	0/21	EA	4
Robideux Nicolas	RISC	JKU Linz	0/21	EA	2
Schaufler Gernot, Dipl.-Ing.	Informatik	JKU Linz	0/21	GA	13
*Scherzer Otmar, Dipl.-Ing. Dr. Univ.-Doz.	Industriemathematik	JKU Linz	0/21	GA	9
Schorn Markus, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	4
Schöberl Joachim, Dipl.-Ing.	Mathematik	JKU Linz	0/21	EA	5
Stadelmeyer Peter, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	3
Stangl Christoph, Dipl.-Ing. Dr.	Industriemathematik	JKU Linz	0/21	GA	7
Stürzlinger-Protoy Wolfgang, Dipl.-Ing. Dr.	Informatik	JKU Linz	0/21	EA	13
Tomuta Elena, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	1
Tran Quoc-Nam, Dr.	RISC	JKU Linz	0/21	EA	3
Vasaru Daniela, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	1
*Volkert Jens, Dr.-Ing. Univ.-Prof.	Informatik	JKU Linz	0/21	GA	12, 13
Wegschaider Kurt, Dipl.-Ing.	RISC	JKU Linz	0/21	EA	4
*Winkler Franz, Dipl.-Ing. Dr. Univ.-Doz.	RISC	JKU Linz	0/21	GA	3
*Zulehner Walter, Dipl.-Ing. Dr. Univ.-Doz.	Mathematik	JKU Linz	0/21	GA	6

Tabelle 2.
Übersicht über die Projektteile. In Spalte 7a ist die Zuordnung des Projektteiles nach dem Code des statistischen Zentralamtes anzugeben

Projektteil Nr.	Titel	Forsch.Richtg. Code St.ZA.	Leiter	Seiten-Nr. Antrag
6	7	7a	8	9
0	Coordination and Service Project		Langer Ulrich	51
1	Proving and Solving in General Domains	1111	Buchberger Bruno	67
2	Proving and Solving over Reals	1111	Hong Hoon	111
3	Symbolic-Numerical Computation on Algebraic Curves and Surfaces	1107	Winkler Franz	141
4	Symbolic Summation and Combinatorial Identities	1120/1111	Paule Peter	171
5	Coupled Field Problems: Advanced Numerical Methods and Applications to Nonlinear Magnetomechanical Systems	2215/1114	Langer Ulrich	200
6	Navier-Stokes Solver	1114	Zulehner Walter	228
7	Large Scale Inverse Problems	1114	Engl Heinz	248
8	Hierarchical Methods for Simulation and Optimal Design with Applications to Magnetic Field Problems	1114/1121	Langer Ulrich	272
9	Estimation of Discontinuous Parameters in Differential Equations	1114	Scherzer Otmar	298
10	Structural Dynamics of Elasto-Plastic Multi-Body Systems: Integrated Symbolic and Numerical Computations	2212	Irschik Hans	318
11				350
12	Sophisticated Data Distribution Systems	1108	Volkert Jens	351
13	High Performance Visualization for High Dimensional Data	1108	Volkert Jens	375

Tabelle 3
Übersicht über im letzten Bewilligungszeitraum geförderten Projekte, deren Weiterführung nicht beabsichtigt ist

Projektteil Nr.	Titel	Forsch.Richtg. Code Stat.ZA.	Leiter
10	11	11a	12

Tabelle 4
Verzeichnis der laufenden Diplomarbeiten und Dissertationen auf dem Gebiet des Forschungsprogrammes nach Projektteilen

Projektteil	Name, Vorname	akad. Grad	Thema	FB/ST/WK/66% DV
13	14	14a	15	16
1	Kriftner, Franz		Formalization of Mathematical Language	
1	Podisor, Ovidiu	Dipl.-Ing.	Polymorphic Languages	
1	Pollack, Robert		Proving in Polynomial Domains	
1	Tomuta, Elena	Dipl.-Ing.	Functor Proving	
1	Vasaru, Daniela	Dipl.-Ing.	Inductive Proving	
3	Aigner, Klaus		Symbolic Computation of and with Offset Curves	
3	Hillgarter, Erik	Dipl.-Ing.	Rational Points on Conics	
3	Mnuk, Michal	Dr.	Algebraic and Geometric Approach to Parametrization of Rational Curves	
3	Stadelmeyer, Peter	Dipl.-Ing.	Puiseux Series - A Fast Method in Computer Aided Geometry	
3	Tran, Quoc-Nam	Dr.	A Hybrid Symbolic-Numerical Approach in Computer Aided Geometric Design and Visualization	
4	Mallinger, Christian	Dipl.-Ing.	Algorithmic Manipulations and Transformations of Univariate Holonomic Functions and Sequences	
4	Nemes, Istvan	Dipl.-Ing.	Difference Equations	ST
4	Riese, Axel	Dipl.-Ing.	q-Hypergeometric Summation	
4	Wegschaider, Kurt	Dipl.-Ing.	Computer-generated Proofs of Binomial Multi-Sum Identities	
5, 6, 8, 12	Kickinger, Ferdinand	Dipl.-Ing.	Tools for the Numerical Simulation of 3D Magnetic Field Problems: Construction, Analysis and C++ Implementation	66% DV
5, 6	Schöberl, Joachim	Dipl.-Ing.	Analysis and Realization of Mixed Finite Element Models in Computational Mechanics	DV
7	Radmoser, Esther	Dipl.-Ing.	Über einige inverse Probleme bei der Stahlerzeugung	66% DV
7	Stangl, Christoph	Dipl.-Ing. Dr.	Optimal Sizing for a Class of Nonlinearly Elastic Materials	

Tabelle 4
Fortsetzung

Projektteil	Name, Vorname	akad. Grad	Thema	FB/ST/WK/66% DV
13	14	14a	15	16
7, 9	Attwenger, Klaus	Dipl.-Ing.	Landweber Iteration for the Solution of Nonlinear Ill-Posed Problems	
7, 9	Blaschke, Barbara	Dipl.-Ing. Dr.	Some Newton type Methods for the Regularization of Nonlinear Ill-Posed Problems	DV
7, 9	Hohage, Thorsten	Dipl.-Math.	Konvergenzanalyse von iterativen Algorithmen bei nichtlinearen inkorrekt gestellten Problemen	66% DV
7, 9	Kindermann, Stefan	Dipl.-Ing.	On the Applicability of Nonlinear Regularization Methods to Thermal Tomography	66% DV
7, 9	Seidel, Alexander	Dipl.-Ing.	Tikhonov Regularisierung für lineare inkorrekt gestellte Probleme in Räumen gemischt diskret-kontinuierlicher Funktionen	
8	Hauser, Klemens		Auslegung von elektrischen Maschinen	
8	Maringer, Robert		Temperaturfeldsimulation und optimale Parameter-auslegung für TWD-Gebäudefassaden	
10	Baldinger, Martin	Dipl.-Ing.	Parametererregte Schwingungen schubelastischer Platten	
10	Blumenschein, Siegfried		Berechnung der Temperatur und Spannungsverteilung in Zylinderköpfen	
10	Handsteiner, Martin		Schwingungsentkoppelung für elektrodynamisch erregte Schwingförderer	
10	Lehner, Christian		Berechnung nichtlinearer Balken mittels Modalanalyse stückweise linearer Systeme	
10	Nelböck, Günter		Simulation eines Antriebsstranges mit einem stufen-losen Getriebemodell	
10	Niederhauser, Dieter		Lokale Schwingungen in komplexen Konstruktionen	
10	Puchner, Klaus		Ermittlung der Wechselwirkung zwischen mechanischen Systemen zuf. Stoßvorgänge	
10	Werner, Andreas		Leistungssteigerung von elektrodynamisch erregten Schwingförderern	

Tabelle 5
Verzeichnis der Forschungsvorhaben, an denen Wissenschaftler des SFB mitarbeiten und die in anderen Verfahren des FWF oder von anderen Förderungsträgern in Österreich gefördert werden

Projekttitel	Bezug zu Projektteil(en)	Name des/der beteiligten WissenschaftlerInnen	Aktenz. (P.-Nr.) od. Antragsdat.	Förderungs-träger
17	18	19	20	20a
A Hybrid Symbolic-Numerical Approach in CAGD	3	Winkler, Franz Tran, Quoc-Nam	P11160-TEC	FWF
Gebietszerlegungsmethoden in der Struktur-mechanik	5, 6	Langer, Ulrich	P10643-TEC	FWF
AUTOGEN	5, 6	Langer, Ulrich	beantragt (12.02.1997)	FFF
Parallel 3D Magnetic Field Computation Nonlinear	5, 8	Langer, Ulrich	P 11215-TEC	FWF
Ill-posed Problems	7, 9	Engl, Heinz	P 10866-TEC	FWF
Mechanics of Smart Structures	10	Irschik, Hans	P11993-TEC	FWF

Tabelle 6
Übersicht über Forschungsarbeiten auf dem Gebiet des SFB, die unter Beteiligung von Mitarbeitern durch Inanspruchnahme von unter Tab.4 nicht angeführten Förderungsträgern durchgeführt werden

Projekttitel	Bezug zu Projektteil(en)	Name des/der beteiligten WissenschaftlerInnen	Aktenz. (P.-Nr) od.Antragsdat.	Förderungs-träger
21	22	23	24	24a

4 Survey of Previous and Requested (Future) Funds

4.1 Übersicht über die dem SFB im letzten Bewilligungszeitraum zur Verfügung gestellten Mittel

See Table 7.

4.2 Zahl der im laufenden Jahr aus der Grundausstattung der Forschungsstätten für den SFB zur Verfügung stehenden Personalstellen

See Table 8.

4.3 Zahl der MitarbeiterInnen, die für das laufende Jahr aus Mitteln der Ergänzungsausstattung bewilligt worden sind

See Table 9.

4.4 Zahl der MitarbeiterInnen, für die Mittel aus der Ergänzungsausstattung im Antragszeitraum für den SFB beantragt werden

See Table 10.

4.5 Übersicht über die aus der Ergänzungsausstattung im Antragszeitraum für den SFB beantragten Sachmittel

See Table 11.

4.6 Liste der Geräte über ÖS 100.000,– (inkl. Mwst.), die dem SFB aus Mitteln des FWF zur Verfügung stehen

See Table 12.

4.7 Liste der Geräte über ÖS 100.000,– (inkl. Mwst.), die dem SFB aus Mitteln der Grundausstattung zur Verfügung stehen

See Table 13.

4.8 Liste der Geräte über ÖS 100.000,– (inkl. Mwst.), die aus Mitteln der Ergänzungsausstattung im Antragszeitraum des SFB beantragt werden

See Table 14.

4.9 Liste der Geräte zwischen ÖS 10.000,– und ÖS 100.000,– (inkl. Mwst.), die an den Forschungsstätten vorhanden sind, aber für die im SFB gleichartige Geräte aus Mitteln der Ergänzungsausstattung im Antragszeitraum des SFB beantragt werden

See Table 15.

4.10 Tables 7 - 15

Tabelle 7
Übersicht über die dem SFB im letzten Bewilligungszeitraum zur Verfügung gestellten Mittel, sowie des Ansatzes für das laufende Jahr und die für den nächsten Antragszeitraum beantragten Mittel

Grundausstattung Hochschule

Jahre	PeK in kS	o.Dot. in kS	a.o.Dot. in kS	Großgeräte > 1.5.Mio.ÖS	SoK	Summe
25	26	27	28	29	30	31
bisher						
-3						
-2						
-1	3.821.000	1.204.000	1.062.000			6.087.000
Summe	3.821.000	1.204.000	1.062.000			6.087.000
beantragt						
1	3.821.000	1.204.000	1.062.000			6.087.000
2	3.821.000	1.204.000	1.062.000			6.087.000
3	3.821.000	1.204.000	1.062.000			6.087.000
Summe	11.463.000	3.612.000	3.186.000			18.261.000

Grundausstattung außeruniv. Forschungseinrichtungen							
Jahre	PeK in kS	MaK	ReK	GeK	SoK gesamt	SoK für WV	Summe
25	33a	33a	33b	34	35a	35b	36
bisher -3 -2 -1 Summe							
beantragt 1 2 3 Summe							

Drittmittel							
Jahre	PeK in kS	MaK	ReK	GeK	SoK gesamt	SoK für WV	Summe
25	37	38a	38b	39	40	41	42
bisher -3 -2 -1 Summe							
beantragt 1 2 3 Summe							

Ergänzungsausstattung							
Jahre	PeK in kS	MaK	ReK	GeK	SoK gesamt	SoK für WV	Summe
25	43	44	45	46	47	48	49
bisher							
-3							
-2							
-1							
Summe							
beantragt							
1	15.142.000	220.000	800.000	5.499.000	1.550.000		23.211.000
2	15.306.000	220.000	800.000	2.650.000	1.350.000		20.326.000
3	15.470.000	220.000	800.000	30.000	1.250.000		17.770.000
Summe	45.918.000	660.000	2.400.000	8.179.000	4.150.000		61.307.000

Tabelle 8
Aufschlüsselung der Gesamtarbeitszeit, die dem SFB aus der Grundausstattung der Forschungsstätte(n)zur Verfügung gestellt wird.

Mitarbeiter	Arbeitszeit in %				Summe Sp. 51-54	Anzahl der beteiligten Mitarbeiter
50	51	52	53	54	55	56
	25	50	75	100		
Prof.	65%	70%	55%		190%	6
Ass.Prof.	120%				120%	5
Univ.Ass.	130%	35%			165%	10
Mag./DI						
MTA						
MTF						
CTA						
TA						
Ingenieur						
Mechaniker						
Laborant						
Summe	315%	105%	55%		475%	21

Tabelle 9
Aufschlüsselung der Mitarbeiter (Gesamtarbeitszeit), die dem SFB aus der Ergänzungsausstattung im laufenden Jahr bewilligt worden sind (in % DV)

Projektteil	wissenschaftliche Mitarbeiter								Summe der Mitarbeiter	
	V.Ass.		Mag./ DI		FB Mag./DI		FB Diplom.			
57	58	58a	59	59a	60	60a	61	61a	62	62a
1										
2										
.										
.										
.										
n										

Projektteil	nichtwissenschaftliche Mitarbeiter						Summe der Mitarbeiter	
	CTA		MTA/MTF		TEC			
57	63	63a	64	64a	65	65a	66	66a
1								
2								
.								
.								
.								
n								

Tabelle 10
Aufschlüsselung der Mitarbeiter (Gesamtarbeitszeit), die für die Antragsperiode beantragt werden (in % DV)

1.Jahr

Projektteil	wissenschaftliche Mitarbeiter				Summe der Mitarbeiter	nichtwissenschaftliche Mitarbeiter			Summe der Mitarbeiter
	V.Ass.	Mag./ DI	FB Mag./DI	FB Diplom.		Sekretär(in)	MTA/MTF	TEC	
67	68	69	70	71	72	73	74	75	76
0	200%				200%	100%			100%
1	100%	200%			300%				
2	100%	200%			300%				
3	100%	200%			300%				
4	100%	200%			300%				
5	100%	200%		200%	500%				
6	100%	200%			300%				
7	100%	200%		200%	500%				
8		200%		200%	400%				
9	100%	200%			300%				
10	100%	200%			300%				
11									
12	200%	100%			300%				
13	100%	200%			300%				

Tabelle 10
Fortsetzung

2.Jahr

Projektteil	wissenschaftliche Mitarbeiter				Summe der Mitarbeiter	nichtwissenschaftliche Mitarbeiter			Summe der Mitarbeiter
	V.Ass.	Mag./ DI	FB Mag./DI	FB Diplom.		Sekretär(in)	MTA/MTF	TEC	
67	68	69	70	71	72	73	74	75	76
0	200%				200%	100%			100%
1	100%	200%			300%				
2	100%	200%			300%				
3	100%	200%			300%				
4	100%	200%			300%				
5	100%	200%		200%	500%				
6	100%	200%			300%				
7	200%	100%		200%	500%				
8		200%		200%	400%				
9	100%	200%			300%				
10	100%	200%			300%				
11									
12	200%	100%			300%				
13	100%	200%			300%				

Tabelle 10
Fortsetzung

3.Jahr

Projektteil	wissenschaftliche Mitarbeiter				Summe der Mitarbeiter	nichtwissenschaftliche Mitarbeiter			Summe der Mitarbeiter
	V.Ass.	Mag./ DI	FB Mag./DI	FB Diplom.		Sekretär(in)	MTA/MTF	TEC	
67	68	69	70	71	72	73	74	75	76
0	200%				200%	100%			100%
1	100%	200%			300%				
2	100%	200%			300%				
3	100%	200%			300%				
4	100%	200%			300%				
5	100%	200%		200%	500%				
6	100%	200%			300%				
7	300%			200%	500%				
8		200%		200%	400%				
9	100%	200%			300%				
10	100%	200%			300%				
11									
12	200%	100%			300%				
13	100%	200%			300%				

Tabelle 11
Übersicht über die aus Mitteln der Ergänzungsausstattung für die Antragsperiode beantragten Sachmittel

1.Jahr

Projektteil	Geräte >100.000 ÖS	Geräte <100.000 ÖS	Material-kosten	Reise-kosten	sonstige Kosten	Werk-verträge	Summe
77	78	79	80	81	82	83	84
0	100.000	180.000	100.000	500.000	1.500.000		2.380.000
1	300.000	70.000	10.000	25.000			405.000
2		140.000	10.000	25.000			175.000
3	600.000	70.000	10.000	25.000			705.000
4		140.000	10.000	25.000			175.000
5	409.117	140.000	10.000	25.000			584.117
6	300.000	140.000	10.000	25.000			475.000
7	500.000	140.000	10.000	25.000			675.000
8	100.000	70.000	10.000	25.000			205.000
9		210.000	10.000	25.000			245.000
10	400.000	140.000	10.000	25.000			575.000
11							0
12	400.000	140.000	10.000	25.000			575.000
13	600.000	210.000	10.000	25.000	50.000		895.000
Gesamtsumme	3.709.117	1.790.000	220.000	800.000	1.550.000		8.069.117
Veränderung gegenüber Bewilligung letztes Jahr							

Tabelle 11
Fortsetzung

2.Jahr

Projektteil	Geräte >100.000 ÖS	Geräte <100.000 ÖS	Material-kosten	Reise-kosten	sonstige Kosten	Werk-verträge	Summe
77	78	79	80	81	82	83	84
0	2.100.000	250.000	100.000	500.000	1.300.000		4.250.000
1			10.000	25.000			35.000
2			10.000	25.000			35.000
3			10.000	25.000			35.000
4			10.000	25.000			35.000
5	300.000		10.000	25.000			335.000
6			10.000	25.000			35.000
7			10.000	25.000			35.000
8			10.000	25.000			35.000
9			10.000	25.000			35.000
10			10.000	25.000			35.000
11							0
12			10.000	25.000			35.000
13			10.000	25.000	50.000		85.000
Gesamtsumme	2.400.000	250.000	220.000	800.000	1.350.000		5.020.000
Veränderung gegenüber Antrag letztes Jahr							

Tabelle 11
Fortsetzung

3.Jahr

Projektteil	Geräte >100.000 ÖS	Geräte <100.000 ÖS	Material-kosten	Reise-kosten	sonstige Kosten	Werk-verträge	Summe
77	78	79	80	81	82	83	84
0		30.000	100.000	500.000	1.200.000		1.830.000
1			10.000	25.000			35.000
2			10.000	25.000			35.000
3			10.000	25.000			35.000
4			10.000	25.000			35.000
5			10.000	25.000			35.000
6			10.000	25.000			35.000
7			10.000	25.000			35.000
8			10.000	25.000			35.000
9			10.000	25.000			35.000
10			10.000	25.000			35.000
11							0
12			10.000	25.000			35.000
13			10.000	25.000	50.000		85.000
Gesamtsumme		30.000	220.000	800.000	1.250.000		2.300.000
Veränderung gegenüber Antrag letztes Jahr							

Tabelle 12
Liste der Geräte über ÖS 100.000,00 (inkl. MWST) Anschaffungswert, die dem SFB aus FWF-Mitteln zur Verfügung stehen (bzw. deren Anschaffung aufgrund bereits erfolgter Bewilligungen beabsichtigt ist)

Gerätebezeichnung	Code	Anschaffg. Jahr	Anschaffg. Preis (inkl. MWST)	Einsatz in Projektteil(en)
85	86	87	88	89
Decstation 5200		1993	198.000	2
SUN Sparcstation 10		1993	215.000	3
SUN ULTRA SPARC		1996	257.601	3
Apollo DN		1990	306.000	4
Workstation DN 4500		1990	296.354	4
SUN ULTRA 170E Creator3D, 4 GB		1996	304.000	5, 8, 12
SUN ULTRA 170, 320 MB, 4GB		1996	330.000	5, 7
Alpha Station 500, 192 MB		1996	350.345	9

Tabelle 13
Liste der Geräte über ÖS 100.000,00 (inkl. MWST) Anschaffungswert, die dem SFB aus Mitteln der Grundausstattung zur Verfügung stehen (bzw. deren Anschaffung aus Mitteln der Grundausstattung, bzw. durch Drittmittel beabsichtigt ist)

Gerätebezeichnung	Code (allenfalls)	Anschaffg. Jahr	Anschaffg. Preis (inkl. MWST)	Einsatz in Projektteil(en)
90	91	92	93	94
SUN 10/51, 96 MB		1993	280.000	8, 12
Parsytec Power Xplorer, 16 x PowerPC 601 mit je 32 MB		1994	1.400.000	8, 12
HP Apollo 735 CRX		1992	545.000	10
HP Apollo 730		1992	454.000	10
HP Apollo 720		1992	370.000	10
HP Apollo 715/50		1993	174.000	10
HP Apollo 700/RX X-Terminal		1993	120.000	10
HP Apollo 700/RX X-Terminal		1993	120.000	10
SGI Indigo R3000, 32 MB, 1 GB		1993	298.552	13
SUN 4 SPARC 2, 64 MB, 4 GB		1992	271.060	13

Tabelle 14
Liste der Geräte über ÖS 100.000,00 (inkl. MWST) Anschaffungswert, die aus Mitteln der Ergänzungsausstattung für die Antragsperiode beantragt sind

Gerätebezeichnung	Code	Anschaffg. Jahr	Anschaffg. Preis (inkl.MWST)	Einsatz in Projektteil(en)
95	96	97	98	99
SGI Origin 2000, 4xR10000, 1 GB Memory, 4.5 GB HD		1999	2.100.000	0-13
SGI O2, R5000SC, 128 MB, 2 GB, 17"		1998	100.000	0
SGI Octane, SI Grafik, 128 MB, 2 GB		1998	400.000	5, 6, 8, 12
SGI Indigo2, R10000, 256 MB, 2 GB		1998	300.000	6
SGI Indigo2, R10000, 256 MB, 2 GB		1999	300.000	5
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	5
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	6
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	8
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	12
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	5, 8
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	12
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	6
SGI Octane, SSI-Grafik, 256 MB,4 GB		1998	600.000	3, 4
SGI Indigo2, R10000, 256 MB, 2 GB		1998	300.000	1, 2
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	1
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	2
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	3
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	4
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	1, 2
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	3 ,4

Tabelle 14
Fortsetzung

Gerätebezeichnung	Code	Anschaffg. Jahr	Anschaffg. Preis (inkl.MWST)	Einsatz in Projektteil(en)
95	96	97	98	99
SGI Octane, R10000, 256 MB, 4 GB		1998	500.000	7, 9
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	7
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	7
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	7
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	9
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	9
SGI Octane, SSI-Grafik, 256 MB, 4 GB		1998	600.000	10, 13
SGI Octane, R10000, 256 MB, 2 GB		1998	400.000	10
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	10
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	10
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	13
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	13
SGI O2, R5000PC, 64 MB, 2 GB, 17"		1998	70.000	13
Farblaserdrucker		1999	100.000	0-13
Speichererweiterung 384 MB		1998	100.000	8
Meßtechnik		1998	409.117	5

Tabelle 15
Liste der Geräte zwischen ÖS 10.000,00 und 100.000,00 (inkl. MWST) Anschaffungswert, die an der Forschungsstätte (den Forschungsstätten) vorhanden sind, aber für die im SFB gleichartige Geräte aus Mitteln der Ergänzungsausstattung beantragt werden.

Gerätebezeichnung	Code	Anschaffg. Jahr	Anschaffg. Preis (inkl. MWST)	Einsatz in Projektteil(en)
100	101	102	103	104
s/w Laserdrucker		1998	30.000	1, 2, 3, 4
s/w Laserdrucker		1998	30.000	5, 6, 7, 8, 9
s/w Laserdrucker		1998	30.000	10, 11, 12, 13

Project 0: Coordination and Service Project

5.1 General Information

Title : Coordination and Service Project

Speaker : Univ.-Prof. Dr. Ulrich Langer
Institute of Mathematics
Johannes Kepler University Linz

Co-speaker : Univ.-Prof. Dr. Dr.h.c. Bruno Buchberger
Research Institute for Symbolic Computation
Johannes Kepler University Linz

5.2 Management Overview

The SFB will certainly be successful only if its activities are effectively coordinated, with a focus on the all-important goal of achieving synergy of the participating research groups. This project is the instrument for organizing and managing the SFB, and provides the service for the hardware and software. The organization structure of the SFB, as described in a separate document (Ordnung für den SFB) in Section 6, which is part of this proposal, fully supports this goal. The designated Speaker of the SFB is Professor Ulrich Langer, Head of the Department for Numerical Mathematics and Optimization, Institute for Mathematics, Johannes Kepler University Linz, and the designated Co-Speaker of the SFB is Professor Bruno Buchberger, Head of the Research Institute for Symbolic Computation (RISC), Johannes Kepler University Linz. The Speaker, the Co-Speaker, and their institutes have considerable experience in managing large projects. They will be supported by a Secretary, a System Engineer and Research Assistant funded by the SFB (see Subsection 5.3, 5.4 and 5.5 respectively). The SFB management includes the following responsibilities for coordination and service:

- Technical and administrative coordination of all project activities.
- Cost controlling: The Finance Commissioner, who can be incorporated into the Executive Board (see Ordnung), will be responsible for the cost control.
- Organization of Meetings, Seminars, Lectures, Workshops and Conferences:
  - At least two **Plenary SFB Meetings** per year.
    All members of the SFB are required to take part in these meetings. One of these meetings will organized in conjunction with the International Annual SFB Workshop (see below).
  - **International Annual SFB Workshop.**
    This workshop will be a focus for an exchange of information between the participants in the SFB and other researchers working on the topics of the SFB. The responsibility for the organization of International Annual SFB Workshop will be delegated to one of the research groups participating in the SFB in dependence of the topics of the workshop. The SFB secretary provides the organizational support.
  - **SFB Colloquium.**
    The SFB Colloquium will mainly offer talks of invited external speakers on the main topics of the SFB. The coordination of the SFB Colloquium will be delegated to a member of the SFB council.
  - **SFB Seminar.**
    The internal SFB Seminar will focus on the scientific communication within the SFB. All members of the projects are required to participate in the seminar. The coordination of the SFB Seminar will be delegated to a member of the SFB council.

  - **Technical Meetings and Internal Workshops.**
    The SFB secretary provides the support for the organization.
  - **Lectures and Courses.**
    The SFB will also invite visiting scientists for giving special lectures and courses on SFB topics, especially, for the young scientists (Ph.D. students and postdocs).

- Coordination of the guest programme.
- Coordination of the travelling activities.
- Administration of the central resources.
- Maintaining the software and the hardware for the SFB.
- Coordinating and supporting the software development (standards, interfaces etc.).
- Maintaining the home page of the SFB.
- Definition of standards for deliverables and reports.
- Maintaining the Technical Report Series of the SFB.

5.3 SFB Secretary

For the administration of the SFB, including the book-keeping of finances, the administration of work contracts, dealing with the authorities in matters concerning foreign co-workers, taking care of visiting scientists including seminar speakers, administration care of new personnel, communication with collaborating institutions in- and outside Austria, etc., etc., a funded position for

1 secretary

is requested. Since the person to be hired must be fluent in English (writing and speaking), possess management and book-keeping skills, and be able to work highly independently and accept responsibility, funds equivalent to the VB I/b level, i.e.

ATS 350.000,– per year

are requested.

In addition, a net-capable personal computer provided with the appropriate software, and a postscript-capable laser printer are needed for the SFB office. For this equipment, funds of

ATS 50.000,–

are requested.

As running costs for the secretary's office (materials, copying, toner, diskettes, postage, telefon, fax, etc.)

ATS 50.000,– per year

are requested.

The office of the SFB will be located at the institution where we are going to rent offices for the SFB.

5.4 Hardware, Software and Technical Service for the SFB

A funded position for

1 Postdoctoral System Engineer

is requested. The system engineer is absolutely necessary for maintaining central hardware and software resources, for coordinating the software updates etc., especially, due to the fact that the research groups participating in the SFB are distributed over three locations (Linz/Auhof, Linz/Vöst, and Hagenberg). Since the person to be hired must have an excellent knowledge in both theoretical and technical informatics, funds equivalent to the VB I/a level, i.e.

ATS 492.000,– per year

are requested.

We request funds for procuring the following central hardware and software resources for the first period (3 years):

- **Number Cruncher: 2.100.000,– ATS**
  For the symbolic and/or numerical solution of large scale problems in the projects we need a computer with a high floating point performance and at least 1GByte main memory. Additionally, this computer will be used as a single processor machine as well as a parallel machine.
  The most promising development at the moment is the *Origin 2000* by Silicon Graphics including the S^2MP concept (Symmetric Scalable Multi-Processing), i.e., the parallel machine may run in distributed or in shared memory mode and is also available as a single processor machine using the whole memory. This offers a wide range of methods applied in solving the most challanging problems of the projects.
  In combination with the local workstations (SGI) one may develop algorithms on smaller problems and run the larger jobs on the Number Cruncher. Although there exists already a 16 processor *Origin 2000* at the Computer Center of the University Linz (partially for commercial use) we need a separate one because the development of parallel algorithms and especially the simulation require exclusive access. The price above is equivalent to an *Origin 2000* with 4 processors and 1GByte memory.

- **Workstation SGI O2 (SC, 20") : 100.000,– ATS**
  This workstation provides the working place for the system administration.

- **Software (for all projects): 700.000,– ATS**
  For the efficient program development, each workstation needs the full program development tools offered by the distributers. Including updates, this request 200.000,– ATS in the first period.
  For visualization purposes several professional visualization tools are needed, e.g., *Iris Explorer*, *AVS*, *Exponent Graphics*. The computer algebra packages *Mathematica*, *Maple* are a basis for the symbolic computation. Additionally, some standard numerical packages like the NAG Compiler/Library or *IMSL* are needed. For comparison of results and for benchmarking we need temporarily a license of some professional FE-package like *NASTRAN*, *MARK* or comparable. The costs are approximately 500.000,– ATS.

- **3 (b/w) laser printers á 30.000,– ATS: 90.000,– ATS**
  In sum 40 people will be involved directly in the projects, not counted the additional staff from the university working partially therein. For documentation, program development, access of literature some printer capabilities are neccessary. The whole project can be roughly clustered into 3 main project groups, each of them will need a separate laser printer. Taking into account the importent role of graphics we need printers with at least 4MB memory.

- **1 colour laser printer: 100.000,– ATS**
  For the analysis, interpretation and presentation of 2D-, and especially 3D-, calculations a colour presentation of the results is absolutely urgent. Therefore, a colour laser printer able to print on paper as well as on tranparencies is needed.
- **1 colour scanner: 30.000,– ATS**
  There is a need to scan technical descriptions, engineering drawings and images for further use in the projects and for an advanced presentation of those projects.
- **1 copy device: 70.000,– ATS**
  The SFB needs a separate copy device, because the SFB offices will be located away from the university.
- **Laptop: 50.000,– ATS**
  For presentation purposes.
- **LCD-Data-Projector: 70.000,– ATS**
  For presentation purposes, especially computer and video demonstrations.

As running costs for the technical equipment (materials, toner, diskettes, service of computers, telefon hotline, etc.)

ATS 50.000,– per year

are requested.

5.5 Scientific Service for the SFB

The SFB applies for a funded position of

1 Research Assistant (Postdoc),

i.e. funds of

ATS 492.000,– per year

are requested. The resarch assistent has to coordinate the cooperation within the SFB. This concerns mainly the scientific aspects of the cooperation, but also scientific documentation (WWW etc.) and some organizing aspects.

5.6 Expenses for Visiting Scientists and External Speakers

For the invitation of lecturers and visiting scientists, we request funds of

ATS 500.000,– per year.

These funds will be distributed by the executive board upon application by SFB participants.

5.7 Travel Support for SFB Participants

A relatively small budget (ATS 25.000,– per year) has been proposed for each project to cover local travel (within Austria and adjoining countries). In addition to this, we request funds of

ATS 500.000,– per year.

for the participation of the SFB co-workers including senior graduate students in international conferences and in scientific meetings with our external partners. These funds will be again distributed by the executive board upon application by SFB participants.

5.8 Special SFB Funds (Katastrophenfonds)

We request funds of

ATS 500.000,– per year.

for supporting special events and unforeseeable expenses, such as special infrastructure investments, transport costs, computer services, repairing equipment etc.

5.9 Special Literature

We request funds of

ATS 100.000,– per year.

for special literature needed in the projects.

5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 0
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.334.000	280.000	100.000	500.000		1.500.000		3.714.000
2	1.334.000	2.350.000	100.000	500.000		1.300.000		5.584.000
3	1.334.000	30.000	100.000	500.000		1.200.000		3.164.000
Summe	4.002.000	2.660.000	300.000	1.500.000		4.000.000		12.462.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 0

Grundausstattung

Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Langer Ulrich, Dr. O.Univ.-Prof.	Numerische Mathematik und Optimierung	Mathematik	25%		zu Beginn	Univ.-Prof.	voll
Buchberger Bruno, DDr. O.Univ.-Prof.	Symbolisches Rechnen	RISC	5%		zu Beginn	Univ.-Prof.	voll
Lindner Ewald, Dipl.-Ing. Dr.	Numerische Mathematik und Optimierung	Mathematik	10%		zu Beginn	Univ.-Ass.	voll
Haase Gundolf, Dipl.-Ing. Dr.	Numerische Mathematik und Optimierung	Mathematik	5%		zu Beginn	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals
für Projektteil 0

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Wissenschaftliches Rechnen	Mathematik	100%		1.Jahr	PostDoc	voll
	100%	1	N.N., Dr.	Systemmanager	Mathematik	100%		1. Jahr	PostDoc	voll
Mag./DI										
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Sekretär(in)	100%	1	N.N.		Mathematik	100%		1.Jahr	DV	voll
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Wissenschaftliches Rechnen	Mathematik	100%		1. Jahr	PostDoc	voll
	100%	1	N.N., Dr.	Systemmanager	Mathematik	100%		1. Jahr	PostDoc	voll
Mag./DI										
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Sekretär(in)	100%	1	N.N.		Mathematik	100%		1.Jahr	DV	voll
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Wissenschaftliches Rechnen	Mathematik	100%		1. Jahr	PostDoc	voll
	100%	1	N.N., Dr.	Systemmanager	Mathematik	100%		1. Jahr	PostDoc	voll
Mag./DI										
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Sekretär(in)	100%	1	N.N.		Mathematik	100%		1.Jahr	DV	voll
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 0

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
	133a	133b	133c	134	134a	134b	134c
Workstation OS2	100.000		SFB	PC (Sekretariat)	50.000		SFB/Mathematik
				Laserdrucker (s/w)	30.000		SFB
				Farbscanner	30.000		SFB
				Kopierer	70.000		SFB
Summe	100.000			Summe	180.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Origin 2000, 4xR10000, 1 GB Memory, 4.5 GB HD	2.100.000		SFB	Laserdrucker (s/w)	30.000		SFB
				Laserdrucker (colour)	100.000		SFB
				Laptop	50.000		SFB
				LCD-Daten-Projektor	70.000		SFB
Summe	2.100.000			Summe	250.000		

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
				Laserdrucker (s/w)	30.000		SFB
Summe				Summe	30.000		

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 0

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
Verbrauchsmaterial Sekretariat	50.000	Konferenzbesuche (zentral)	500.000	Besucher	500.000		
				SFB-Spezialfonds	500.000		
Verbrauchsmaterial Service	50.000			Software (für alle Projekte)	400.000		
				Literatur (für alle Projekte)	100.000		
Summe	100.000	Summe	500.000	Summe	1.500.000	Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
Verbrauchsmaterial Sekretariat	50.000	Konferenzbesuche (zentral)	500.000	Besucher	500.000		
				SFB-Spezialfonds	500.000		
Verbrauchsmaterial Service	50.000			Software (für alle Projekte)	200.000		
				Literatur (für alle Projekte)	100.000		
Summe	100.000	Summe	500.000	Summe	1.300.000	Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
Verbrauchsmaterial Sekretariat	50.000	Konferenzbesuche (zentral)	500.000	Besucher	500.000		
				SFB-Spezialfonds	500.000		
Verbrauchsmaterial Service	50.000			Software (für alle Projekte)	100.000		
				Literatur (für alle Projekte)	100.000		
Summe	100.000	Summe	500.000	Summe	1.200.000	Summe	

Project 1: Solving and Proving in General Domains

5.1 General Information

Title : Solving and Proving in General Domains

Field of research : Symbolic Computation

Principal investigator : Univ.-Prof. Dr. Dr.h.c. Bruno Buchberger
Research Institute for Symbolic Computation
Johannes Kepler University Linz

5.2 Abstract

The goal of this subproject is to design and implement an automatic theorem prover in natural deduction style, for the use of the working mathematician. This prover will be an interactive tool both for

- presentation of mathematical knowledge and
- developing mathematical knowledge

in the form of

- theorems and their (interactive) proofs and
- algorithms and their behavior.

The prover will integrate, for the first time, the three essential ingredients of mathematics: proving, solving and computing. It will build upon the intimate relationship between mathematical theories and mathematical algorithms.

This goal will be achieved by further developing the existing techniques for automatic proving, but shifting the focus from the built-in "black-box" engine style to a "white-box" open style, in which the user can easily visualize and understand the proof at the desired level of detail, can locate reasons of failure, can interact and guide the proof steps - and finally can obtain the proofs exactly in the form in which they can be included into papers, lecture notes, etc.

Moreover, by using a particular functor based approach, the new system will be able to assist the user in the routine parts of building new mathematical theories and algorithms, in the same natural style in which human mathematicians work. This functor based approach will allow the prover to incorporate and use proving techniques which are specific to each mathematical domain.

Also, the system will be able to use advanced algorithms from specific areas of mathematics (e.g. algebraic algorithms, numerical algorithms, etc.) for solving queries related to those particular domains, hence it will also act as a front-end for the interface between the mathematician and various solving and computing software tools developed in the frame of the other subprojects.

5.3 State of the Art

The Integration of Computer Algebra and Theorem Proving The integration of computer algebra and theorem proving was and is one of the most important goals of the Journal of Symbolic Computation, see the editorial [20]. However, although in this journal both papers on computer algebra and theorem proving were published, the issue of integrating the power of computer algebra and of theorem proving in one system is addressed by authors only very recently [30, 94, 61].

The current situation is that, by the joint effort of groups both from academia and industry, we have

- wonderful systems for computer algebra (that often integrate numerical and graphical facilities) (for an overview see [8], [59] and [119]),

- and amazingly powerful systems for theorem proving (for an overview see [9], [62], [98]).

Computer algebra systems (or sometimes also called "symbolic computation systems" or simply "mathematical software systems") fall into two classes:

- general purpose computer algebra systems like Axiom, Derive, Macsyma, Maple, Mathematica, Reduce (that try to incorporate algorithms for a broad spectrum of mathematical areas), and
- special purpose computer algebra systems like MuPAD, Cayley (Algebra and Number Theory), Cocoa (Computations in Commutative Algebra using Groebner Bases), GAP (Groups and Discrete Structures), Magma (Group Theory), Macaulay (Algebraic Geometry and Commutative Algebra using Groebner Bases).

Theorem proving systems fall into the following classes:

- General theorem provers (for some version of predicate logic). Most of these provers are based on Robinson's (see [104]) resolution method. (For an overview on general theorem provers see [88], [89].)
- Special theorems provers that produce proofs for special areas of mathematics, in particular induction provers (for an overview on this area see [12], [80], [118]; also, see [111], [112] for an example of a special prover for set theory).
- Special "black-box" decision algorithms for special classes of formulae, notably decision algorithms that reduce the validity problem for these classes to algebraic problems, e.g. polynomial ideal membership, cylindrical algebraic decomposition, Cayley factorization etc.. (For an overview see [9].)

Only in recent years people have started to consider the integration of both the power of computer algebra and theorem proving into joined systems. It is natural that this can be done by starting "from either end of the tunnel":

- *Proving based approach*: One can start from a proving system and strive for gradually implementing mathematical algorithms into these systems.
- *Algebra based approach*: One can start from a computer algebra system and strive for gradually implementing proof-support into these systems.

The proving based approach is now being pursued, for example, in the following systems: Otter [93], Isabelle [97], NQTHM (Boyer-Moore [13]), HOL [67], Coq [74], Oyster-Clam [118], [71]), Nuprl ([55]), ΩMEGA [4], MIZAR [117], IMPS [60]. Some of the results are encouraging but it seems that there is still a long way to go for making such a system available to the working mathematician. The most advanced experiment in the direction we are interested is the current work within the Nuprl group: They work on implementing the part of mathematics necessary for formalizing the Groebner bases theory within the system, see [78]. Also, in the work of the group headed by P. Suppes, see [111], [112], quite remarkable progress was made on practical computer-aided theorem proving in the area of basic set theory and basis calculus.

The literature on the algebra based approach is extensively documented in K. Homann [70], particularly interesting work is done by the TASSO group (see e.g. [5]) and IMPS [60, 61], The emphasis of the groups that currently work on this approach is, however, on establishing software links between algebra and theorem proving systems whereas we are advocating the extension of existing computer algebra systems by proving potential within the system. A work that comes close to what we have in mind is [48]. In this paper, an extension of Mathematica by proving facilities in elementary calculus is described. However, a detailed analysis of this prover shows that, actually, it is not really doing proofs including the essential handling of quantifiers but, rather, it is doing rewriting with the elementary notions of calculus (like limit, derivative etc.) *after* certain rewrite rules have already been proved for these notions by a human.

We also should mention that, in preparation of our project, we installed all the systems that currently try to combine (part of) computer algebra and (part of) theorem proving and briefly mentioned above (notably Isabelle, Analytica, NQTHM, HOL, Coq, Oyster-Clam) in our lab in the frame of a seminar in summer semester 1996 and experimented with the systems in a systematic way so that their proving power could be compared. Summarizing, we obtained the impression that, depending on the class of formulae, some of these systems are quite strong but, still, there is a long way to go to make them practically interesting for the support of every-day mathematical routine proving.

We will now give more specific comments on the present state of the art. These comments will be grouped by the paragraphs headings used in the subsubsections on the objectives and methods of our project.

A General Formulation of the Objectives The most recent formulation of the objective of combining the strength of computer algebra and theorem proving is given in the TMR (Training and Mobility of Researchers - EU 4-th Frame Programme) proposal *"Calculemus - Systems for Integrated Computation and Deduction"*, see [76].

Specification and Implementation of a Mathematical Language A version of higher order predicate logic without extensionality that comes closest to what we need in our project is given in [74]. However, we want to add the concept of sequence variables right into the logic system in order to make the rewrite part of Mathematica a proper sublanguage of this logic. Also, set theory will be treated differently.

Mathematical Domains and Functors Functors in the way we consider it in this project are a basic construct in the ML language, see [96]. Our treatment of the carrier of the domain generated by a functor, however, is different and, in fact, more flexible. In the area of computer algebra, two prominent systems have based their design on a categorical view: Axiom and Magma.

Axiom, see [79], is a third generation computer algebra system, with a design concept based on abstract, parametrized datatypes and polymorphic programming. Axiom's abstract datatypes are called categories and are similar to categories in the mathematical sense. The system also provides concrete data types called domains.

The Magma system, see [44], is based on the concept of *magmas* which, roughly, are structures with a carrier set and one or more laws of composition. A set of magmas sharing a common representation and a common set of operations forms a *category.* At the roots of hierarchical trees are varieties. Functors are provided for moving from one variety to another.

Unlike the system we are designing neither Magma nor Axiom perform automated reasoning on the specifications of the algebraic structures they provide.

Proving in mathematical domains (introduced by definitions and axioms - but not using functors) was considered in [122], and the attempted solution is based on proof programming - the user has to provide a proof-program for each theorem. The IMPS group [61] considers proving in mathematical domains using the concepts of "theories" and "contexts". A theoretical taxonomy of mathematical domains and its applications for symbolic computation is presented in [87].

A General Prover for Higher-Order Predicate Logic In the systematics of logic calculi, our way of treating predicate logic is a combination of "sequent calculi" and "natural deduction": Our inference rules are basically sequent calculus rules, i.e. they describe the reduction of "proof situations" (sequents) to simpler situations. However, they way these rules are applied in the actual prover is in the spirit of natural deduction, i.e. in each proof step we compose a proof from partial proofs. Also, we do not strive for the minimality of the calculus but, rather, for a calculus that produces proofs that imitate typical proofs by humans as close as possible. In addition, we impose an order on the sequence in which the inference rules have to be applied.

For the sequent calculus and natural deduction, see for example [109], [90], [63], [116]. Although these calculae are complete, an efficient method for proof-searching (comparable to the resolution method for formulae in clausal form) is not yet known - thus the research proposed here has also a challenging long-term aspect. The method proposed by Gallier [63] (and later refined and implemented e.g. in [46, 45]) is basically scanning the Herbrand Universe. More efficient is the connection method of Bibel [6], which can be used for proof-search in sequent calculus as shown in [47].

Theorem provers built on sequent calculi or natural deduction are, for example: UT (see [8]), Jape (see [10]), Analytica (see [48]), the provers described in [52], [5], etc.

Provers Imitating Human Proof Techniques The question of "heuristics", i.e. the question of how to simulate "invention" in proving was heavily studied, see for example [7], [42]. However, the imitation of human proof techniques for the routine parts of the proofs in the various areas of mathematics was not so much pursued so far in the literature. The work we are aware of is [64], [111], [112], [118], [108], [4].

Natural-style proof production and presentation is also investigated in relation to proving program correctness - see TATAMI [66], SEAMLESS with CoGLay [57, 58], TAP with KIV [2, 102].

Quite some effort is directed into *transformation* of proofs into natural ones - see the sub-paragraph of proof simplification below. However, we follow the approach of generating a natural-style proof in the first place, which we think is more effective than trying to transform a non-natural (e.g. resolution) proof.

Special Black-Box Provers and Solvers The state of the art of the algebraic "solvers" available in the current mathematical software systems (for linear and non-linear systems of algebraic and transcendental equations and inequalities over the reals and complex numbers and for various classes of differential equations) is documented in the text books on computer algebra, see for example [10], [53], [65], [82], [119]. Most of these solvers are available in Mathematica (or in one of the Mathematica extension packages) anyway, so they are naturally available in the system we are going to develop.

In our project we will put more attention on a second class of "solvers" that emphasize the domain-dependent and universal algebra aspect. In this context, the notion of "solving" is basically identical with the notion of "unification" with respect to various (equational) theories. The search for "most general unifiers" is basically a search for the representation of "the most general solutions" of a general system of equations in the closed form of predicate logic terms. The techniques for solving such systems have been developed, over the past three decades in the "rewriting" and "functional logic programming" communities and are documented, for example, in the following books and survey articles: [1], [54], [69], [81]. These techniques will be re-implemented in our system because we need them both stand-alone but also as subalgorithms in the various special provers.

The black-box provers based on algebraic algorithms we have in mind are the following: provers for geometrical theorems based on Ritt's method of characteristic sets, see [120]; provers for geometrical theorems based on the Groebner bases method, see [85]; provers for the theory of real closed fields and related theories based on Collins' method and variants thereof, see the original article [20] and the literature survey in project P2 by H. Hong; provers for geometrical theorems based on Cayley factorization, see [110]; provers for combinatorial identities based on the Zeilberger approach (difference ideals by non-commutative Groebner bases), or Paule's approach (extending the Gosper algorithm by Greatest Common Factorization), see [123], [95] and the literature survey in project P4 of this SFB. These provers will be provided and extended in the projects P2, P3, and P4 of this SFB. We will access these solvers by linking them to our system using MathLink.

The Nature of Proofs Generated by the Functor-Based Provers In the literature, some consideration (but not sufficiently much) has been given to natural language and structured presentation of the proofs generated by automated theorem provers: [112], produces natural language proofs for the use of the prover in the classroom. Analytica uses a variant of natural deduction similar to the one developed by Bledsoe, see [8], at the University of Texas. The system generates LaTeX code for the (human-like) proofs produced. Interaction with the Coq system is done through the CtCoq Proof Environment, a complex X Window interface which offers graphical controls for proof construction. A pseudo-natural English explanation of the proof is produced upon request, see [56]. Nuprl, see [55], associates display forms with term constructors, thus controlling paranthesization, iteration of terms, elision of subterms, etc. The output is displayed in a fixed-width ASCII font, extended width roughly 60 characters, representing common mathematical symbols. No two dimensional layout of formulae is currently possible.

A "First International Workshop on Proof Transformation and Presentation " with the participation of our group was organized in April 8-10, 1997, in Dagstuhl (Germany) [101] - references to the work presented there are given in various paragraphs of this section.

Advanced Stages *Automatic Theory Generation*: Automatic theory generation as described in the objectives of this proposal, has not been studied systematically so far. However, some particular proof techniques may be viewed under the more general aspect of theory generation: The Knuth-Bendix completion procedure, first, "completes" the (equational) knowledge base before being able to prove (disproving) arbitrary (equational) formulae by direct simplification, see [83], [1]. Cayley factorization as described in [110] does not only prove geometrical theorems (in coordinate-free presentation) but it is also able to generate conjectures to a certain extent.

Proof Programming Versus Proving: In the Coq system, [74], the automatic generation of inductive proof checkers (not provers) from inductive domain specifications is available. Also, in quite some proving systems, "tactics" are available that allow the user, to a certain extent, to compose his own prover from elementary building blocks without going through the details of programming every detail, see [4], [67], [97], [118]. The interaction with the user is further developed upon OYSTER-CLAM [41], which uses "critics" for identifying failures/weak points in the proofs and then asks for human decisions [75].

Proof Simplification and Presentation: All the literature on proof theory can, of course, be considered as dealing with the transformations and possible simplifications of given proofs, see for example [114], [116].

More practically, there has been a lot of interest in recent years on the transformation of proofs generated by resolution provers into proofs that are more in the style of proofs produced by humans, see [72], [73], [100]. A related area is the realization of tools for presenting proofs in an easy-to-understand style, see ATINF with GLEF [43], the add-on to Coq of [51], the Jupe calculator [10, 11], EXPLAIN for THINKER of [99], and TkWinHOL [68, 86].

Speeding Up the System: The task of Mathematica compilation is currently discussed internally in the Mathematica community but not yet documented in papers. Of course, efficient compilation of functional languages is a subject intensively studied over the past years. The language that seems to excel in this respect is CLEAN, see [14]. However, the real challenge will be the efficient integration of Mathematica's sequence variables into the compilation techniques for functional languages.

A Benchmark: Computer-Supported Writing of Math Textbooks Very little is published on the use of provers as an integral component of actual mathematical texts. The most systematic experiments into this direction seem to be [77], [111] and [112]. An impressive effort for providing a computer-aided environment is MIZAR (see [117] and [106]). However, the emphasis in this project is rather on proof-checking and on maintaining a large database of theorems. Also, the syntax of the language is quite restrictive, quite similar to that of a programming language. This approach is further developed in DECLARE [113].

The Impact on Math Education The interactive use of computers (and in particular of computer algebra systems) for mathematical education is a rapidly expanding area of research (see e.g. the recent international workshop MaTILDA'97 [91] with our participation). For an overview of computer aided mathematical tutoring systems see [49] and [121].

Again, very little experience was gathered on the use of provers in math education. Some (rare) references are: [111], [112], and [3] and the ongoing work described in [49].

5.4 Previous Work

In describing our previous work on topics relevant for this project, we adhere to the structure of the subsubsections on objectives and methods described below. For additional details please refer to the proceedings of the *First International Theorema Workshop* (Hagenberg, Austria, June 9–10 1997), available from RISC as research report 97-20 and also on the internet at `http://www.risc.uni-linz.ac.at/conferences/Theorema`.

General Formulation of the Topic When we founded the Journal of Symbolic Computation (JSC) we already formulated in the editorial, see [20], the "integration of computer algebra with theorem proving" as the unifying feature of the journal and as a prominent future goal for symbolic computation. As a result, the JSC has permanently tried to be a forum for both the computer algebra and the theorem proving community. However, only recently, serious attempts started to integrate the two potentials in unified systems.

We renewed the specification of this goal, in more concrete terms, in [30] and [25] advocating the approach of starting from a computer algebra system and adding theorem proving capability.

Finally, in [7], [26], [28] and [1], we formulated the exact goals, and methods to be used, for a project achieving the goal of creating and integrating system for "computing, solving, and proving", which we now call the "*Theorema*" project (see also `http://www.risc.uni-linz.ac.at/software/Theorema/`). In these papers we also reported on first results achieved.

Specification and Implementation of a Mathematical Language In [7] we gave a rough analysis of the particular version of higher-order predicate logic we want to develop and use as a basis for our system. In [15], for the purpose of experimenting with this language, we worked out the introductory semester of mathematics for software engineers in this language.

Mathematical Domains and Functors The structural importance of functors for our project is described in [7] and [26]. In these papers, we also describe the way how functors can be implemented in Mathematica in more detail. In [1], [115] we extend the implementation of functors to the automatic generation of knowledge bases from functor specifications.

Computing, Solving, Proving Our basic view about the interaction of these three fundamental notions is presented in [26] (and also in the corresponding subsection of *Objectives, Methods, Programme and Schedule*).

Choice of a Software System After a phase of systematically analyzing the logical strength (in particular the facilities for generic programming) and the performance of the currently available software systems, already in [23], we reported on some important aspects of using Mathematica. In [28], we give a thorough analysis of Mathematica w.r.t. its suitability as an implementation frame for our project.

A General Prover for Higher-Order Predicate Logic In [33] and [34], we give a first report on an early prototype for the general predicate logic prover we are developing for our project. The prover is based on rules (for humans) for generating predicate logic proofs, which we developed in [12], and in [15]. These rules are also used in our "Thinking, Speaking, Writing" course for training general working techniques with our graduate students at RISC, see [16].

Special Provers Imitating Human Proof Techniques and Important Classes of Propositions In [32], [39, 115, 40], we already developed and implemented three examples of special provers for some particular functors (natural numbers, lists, complexification, quotient field) and some special classes of propositions. A survey is given in [1]. In [39, 115] we started to analyze the "category membership" class of propositions as an important candidate for automated proving.

Special Black-Box Provers and Solvers In [9], we gave a survey on special "black-box" provers based on algebraic methods (Groebner bases, characteristic sets, cylindrical algebraic decomposition). Of course, all our research tradition (starting from [2], [3]; for a survey see [5]) is in this area.

The Nature of Proofs Generated by the Functor-Based Provers In [33, 32], we worked out the details of how natural language proofs using "nested cells" representation can be realized in Mathematica.

Advanced Stage: Theory Generation Versus Theorem Proving Based on the inductive prover described in [32] we already started to set up experiments with the theory generation method using a failure analyzer together with a prover. However, we did not yet document this work in a paper.

Advanced Stage: Speeding Up the System We gave a detailed analysis of the comparative speed of C and Mathematica (and a couple of other systems) in [23] and [1]. In [92] we started to think about a compiler for Mathematica by analyzing in detail the Mathematica version and a corresponding C version of one of our provers. In [24], we defined the particular subset of Mathematica for which an efficient compiler seems to be possible, desirable, and also sufficient for the purposes of this project. As a preparatory work for Mathematica compilation, at RISC two PhD theses have addressed the issue of efficient compilation of functional languages: [84], [107].

A Benchmark: Computer-Supported Writing of Math Textbooks In the past, we have already started a couple of times to write a book on Groebner bases. However, since we wanted to write an interactive version with the algorithms integrated into the text and also logically integrated into the underlying mathematical language and, furthermore, formulated in a generic way, we were held back by the lack of an appropriate mathematical software system. With the advent of Mathematica 3.0 and our method of implementing functors in Mathematica, we believe that time has come now when we will be able to write a textbook in the style we envisaged. The support for the routine parts of the proofs is an extra facet, which we will separate however from the other methodological goals in writing the book. For the functorial formulation, our early axiomatic approach to Groebner bases in [19], may be viewed as a preparatory work.

The Impact on Math Education We were quite heavily involved in the discussion and practical experimentation of the impact of mathematical software systems on math education. For example, we developed the "white-box / black-box principle" for a balanced usage of mathematical software systems in math education, see [22]. We expanded this involvement recently by joining a European consortium on writing interactive textbooks, see [103] with the additional aspect of interactive teaching over the network. Our intensive experimentation with teaching (formal) proving for freshmen and also graduate students, documented in [15], [16] and [12], is a broad basis for studying the impact and use of the provers to be developed in our project for math education.

5.5 Cooperations

Over the past 18 months, we had interactions (four joined meetings and quite a few extra meetings with individuals) on the topic of integrating computer algebra with theorem proving with the following European groups, which resulted in the preparation of the TMR (Training and Mobility of Researchers - EU 4-th Frame Programme) proposal *"Calculemus - Systems for Integrated Computation and Deduction"* (see [76]):

- IRST (Trento) - Prof. Fausto Giunchiglia,
- Univ. Edinburgh - Prof. Alan Bundy,
- Univ. Karlsruhe - Prof. Jacques Calmet,
- Univ. Nijmegen - Prof. Henk Barendregt,
- Univ. Roma 3 - Prof. Alfonso Miola,
- Univ. Saarbrücken - Prof. Jörg Siekmann,
- INRIA (Sophia Antipolis, Nice) - Prof. Yves Bertot,
- LEIBNIZ-Grenoble - Prof. Dongming Wang.

In addition, we have a close cooperation on computer algebra and functional logic programming with the group of Professor Tetsuo Ida, University of Tsukuba, Japan, Institute of Information Science. After quite some discussions combining our work on proving and solving and joint supervision of student projects in this area, we will have a first joint workshop in June 1997 at RISC. Also, we have a joint project funded by IPA (Information-Technology Promotion Agency, Japan) on using the network for interactive math education in which the PFU company (a subsidiary of Fujitsu) is a partner. (Recently we organized the First International Theorema Workshop together with these partners, at Hagenberg, 9–10 June – see proceedings in RISC-Reports series 97-20, also available on our home page.)

We also have a small joined project with Fujitsu in Numazu (Japan) on studying the integration of theorem proving into Fujitsu's own computer algebra system "RISA/ASIR".

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

A General Formulation of the Objectives The project aims at *expanding the current computer algebra systems by solvers and provers for general mathematical domains.*

In the subsequent paragraphs, we will, first, clarify the notions of "domain", "prover", and "solver" and, then, expand the general objective into more detail.

Mathematical Domains and Functors A mathematical "*domain*" is a set of objects (the "carrier" of the domain) together with a collection of operations (functions and predicates) on these objects. Starting from a few basic domains as, for example, the natural numbers, the infinite "tower" of mathematical domains can be generated by (finitely many) "functors". A *functor* is a function that generates a new domain from given domains (and additional parameters), i.e. it describes the carrier set of the new domain in terms of the carrier sets of the given domains and the operations on the new domain in terms of the operations in the given domain.

For *example*, a "polynomial functor" generates the domain of "polynomials" from a domain of "coefficients" and a domain of "power products", i.e. it defines the set of polynomials in a particular representation (data structure) and defines the operation of addition, multiplication etc. on these polynomials. (Note that for each choice of a particular data structure for polynomials we have a different functor. From the point of view of abstract algebra, the polynomial domains generated by different polynomial functors are isomorphic and, hence, are not distinguished. However, from the computational point of view, it is important to distinguish between the different ways of generating the domain of polynomials because the operations defined by the different functors may have very different complexity!) Other examples of functors are: the functor that generates the domain of lists over a given domain; the functor that generates the domain of matrices over a given domain; the functor that generates the domain of formal power series over a given domain; the functor that generates the domain of functions over a given domain; etc.

Some of these functors are "algorithmic" in the sense that the definition of the carrier set and the operations of the new domain uses only "algorithmic" language constructs (e.g. induction and bounded quantification) whereas *other functors are "nonalgorithmic"* in the sense that the definition of the carrier set and the operations of the new domain also uses "nonalgorithmic" language constructs (e.g. the general existential quantifier, the set theoretic choice operator, or the general set generation quantifier (the general "set braces")). (Note that we use a "relative" notion of algorithm here: The definitions of the carrier set and the operations of the new domain in an algorithmic functor are algorithmic *relative* to the the operations in the given domain, which - in the formulation of the functor - are considered as "black boxes").

If functors are used only for computational purposes (i.e. for building up a "tower of domains" in which we can compute) then it is of course important to use only algorithmic functors. (In fact, it is one of the fundamental problems of computer algebra to invent mathematical results by which nonalgorithmic functors can be replaced by algorithmic functors that construct domains isomorphic to the domains constructed by the nonalgorithmic functors. In many cases, these mathematical results are quite nontrivial. A well-known example is replacing the residue class functor modulo polynomial ideals by a canonical simplification functor based on Groebner bases.)

If, however, we would also like to prove and disprove properties of the domains generated by the functors and *solve problems in these domains* then it is well possible to invent *algorithmic* (i.e. computer-supported or fully automatic) provers and solvers also for nonalgorithmic functors. (For example, the construction of the real numbers from the rationals proceeds by a functor that is necessarily *nonalgorithmic* in many ways. However, for example, Collins' quantifier elimination procedure is an *algorithmic* method by which a highly expressive class of properties about the real numbers - the statements of the "first order theory of real closed fields" - can be automatically proved or disproved. At the same time and dually, Collins' method is also a powerful solving method for this class of formulae.)

Computing, Solving, Proving

In an oversimplified view, given a "knowledge base" K of formulae,

- a "*computer*" for K (in an abstract sense) enables the user to provide an expression (term, formula, program) T with a free variable x and a value v (from an appropriate domain) and "evaluates" $T_{x\leftarrow v}$ (T with v substituted for x) w.r.t. K,
- a "*solver*" for K enables the user to provide an expression T with a free variable x and produces (all) values v for which $T_{x\leftarrow v}$ holds w.r.t. K, and
- a "*prover*" for K enables the user to provide an expression T with a free variable x and decides whether, for all values v, $T_{x\leftarrow v}$ holds w.r.t. K.

(For ease of notation, we restrict ourselves in this formulation to only one free variable x. Of course, x can also be viewed as a tuple of variables.)

Of course, computing, solving, and proving are mutually dependent. For example, a prover for a certain class of existentially quantified formulae, essentially, is a solver. Also, certain solvers may need proving potential as a subroutine. Both solvers and provers are expressions that are evaluated on (abstract) computers. Anyway, from the point of view of a user, computers, solvers, and provers are doing three different things with a given expression T. (A more detailed analysis of "computing", "solving", "proving" is given in [26]).

Note that, in the above sketch, T can be an arbitrary complex formula in some language (in our project, preferably, a version of higher order predicate logic), for example a formula containing quantifiers to an arbitrary depth of nesting. Hence, computing, solving, and proving can be arbitrarily complex and demanding tasks depending on the class of formulae admitted. It is the essence of our approach, that we want to structure the task of (automated) solving and proving by a functorial build-up of mathematics by which the unmanageable "flat" search-space of "mathematics" is structured in manageable layers. In each transition from one layer to the next (described by one functor), on the one hand, the available "knowledge base" (of definitions, axioms, temporary assumptions, etc.) is quite limited and, on the other hand, the corresponding arsenal of special proof techniques goes far beyond what is available in general automated provers (and solvers), e.g. provers based on the resolution principle.

It is this combination of limited knowledge bases and additional, special, proof techniques that should make it possible to provide prover/solver systems that show a new level of computer-support for the problem solving cycle of working mathematicians.

Examples of Functors for which Special Provers and Solvers Should Be Designed and Implemented In a slightly simplified but basically sound view, in the accompanying projects P2 (Hoon Hong), P3 (Franz Winkler), and P4 (Peter Paule) computer-supported provers and solvers will be designed and implemented for the fixed and mathematically fundamental domains of the real numbers (P2), the complex numbers (P3), and the natural numbers (P4). RISC has a long research tradition in these areas.

In contrast, in this project, we want to emphasize the aspect of designing and implementing provers and solvers for "arbitrary" domains. However, *this arbitrariness is structured in a tower* by the functor-based view. Hence, provers and solvers studied in this project will be attached to functors rather than to domains. Here is a list of the most important functors for which we intend to design and implement special provers and solvers:

- The functors that build the basic data structures of computer science, like nested lists over a domain, finite sets over a domain, queues over a domain etc.
- The functor that generates the free term algebra over a domain.
- The functor that generates the factor domain modulo a congruence over a domain.
- The functor that generates the simplified domain of a given domain w.r.t. a canonical simplifier.
- The functor that generates (ring, group, lattice, ...) polynomials over a domain.
- The functor that generates the Cartesian product over a domain.
- The functor that generates a subdomain over a domain (w.r.t. to a subcarrier).
- The functor that generates the domain of matrices over a domain.
- The functor that generates the domain of arbitrary sets over a domain.
- The functor that generates the domain of functions over a domain.
- The functor that generates formal power series over a domain.

- The functor that generates a differential (difference) structure over a given domain.
- The functor that generates a topology over a domain (e.g. w.r.t. a metric).

Examples of Propositions to be Proved and Problems to be Solved Automatically In general terms, we strive for enhancing the proving and solving power of existing computer algebra systems to such an extent that the *routine parts* of proofs and the routine parts of solving can be computer-supported or fully automated. This means, that given the definition of the functor that governs the particular area of mathematics under study and given some knowledge about the domain to which the functor is applied, the particular prover (solver) should be able to prove (solve) relatively simple formulae involving the operations of the domain constructed by the functor. We do not intend (nor do we believe it to be realistic or even desirable) to strive for provers (solvers) that can provide "ingenious" ideas in proofs or solving processes. However, our prover will allow the user to introduce such ingenious ideas and thus complete even more complicated proofs.

As modest as this goal may seem, we think that achieving this goal can *take away a big portion of the tedious but necessary every-day work* of a mathematician and will be *a major step forward in the sophistication of mathematical software systems.* Also, we hold that *present mathematical software systems do not yet give this type of support.* And, moreover, we believe that time has come (given the amazing theoretical and practical recent advances of current mathematical systems) that *such type of support can be generated* by

- a systematic use of available and carefully worked out mathematical methods,
- the integration and combination of various already available special automated theorem proving methods, and
- most importantly, a careful analysis of the proving and solving methods used by human mathematicians in the various areas of mathematics. (Here, in our terminology, an "area" of mathematics is basically defined by the functor that generates the respective domain or class of domains studied.)

Here are some examples of classes of properties to be proved automatically by the methods to be developed in this project:

- *Category membership properties*, i.e. properties of the type: "If domain D_1 belongs to a certain category C_1 (defined, for example, by equalities; e.g. the category of rings) and D_2 is the result of applying functor F to D_1 then D_2 belongs to category C_2". (Example: "If D_1 is a ring and D_2 is the polynomial ring over D_1 (taken as coefficient domain) then D_2 is a ring.")
- *Rewrite properties*, i.e. properties that establish "rewrite rules" for concepts defined by (nested) quantifiers. The structure of such properties is, for example: "If $P(x)$ and $P(y)$ then $P(C(x,y))$ (where P is a predicate defined by a formula involving nested quantifiers and the operations in the given domain and C is an operation in the new domain generated by the functor studied)." (Example: "If f_1 is continuous and f_2 is continuous then $f_1 + f_2$ is continuous." Another example: "$\lim(f+g) = \lim f + \lim g$". Here, the functor under study is basically the functor that generates the function domain over a given domain.)

Again, these classes may seem to be quite limited. Note, however, that the analysis of text books in undergraduate mathematics (algebra and analysis) shows that category membership and rewrite properties already cover most of the theorems proved in the text and the exercises. In fact, the above characterizations already cover quite non-trivial mathematical facts. For instance, the main theorem of the Groebner Bases theory [5] can be expressed (in the Theorema language) as follows:

$$\mathrm{GroebnerBasis}(F) \Longleftrightarrow \forall_{f,g\in F}\mathrm{SPolynomial}(f,g) \longrightarrow_F^* 0$$

(Which reads: "F is a Groebner Basis if and only if the S-Polynomial of any pair of elements of F reduces to zero w.r.t. to the reduction relation induced by F.) This equivalence is nothing else than a *rewrite rule* for the concept of Groebner Bases (which is initially defined by a non-algorithmic formula), however it gives an *algorithmic criterion* for verifying that this property holds. Moreover, the proof of this property is an expression of the algorithm for constructing Groebner Bases.

The Nature of Proofs Generated by the Functor-Based Provers Both the most popular universal theorem provers (based on the resolution method) and the special provers that reduce automated proving for certain classes of formulae to (algebraic) algorithms (see projects P2, P3, P4) do normally not care about whether the "proofs" generated are human-readable. In fact, these methods are not meant to imitate proving done by humans but, rather, yield "black box" decisions about the validity of the given formula with no "explanation" aspect. (An explanation in the sense of "telling by which inference rules using which knowledge the intermediate, and the final, conclusions are reached" cannot be given by these methods because, essentially, they don't proceed by applying inference rules.)

Although we do not exclude that, for some of our proof problems, we will apply or develop "black box" methods, our emphasis in this project will be on proofs that imitate the way how human mathematicians are doing proofs in a certain area. Also, ultimately, the proofs should be given in (a technical version) of natural language and, moreover, these natural language proofs should be presented in interactive notebooks in the form of "nested cells" that can be "opened" or "closed" (by clicking into them) in such a way that the reader of a proof can determine by himself, which parts of the proof he wants to study to what level of detail. This feature is important because lengthy proofs that are arranged linearly do not fulfill the purpose of "explaining things" well.

The situation may be similar, but not completely identical, in the case of solvers. Mathematicians are used to getting no "explanations" whatsoever how a solver (for example a solver for multivariate algebraic systems of equations) derived its answers. Thus, "black-box" solvers are widely accepted whereas "black-box" provers are not. Anyway, we will devote some effort to studying the question of presenting the steps of finding "solutions" in a similar way as presenting the steps of proving a proposition. This may, at least, have some impact on the applications of our work in math education, see below. However, it also addresses the long-standing discussion of adding an "explanation" component to the built-in solvers of current computer algebra systems. (The current "tracing" facilities of these systems are not satisfactory for this purpose because they lack the features of natural language explanations and of presentation of long derivations in "nested cells" as explained above.)

Advanced Stage: Theory Generation Versus Theorem Proving In real-life mathematical proving, propositions are rarely proved individually. Rather, starting from axiomatic assumptions definitions, a collection of theorems of increasing complexity is built-up until one reaches a situation where the "really interesting" theorems are attacked that most times need nontrivial human insight (typically gained from a careful analysis of nontrivial examples) for being proved. (More accurately, the proof of such theorems needs human insight in a few critical steps, whereas the rest may again be routine.)

Therefore, in an advanced stage of our project, when sufficiently many special provers will have been implemented and sufficient experience on the interaction of these provers (and on the interaction of these provers with various solvers) will be available, we intend to study particular strategies by which this "theory generation" aspect, that goes beyond the simple theorem proving aspect, can be simulated and supported within our system.

Advanced Stage: Proof Programming Versus Proving In a later stage of the project, after having gained sufficiently much experience with implementing a variety of special provers in various areas of mathematics, we think that it will be possible to extend and systematize the system in such a way that a potential user is provided with a library of high-level routines by which, with only little programming effort, he will be able to write his own special provers according to his particular needs in his working area.

As a general direction, by providing such a system, mathematicians working in a specific area would more and more become "proof programmers" instead of being "provers".

Advanced Stage: Proof Simplification One could design provers in such a way that they backtrack over the proof generation process and try to find "minimal" (most elegant?) proofs by trying out (by backtracking) the various inference rules that may be applicable in a given proof situation.

However, we think it is more efficient (and in tune with the common practice of mathematicians) to try, first, to find a proof at all and, then, to "post-process" the proof for eliminating redundancies, finding short-cuts etc. We intend to embark on this topic in a later stage of the project when sufficiently many special provers are available for being able to study the proofs generated in a more systematic way.

Advanced Stage: Speeding Up the System It may turn out that Mathematica, although an elegant programming tool for implementing provers, may be too slow for real-life examples. (Current experience, however, with simple proofs of 5-10 pages indicates that Mathematica seems to be amazingly fast for this type of applications, see also the timing experiments in [92].) We therefore will think about replacing Mathematica as a programming language by a compiled rule-based language or, more probably, we will write a compiler for the part of Mathematica language which we actually use in our project. (However, we will stay with using the marvelous front-end of Mathematica 3.0.)

A Benchmark: Computer-Supported Writing of Math Textbooks As a benchmark for our project we take *writing an interactive textbook on a part of computer algebra* and evaluating the amount of system support that can be given in all intermediate stages of this process:

- The stage of setting up (and revising) *formal parts of the book* (the particular ways the tower of domains is built up by particular functors, the particular choice of the definitions, the formulations of the propositions etc.)
- The stage of *proving propositions.*
- The stage of transforming the algorithmic content of theorems into *algorithms* that can be used interactively.
- The stage of enriching the formal parts by *examples, exercises, graphics, animation etc.* that can be treated interactively.
- The stage of text production, text organization etc.

The stage of formulating interactive algorithms and computational examples including animated graphics and text production and organization including typeset interactive mathematical formulae is well supported by the most advanced versions of current mathematical software systems.

The challenge is *the degree by which the routine parts of the proofs can be carried out by our proving system.* We think that computer-support in the routine parts of the proofs is a most desirable tool when writing a book because, although these proofs are well-known, their particular set up crucially depends on the particular choice of definitions used in the text. These definitions, however, may change quite some times in the course of writing the book and, hence, the proofs must be re-done (with minor but important variations) correspondingly. Often, the way things can be proved (or cannot be proved) is a feedback for a desirable or necessary re-design of the definitions (or may even show that the definitions are not yet appropriate or complete.)

Also, our particular way of presenting proofs will make it possible to present in the printed version of the book only the most important parts of the proofs and, still, give the reader a possibility to study them to further levels of detail when he opens the corresponding cells in the interactive version of the book. This is particularly true also for the parts of the exercises that are proofs.

It is near at hand that, as a topic for the benchmark book, we will choose *Groebner bases* for various reasons:

- We are supposed to understand this area well so that we do not have to struggle with the mathematical aspect of it but, rather, can *concentrate on the methodological aspect* of the endeavor.

- A textbook on Groebner bases will necessarily have to cover parts of *both nonalgorithmic and algorithmic mathematics*. In fact, the main theorem of Groebner bases theorem (the theorem that shows that F is a Groebner bases iff all S-polynomials of F reduce to zero; see [3]) just effects the transition from the nonalgorithmic notions of polynomial ideal theory to certain algorithmic notions like "reduction". Our provers should be able to prove the routine parts of both the nonalgorithmic and algorithmic parts of the theory.

- Although, by now, there are a couple of very good textbooks on Groebner bases available, an interactive textbook is still missing.

In Figure 1 we give a sketch of an interactive math session which we would like to be able to carry out in the proposed mathematical software system (comments in footnote size).

The Impact on Math Education As a side effect we plan that the results of this project should also be used for improving the potential of computer algebra system for a new degree of sophistication in interactive mathematical education at all levels starting from senior high school level, covering undergraduate and graduate teaching and including the area of recurrent adult training, which will be particularly important for the future.

In particular, we believe that, in the frame of academic mathematics and computer science education, formal training and proof training is a problem worldwide. The ability of math and computer science students (even at the beginning and sometimes even at the end of PhD study) for carrying out proofs is in a miserable stage. Intensive interactive training with a good teacher would be absolutely necessary but is neglected partly for philosophical reasons partly because advisors do not want to spend their time for this part of the education. However, it is our firm belief that learning how to formulate concepts in a formally impeccable way and how to prove or disprove conjectures is the essence of math and computer science education. Improvements in this part of the education will have a dramatic positive impact on the quality of mathematics, software, and software documentation produced worldwide.

We believe that a new generation of proof generating programs that produce well structured proofs in natural language and with the ability of determining the desired level of proof details produced can be an important tool for improving the situation. Such a tool will not eliminate the necessity of person-to-person training. However, it can lay a solid foundation on which more sophisticated teaching can be based.

Hence, it is also one of the objective of this project to try out the proof system - wrapped into software tools for the interactive usage of the system over the network - in the first semester education of mathematics and computer science students (both at the university and the "Fachhochschulen") and to document the results of these experiments in a systematic way.

5.6.2 Methods

Specification and Implementation of a Mathematical Language As a frame for the project, the exact specification of *a formal language for all of (nonalgorithmic and algorithmic) mathematics is necessary.* We choose a version of higher order predicate logic with the following particular features:

BEGIN OF SESSION:

Definition (user-provided):

Polynomials$(C, P) :=$ Functor$(\ldots)$.

(A formal definition, e.g. as a set of inductively defined ordered lists, of the domain of polynomials in terms of a domain C of coefficients and a domain P of formal power products.)

Theorem (user-provided):

If C is a ring and P is a commutative semigroup then Polynomials$[C, P]$ is a ring.

Proof (computer-generated with a hint about which prover(s) should be used):

Let $P :=$ Polynomials(C, P).

We show that $+_P$ is associative by induction. ...

(proof details on request in "nested cells".)

We show that $+_P$ is commutative by induction. ...

(proof details on request in "nested cells".)

(etc.)

Definition (user-provided):

... reduction ... S-polynomials ... Groebner-basis ...

Theorem (Algorithmic Characterization of Groebner-Bases) (user-provided):

G is a Groebner-bases $\Leftrightarrow$ normalfForm(S-polynomial $(f, g), G) = 0$.

Proof (computer-generated with a few hints about which prover(s) should be used and a few human interactions during the proof):

Question (user-provided):

$\{xy^2 - x, x^2y + 2y\}$ is Groebner-basis?

Answer (computer-generated: by application of the characterization theorem, which is also an algorithm! Note that in this situation it is important that our version of predicate logic contains a sub-language of executable formulae as logic-internal programming language):

False.

(After more computer-supported mathematics by which a non-linear polynomial solver is derived from the above characterization theorem and after "lifting the solver from the object level to the meta-level":)

Query (user-provided):

Such x, y that $\{xy^2 - x, x^2y + 2y\}$.

Answer (computer-generated with a hint by the user about which solver should be used):

$(x = 0 \wedge y = 0)\vee$
$(x = \sqrt{2} \wedge y = 1)\vee$
$(x = \sqrt{2} \wedge y = -1)\vee$
$(x = -\sqrt{2} \wedge y = 1)\vee$
$(x = -\sqrt{2} \wedge y = -1)$.

END OF SESSION.

Figure 1: Sketch of an interactive math session.

- *Extensionality is not included* into the logical axioms. Namely, we will use extensionality only for sets (which can also be value-tables of functions), but not for all objects (which can also represent functions having a certain algorithmic behavior). This is necessary in order to distinguish functions which have the same value-tables, but different algorithmic behavior.

- We include the concept of "*sequence constants*", a concept borrowed from Mathematica but not normally incorporated into predicate logic.

- Higher order equational logic is used as the *"logic-internal" programming language.*

- *Set theory* (including the axiom of extensionality) will be a special sublanguage within this language.

The *syntax* of this language will be such that

- it comes close to the *notation used in most of the mathematical textbooks* and

- the universal programming language contained in it can be implemented right away as a *syntactical variant of Mathematica 3.0* (using the syntax extension facilities of Mathematica 3.0).

The *semantics* of this language is intuitively clear. However, giving a formal semantics will be a major task. We will do this in an evolving procedure that defines and re-defines some of the language concepts during the process of using it in practical experiments of writing major pieces of mathematical texts.

The *proof system* of the language will be given in the form of a general computer-supported prover and various special provers. This is identical with the main objective of the project.

The motivation for this particular choice of language is given in various recent papers by B. Buchberger, see the subsubsection on "previous work" above. The main point is that the Bourbakistic system of Zermelo-Frankel set theory as a uniform frame for mathematics is practically too weak for the algorithmic parts of mathematics.

Choice of a Software System The implementation of the system proposed in this project could be realized in three different ways:

- One could *start from scratch* and design a completely new system. Given the theoretical and practical power and sophistication of current computer algebra and theorem proving systems, this would be a tremendous waste of effort.

- One could *start from an existing theorem proving system* and expand it by mathematical "content" both in terms of theorems and algorithms. However, we think it is fair to say that general predicate logic theorem provers are not powerful enough for practical proving and both general and special theorem provers have relatively weak front-ends for producing interactive mathematical text as compared to recent computer algebra systems, e.g Mathematica 3.0. Also, they have relatively little built-in algorithmic mathematical content as compared to the huge algorithm libraries available in recent computer algebra systems. Finally, we are not really satisfied with the "explanation component" of most theorem proving systems.

- One could *start from an existing computer algebra system* and expand it by facilities for mathematical proving. The advantage is that these systems have a strong mathematical content and some of them have a very attractive front-end for producing serious mathematical text. The disadvantage of this choice is that current computer algebra systems give practically no support for mathematical proving.

We choose the third alternative but we admit that there are also good reasons for the second alternative (mainly the careful logical design of most of these systems) and that our decision is also based on the personal bias of our own research tradition.

More specifically, we choose to base the implementation part of our project on *Mathematica 3.0* (at least in the prototype phase). Here are the reasons for this decision (see also the recent papers by B. Buchberger discussed in the subsubsection on “previous work” above):

- Essentially, the innermost part of *the Mathematica language is identical to higher-order equational logic.* As a consequence, Mathematica can be viewed as a “logic-internal” programming language and, thus, the language gap between computing and proving is closed in a natural way. In other words, formulae with an algorithmic content that are proved by one of our provers can be taken unchanged also as programs because the evaluation of such programs in Mathematica is nothing else than a restricted usage of the two basic inference rules of equational logic, namely substitution and replacement. This is a subtle point which may not be very interesting for practically minded people but, in fact, the possibility of viewing Mathematica as a logic-internal programming language is our main theoretical reason for choosing Mathematica (whereas the following reasons are more of a practical nature).

- Mathematica has an attractive *arsenal of built-in functions* (like substitution, matching etc.) for formula manipulation, which are useful building blocks for programming the various provers in our system.

- Mathematica provides the *“notebook” facility* by which mathematical papers can be nicely structured and “active text” (programs that can be called from within the paper) can be intermingled with ordinary passive mathematical text.

- The new version 3.0 of Mathematica has highly sophisticated mathematical *typesetting facilities* even for executable formulae in the “input cells” of Mathematica “notebooks”. In particular, Mathematica 3.0 also allows to change and extend its syntax and to attach user-defined semantics with syntactical notation.

- The text in notebooks can be structured in *nested cells* of arbitrary nesting depth. Such notebooks can be produced by Mathematica programs (e.g. our provers). This allows an elegant and novel way of presenting proofs in nested form as is demonstrated in Figure 2.

In a later stage of the project, for efficiency reasons, we may decide to replace the Mathematica interpreter by a compiler for that part of Mathematica that we actually use (which we call “Mathematica-R” in [24]).

Implementation of Functors We have shown, see the papers discussed in the subsubsection on “previous work”, that functors in the sense of ML (but with more flexibility in the definition of the carrier sets of the domains generated by functors) can be easily implemented in Mathematica by combining the following three built-in concepts of Mathematica:

- module,
- higher-order variables,
- Currying.

In our implementation of the concept of functor, in the spirit of higher order logic, carrier sets are replaced by decision methods (algorithms in the case of algorithmic functions) for membership in the carriers. Also, using the syntax extension facilities of Mathematica 3.0, one can establish a notation for the operations in domains generated by functors that closely resembles the ordinary mathematical

Prove

(D) $((\exists_x P[x]) \Rightarrow Q) \Leftrightarrow \forall_x P[x] \Rightarrow Q$

with no assumptions.

We prove (D) by natural deduction.

We prove (D) in both directions.

Direction from left to right:
We assume

(D.LA) $(\exists_x P[x]) \Rightarrow Q$

and show

(D.RC) $\forall_x P[x] \Rightarrow Q$.

For proving (D.RC) we prove, for arbitrary but fixed values,

(D.RC') $P[x_0] \Rightarrow Q$.

We prove (D.RC') by the deduction rule. We assume

(D.RC'.H) $P[x_0]$

and show

(D.RC'.C) Q.

For proving (D.RC'.C), by (D.LA), it suffices to prove

(D.LA.A) $\exists_x P[x]$.

Formula (D.LA.A) is proved because it is instantiated by (D.RC'.H).

Direction from right to left:We assume

(D.RA) $\forall_x P[x] \Rightarrow Q$

and show

(D.LC) $(\exists_x P[x]) \Rightarrow Q$.

We prove (D.LC) by the deduction rule.We assume

(D.LC.H) $\exists_x P[x]$

and show

(D.LC.C) Q.

By (D.LC.H) we can take appropriate values such that

(D.LC.H') $P[x_0]$.

¿From (D.LC.H') and (D.RA) we obtain by modus ponens

(D.RA.D.LC.H') Q.

Formula (D.LC.C) is true because it is identical to (D.RA.D.LC.H').

Figure 2: Example proof, automatically generated.

notation in algebra textbooks. Thus, many of the usual mathematical definitions of functors (as long as they are algorithmic) immediately become executable code.

In [1], we started to make functor definitions to become themselves objects that can be processed. This is necessary as soon as one starts to view functors not only as mechanisms for defining new domains in which one can compute but also as mechanisms that transport knowledge from the given domains to the domains generated by the functors. In concrete terms, in propositions of the form "category membership" as explained in the subsubsection on the project objectives, the carrier and operation definitions contained in a functor must be processed, together with the knowledge for the given domain in order to generate the knowledge base and the set of goals for the proof do be carried out.

The automatic generation of knowledge bases before the actual proving process starts is an aspect whose practical importance for real-life proving has not been duly remarked in the theorem proving literature. We want to put a particular emphasis on this in the frame of our project.

A General Prover for Higher-Order Predicate Logic In a general strategy to link existing provers and solvers to our system via MathLink (see below), we will also experiment with using existing general provers for higher-order predicate logic as a component of the system.

However, as a basic tool that will be called at various places in our special provers, we also will rely on a *general prover for our particular version of higher-order predicate logic based on the strategy of imitating human proofs* in predicate logic. In fact, the design and implementation of this prover is already well under way, see [1]. It handles "*proof situations*" that, roughly, consist of a "goal" (the predicate logic formula to be proved) and a "knowledge base" (predicate logic formulae used as assumptions). In one proof step, the prover proceeds from a proof situation to one or more new proof situations by using various inference rules. The *inference rule* to be applied in a given proof situation is triggered by the outermost symbols of the formulae constituting the goal and the current knowledge base. Thus, basically, our prover is a "sequent calculus". However, striving for "natural" and easy-to-read proofs, we formulate and use many more rules than the ones that are usually compiled in the "natural deduction calculi" in logic texts (which strive for minimality). These rules are taken from [12] and are the ones which we also use at RISC in the formal proof training course for graduate students.

These rules can be formulated in a natural way and nearly unchanged in Mathematica. Starting from an initial proof situation, we produce a "*proof object*" containing this proof situation. In each proof step this proof object is expanded until we, finally, obtain a proof object that represents the proof, i.e. it contains all the information on the intermediate proof situations and the inference rules used in each step of the proof. The proof object is an abstract object that is not meant to be read by humans. However, it contains all the information necessary to produce, in a second step, a proof in natural language and well structured in "nested cells", see Figure 2.

Special Provers Imitating Human Proof Techniques *The core of our project is the development of special provers for the various fundamental functors of mathematics.* As a first approach, these provers will imitate the proof techniques used by human mathematicians for proving properties of the domains generated by these functors.

Hence, our main method in this part of the project will be *a thorough analysis of the proof techniques used by humans in particular areas of mathematics.* (Recall that, in our view, "areas" of mathematics are characterized by functors). This approach may seem to be naive. However, first attempts documented in [7], [26], [28], [1] show that this approach is quite promising. The proofs generated, for example, by our induction provers for natural numbers, lists, and polynomials are nontrivial, well structured, and easy to read. (In this context, by "nontrivial" we do not mean "ingenious" but at least of such a nature that, in experiments, average math students have some problem in getting the proof done correctly, thoroughly, and in good style).

Also, more importantly, the profound and theoretically systematic approaches to theorem proving based on techniques like resolution have not kept the promise of supporting "real-life" mathematical theorem proving. (They have produced other important "side effects" though as, for example, the logic programming technology.) Hence, even the originator of the resolution method, Alan Robinson, in his recent talks, see [105], advocates that the analysis of real-life human proofs deserves renewed interest.(What he advocates is, however, not exactly the same as what we have in mind: His suggestion goes more into the direction of analyzing the "ingenious" invention in human proofs whereas we emphasize here analyzing the routine parts of these proofs in special areas.)

This should not be confused with the introduction of general "heuristic techniques" in proving. Heuristic techniques (imitating some aspects of "creativity") may be desirable and we do not exclude that we will integrate them into our provers at some stage. However, our main effort will concentrate on the careful analysis of the proof techniques used by humans in the various areas of mathematic which will lead to well described proof strategies that can be turned into proof algorithms for well-defined special classes of formulae in the areas under study. In more detail, the methodology proceeds in the following cycle:

- Take a functor and a quite limited class of formulae describing properties of the domains generated by the functor.
- Analyze human proofs for some examples in this class of formulae.
- Turn the result of the analysis into a prover for this class of formulae.
- Try the prover on many examples of formulae in this class until it can produce the proofs of the formulae in this class.
- Try the prover for formulae in a broader class of formulae, analyze the reason for its failure and compare the failing proofs with successful proofs by humans.
- Go to the beginning of the cycle for the broader class.

We have pursued this strategy successfully in a couple of examples of functors and formulae classes and believe that the approach is worth the effort. A particular challenge of this approach is the mutual interaction of special provers and the interaction of the special provers with the general predicate logic prover. Enormous work is needed for pursuing this approach.

We did not yet pursue the idea of creating "natural solvers" for the individual functors. We think this idea is quite near-at-hand but we did not yet find the time to pursue. Thus, we must leave it open at the moment whether this avenue will be pursued in our project.

Special Black-Box Provers and Solvers Of course, we will also link the special "black-box" provers and solvers (that translate proving and solving problems to algebraic problems that have no immediate direct interpretation as proof problems) known in the literature, partly developed at our institute over the past years, and also those to developed in the projects P2, P3, P4 of this SFB to our system. Software-technologically, this can easily be done by the MathLink facility which we already tested for this purposes and found it completely satisfactory. The only adaptation necessary is an interface for translating back and forth between the various formats for the representation of formulae in our system and in the various black-box provers and solvers.

A particular emphasis in this part of the project will be put on integrating the techniques developed over the past decades in the functional logic community (critical pair completion, unification w.r.t. to various equational theories, narrowing etc., see [1], [54], [81], [69]) into our proving / solving system. Since these techniques are so fundamental and, also, driven by the definition of general domains, we will directly implement them in Mathematica in intimate interaction with our own techniques rather than link them as black boxes via MathLink.

Beyond linking existing black-box provers and solvers, we expect that the careful analysis of human proof techniques for the various areas of mathematics may also lead to the invention of new "black-box" provers in some of the areas. We are optimistic about this because, for example, the well-known Knuth-Bendix method for proving first order equalities w.r.t. to sets of equalities was detected in 1967 in the course of a careful analysis of the human proof methods for equality reasoning that were used at that time, see the introduction of [1]. We can confirm the same about the Groebner bases method, which resulted in 1965 from a careful analysis of the reduction process modulo polynomial ideals, see [2]. However, it would be unrealistic to predict and unfair to expect the invention of new black-box solvers with certainty because, by nature, mathematical invention is unpredictable.

Proof Presentation The innovative method of proof presentation in "nested cells" described in the subsubsection on objectives is made possible by a new tool available in Mathematica 3.0, namely producing notebooks with arbitrarily deeply nested cells under the control of a user program.

It is important that our provers will be structured in such a way that the actual provers generate "abstract proof objects" (see above) on which post-processors can operate that transform the abstract proof objects into natural language proofs in nested cells presentation so that the logic part is cleanly separated from the presentation part.

In [28, 33, 32], we already worked the details of this approach out. Thus, the technology for this part of the project is completely available.

Theory Generation As soon as, for a particular functor and a particular class of formulae, a prover has been implemented one can use it not only for proving individual propositions but can use it in the "theory generation" style humans are using their proving potential. For this, it is crucial that provers do not only present of proof of propositions in cases where they manage to produce a proof but also report the exact place at which an attempted proof failed and analyze which subformula could not be proved under which assumptions. Often, this analysis gives a very clear hint about which "lemma" one should try before resuming the failing proof of the main proposition.

In such a situation one can make an attempt to prove the lemma (using the same prover). If the prover succeeds to prove the lemma one can go back to the proof of the main proposition. Often, the resumed proof succeeds (using the same prover) after adjoining the proved lemma to the knowledge base. This procedure can be applied recursively and can be fully automated as soon as one has good failure analyzers in addition to provers.

If confronted with a "challenge" (i.e. a proposition to be proved) such a combined prover / failure analyzer eventually does not only give back a proof (or at least a proof attempt) of the given challenge but, in addition, often generates an expanded knowledge base, i.e. it generates a part of the theory defined by the original knowledge base.

We already experimented with this approach (and other approaches) successfully but did not yet publish on this topic. We expect that this general approach will add an additional interesting and powerful facet to our project work.

Proof Programming It should be possible, to a certain extent, to automate the generation of special provers for particular functors. For example, various inductive provers for inductively defined domains share a common structure. The differences between the individual provers in this class are determined by the set of inductive clauses that define the (decision algorithm for the) carrier set of the domain generated by the individual functors. We already did some preliminary research into this direction and it is basically clear how this automated generation of provers could be realized. Still, a decent amount of work is needed for working out the details.

We are aware of the literature on "tactics" used as proof programming tools in existing (general and special) theorem provers and, of course, we intend to use the available experience gained in the pertinent papers. However, we think that a lot more can be done in a system that tries to integrate a general predicate logic prover (general predicate logic provers) with a variety of special provers for many areas of mathematics.

Proof Simplification Methodologically, for this part of the project it is crucial that our provers, first, generate abstract proof objects that can be post-processed by various post-processors (for example, a natural language proof presentation program). Proof simplifiers are then just another class of post-processors.

Speeding Up the System We already clarified and will further clarify the exact specification of that part of the Mathematica language that is necessary and sufficient for implementing provers and will write a compiler (most probably into Java) for this subset of Mathematica.

Computer-Supported Writing of Math Textbooks The method for this part of the project is basically clear: While continuing to write (an interactive version of) the benchmark book on Groebner bases in the traditional way, we will at the same time try out to what extent the routine parts of the proofs in the book can be produced (possibly with certain technical hints by the author) by our proving system. The production of the book can go through a new cycle every time the exact definitions of the concepts involved will be changed and this should be relatively easy having the new system support.

Application in Math Education The method for this is also straight-forward: We will use our new proving system in our existing course "Introduction to Mathematics: The Method of Mathematics", which concentrates on the formal techniques of mathematics including formal reasoning, at all places where this is appropriate. Any time when it comes to training certain proving techniques, we will use the respective prover of our system to set up an interactive training session with the students.

For this, it is necessary to dock this project to our projects on implementing a high-level system for the coordination of interactive tasks in distributed networks.

5.6.3 Programme and Schedule

We divide the proposed work into the following subtasks. For each task a Mathematica notebook containing the software implementation and complete documentation including the underlying mathematics will be delivered.

1. **Software Coordination**

   All software produced in the frame of the project including the pertinent documentation must be permanently maintained, updated and integrated into one current version.

   Time: Months 1-36

   Effort: 9 mm (man months)

   To be done by Văsaru.

2. **Language**

   Work out the syntax and informal semantics of the particular version of higher order predicate logic which will be the basis of our entire project. Particular attention will be paid at working out the details of sequence constants and variables. The algorithmic sublanguage contained in this language with syntax of typesetting quality (recursive equational definitions and bounded quantifiers) will be completely implemented in Mathematica 3.0.

   Time: Months 1-6

   Effort: 6 mm (man months)

   To be done by Buchberger and a diploma student.

3. **Functors**

   Extend the concept and implementation of functor to include a completely general automatic generation of knowledge bases for the generated domains from the knowledge base of the given domains and the functor definition. Implement a good syntax for such functors.

   Time: Months 1-6

   Effort: 6 mm.

   To be done by Tomuţa.

4. **Predicate Logic Prover**

   Finalize the general predicate logic prover.

   Time: Months 1-3

   Effort: 3 mm.

   To be done by Buchberger, Jebelean.

5. **Special Provers for Algorithmic Functors**

   Extend the existing provers for natural numbers, lists, and polynomials to more complicated properties and, along these lines, design and implement provers for the other basic algorithmic functors (e.g. finite sets, term algebra, canonical simplification, boolean polynomials, matrices etc.) of mathematics.

   Time: Months 1-18.

   Effort: 36.

   To be done by Buchberger, Jebelean, Văsaru, Tomuţa, and diploma students.

6. **Special Provers for Nonalgorithmic Functors**

   Design and implement special provers for the basic nonalgorithmic functors of mathematics (e.g. general sets, general functions, power series) with an emphasis on the functors used in analysis.

   Time: Months 7-24.

   Effort: 36.

   To be done by Buchberger, Jebelean, Văsaru, and diploma students.

7. **Solvers for Domains Generated by Functors**

   Investigate the notion of solvers corresponding to functors and design and implement such solvers for a few instances of functors. Investigate the interplay between the provers and solvers for a given functor.

   Time: Months 16-24.

   Effort: 18.

   To be done by Buchberger, Văsaru, Tomuţa, and diploma students.

8. **Incorporate Algebraic Black-Box Provers and Solvers**

   Incorporate the algebraic black-box provers and solvers to be implemented in the projects P2, P3, P4 and the ones built-in in Mathematica by designing a data exchange format and using MathLink.

   Time: Months 13-36.

   Effort: 6.

   To be done by diploma students.

9. **Incorporate Rewrite Black-Box Provers and Solvers**

   Incorporate the rewrite black-box provers and solvers described in the literature and partly available in academic systems by re-implementation in Mathematica.

   Time: Months 13-36.

   Effort: 24.

   To be done by diploma students under the supervision of Jebelean.

10. **Advanced Stages**

    Experiment with the ideas of theory generation, proof programming, and proof simplification using the provers (and solvers) implemented and incorporated into the system.

    Time: Months 25-36.

    Effort: 24.

    To be done by Buchberger, Jebelean, Văsaru, Tomuţa.

11. **Mathematica Compiler**

    Design and implement a compiler into JAVA for the rewrite sublanguage of Mathematica.

    Time: Months 1-24.

    Effort: 24.

    To be done by Buchberger and 2 PhD students not paid from this project.

12. **Application to Proof-Supported Text Book**

    Experiment with the proof system as a support in text book writing.

    Time: Months 13-36.

    Effort: 24.

    To be done by Buchberger and diploma students.

13. **Application to Math Education**

    Experiment with the proof system as a support in interactive math education over the net.

    Time: Months 12-36.

    Effort: 24.

    To be done by Buchberger, Jebelean, PhD students and high-school teachers not paid from this project.

5.7 Integration with the SFB

P1, P2, P3, and P4 are intimately connected by the following basic philosophy: All four projects consider proving and (exact) solving but in different domains:

P1 in general domains defined by functors,

P2 over the reals,

P3 over the complex numbers,

P4 over the natural numbers.

P1, in addition, will strive for providing a uniform logic and software front-end (based on Mathematica) from which the user can call and use the various provers and solvers developed in all four projects P1, P2, P3, P4.

P5 - P11 The interaction is two-fold:

- The provers developed in P1, in particular the special provers for proving properties of (real) functions can be used in establishing the theory behind the solvers to be developed in the frame of the projects P5, ... P11. Also, as the project advances, prototype systems will be available to the researchers in the other projects to support them in their mathematical work.
- The software developed in the other projects will implement solving and computing in particular mathematical domains, hence it can be used as "black-boxes" in a logical framework for proving in these domains.

5.8 Detailed Budget

5.8.1 Requested Personnel

The tasks are described in detail in subsection 5.6.3:

1. **Software Coordination**
2. **Language**
3. **Functors**
4. **Predicate Logic Prover**
5. **Special Provers for Algorithmic Functors**
6. **Special Provers for Nonalgorithmic Functors**
7. **Solvers for Domains Generated by Functors**
8. **Incorporate Algebraic Black-Box Provers and Solvers**
9. **Incorporate Rewrite Black-Box Provers and Solvers**
10. **Advanced Stages**
11. **Mathematica Compiler**
12. **Application to Proof-Supported Text Book**
13. **Application to Math Education**

The co-workers are:

A O.Prof.Dr. Bruno Buchberger (principal investigator)

B Dr. Tudor Jebelean (post-doc)

C DI Daniela Văsaru (PhD student)

D DI Ileana Tomuţa (PhD student)

E Diploma students and other RISC collaborators.

Buchberger will contribute to the project with 25% of his working time, without being paid from the project.

Jebelean (1 full-time post-doc position), Văsaru and Tomuţa (2 66% PhD positions) will be covered from the project.

Additionally, and under the guidance of the main researchers, some parts of the project will be carried out by diploma students and other RISC collaborators who will not be paid from the project.

The chronological order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12
(1)	C	■	■	■	■	■	■
(2)	A, E	■					
(3)	D	■					
(4)	A, B	■					
(5)	A, B, C, D, E	■	■	■			
(6)	A, B, C, D, E		■	■	■		
(7)	A, C, D, E			■	■		
(8)	E					■	■
(9)	B, E			■	■	■	■
(10)	A, B, C, D					■	■
(11)	A, E	■	■	■	■		
(12)	A, E			■	■	■	■
(13)	A, B, E			■	■	■	■

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 1 powerful workstation including special software like Mathematica 3.0, which amounts to **ATS 300.000,–** in the first year. This workstation is used for time consuming codes (also used by project P2).
- 1 workstation, which amounts of **ATS 70.000,–** in the first year.
  The workstation serve as additional workplace for the employees of this project.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each participant in this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 1
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	370.000	10.000	25.000				1.553.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	370.000	30.000	75.000				3.919.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 1

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Buchberger Bruno, DDr., O.Univ.-Prof.	Symbolic Computation	RISC	25%		1. Jahr	Univ.-Prof.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 1

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Jebelean Tudor, Dr.	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Tomuta Elena, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Vasaru Daniela, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Jebelean Tudor, Dr.	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Tomuta Elena, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Vasaru Daniela, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs- stätte (Institut)	% Arbeits- zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs- verhältnis	Beschäftigungs- ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Jebelean Tudor, Dr.	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Tomuta Elena, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Vasaru Daniela, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 1

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Indigo2, R10000, 256 MB, 2 GB	300.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	300.000			Summe	70.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 1

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 2: Proving and Solving Over Reals

5.1 General Information

Title : Proving and Solving Over Reals

Field of research : Computer Algebra and Computational Logic

Principal investigator : Univ.-Doz. Dr. Hoon Hong
Research Institute For Symbolic Computation
Johannes Kepler University Linz

5.2 Abstract

OBJECTIVE: We will develop mathematical theories, algorithms, and software libraries/packages for efficiently proving/solving real algebraic constraints (quantified boolean expressions of polynomial equations/inequalities over real numbers) of moderate sizes.

MOTIVATION: Many important and difficult problems in mathematics, scientific, engineering and industrial computations can be reduced to that of proving/solving real algebraic constraints. (See Section 5.6 for the details). Thus the availability of efficient algorithms/softwares for real algebraic constraint proving/solving will significantly increase the problem solving power in science and industry.

STATE OF THE ART: We already have algorithms/softwares that can *in principle* prove/solve *all* the real algebraic constraints. We also have algorithms/software that are *fast enough* for *small* inputs (up to 4 variables) or inputs from certain *sub*-classes. These are already used by scientists and engineers for solving small problems. But we do *not yet* have fast algorithms/softwares for *moderate* size inputs. There are numerous important *real-life* problems of moderate size (with about 10 variables).

MAIN THRUST: Thus, the main thrust of of this project will be focused on devising methods/software for *moderate* size inputs. We expect that this will require combining methods from computer algebra, numerical analysis, interval analysis, and developing new mathematical theories and software techniques.

METHODS: Through the experience/experiments with the existing methods/tools, we have identified several sources of inefficiency and also conjectures for possible improvements and new methods. Based on these we formulated 9 research ideas to pursue: pruning projection by box approximation, using intermediate results of projection, using convexity for bounded quantifiers, multivariate tightening, integrated combinatorics, approximate quantification, exact division, use of chain rule, and approximate simplification. Each research idea is rich/heavy enough to be pursued by one person throughout one year (working 2/3 time).

DELIVERABLES: We will deliver for each of the 9 tasks (based on the 9 ideas listed above) the followings: one scientific report (in LaTeX), one software package (in C++ or Java), one software documentation (in HTML), one graphical user interface to the software (in Java).

5.3 State of the Art

Around 1930, Tarski [84] opened the area by proving constructively that the theory of real closed field admits quantifier elimination. (every real algebraic constraint is equivalent to a real algebraic constraint without quantifiers. This was an epoch making event in the foundational studies in the mathematics and logic because it meant that not only the elementary real algebra but also various mathematical theories built on real numbers are also decidable/solvable, for instance, the elementary algebra of complex numbers, that of quarternions, that of n-dimensional vectors, and the elementary geometry (Euclidean, non-Euclidean, projective).

In [20], Collins (a faculty at RISC during 1991-1996) introduced a new method which has a much better computing time bound than Tarski's (doubly exponential in the number of variables rather than non-elementary, thus the infinite tower of exponents is reduced to two floors). Collins' method went through various improvements: clustering [2], smaller projections [73, 2], partial CAD [3, 1], solution formula construction [6]. strict inequalities [74] and equational constrains [21]. Now the method has been implemented twice completely [2, 3]. The implementation of [3] is currently used in several small engineering/scientific applications.

During last decade, there was an intensive research on improving asymptotic worst case computing bounds [5, 32, 38, 37, 14, 15, 41, 76, 77, 78, 91]. The key idea is that a consecutive block of same quantifiers can be eliminated by a single projection in an exponential time (in the number of variables). Thus, the total complexity is doubly exponential in the number of quantifier alternations, not on the number of variables. If all quantifiers are the same (1 quantifier-block), then the total complexity is singly exponential in the number of variables.

Recently, there have been also efforts for developing methods that work on restricted class of inputs. Such research is motivated by the observation that one can identify interesting and useful sub-class of problems and that one might be able to develop more efficient (in practice) methods for them.

In [88], Weispfenning investigated the complexity of quantifier elimination for *linear cases.* He proved that the worst case asymptotic complexity stays the same (doubly exponential in the number of quantifier alternations) in spite of the linear restriction. However, this and the subsequent work [70] showed that one can devise much faster (in practice) methods for moderate size inputs. In [90], Weispfenning generalized his linear algorithm to quadratic and cubic cases. In [11, 12], Hong devised an algorithm that eliminates a quantifier from a formula which is *constrained by a quadratic equation.* The output formulas are made of resultants and their variants called *slope* resultants. The slope resultants can be, like the resultants, expressed as determinants of certain matrices. The computing time of the method is linear in the input length.

In [35], Gonzales Vega gave algorithms for formulas with single atomic formula. The algorithms first compute finite number of polynomials and select among all the possible sign conditions over these polynomials those making the considered formula true. The main mathematical tool used is the Sturm-Habicht sequence [36] which is essentially a careful adaptation of Sturm's sequence to the subresultant chain.

In [24, 22, 21], Hong investigated how various fundamental operations (such as resultants, sub-resultants, multivariate resultants, Groebner basis) used in real algebraic constraint solving behave under composition. He showed that under certain mild conditions, one utilize the composition structure to speed up the whole computation dramatically.

Summarizing, the *current state of the art* of real algebraic proving/solving is as follows:

- We *already have* algorithms/softwares that can *in principle* prove/solve *all* the real algebraic constraints.

- We *already have* algorithms/software that are *fast enough* for *small* inputs or inputs from certain *sub*-classes. These are already used by scientists and engineers for their problem solving.

- We *need* to develop faster algorithms/softwares for *moderate* size inputs. There are numerous important *real-life* problems of moderate size (with about 10 variables).

Thus, the *next* step is to develop fast methods for moderate size inputs.

5.4 Previous Work

At RISC, we have been actively carrying out research in the area of real algebraic constraint solving. George Collins, one of the pioneers of the area, has been in the faculty during 1991-1996. Hoon Hong, his former PhD student, has also been a faculty since 1990 until now.

Our main research activity was to investigate ways to achieve efficiency for small or moderate size inputs (reducing the constants which are ignored during the asymptotic complexity analysis). These have been reported in various scientific papers, for instance in [2, 3, 1, 6, 5, 4, 12, 9, 29, 11, 10, 9, 21, 17, 19, 24, 22, 23, 6, 31, 26].

Type	Number
In Refereed Journals	13
In Refereed Conference Proceedings	18
In Refereed Books	4
In Technical Report Series	46

Below, we give a brief summary of these.

The first approach that we took was to improve a general algorithm (the cylindrical algebraic decomposition of Collins) for small inputs. The algorithm consists of three phases: *projection*, *lifting*, and *solution formula construction*. We have improved each phases using various ideas from elimination theories, lazy computation, logic simplification, etc. By combining these improvements, the method could handle many small size inputs, reducing computing times from several (expected) months/years to several seconds/minutes.

The next approach that we considered was *specialization*. We hoped to find efficient methods for some special sub-classes of general problems. But then, we did not want to work on "useless" sub-classes. We decided to work on only those sub-classes that naturally arise In serious applications. We came to find several "useful" classes through contacts with other disciplines (programming language design, scientific computation, mechanical engineering, electrical engineering, etc). For some of them, we devised much more efficient methods (than any general methods).

Recently, we began to observe that often the input formulas arising from applications have certain structures, in particular, *composition structure*. As a simple example, we encountered the polynomial $f = (x^2+y^2-1)^4+(x^2+y^2+1)^4-1$ which can be obtained from the polynomial $g = x^4+y^4-1$ by replacing the variables x and y by the two polynomials $h_x = x^2+y^2-1$ and $h_y = x^2+y^2+1$ respectively. In a word, f is a composition of g by (h_x, h_y), written as $f = g \circ (h_x, h_y)$. Composed objects (polynomials) occur often in real-life problem solving because the underlying mathematical models are usually hierarchically structured. Naturally, we begin to investigate about how to utilize the composition information In order to speedup various fundamental elimination operations such as subresultants [40, 19, 7, 8, 82, 36, 33, 34] (which is the main machinery of the cylindrical algebraic decomposition method [20]), Groebner basis [9, 10, 13, 11, 12, 29, 89, 4] and Multivariate (Macaulay) resultants [71, 17, 31, 93, 30, 65, 95, 18, 83, 16, 66, 72, 67]. We have succeeded in proving that each elimination operation "roughly" commutes with composition, which immediately gives an efficient method (by just following the alternative path in the commutative diagram).

Often solution sets are quite complicated, and thus there is not much hope in obtaining simple formulas describing them. Further often the solution sets are made of algebraic points of very high degrees. But in many applications, it is not necessary to know the exact shape of the solution set. It is sufficient to have approximate description (to a given precision). Thus, we devised methods for *approximately solving* of real algebraic constraints. The method combines the ideas from computer algebra, numerical analysis and interval mathematics.

Finally, most methods for proving/solving real algebraic constraints are highly highly parallelizable (they are many independent time-consuming tasks). We have parallelized the partial CAD method on workstation network, which often gives 'super-linear' speed up due to the specularative parallelism involved.

5.5 Cooperations

We have been cooperating with the following institutions / persons:

- University of Vienna, Austria (Zima, Fahringer)

  We have carried out two joint research project: CEI-PACT, FWF Schwer-punkt on parallel computation. In particular, we have been developing volume computation methods for their automatic parallelizing compiler for Vienna Fortran.

- University of Passau, Germany (Weispfenning)

  We have provided our software to them and they integrate it to their software in solving some large non-trivial problems.

  We have been also carrying out joint research on how term orderings (in Groebner basis) behave under composition.

- University of Marseilles, France (Colmerauer):

  We have been developing efficient real algebraic constraint solvers for constraint logic programming languages, under the European Union project ACCLAIM.

- University of Renne, France (Roy)

  We have been developing efficient solvers for real algebraic constrains under the European Union project POSSO.

- University of Santander, Spain (Recio, Gonzales-Vega)

  We have been developing efficient solvers for real algebraic constrains under the European Union project POSSO.

- University of Prague, Czeck (Liska)

  We have been applying the theory/software of real algebraic constraints for the stability analysis of partial differential equations and their numerical schemes.

- University of Linkoping, Sweden (Jirstrand)

  We have provided our software to them. They have been applying it to various problems arising from non-linear control system design.

- University of Patras, Greece (Ioakimidis)

  We have helped them to solve various problems arising mechanical engineerings.

- University of Glasgow, England (Loidl)

  We have been studying how to parallelize quantifier elimination method using functional languages (Haskell).

- University of Delaware, USA (Collins, Brown)

  Collins was a faculty at RISC until June of 1996. Since Collins joined University of Delaware, we have been continuing joint research in improving the method of cylindrical algebraic decomposition.

- University of Kent, USA (Wang)

  We have been sharing various software tools for parallelizing symbolic computations algorithms (in particular quantifier elimination).

- University of Nex Mexico, USA (Steinberg, Robideux)

  We have been applying the theory/software of real algebraic constraints for the stability analysis of partial differential equations and their numerical schemes.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

The **objective** of this project is

> **to develop mathematical theories, algorithms, and software libraries/packages for efficiently proving/solving real algebraic constraints.**

In the following, we elaborate on the phrase: efficiently proving/solving real algebraic constraints.

- Real Algebraic Constraints: By *real algebraic constraints*, we mean expressions (well formed formulas) constructed from

  - rational numbers,
  - variables (ranging over real numbers),
  - arithmetic function symbols such as $+$, $-$, $\times$, $/$,
  - relation symbols such as $=$, $>$, $\geq$, $\neq$,
  - logical connectives such as $\wedge$, $\vee$, $\neg$, $\Leftarrow$,
  - quantifiers such as $\forall$, $\exists$.

  Formally put, they are formulas in the first order theory of real closed fields. Here are some simple examples:

  $$x^2 + y^2 = 1 \quad \wedge \quad x < y$$

  $$(\forall x) \;\; x > 0 \quad \Rightarrow \quad ax^2 + bx + c > 0$$

  $$(\forall \epsilon)(\exists \delta) \;\; |x| < \delta \quad \Rightarrow \quad |ax^2 + bx| < \epsilon.$$

  In the last example, $|x| < \delta$ is a short-hand for $-\delta < x \wedge x < \delta$. In the similar way, we can Introduce various other short-hands such as $\sqrt{}$, max, min, etc.

- Proving: A variable which is not bound by a quantifier is called to be *free*. A real algebraic constraint without free variables is called a real algebraic *sentence*. For a simple example,

  $$(\forall x) x^2 + x + 1 > 0$$

  is a sentence. A sentence is either true or false. The above example sentence is true. By *proving*, we mean to verify that a given sentence is true. More generally, we also want to *decide* if a given sentence is true or false.

- Solving: A real algebraic constraint with at least one free variable defines a subset of the free variable space. For example, the constraint

  $$x^2 + y^2 \leq 1$$

  defines the unit disc in the real plane. We naturally call it the *solution set*. By *solving*, we mean to extract some useful information about the solution set. Depending which information we want to extract, we have different sub-problems. Among various sub-problems, we will concentrate our effort on the followings:

Problem	Desired Information about Solution Set
Quantifier Elimination	Quantifier-free formula describing the solution set
Box Approximation	Boxes that contain (are contained in) the solution set
Volume Computation	Volume of the solution set

  These choices are based on the extensive observation that almost every application problem can be reduced to one of these sub-problems.

- Efficient: By now, it is well understood that the real algebraic constraint solving is intrinsically intractable in the large and worst cases (exponential asymptotic complexity). Thus by *efficient* solving, we do *not* mean to reduce the asymptotic complexities. Rather we mean solving fast the inputs of moderate sizes or important special cases with certain structures.

The **motivation** for this project comes from the fact that

> **many important and difficult problems in mathematics, scientific, engineering and industrial computations can be reduced to that of proving/solving real algebraic constraints.**

To mention a few examples,

- *Mathematics*: The Hilbert 16th problem [42, 39, 94, 1, 87] (which asks for the classification of the topological types of regular curves in the real projective plane) can be formulated and investigated algorithmically as that of algebraic constraint solving problem [3, 79, 28, 80, 81, 7]. Further, virtually all elementary algebra and geometry can be reduced to that of algebraic constraint solving [85, 86]

- *Scientific computation*: Ensuring stability is important for devising good numerical schemes for solving (partial) differential equations. The problem of finding the stability region (for the parameters such as grid distances) can be formulated and tackled as that of finding quantifier-free formula describing of solution sets which are initially described by quantified formulas [69]. As another example, the rigorous study of convergence of the Newton-Raphson method can be carried out in this framework [68].

  Further, various fundamental questions (such as existence, uniqueness, convergence, convergence rate) arising in inverse problems can be formulated as proving/solving over *real* Hilbert space. Many of these problems can be reduced to the problem of proving/solving over the *reals* by first carrying out natural deduction/rewriting on Hilbert space until formulas involving only the symbols of the language of real algebraic constraints are obtained.

- *Engineering / Industrial computation*: Many problems in linear/non-linear control engineering can be reduced to that of algebraic constraint solving such as stationarizable sets, ranges of controllable outputs, following a parameterized curves, constrained reachability, etc [75, 64]. Most of non-linear geometric modeling can be reduced to that of "approximately" solving algebraic constrains. Further, optimization and simulation of linear, piece-wise linear, and non-linear models can be carried out as (existentially quantified) constraint solving [92].

- *Computer Science*: The "Constraint Logic Programming" (CLP) languages [25, 26, 27, 63, 62] are high-level declarative languages which generalizes the language PROLOG [23, 24] in that the unification is replaced by constraint solving. There are several dedicated scientific conferences and a few companies which develop and distribute CLP softwares. Real algebraic constraint solvers form the core (engine) of the CLP languages.

  A fundamental problem in automatic parallelization of sequential programs is to estimate the load of each processor under a given data partition scheme. This problem can be reduced to that of finding the volume of the solution set of certain real algebraic constraints (which arise from the loops and the conditionals used in the program).

5.6.2 Methods

In the objective section, we identified the following four sub-problems to tackle: *proving*, *quantifier elimination*, *box approximation* and *volume computation*. It turns out that the two sub-problems, proving and quantifier elimination, can be studied in one framework since proving is a special case of quantifier elimination where there are no free variables.

We will pursue various promising ideas (sketched below) for achieving efficiency for each sub-problems. These ideas have been identified during our previous extensive research in the area, and we have strong feeling that they will yield significant efficiency.

<u>PROVING AND QUANTIFIER ELIMINATION:</u>

Idea 1: *Prunning Projection by Box Approximation.*

All known quantifier elimination methods *project* the polynomials in the input formula down to the lower dimensional space. This process produces many and huge polynomials in order to ensure that the "worst case" is covered, causing time and space blowup.

But the worst case occurs rarely and thus often the many huge polynomials are in fact unnecessary. Unfortunately, the present algorithms discover this fact only at the very last stage of their execution. That is too late since we already consumed huge computing time on working uselessly with those polynomials.

Thus, it is very important to detect the unnecessary projection polynomials and remove them as soon as possible. Obviously, this detection process should be cheap. If not, it defeats its own purpose. The proposed idea here is to use the *box approximation method.*

To illustrate the idea, consider the following simple example:

$$(\exists y)(\forall z)F(x,y,z)$$

where F is a quantifier-free formula. Suppose that the polynomials $P_i(x,y)$'s are obtained by projecting the polynomials in F. Let S be the solution set of the formula

$$(\forall z)F(x,y,z).$$

Now it can be easily shown that if the zero set of $P_i(x,y)$, that is $\{(x,y)|P_i(x,y)=0\}$, does not intersect with the boundary of the solution set S, then P_i is not necessary.

But how do we check this inexpensively? Here comes in the box approximation idea. We approximate the boundary of the solution set S and the zero set of P_i by two sets of boxes respectively. Then we check if two sets of boxes intersect. If they do not intersect, we know definitely P_i can be removed safely. If they do intersect, we do not know (since boxes are only approximations), and thus we keep P_i.

Box approximation can be done efficiently if we do not require too much precision. We conjecture that in most cases, low precision will be sufficient. Testing if two sets of boxes intersect is an easy combinatorial task.

Idea 2: *Using Intermediate Results of Projection During Lifting*

The lifting phase of the quantifier elimination algorithm (cylindrical algebraic decomposition) repeats the followings: (1) Evaluate a k-variate projection polynomial on an real algebraic point in the $k-1$ dim space, obtaining a univariate polynomial with real algebraic coefficients. (2) Isolate the real root of the univariate polynomial. Usually, the step (2) is very time-consuming, and we need to speed up this step.

We observe that during the projection phase the (sub)resultants of the projection polynomials are computed. The usual way of computing the resultants is via polynomial remainder sequence. Thus, the polynomial remainder sequence of the projection polynomials are available as by-product of the projection phase. The idea is to utilize these during the lifting phase.

During the lifting phase, we evaluate the polynomial sequence on a point in $k-1$ dim space. Then after suitable adjustment of signs we obtain a Sturm sequence almost for free, which can be immediately used for root isolation via the inexpensive repeated bisections.

This approach has a further benefit because Sturm sequence method does *not* require that the polynomials are square free. Thus we do not need to carry out the expensive square free factorization before root isolation.

Idea 3: *Using Convexity for Bounded Quantifiers.*

Consider the formula $(\forall x \in B) F(x)$ where $x = (x_1, \ldots, x_n)$ and B is a box in $\mathbf{R}^n$ and F is another formula. We say that the quantifiers are *bounded* by B. Such bounded quantification arise often in real-life problems such as *robust* stability of control systems. In fact, it can shown that any formula can be converted into an equivalent formula with only bounded quantifiers. (This is true for real algebraic constraints, but not true if we allow transcendental functions.)

For several interesting and important class of problems, the solution set of F turns out to have nice properties. For example, the the solution set of the formula arising from the famous Kharitonov stability [] is convex.

In the convex case, we only need to check F on the vertices of B, obtaining the equivalent formula

$$\bigwedge_{p\,:\ \text{vertex of}\ B} F(p).$$

Hence, we eliminated all the n universal quantifiers.

Sometimes, the solution set of F might not be convex, but k-convex. We say that a set S is k-convex if for every k-dim box I we have that $\partial I \subseteq S$ implies $I \subseteq S$. (The set S is convex iff it is 1-convex.)

Suppose the solution set of F is known to be k-convex. Then we only need to check F on the $k-1$ dimensional faces of B, obtaining the equivalent formula

$$(\forall x \in B_k)\ F(x)$$

where B_k is the set of the points on all the $k-1$ dimensional faces of B. Thus, we have eliminated $n-(k-1)$ universal quantifiers.

The main research effort will be on developing mathematical theories and algorithms for proving/checking the k-convexity of a given F. We will study carefully the proof of Kharitonov's theorem (and its generalizations) to find ways to generalize it to larger class of formulas.

BOX APPROXIMATION:

Idea 4: *Multivariate Tightening.*

The box approximation algorithms usually repeat the following two kinds of operations: (1) Approximation of the solution set of an atomic formulas by a collection of boxes. (We call this process *tightening.*) (2) Carry out the logical operations (boolean connectives and quantifiers) on the boxes. (These are combinatorial in nature.) Both are time-consuming. Here we discuss an idea for improving (1). Later we will discuss another idea for improving (2) (under Idea 5).

Consider an atomic formula $P(x_1,\ldots,x_n)\ \rho\ 0$ and a box B in n-dim space, where ρ is a relational operator such as $=,\neq,>,\geq$. The tightening step computes disjoint boxes $B_1,\ldots,B_\ell$ such that

$$B_1\cup\cdots\cup B_\ell \quad\supseteq\quad S(P\ \rho\ 0)\cap B.$$

Currently this is done by carrying out the tightening for each coordinate one after the other. One can say that it consists of several univariate tightening. This process is quite time consuming. Further this process sometimes gets *saturated*, and requires bisection of boxes. For a simple example, consider the formula $x-y=0\wedge x+y=0$ over $[-1,1]^2$. Note that we cannot tighten any further $[-1,1]^2$ by $x-y=0$. Likewise we cannot tighten any further $[-1,1]^2$ by $x+y=0$ either. Thus, in order to continue, we are forced to carry out bisection of the box $[-1,1]^2$. Often such situation causes enormous numbers of bisections, slowing down the algorithms.

One idea to avoid such blowup is to develop a *multivariate* version of tightening. Here we carry out tightening on a conjunction of atomic formulas. For instance, we could carry out multivariate Newton iteration. The details are not yet known and will be studied during the project.

Idea 5: *Integrated Combinatorics.*

The box approximation algorithms, as mentioned above, involve combinatorial computation with boxes. As expected, this part causes combinatorial blowup, (too many cases to consider). One of the main reason for such blowup is due to the "blind" recursive nature of the algorithms. For this instance, consider the formula

$$F(x)\wedge G(x)$$

over B. The current algorithm approximate F over B by boxes and G over B by boxes. These two approximations are carries out *independently.* Then the resulting boxes go through the intersection (conjunction). A better way to organize this is to approximate F over B first and then approximate G on the *resulting boxes.* This will often greatly cut down the computing time for approximation of G. In a sense, we have an *integrated* combinatorics instead of a recursively modularized one.

We will pursue this intuition in order to find a general method which works for arbitrary formulas. It seems that this will require some kind of dynamic programming together with incremental/lazy computation.

Idea 6: *Approximate Quantifiers.*

One of the most time consuming parts of the box approximation algorithms is the box quantifier elimination. A trivial example illustrate the reason:

$$(\exists y \in I)\ \ x = y.$$

Obviously the solution set is the whole real line, since for every x we can choose $y = x$. But this requires working with low-dimensional set (dimension 1 instead of 2), which is, in general, difficult to do since we usually need to work with real algebraic numbers. (In this trivial example, we do not need to work with real algebraic numbers, but in general we will have to).

Fortunately, discussing with several engineers, we learned that in most real-life problems, "approximate" quantification is acceptable. For instance, we could introduce the ϵ-existential quantifier defined by:

$$(\exists_\epsilon x \in B)\ \ F(x)$$

is true iff $V(S(F))/V(B) > \epsilon$, where $S(F)$ is the solution set of F and $V(T)$ is the volume of the set T. Then we can define the ϵ-universal quantifiers by

$$(\forall_\epsilon x \in B)\ F(x) \iff \neg(\exists_\epsilon x \in B)\ \neg F(x).$$

The following examples illustrate the approximate quantifiers:

$$(\exists x \in [0,1])\ \ x = 1$$

is true, but

$$(\exists_0 x \in [0,1])\ \ x = 1$$

is false, since the solution set of $x = 1$ is of measure 0. Likewise

$$(\forall x \in [0,1])\ \ x \neq 1$$

is false, but

$$(\forall_0 x \in [0,1])\ \ x \neq 1$$

is true, since the exception for $x \neq 1$ is of measure 0.

We will develop this initial intuition into a full complete theory and develop suitable algorithms for working with them. It will be also necessary to find out for which class of problems the exact quantifiers can be safely replaced by the approximate ones.

<u>VOLUME COMPUTATION:</u>

Idea 7: *Exact Division.*

Experiment with the existing methods show that their inefficiencies mainly stem from the coefficient size blowup. For example, an input with just 3 bit coefficients with 7 variables can produce intermediate results with 300 bit coefficients! In fact, it seems that their sizes grow exponentially!

But we also observed that these collection of coefficients often have a very large greatest common divisor (gcd). After factoring out the gcd, the resulting coefficients are much smaller. Further it seems that their sizes grow only linearly.

These observations suggest some deep theorem concerning the hidden structure of the existing methods. We will make extensive effort to dig out the hidden structure. The initial approach will be to see if there is any connection between this and the well known Bariess exact division theorem for Euclidean algorithm. But the volume algorithm is much more complex than the Euclidean algorithm, and thus it might require quite different proof technique.

Once we have understood the hidden structure, we will devise methods for systematically factoring out the gcd's (but without computing them). It is expected that this process will dramatically improve the efficiency of volume computation.

As a prerequisite to applying the exact division, we first will have to devise methods for carrying out all the arithmetic over integers (instead of over rational numbers as done right now).

Idea 8: *Use of Chain Rule*

The volume computation algorithms require repeated definite integration of polynomials over ranges given by linear expressions. For example, we need to carry out integration such as

$$\int_{L(x,y)}^{U(x,y)} P(x,y,z)\, dz$$

where P is a polynomial and L and U are linear expressions. This is naturally done in two steps. (1) Carry out the indefinite integration of P obtaining Q. (2) Expand the expression

$$V(x,y) = Q(x,y,U(x,y)) - Q(x,y,L(x,y)).$$

The reason for $V(x,y)$ is to prepare for the next integration in y.

This expansion cause much blowup. Even when P, U, L are all very sparse, after the expansion, V gets very dense with huge coefficients. This is another main source of inefficiency. In order to achieve efficiency, we need to preserve the sparsity.

One idea starts from the simple observation that we can *sometimes* carry out the next integration (in y) without expanding V, by using chain rule. For a trivial example,

$$\int (x+2y)^2 dy = 1/3(x+y)^3 \times 2.$$

In this case, we can just keep the *decomposed* form for the output (without expanding) so that it can be used again during the next integration. Thus the research will be on making this process (use of chain rule) *always possible*. It seems that this could be done via suitable perturbation or affine transformation of the input.

Idea 9: *Approximate Simplification.*

Often we want to compute the volume *parametrically*. In order to understand what it means, consider the formula

$$F(p,q,x,y).$$

Given values for p and q, we can view F as a formula in x and y. Let $S_{p,q}$ be the corresponding solution set in the x, y space. Now we would like to find a "symbolic" expression in p and q that gives the volume of $S_{p,q}$.

We have already developed enough mathematical theories and algorithms for doing this. But the outputs are often very large since the complicated shape of the solution sets requires numerous case distinctions. More precisely, the output is in general a binary decision tree where each internal node is a condition on p and q (a quantifier-free formula in p and q) and each leaf is a symbolic expression in p and q for the associated volume. Our experiments show that the tree is often very large. For instance, one line input in just four variables can result in one page output! Unfortunately, these complexity is intrinsic and thus cannot be simplified by removing inconsistent and redundant branches in the tree.

Fortunately, however, we observe that in many practical applications, it is not necessary to have exact volumes. Approximation is sufficient. Now the key idea is that nearby a complicated solution set there might be a simple solution set whose volume can described by a simple tree. Thus, we only need to find a simple solution set near the complicated solution set. We will develop mathematical theories and algorithms for the idea.

5.6.3 Programme and Schedule

The total work will be divided into 11 tasks:

Task 1–9: In these tasks, we will investigate the research ideas described above, devise algorithms, develop software packages, document them, and produce scientific papers.

Task 10: In this task, we will integrate the tools from this project with the tools from other projects. For this, various software engineering issues will be investigated.

Task 11: In this task, the principal investigator will carry out planning and guidance of the research activities of the paid co-workers.

Each research idea is rich/heavy enough to be pursued by one person throughout one year (working 2/3 time). Thus, each research task has been scheduled to one year period. The integration and the management tasks need to be carried out throughout the project. The detail schedule is given below.

Task	Description	Period	Paid Man-Year
Task 1	Pruning Projection by Box Approximation	1st year	2/3
Task 2	Using Intermediate Results of Projection	2nd year	2/3
Task 3	Convexity for Bounded Quantifiers	3rd year	2/3
Task 4	Multivariate Tightening	1st year	2/3
Task 5	Integrated Combinatorics	2nd year	2/3
Task 6	Approximate Quantification	3rd year	2/3
Task 7	Exact Division	1st year	2/3
Task 8	Use of Chain Rule	2nd year	2/3
Task 9	Approximate Simplification	3rd year	2/3
Task 10	Integration	Throughout the project	$1 = 1/3 \times 3$
Task 11	Project Management	Throughout the project	0

Deliverables: Each research task (Tasks 1 through 9) will have the following deliverables.

- 1 scientific report (in LaTeX)
- 1 software package (in C++ or Java)
- 1 software documentation (in HTML)
- 1 graphical user interface to the software (in Java)

5.7 Integration with the SFB

Project 2 will use the results from several other projects and the results from Project 2 will be used by also several other projects.

The tools from Project 2 will be integrated with the tools from Project 1 as a *black-box* prover/solver. Together, we will prove/solve many problems over real Hilbert space, where the tools from Project 1 will reduce, via natural deduction/rewriting, the problem over real Hilbert space to that over the reals, which can be in turn tackled by the tools from Project 2.

Moreover, the tools from Project 3 will be used as a quick *pre-filtering* method. It is based on the observation that if a universally quantified sentence is true over complex then it is also true over real and that it is often much easier to work on complex numbers.

Apart from this the tools from Project 4 will be used to reduce various problems involving both integers/reals to the problems involving only reals.

Many fundamental questions in inverse problems (such as existence, uniqueness, regularization, convergence, convergence rate) require proving/solving over real Hilbert space. The tools from Project 2 and Project 1 will be combined to tackle them, where the tools from Project 1 will be used to reduce the problems over real Hilbert space to those over the real numbers, which will be in turn tackled by the tools from Project 2. This gives a strong link to Project 7

Project 8 deals with hierarchical methods for simulation and optimal design. In their applications to magnetic field problems nonlinear constraints occur regularly. These constraints can be simplified using tools provided by Project 2, e.g. by solving systems of nonlinear equations. Project 8 can use these simplification techniques for speeding up simulation and design methods.

In developing efficient methods for real algebraic constraint solving, it is helpful to visualize solution sets (semi-algebraic sets). Such visualization very often provide essential intuition and conjectures about the shapes of the solution sets, which can be utilized for speeding up the solving process. We will use the methods/tools developed by Project 12 for this purpose.

5.8 Detailed Budget

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12
Task 1	B, A						
Task 2	B, A						
Task 3	B, A						
Task 4	C, A						
Task 5	C, A						
Task 6	C, A						
Task 7	D, A						
Task 8	D, A						
Task 9	D, A						
Task 10	B						
Task 11	A						

The symbols A, B, C and D are assigned to the following persons working on the corresponding problems:

A = Hoon Hong (Univ. Dozen. Dr., the principal investigator),

B = Nicolas Robideux (Postdoc, full-time)

C = Manfred Minimair (Dipl.-Ing. Ph.D. student, 2/3-time)

D = To be chosen (Ph.D. student, 2/3-time)

The thick line stands for 2/3-time and the thin line stands for 1/3-time.

5.8.1 Requested Personnel

One full-time post doc positions (S 492.000/year) and two doctoral positions for Ph.D. students, which are paid as 2/3 job (S 328.000/year), are required for this project.

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 2 workstations, which amounts to a total of **ATS 140.000,–** in the first year.
  The workstations serve as additional workplaces for the employees of this project.

- For time consuming codes, the powerful workstation of project P1 will be used.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 2
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	140.000	10.000	25.000				1.323.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	140.000	30.000	75.000				3.689.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 2

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Hong Hoon, Dr., Univ.-Doz.	Computeralgebra, Geometrie	RISC	25%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 2

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Robideux Nicolas	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Minimair Manfred, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs- stätte (Institut)	% Arbeits- zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs- verhältnis	Beschäftigungs- ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Robideux Nicolas	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Minimair Manfred, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Robideux Nicolas	Symbolic Computation	RISC	100%		1. Jahr	V.Ass.	voll
Mag./DI	100%	1	Minimair Manfred, Dipl.-Ing.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Symbolic Computation	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 2

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe				Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 2

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 3: Symbolic-Numerical Computation on Algebraic Curves and Surfaces

5.1 General Information

Title : Symbolic-Numerical Computation on Algebraic Curves and Surfaces

Field of research : polynomial elimination theory, algebraic geometry, computer aided geometric design, geometric theorem proving

Principal investigator : Assoc.-Prof. Doz. DI. Dr. Franz Winkler
RISC-Linz
Johannes Kepler Universität Linz

5.2 Abstract

In computer aided geometric design (cagd) algebraic curves and surfaces play an essential rôle in modeling physical and virtual objects. The main goal of the project is the improvement and/or perfection of existing methods and the derivation of new methods for designing, manipulating, and visualizing algebraic curves and surfaces. Algebraic curves and surfaces can be represented in different ways, e.g. implicitly by a defining polynomial equation, parametrically by rational functions, or locally by Puiseux series or places. Every one of these representations has its own particular advantages, and so we need to have efficient algorithms for changing representations.

In the past few years our research group has been working on symbolic methods for efficient computation of parametrizations of algebraic curves. This involves genus computation, complete analysis of the singularities, and determination of a system of adjoints. For instance, we have been able to derive an algorithm for determining an "optimal" parametrization, i.e. a parametrization having coefficients in the simplest possible ground field. However, there is still much room for improvement. Currently we are using blow-ups and quadratic transformations in the computation of genus and adjoints. This can probably be done much more efficiently by using local Puiseux expansions. There are hints in the literature on using series for genus computation, but for determining the adjoints we need more research. One problem that has ultimately to be solved in the parametrization process is the determination of simple points on the curve, of course with coordinates in a simplest possible ground field. We are working on solving this problem for various practically interesting ground fields, such as $\mathbf{Q}$, rational functions over $\mathbf{Q}$, or finite fields.

This parametrization of algebraic curves is particularly interesting in computer aided geometric design (cagd), where one usually models the boundaries of objects by algebraic curves or surfaces in parametric form. The classical approach to cagd is numerical in nature, i.e. the boundary patches are approximated to high enough accuracy. In such a numerical approach it can be a problem to trace along a curve, in particular near a singularity. The Jacobian matrix vanishes at a singularity, creating problems with Newton approximation. We want to use fast numerical methods when possible, and symbolic algebraic methods when necessary for topological correctness. This combination of symbolic and numerical tools is particularly important in visualization of geometric objects. Recently successful hybrid symbolic/numerical algorithms have been developed in a Ph.D. thesis. We intend to continue this promising work.

One important problem in cagd is the computation and investigation of offset curves and surfaces, i.e. curves or surfaces which keep a certain distance from some base curve or surface. In our group we are currently implementing and testing new algorithms for offset curves. Also the above mentioned problem of finding simple points over certain ground fields could probably lead to automatic determination of offset surfaces to interesting classes of curves and surfaces in cagd, such as pipe and canal surfaces.

In the last decade various new approaches have been presented for automatically proving or disproving geometrical hypotheses. Here both the hypotheses and the conclusions are expressed in terms of algebraic curves, surfaces, or higher dimensional objects. Elimination methods such as resultants, characteristic sets, and Gröbner bases play a crucial rôle in all these methods for geometric theorem proving (gtp).

Dixon resultants could bring a decisive improvement in complexity of the gtp algorithms. Our group has some very promising results in this direction and we intend to continue our investigation in gtp.

Over the years we have been collecting our algorithmic developments, and we have implemented them, together with the work of other groups, in our program system CASA. This system CASA is a tool for describing, constructing, investigating, and visualizing curves, surfaces, and higher dimensional varieties in constructive algebraic geometry over an algebraically closed field, such as the complex numbers. CASA has been presented at several conferences, and it is also used by researchers at other universities. We plan to keep developing and improving this program system CASA.

5.3 State of the Art

<u>The parametrization problem</u>

An algebraic plane curve $\mathcal{C}$ can be represented as the set of zeros of a squarefree polynomial $f(x,y) \in \mathbb{C}[x,y]$ (or over any other algebraically closed field), i.e.

$$\mathcal{C} = \{(x_0, y_0) \in \mathbb{C}^2 \mid f(x_0, y_0) = 0\} .$$

We call this representation the *implicit representation* of $\mathcal{C}$ and f the *defining polynomial* of $\mathcal{C}$.

Some irreducible curves, namely exactly those with genus 0 (i.e. those having the highest possible count of singularities), cannot only be defined implicitly by a polynomial, but also by a *(rational) parametrization*. Let $u, v \in \mathbb{C}(t)$ be rational functions in t over the ground field $\mathbb{C}$, not both constant. We call (u, v) a parametrization of $\mathcal{C}$, iff (except for finitely many points)

$$\mathcal{C} = \{(u(t), v(t)) \mid t \in \mathbb{C}\} .$$

Similarly we can define implizit and parametric representations of algebraic surfaces.

Given a curve $\mathcal{C}$ by a parametrization, the defining polynomial can be computed in a rather straight forward way by elimination theory. The reverse problem, namely computing a parametrization of $\mathcal{C}$ given its defining polynomial f, is treated algorithmically in [2], [69], [57] and [58]. Whereas the algorithm given by van Hoeij uses an integral basis of the algebraic function field $\mathbb{C}(x)[y]/(f)$ to compute a parametrization, the algorithm of Sendra and Winkler uses the system of adjoints of $\mathcal{C}$. If we start from an implicitly defined algebraic curve over, say, the rational numbers $\mathbb{Q}$, we are able to find a parametrization (if it exists) in a smallest possible field extension of $\mathbb{Q}$. The two basic subproblems which have to be solved are

- the analysis of the singularities of $\mathcal{C}$ and the determination of the system of adjoint curves, and
- the determination of a simple point on $\mathcal{C}$ with coefficients in a simplest possible field, i.e. in an algebraic extension of $\mathbb{Q}$ of lowest degree.

For the analysis of the singularities and the computation of the adjoints we currently use blow-ups and quadratic transformations of the curve.

By a birational transformation a parametrizable curve, i.e. a curve of genus 0, can be reduced to a line if the degree of the curve is odd and to a conic if the degree of the curve is even. Any simple point on the transformed curve over a particular field yields, by the inversion of this birational transformation, a simple point on the original curve over the same field. So the second problem, the determination of a simple point on the irreducible parametrizable curve $\mathcal{C}$, is trivial for curves of odd degree, and it is reduced to the same problem for irreducible conics otherwise. This means that we are able to find (or determine that there are no) simple points over $\mathbb{Q}$, $\mathbb{R}$, and algebraic extensions of $\mathbb{Q}$. The crucial tool is the constructive version of the Theorem of Legendre (about quadratic residues), as described for instance in [33], [56]. Complete algorithms and and implementation are given in [31], where also extensions to other fields are investigated.

The complexity of our parametrization algorithm was analyzed in [46]. It turns out to be polynomial if the curve has only ordinary singularities.

Puiseux series expansion

A point $(x_0, y_0) \in \mathcal{C}$ has *multiplicity* m if, for all $i + j < m$, $\frac{\partial^{i+j} f}{\partial x^i \partial y^j}(x_0, y_0) = 0$, but for $i + j = m$ at least one $\frac{\partial^{i+j} f}{\partial x^i \partial y^j}(x_0, y_0) \neq 0$. All points of multiplicity greater than 1 are called *singular points.* A singular point (x_0, y_0) with multiplicity m is called an *ordinary singularity* if there are m different tangents at (x_0, y_0) to $\mathcal{C}$.

If $(x_0, y_0) \in \mathcal{C}$ is a non-singular point (we assume w.l.o.g. $\frac{\partial f}{\partial y}(x_0, y_0) \neq 0$) we know from the implicit function theorem that there exists a *power series* $c(x) \in \mathbb{C}[[x]]$, such that

- $c(x_0) = y_0$,
- $f(x, c(x)) = 0$, and
- for all $(x_1, y_1) \in \mathcal{C}$ in some neighbourhood of (x_0, y_0), we have $c(x_1) = y_1$.

The power series $c(x)$ can be seen as a local parametrization of the curve $\mathcal{C}$ at the point (x_0, y_0).

On the other hand, if $(x_0, y_0) \in \mathcal{C}$ is a singular point, no such power series $c(x)$ exists, but there are finitely many *fractional power series* or *Puiseux series* $\gamma_i(x) \in \mathbb{C}\langle\langle x \rangle\rangle$, see [48] and [54], such that

- $\gamma_i(x_0) = y_0$, for all $\gamma_i(x)$,
- $f(x, \gamma_i(x)) = 0$, for all $\gamma_i(x)$, and
- for all $(x_1, y_1) \in \mathcal{C}$ in some neighbourhood of (x_0, y_0), there is exactly one $\gamma_i(x)$ with $\gamma_i(x_1) = y_1$.

Again, the Puiseux series $\gamma_i(x)$ can be viewed as local parametrizations of irreducible branches of the curve $\mathcal{C}$ through the point (x_0, y_0).

Resolution of singularities of plane curves

Each singular point of a curve $\mathcal{C}$ can be characterised by several basic invariants such as the number of irreducible branches through it, the Milnor number, the multiplicity or the neighbourhood graph, see [11], [70]. In order to be able to compute those invariants we need to transform the curve $\mathcal{C}$ birationally into a curve $\mathcal{C}'$ which has only ordinary singularities. The curve $\mathcal{C}'$ together with the birational transformation is called *resolution of singularities.*

One well known way of resolving singularities is with the help of *quadratic transformations* [70]. In order to resolve a singularity it may be necessary to apply several quadratic transformations successively. As each quadratic transformation doubles the degree of the defining polynomial, computation becomes in many cases very time and memory space consuming or even impracticable.

Another way singularities can be resolved is by computing *Puiseux series expansions*, cf. e.g. [11]. Each Puiseux expansion at a singular point (x_0, y_0) corresponds bijectively to an irreducible branch of $\mathcal{C}$ through (x_0, y_0) and defines a finite sequence of so called *Puiseux pairs.* The Puiseux pairs of the irreducible components together with their intersection multiplicities completely describe the topological type of the singularity and allows one to compute the above mentioned invariants.

Other methods for resolving singularities can be found in [37] *(Efficient birational reparametrization)* or [49] *(Toroidal resolution).*

Having a resolution of all singularities of a curve we are also able to compute global invariants, e.g. the genus, which is of interest when one wants to parametrize curves as shown in the next paragraph.

Resolution of singularities of quasi-ordinary surfaces

As mentioned above, Puiseux series expansions can be used to resolve singularities of plane curves. Although this is no longer true for surfaces (the field $\mathbb{C}\langle\langle x_1,\ldots,x_n\rangle\rangle$ is not algebraically closed for $n>1$), there is an important class of surfaces, so called quasi-ordinary surfaces, for which this holds (known as Jung-Abhyankar theorem [1], [44]).

A regular polynomial $f\in\mathbb{C}[[x_1,\ldots,x_n]][z]$ is called *quasi-ordinary (q.-o.)* if its discriminant $D_z(f)\in\mathbb{C}[[x_1,\ldots,x_n]]$ w.r.t z is of the form $D_z(f)=x_1^{\alpha_1}\ldots x_n^{\alpha_n}\zeta$, $\zeta\in\mathbb{C}[[x_1,\ldots,x_n]]$ and $\zeta(0)\neq 0$. We call a surface q.-o. if it is defined by a q.-o. polynomial.

As in the case of plane curves, each generalized Puiseux expansion defines a finite sequence of pairs which are now called *distinguished pairs*. In [42] and [27] it is shown how these distinguished pairs are related to the theory of resolution of singularities of q.-o. surfaces.

An algorithmic way to compute Puiseux expansions for q.-o. surfaces is given in [3]

Automated Geometric Theorem Proving and Dixon's Resultant

Automated Geometric Theorem Proving (GTP) deals with developing algorithms which automatically produce proofs for given theorems. GTP is on the one hand an interesting research goal in itself. On the other hand, it is of great influence for topics like solid modeling, computer-aided geometric design, robotics and robot motion planning, computer vision and many other related topics (see [12, 13, 15, 14], [21], [40]). One possible general outline for automated geometric theorem proving by algebraic methods can be described as follows:

1. Choose a coordinate system and translate the geometric theorem into an algebraic statement.
2. Carry out the required algebraic manipulations.
3. Retranslate the algebraic conclusions into geometric statements.

In 1951, Tarski ([59]) gave a first algebraic decision method for elementary geometry. This decision method was far from practical use, but a first theoretical breakthrough was made. Later improvements, like Collins' cylindrical algebraic decomposition (CAD) method ([22]), led also to practical algorithms which can be used to prove elementary geometric theorems by algebraic methods. For the first step, one can choose a coordinate system in a heuristic manner and translate the geometric theorem into an algebraic statement. Recently, some researchers suggest using other geometric entities such as distances, vectors, volumes, brackets, etc. instead of point coordinates (see [23], [20], [19], [30], [41], [55]). For example, for the case of projective geometry we can use the following hierarchy:

1. Grassmann algebra (also called Cayley algebra).
2. Bracket algebra.
3. Coordinate algebra.

Roughly speaking, Grassmann algebra is a multilinear algebra where projective subspaces are presented by their Plücker coordinates (see [25], [73]). Operations like join ($\vee$) and meet ($\wedge$) of projective subspaces can be carried out directly. There is a one-to-one correspondence between projective incidence properties and terms in the Grassmann algebra. Unfortunately, it is difficult to check directly whether two terms of the Grassmann algebra are identical. Any Grassmann algebra term can be easily expanded into a bracket algebra polynomial. Using this fact, one has a simple procedure for translating projective incidence properties into bracket algebra polynomials. However, up to now the converse problem, namely Cayley factorization, is not solved satisfactorily. There is a theoretical result proved by Sturmfels and Whiteley stating that every bracket algebra polynomial can, after multiplying with a suitable bracket polynomial, be factorized into a Grassmann algebra term. But the algorithmic part of Cayley factorization is only solved for special cases. After introducing coordinates, every bracket algebra expression can be expanded into a polynomial of the usual coordinate algebra. In the coordinate algebra, the geometric objects are directly represented by a suitable parameterization (vectors for points, center and radius for spheres, etc.).

The calculations are carried out directly, and arbitrary geometric objects can be expressed. Relations between geometric objects are expressed by suitable polynomials in the parameters. However, in general not all coordinate systems can be translated into a bracket expression. Only those which are invariant under projective transformations can be so translated. Moreover, in general it is difficult to recover the geometric meanings from the algebraic equations on the coordinate level.

In this project, we will concentrate on the algebraic manipulation step of the general outline for automated geometric theorem proving by algebraic methods as mentioned above. So far, three well-known methods are mostly used for this step, namely Ritt's characteristic set method, the Gröbner bases method and the resultant method. The first two methods have successfully been used to prove elementary geometric theorems, but they are still far too inefficient for practical application to problems arising from geometric modeling and CAGD. Meanwhile, the resultant method is an efficient method for the univariate case but not suitable for multivariate cases. Fortunately, Dixon's multivariate resultant, a recently rediscovered fast method in elimination theory, has been shown to be a promising tool. In contrast to the successive resultant computation techniques which eliminate variables one by one and compute numerous intermediate resultants before finally computing the resultant of the whole set, Dixon's resultant creates a much smaller matrix and avoids such intermediate results, and hence is much faster and also saves memory space.

Hybrid Symbolic-Numerical Visualization

Approximation and representation of one-dimensional algebraic sets in higher dimensions is a fundamental and difficult problem in Computer Aided Geometric Design (CAGD) and solid modeling. For example, the intersection of two parametric surfaces can be seen as a space curve in 4-dimensional space and the intersection of an implicit surface with an r-offset surface of another implicit surface can be seen as a space curve in 6-dimensional space. Due to its importance, there have been persistent efforts in devising algorithms for this problem (see [9], [32], [72], [50], [51], [39]). The main issue in the problem is the efficient discovery and description of all features of the solution with the proper precision required by the underlying geometric modeler. Reliability and efficiency of intersection algorithms are two basic prerequisites for their effective use in any geometric modeling system. The handling of near singular cases, small loops, etc, by the algorithm is essential.

In a first naive approach to the visualization of 1-dimensional intersection varieties, one might decompose it into irreducible varieties, project these components individually onto plane curves, represent these plane curves, and use the inverse of the birational projection for creating an image of the original intersection variety. Unfortunately, this naive approach is extremely inefficient and requires an excessive amount of memory, especially when we have to deal with points with real algebraic number coordinates. Moreover, the high degree of the projected plane algebraic curve, which is, in general, the product of the degrees of the surfaces, leads to difficulties when analyzing the topology of the plane algebraic curves.

On the other hand, we can trace one-dimensional algebraic sets numerically (see [6], [8], [52], [38]). The general structure of algorithms using this approach is:

(1) Find an initial point on the curve.

(2) Obtain an estimate of the next curve point by constructing a local approximation of the curve and by taking a step of a specific distance along the approximation.

(3) Refine the new point estimate to a curve point.

The method involves generating a sequence of points for each separated branch of the algebraic set by stepping from a given point on the required branch in a direction prescribed by the curve's local differential geometry. The advantages of this approach are that we can directly trace a curve in higher dimensions and the algebraic degrees involved are often low, which will increase the numerical accuracy of the method. However such methods are by themselves incomplete in that they require starting points for every branch of the solution. Finding the starting points in real affine space is a difficult task.

In most cases, initial starting points for the trace can only be found by the intersections of the curve to be traced with the boundary of a given domain. Finding the starting points in higher dimensions is even harder since the complexity grows exponentially with the dimension. Moreover, in case of a reducible one-dimensional algebraic set, several branches of the curve will be traced several times and additional singularities might be created on the curve. Moreover, the method is not reliable and has great difficulties when tracing through singularities. The reason stems from this fact: a numerical tracing scheme technically requires formulating and solving a linear system of equations. Such a system is formulated both for determining an approximation to the curve at a given point, as well as when refining an estimate of the location of a point on the curve with Newton iterations. At a curve singularity, the linear system is singular, and nearby the condition number of the system is so large that roundoff errors destroy all accuracy of the estimate.

The program system CASA

The program package CASA (Computer Algebra Software for constructive Algebraic geometry) is designed for performing computations and reasoning about geometric objects in classical algebraic geometry, in particular affine and projective algebraic geometry over an algebraically closed field F of characteristic 0. Moreover, the field F has to be a computable field in the sense of the underlying computer algebra system Maple, i.e. all the arithmetic operations have to be available in the system. In the absence of any special indication of the field, CASA always assumes that the field of computation is the rational numbers $\mathbb{Q}$ or a finite algebraic extension thereof. Previously several experimental versions of CASA have been available and operational at a number of European university departments and research institutions.

The objects that CASA deals with are algebraic sets in four different representations.

- *Implicit representation:* An algebraic set is the set of common zeros of a system of polynomial equations. To give an algebraic set in implicit form means to give finitely many polynomials.
- *Projected representation:* As a consequence of the primitive element theorem every irreducible d–dimensional algebraic set in n–dimensional space is, after a suitable linear transformation of coordinates, birationally projectable onto an irreducible d–dimensional algebraic set in $(d+1)$–dimensional space, which can be specified by a single polynomial in $d+1$ variables. This can be generalized to unmixed-dimensional algebraic sets. An algebraic set in projected form is given by a polynomial and a tuple of rational functions (specifying the birational mapping).
- *Parametric representation:* Some irreducible algebraic sets can be parameterized by rational functions. An algebraic set in parametric form is given by a tuple of rational functions that parameterizes the algebraic set.
- *Representation by places:* All algebraic curves can be parameterized by a set of power series that are convergent around a point of the curve. An algebraic set is given by places if for each branch passing through a certain point on the algebraic set a tuple of power series that parameterizes the algebraic set around the point is specified.

CASA also works with the polynomial ideals corresponding to these geometric objects.

The operations available in CASA include

- ideal theoretic operations $+, *, \cap, /$,
- creating algebraic sets in different representations,
- generating curves of fixed multiplicities at given points,
- intersection, union, and difference of algebraic sets,

- computing tangent cones and tangent spaces,
- computation of the dimension of an algebraic set,
- decomposition into irreducible components,
- transformations of algebraic sets to hypersurfaces,
- computation of the genus of a curve,
- rational parameterization of curves,
- implicitization of parametrically given algebraic sets,
- Puiseux series expansions,
- plotting both explicitly and implicitly given curves and surfaces,
- computation of syzygy-bases.

For more information see [28], [71], [74], [6].

5.4 Previous Work

Parametrization, analysis of singularities, Puiseux series:

As described above, our group has been working extensively on parametrization of curves and related topics. We give a list of previous publications of our research group on the topics of this project proposal.

- J.R. Sendra, F. Winkler. *Symbolic Parametrization of Curves.* J. Symbolic Computation **12** (1991), p. 607–631.
- B. Wall. *On Implementations of Puiseux Series Expansion in a Computer Algebra System.* Technical Report RISC-Linz 92-40. (1992)
- J. Schicho. *On the choice of pencils in parametrization of curves.* J. Symbolic Computation **14** (1992), p. 557–576.
- F. Winkler. *On Symbolic Parametrization of Algebraic Curves.* Proc. "14th IMACS World Congress", Atlanta, Georgia, W.F. Ames (ed.), **vol.3** (1994), 1542–1544.
- M. Mňuk, J.R. Sendra, F. Winkler. *On the complexity of parametrizing curves.* Beiträge zur Algebra und Geometrie **37/2** (1996).
- F. Winkler. *Parametrized Solutions of Algebraic Equations.* J. Mathematics and Computers in Simulation **42/4-6** (1996), 333–338.
- J.R. Sendra, F. Winkler. *Parametrization of Algebraic Curves over Optimal Field Extensions.* J. Symbolic Computation **March/April** (1997).

Automated Geometric Theorem Proving and Dixon's Resultant

In the algebraic manipulation step of the general outline for automated geometric theorem proving by algebraic methods mentioned before, we often have to eliminate several variables from a system of equations. Theoretically, the Gröbner bases method, Ritt's characteristic set method or successive Sylvester resultant computations can be used to achieve our demands. But they are inefficient and require a lot of memory space.

Meanwhile, Dixon's resultant is an efficient method to simultaneously eliminate several variables from a system of nonhomogeneous polynomial equations at a time. In contrast with the successive resultant computation techniques which eliminate variables one by one and compute numerous intermediate resultants before finally computing the resultant of the whole set, Dixon's resultant creates a much smaller matrix and avoids such intermediate results, and hence is much faster and also saves memory space.

But unfortunately, Dixon's resultant does not work for most algebraic and geometric problems. Originally, Dixon's resultant was a method for obtaining the resultant of a set of three generic bidegree polynomials (see [24]). This is a generalization of Cayley's formulation [17] of Bezout's efficient method for computing the resultant of two univariate polynomials. Dixon had generalized his method to any $n+1$ generic n-degree polynomials in n variable – a condition which cannot be satisfied by most problems arising in practice. For most practical problems, the matrix set up in Dixon's method, the Dixon matrix, becomes singular or even nonsquare. As a consequence, Dixon's resultant vanishes identically, without providing any information about the common solutions of equations. There are some efforts to obtain nonzero conditions by perturbing the polynomial system (see [18], [16]) or checking if there exists a submatrix of the Dixon matrix with one column less and strictly smaller rank than the Dixon matrix when the Dixon matrix is square and singular (see [36], [35]). However these efforts either suffer from the facts that the method is not automatic, requires human expertise and enlarges the size of Dixon matrix with larger entries; or requires a precondition on the system of equations and lacks of a formal explanation.

In our work [9, 10, 12, 13], by using techniques from pseudoinverse theory, we overcome some of the above obstacles and extend Dixon's resultant to an arbitrary system of $n+1$ nonzero polynomials where the Dixon matrix can be singular or even nonsquare. It turns out that the result in [36] is a special case of our results. Note that this approach can also be used to extend other multivariate resultant methods such as Macaulay resultant or sparse resultant.

The following is a list of publications on this topic:

- Q.-N. Tran. *A Hybrid Symbolic-Numerical Method for Tracing Algebraic Curves in Higher Dimensions.* In "ICCAM-96 Conference", Leuwen, Belgium, preprint (1996).
- Q.-N. Tran. *Intersection of Surfaces.* In "The Seventh Mathematics of Surfaces", Dundee, U.K. (1996).
- Q.-N. Tran. *Extending Dixon's Resultant using Pseudoinverse Matrices.* Preprint (1997).
- Q.-N. Tran. *On the Dimension of the Irreducible Components of an Algebraic Set.* Preprint (1997).

<u>Hybrid Symbolic-Numerical Visualization</u>

In [4, 8], the author presented a hybrid method for tracing the intersections of two implicit surfaces in 3-dimensions. That method overcomes the main difficulties of numerical tracing, namely finding a sample point for every real branch and marching through singularities by using techniques for real root isolation of polynomials with real algebraic number coefficients and the continuation method for solving polynomial systems. However, that method would lose its advantages in higher dimensions because we have to use much more symbolic computations in these cases.

The following is a list of publications on this topic:

- Q.-N. Tran. *A Hybrid Symbolic-Numerical Method for Tracing Plane and Space Algebraic Curves.* In "11th European Workshop on Computational Geometry CG'95", Linz, Austria (1995).
- Q.-N. Tran. *A Hybrid Symbolic-Numerical Approach in Computer Aided Geometric Design (CAGD) and Visualization.* Ph.D. thesis, RISC-Linz, Univ. Linz (1996).

The program system CASA

CASA has been developed at RISC-LINZ over the last years, starting in 1990, by our research group under the direction of the author. Several grants by the Austrian *Fonds zur Förderung der wissenschaftlichen Forschung* have been instrumental for reaching this stage of the system. Many people have contributed to CASA in different ways. The names of the main contributors are R. Gebauer, M. Kalkbrener, M. Mňuk, R. Sendra, P. Stadelmeyer, Quoc-Nam Tran, B. Wall, F. Winkler.

The following is a list of publications on this topic:

- R. Gebauer, M. Kalkbrener, B. Wall, F. Winkler. *CASA: A Computer Algebra Package for Constructive Algebraic Geometry.* Proc. "International Symposium on Symbolic and Algebraic Computation 91 (ISSAC'91)", Bonn, Germany, S.M. Watt (ed.), ACM Press (1991), p. 403–410.
- F. Winkler. *Algebraic Computation in Geometry.* J. Math. and Comp. in Simulation **42/4-6** (1996), 529–537.
- M. Mňuk, F. Winkler. *CASA — A System for Computer Aided Constructive Algebraic Geometry.* Proc. "Internat. Symp. on Design and Implementation of Symbolic Computation Systems (DISCO'96)", Karlsruhe, Germany, J. Calmet and C. Limongelli (eds.), Springer-Verlag, LNCS 1128 (1996), p. 297–307.

5.5 Cooperations

Universidad de Alcalá in Madrid, and Universidad de Cantabria in Santander, Spain:

For many years now our research group is in close contact with the group of Prof. J.R. Sendra at the Universidad de Alcalá in Madrid and with the group of Prof. T. Recio at the Universidad de Cantabria at Santander. During several visits and guest professorships we have collaborated scientifically on computer algebra in general and constructive algebraic geometry in particular.

Several papers have been jointly published ([57], [58], [46], technical reports). I gave an invited talk at the conference "Encuentro de Algebra Computational y Aplicaciones (EACA 95)" in Santander, September 1995. Together with Prof. Sendra and Prof. C.M. Hoffmann of Purdue University I have just recently edited a Special Issue of the Journal of Symbolic Computation on *Parametric Algebraic Curves and Applications* (to appear March/April 1997). Together with Prof. Sendra I am writing a book on *Computational Methods for Algebraic Curves*, to be published by Springer-Verlag Wien New York in the series *Texts and Monographs in Symbolic Computation.* Because of this intensive collaboration, the Universität Linz and the Universidad de Alcalá have established an official university partnership. Under the Scientific/Technical Agreement between Austria and Spain, Prof. Sendra and I had a joint project (Accion Integrada) in 1991, and another such project, mainly for exchanging visitors, was granted for 1997.

This very fruitful cooperation should be continued during and hopefully also with the help of this project. In particular, we want to work together with Prof. Sendra on applications of symbolic computation to problems in computer aided geometric design, such as the parametrization of offset curves and surfaces.

Purdue University, USA:

Our group is in contact with the groups of Prof. C.L. Bajaj and Prof. C.M. Hoffmann at Purdue University. The point of contact is mainly applications in computer aided geometric design and visualization of geometric objects.

As mentioned above, I have been co-editing a special issue of the JSC with Prof. Hoffmann. Prof. Bajaj and I have been visiting each other in the last few years. He was an invited speaker at the workshop "Algebraic Approaches to Geometric Reasoning", organized by D. Wang, H. Hong, and myself in 1992. On the other hand, I was an invited speaker at his session on computer aided geometric design at the 1994 IMACS World Congress in Atlanta, and I visited him and Prof. Hoffmann at Purdue University.

Since we also plan to work on hybrid symbolic-numerical algorithms for visualization of algebraic curves and surfaces, a continuation of this cooperation is highly desirable.

European project "POSSO" (ESPRIT BRA 6846):

The European research project "Polynomial System Solving" was carried out between September 1992 and November 1995. The project was devoted to theoretical and practical advances in polynomial elimination theory. New and up-to-date implementations of the method of characteristic sets, various resultant methods, and the Gröbner bases method were created and applied successfully to problems appearing in applications, such as robotics.

The participation of RISC-Linz in this project was directed by F. Winkler. Our contributions came mainly in the fields of fast basic arithmetic, characteristic sets, a parallel implementation of the Gröbner bases algorithm, and algorithms in the geometry of algebraic curves and surfaces.

Teams from the following institutions participated in POSSO:

- Università di Pisa (project coordinator),
- University of Bath,
- Université Paris VI,
- Université de Nice,
- Universitad de Cantabria en Santander,
- Universität Hagen,
- RISC-Linz,
- University of Stockholm.

European HCM Network "SAC":

The European HCM Network "Symbolic and Algebraic Computation" started in January 1995 and lasts until December 1997. The goal of the project is to create a European information network on symbolic and algebraic computation. We are doing this through various sites on the World Wide Web, workshops and conferences, and the exchange of students and researchers between the partner institutions.

The participation of RISC-Linz in this project is directed by F. Winkler. Our activities were and still are mainly oriented towards an information system for job opportunities and conferences, the creation of on-line tutorials for Gröbner bases, quantifier elimination, and parametrization of algebraic curves, the starting of an Austrian Working Group for Computer Algebra, and the edition of a quarterly SAC Newsletter.

Teams from the following institutions participate in SAC:

- Amsterdam CAN/RIACA (project coordinator),
- University of Bath,
- Università di Genova,
- RISC-Linz,
- Université de Nice,
- Universität Paderborn,

- Universidad de Cantabria en Santander,
- ETH Zürich.

Chinese Academy of Sciences (Academia Sinica) and Fudan University, Shanghai:

In the frame of a research cooperation between the Austrian FWF and the NSF of China, I visited the Academia Sinica in Beijing (Prof. Wu Wen-Tsün) and the Computer Science Department of Fudan University in Shanghai (Prof. Dingjia Xin) for a month in 1993. We extensively exchanged ideas on geometric theorem proving, coding theory, and the method of Gröbner bases. This cooperation was continued when Prof. Xin visited me at RISC-Linz in October-December 1993.

For 1997 we are again planning exchange visits and scientific contacts, pending a financial decision by the FWF.

Austrian Working Group for Computer Algebra (OACA):

In September 1996 I organized a Workshop on Computer Algebra at the University of Klagenfurt. During this workshop we founded an Austrian Working Group for Computer Algebra (OACA). I am currently the first chairman of this working group.

The main activity of OACA is the formation of an inofficial forum for the exchange of new research results, specific education of students in this field, and the organization of a yearly workshop.

Teams from the following institutions participate in OACA:

- RISC-Linz,
- Institut für Numerische und Angewandte Mathematik, TU Wien,
- Institut für Geometrie, TU Wien,
- Universität Klagenfurt,
- Universität Innsbruck.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

Parametrization of curves and surfaces

The extension of Legendre's theorem to fields other than the rationals, e.g. $\mathbb{Q}(t)$, and fields of finite characteristic is to be further investigated. This will lead to better parametrization algorithms for algebraic curves than what we have currently.

We intend to further investigate the symbolic approach to the rational parametrization of algebraic curves and hypersurfaces in general, as begun in [5].

Certain algebraic surfaces, such as offset surfaces to rational space curves, can be rationally parametrized if we can determine a rational family of points of the corresponding envelope, see [53]. The algorithms developed in [31] should be applicable to this problem.

Resolution of singularities and system of adjoints

We want to develop a fast algorithm for *resolving singularities* of plane algebraic curves based on Puiseux series expansions, trying to extend and combine ideas of [26], [49], [37]. Furthermore we are interested in a theoretical as well as practical time complexity analysis of our algorithm (compared to [60]).

In the parametrization algorithm [58] it does not suffice to have full knowledge about the singularities but also the *system of adjoints* (see [43]) is needed. Therefore we are looking for an algorithm which computes along with the Puiseux expansion also conditions for the system of adjoints.

If it were possible to do this in polynomial time, the whole problem of parametrization of plane curves as described in [46] would be solvable in polynomial time.

In a second step we want to develop an algorithm to resolve singularities of q.-o. surfaces. This requires computation with algebraic power series, see [4]. It will be a subject of further investigation to determine whether this yields also an efficient algorithm to compute the system of adjoints and how well this is suited to parametrize q.-o. surfaces.

Singularities of space curves

Puiseux series expansions can always be seen as local parametrizations. Hence a Puiseux expansion in a singular point of a one-dimensional variety gives detailed information about the branching of the set of zeros of the corresponding system of non-linear equations. This is especially of interest in combination with numerical methods, which generally fail at singular points, e.g. tracing of curves in higher dimension.

Automated Geometric Theorem Proving and Dixon's Resultant

Roughly speaking, our extended Dixon's resultant method leads to the computation of an exact solution of a system of linear equations with multivariate polynomial coefficients. Direct methods such as Gaussian, Gauss-Jordan or fraction-free Gaussian elimination ([7]) are inefficient due to the coefficient growth and degree growth – which have been alternately referred to by the phrase "intermediate expression swell". ¿From a practical point of view, multivariate interpolation techniques known in the literature are inefficient due to the size of the determinant polynomial. On the one hand, frequently the Dixon's resultant has a degree bound which is greater than 15 and a term bound which is greater than 10^{10}. In other words, the determinant polynomial is far from a dense multivariate polynomial. That means methods for multivariate dense polynomials such as in [45], [29] and [76] are not suitable for our case. On the other hand, frequently the Dixon's resultant is not equal to zero and has a large number of actual terms (1000 to 2500 terms). That means we cannot use the methods for multivariate sparse polynomials which involves the use of Vandermonde matrices such as Zippel's algorithm ([75, 76]) or Ben-Or and Tiwari's algorithm ([10], [34]). In this proposal, we plan to concentrate on deriving algorithms based on modular and multivariate sparse interpolation methods which work on the actual terms of the determinant polynomial.

Hybrid Symbolic-Numerical Visualization

Our goal is that we would like to derive new hybrid methods that use exact computation or numerical computation when needed. Our previous results, such as the "Extended Newton Method", an iterative method for finding the roots of an arbitrary system of equations (see [2], [4], [7], and [8] for more details), are a sound basis for starting the development of such methods. We also plan to avoid the expensive computation of the irreducible decomposition of the algebraic set. Our algorithms for one-dimensional algebraic sets in higher dimensions should overcome the main difficulties of numerical tracing, namely finding a sample point for every real branch. The methods should not require the expensive computation of irreducible decomposition. Moreover, we want to avoid duplicate tracing and introduction of additional singularities in tracing reducible space curves. The method should also overcome the difficulties of roundoff errors near the singularities and component jumping.

The program system CASA

As mentioned before, the main goal of the project is the improvement and/or perfection of existing methods and the derivation of new methods for designing, manipulating, and visualizing algebraic curves and surfaces. Therefore, together with our research on theoretical side, we need to implement the new and/or improved algorithms for getting experiences and checking the theoretical ideas. We will incorporate our implementations into the CASA system, an ongoing computer algebra system for constructive algebraic geometry which has been developed by our group at RISC-Linz institute over the last 6 years.

5.6.2 Methods

For the goals in parametrization and singularity analysis we want to explore in depth the use of local parametrizations by Puiseux series instead of the blow-up we are currently using.

Dixon resultants will be the crucial tool in our research on automated geometric theorem proving.

5.6.3 Programme and Schedule

The work in the project can roughly be divided into the following subtasks.

(1) Theoretical work on application of Puiseux series for computation of genus and adjoints of curves: in his dissertation work P. Stadelmeyer is already making progress in this direction. We expect this work to continue into the first year of the project.

(2) Complexity analysis of Puiseux series in computation of genus and adjoints: after developing a theoretical framework for this topic in (1), we want to compare it to blow-up methods we are currently using. Such a comparison includes both theoretical and practical complexity analyses. The work is planned to be carried out by P. Stadelmeyer in the second year of the project.

(3) Finding simple points on curves over various ground fields: in his recent diploma thesis E. Hillgarter could apply the theory of Legendre to this problem, over the rational numbers. Work on other fields is expected to last for the first few months of the project.

(4) Application of symbolic algorithms for algebraic curves and surfaces to problems in computer aided geometric design, such as offset curves and surfaces: currently a diploma student of mine (K. Aigner) is working on symbolic parametrization of algebraic curves. This and other applications of symbolic methods to problems in computer aided geometric design is to be investigated in later stages of the project.

(5) Visualization of algebraic curves and surfaces: in his dissertation Q.-N. Tran started to develop hybrid symbolic-numerical methods for visualization of algebraic varieties. We plan to continue this work in the first year of the project.

(6) Geometric theorem proving: this important topic will be treated mainly in the second and third year of the project.

(7) Development and improvement of the program system CASA: the system CASA needs constant development and improvement.

5.7 Integration with the SFB

The project is well integrated with the overall SFB, because we both intend to provide symbolic methods for traditionally numerical packages in computer aided geometric design, and we intend to make use of advanced graphical facilities for visualizing and rendering algebraic curves and surfaces. More specifically, we see the following links to other parts of the overall SFB:

- cagd is traditionally approached numerically, we want to come from the symbolic side and actually try to integrate these two approaches. So we want to provide tools for use in numerical cagd packages, like exact topological analysis, exact tracing through singularities, parametrization of algebraic curves and surfaces used in cagd, determination of offset curves/surfaces and blending surfaces. The ultimate goal is to produce software that can be linked to existing numerical libraries;

- we will need advanced graphical techniques for visializing and rendering algebraic curves and surfaces. While we will develop hybrid symbolic-numerical algorithms for topological analysis and faithful plotting, we definitely want to rely on graphical tools for shading, hidden line removal, and similar problems.

5.8 Detailed Budget

Personnel:

- A = Doz. Dr. Franz Winkler (proposer of the project)
- B = Dr. Tran Quoc Nam (post-doctoral researcher)
- C = Dipl.-Ing. Peter Stadelmeyer (Ph.D. student paid as a 2/3-job)
- D = Dipl.-Ing. Erik Hillgarter (Ph.D. student paid as a 2/3-job)

Work plan and time table:
The work in the project can roughly be grouped in the following way (compare 5.6.3):

(1) Theoretical work on application of Puiseux series for computation of genus and adjoints of curves

(2) Complexity analysis of Puiseux series in computation of genus and adjoints

(3) Finding simple points on curves over various ground fields

(4) Application of symbolic algorithms for algebraic curves and surfaces to problems in computer aided geometric design, such as offset curves and surfaces

(5) Visualization of algebraic curves and surfaces

(6) Geometric theorem proving

(7) Development and improvement of the program system CASA

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 ... 6	7 ... 12	1 ... 6	7 ... 12	1 ... 6	7 ... 12
(1)	A, C	████	████				
(2)	C			████	████		
(3)	A, D	████					
(4)	A, D		████	████	████	████	████
(5)	B	████	████				
(6)	A, B		████	████	████	████	████
(7)	A - D	████	████	████	████	████	████

5.8.1 Requested Personnel

As mentioned in Section 5.6.3, one full-time post doc positions and two doctoral positions for Ph.D. students, which are paid as 2/3 job, are required for this project.

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 1 powerful graphic workstation including special graphic software, which amounts to **ATS 600.000,–** in the first year.
  The aims of the project require a high quality graphical device.
- 1 workstation, which amounts of **ATS 70.000,–** in the first year.
  This workstation serve as additional workplace for the employees of this project.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 3
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	670.000	10.000	25.000				1.853.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	670.000	30.000	75.000				4.219.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 3

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Winkler Franz, Dipl.-Ing. Dr., Univ.-Doz.	Computeralgebra, Geometrie	RISC	25%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 3

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Tran Quoc-Nam, Dr.	Computer aided geometric design	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Stadelmeyer Peter, Dipl.-Ing.	Algebraische Geometrie	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Hillgarter Erik, Dipl.-Ing.	Computer-Algebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Tran Quoc-Nam, Dr.	Computer aided geometric design	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Stadelmeyer Peter, Dipl.-Ing.	Algebraische Geometrie	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Hillgarter Erik, Dipl.-Ing.	Computer-Algebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Tran Quoc-Nam, Dr.	Computer aided geometric design	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Stadelmeyer Peter, Dipl.-Ing.	Algebraische Geometrie	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Hillgarter Erik, Dipl.-Ing.	Computer-Algebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 3

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Octane, SSI-Grafik, 256 MB, 4 GB	600.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	600.000			Summe	70.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 3

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 4: Symbolic Summation and Combinatorial Identities

5.1 General Information

Title : Symbolic Summation and Combinatorial Identities

Field of research : symbolic summation, combinatorial identities, (q-)hypergeometric series, holonomic functions, difference equations, difference fields, Gröbner bases and elimination in noncommutative rings

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5.2 Abstract

The algorithmic problem of symbolic summation can be viewed as the discrete analogue of the well-known problem of "symbolic integration" or "integration in finite terms".

Typical applications for symbolic summation algorithms are combinatorial identities. Roughly spoken, these identities arise when the elements of a given discrete set are counted in two different ways. For instance, counting the number of all subsets of a set with n elements could be done by summing all k-subsets, i.e., $\sum_{k=0}^{n}\binom{n}{k}$, or, alternatively, by counting all n-tuples with entries 0 or 1, which gives 2^n. The resulting identity is the special case $x = 1$ of the binomial theorem $\sum_{k=0}^{n}\binom{n}{k}x^k = (1+x)^n$, which again finds generalizations in certain other combinatorial contexts (e.g., so-called "q-analogues").

Examples for automatic treatment of summation problems range from closed-form evaluations of elementary type as, e.g., the binomial theorem, to number-theoretic results as, e.g, the celebrated Rogers-Ramanujan identities in additive number theory. But even for very simple situations as, for instance, the identity resulting from the different subset-counts above, automated proving or closed-form evaluation has for a long time been considered as algorithmically unfeasible; see, for instance, Knuth's book ([11], Exercise 1.2.6.63).

This situation has changed only recently due to Zeilberger's "holonomic systems approach" [56]. Exciting applications, (e.g., "one-line" proofs of the Rogers-Ramanujan identities [16], or in the context of Apery's irrationality proof for $\zeta(3)$; see [25] and [53]) lead to renewed intensified research in the classical symbolic summation problem.

Since the beginnings of these new developments in the early 90's, the group of the proposal author has contributed to the field in various significant ways. For instance, the standard reference in the area, i.e., the book [25] by Petkovšek, Wilf and Zeilberger, points to the Paule/Schorn package [1] as *the* standard Mathematica implementation of Zeilberger's "fast" algorithm. Another software that is going to become standard, is Riese's implementation [21] of a q-analogue of this algorithm. It is based on the proposal author's concept of "greatest factorial factorization" of a polynomial [17], which can be seen as a difference operator analogue to square-free factorization, the latter being related to differentiation. In addition, besides editing the JSC (Journal of Symbolic Computation) special issues on "Symbolic Computation in Combinatorics", [30] and [31], the first JSC issues of that kind, the proposal author was invited to organize a meeting (1993, at MSI Cornell) on that topic that for the first time brought together the most active researchers in the area.

In spite of its historical roots and the exciting and promising achievements made over the last years, one really has to emphasize that symbolic summation became a promising and well-recognized subbranch of computer algebra only recently. And in view of the novelty of these developments it is evident that still much more needs to be done, in theory as well as concerning implementation.

The main objective of this proposal is research in algorithms design for symbolic summation and holonomic functions. The theoretical work is guided and motivated by concrete problems from the area of combinatorial identities. Vice versa, the proposed research in algorithms will stimulate research in the application areas, because the newly designed algorithms will significantly enhance the number of

situations where nontrivial parts of research in combinatorics and in related fields can be left to the computer.

Summarizing, the general project goal is the development of computer algebra algorithms for automated proving or closed-form evaluation of summation identities arising in combinatorial context. In order to accomplish this goal, the problem of *proving* or closed-form evaluation will be transformed into problems of *solving*. This, for instance, means: solving linear systems of equations with rational function coefficients, finding (symbolic) solutions of difference equations, or finding (e.g., by applying Gröbner bases theory) certain operators in annihilating ideals that arise in the context of certain noncommutative difference operator algebras and corresponding (left-)modules. It is a fundamental aspect of the proposed research that its goals can only be achieved by effective interaction of mathematical theory and practical implementation of efficient algorithms.

5.3 State of the Art

The general theme of the proposed research is the development of computer algebra algorithms for symbolic summation and combinatorial identities. Besides the problem settings specified in the subsections below, on a more global level the reasons for carrying out the proposed research are:

(i) In spite of its historical roots, this area, due to Zeilberger's "holonomic systems approach", became a promising and well-recognized subbranch of computer algebra only recently.

(ii) There is a strong interest of a broad scientific community due to the wide applicability of summation and holonomic function algorithms. Besides the more or less "canonical" examples consisting in automatic proofs or derivation of combinatorial identities, applications go far beyond assisting the formula-manipulative part of combinatorial work. In fact, they are ranging from pure mathematics (e.g., number theory or special functions [24]) to computer science (e.g., analysis of algorithms [44]) and physics (e.g., "partition function" computation [12] or lattice path problems [19]).

ad (i): Until recently, automated proving or closed-form evaluation of *definite* sums as, e.g., the binomial theorem, has been considered as algorithmically unfeasible. In contrast, for *indefinite* symbolic summation some major progress around 1980 was made by Gosper's decision procedure for indefinite summation of hypergeometric sequences [14], and by Karr's algorithmic theory of "summation in finite terms" [21], established within the framework of certain difference field extensions. This situation changed drastically in 1990, when Zeilberger presented his "holonomic systems approach to special function identities" [56]. In the special case of hypergeometric summand sequences, Zeilberger's breakthrough consists in the observation that Gosper's algorithm for indefinite summation effectively can be put into action for treating definite sums [55]. More general, a good deal of Zeilberger's original approach can in principle be carried over to an algorithmic proof theory for hypergeometric (ordinary and "q") multisum/integral identities [15]. But in view of the novelty of these developments it is evident that still much needs to be done, in theory as well as concerning implementation.

ad (ii): A significant part of the proposed research is motivated by "real-life" problems which naturally arise in enumerative combinatorics in connection with (multi-)summation, difference equations, generating functions, etc. However, the need for computer-assistance in solving problems of this kind is not exclusively restricted to the field of combinatorics. This is also confirmed by the many requests that have been communicated to the proposal author by pure mathematicians, computer scientists, and also physicists. Indeed, the notion of holonomic function (which includes binomial sums or multisums, (q-)hypergeometric series, orthogonal polynomials, etc.) is broad enough to explain this wide range of applicability of the algorithms proposed to be developed.

In the following we briefly describe the state of art in the field of the proposed research. For that, we introduce a partition into subareas; some of those might be more closely related whereas others might not.

5.3.1 Indefinite Summation Algorithms

As already mentioned, around 1980 two major achievements were made in this area, namely Gosper's decision procedure for indefinite hypergeometric summation and Karr's algorithm based on difference field theory. Besides extending the algorithmic tool-box to definite sum applications, the recent developments also brought along a renewed interest in indefinite methods. As an example, for applying Zeilberger's ideas to q-hypergeometric summand sequences one needs a q-analogue of Gosper's algorithm. This was done, following different approaches, by Zeilberger, Koornwinder [51], and the proposal author [21]; but also Karr's setting is general enough to contain an algorithmic answer for this case. Nevertheless, up to now the relation between Karr's machinery and Gosper type summation is not fully understood. Currently there exists no implementation of Karr's algorithm, but an appropriate prototype version would greatly help in all investigations related to Karr's theory. (A first attempt in this direction currently is made by K. Eichhorn within a diploma thesis supervised by the author of this proposal.) For instance, there are several challenging open problems, already posed by Karr, concerning possible extensions of his approach. Constructive answers would significantly enlarge the class of indefinite summable sequences.

Another example is provided by a special instance of hypergeometric summation, namely the indefinite summation of rational sequences. Only recently Pirastu and Strehl [42] obtained a complete solution for the generic numerator case by relating the structure of the underlying difference equation to Petkovšek's canonical form of Gosper's representation of rational functions. However, several other questions can be raised in this context, for instance, how proper q-analogues would look like, etc.

5.3.2 Definite Summation Algorithms

With respect to Zeilberger's "fast algorithm" for definite (q-)hypergeometric summation, among others the following two most serious problems remain to be solved: one concerns its efficiency-bottleneck, namely the need to design fast algorithms for solving linear systems of equations over rational function fields; the second problem is with respect to order-minimality. It is a well-known fact that Zeilberger's algorithm does not always deliver recurrence representations of *minimal* order [1], [16], [25]; any explanation of this phenomenon would be of great theoretical and algorithmic relevance.

Apart from Zeilberger's "fast algorithm" and its q-analogue, important open questions in definite summation are: extensions to nonhypergeometric summands (e.g., harmonic numbers or bibasic terms), systematic exploitation of (q-)WZ-duality (like Gessel's account [13] for $q = 1$), automatic treatment of (q-)hypergeometric contiguous relations (first results by Takayama [48]; see also the attempts by Roach [45]), and algorithms for related difference equations.

5.3.3 Definite Multisum Algorithms

As shown by Wilf and Zeilberger, a good deal of Zeilberger's original approach can in principle be carried over to definite multisums [15]. But prototype implementations show [1], even for innocent looking doublesum evaluations, that the situation is completely different from the mostly "nice" working single-sum case. (Recently Krattenthaler communicated a triplesum that up to now has been resistant to any computer attack.) Thus there is an urgent need to find improvements with respect to efficiency and data representation, or algorithmic alternatives to the method.

5.3.4 Holonomic Function Identities

Zeilberger in his initial "holonomic systems approach" paper [56] observed that most special function identities allow a computer-treatment within the setting of holonomic functions. These functions can be described as solutions of so-called holonomic systems which, informally spoken, are "maximally overdetermined" systems of linear differential-recurrence equations with polynomial coefficients in several continuous and discrete variables. These systems correspond to (left-) ideals of annihilating differential-difference operators and serve as finite representations (together with finitely many initial conditions) for holonomic functions. (The notion "maximally overdetermined" is made precise within Bernstein's theory of holonomic systems; see also Björk's book [18].) A further crucial point is that holonomic functions satisfy nice closure properties with respect to operations like addition, product, definite and indefinite sum, and integral. Thus any identity between holonomic functions involving these operations in principle can be proved or refuted. The task of transforming holonomic theory into concrete algorithms and efficient implementations for the treatment of general classes of special function identities is highly nontrivial; at present this has been solved for restricted classes only. Besides the significant contributions by Takayama [49], [50], until now the most promising steps in this direction have been made by Chyzak and Salvy [10].

5.3.5 Combinatorial Identities Applications

In spite of the fact that to a certain extent all the algorithmic research related to the previous subsections is motivated by combinatorial and special function problems, we identify some subproblems from the field of combinatorial identities that deserve particular interest.

(i) Bailey chains: In connection with a fundamental transformation lemma for certain q-hypergeometric sums due to Bailey, Andrews [12] developed a general theory of Bailey chains. In his Ph.D. thesis [5], the author of this proposal independently discovered the importance of the underlying iteration mechanism. This theory plays a fundamental role in special functions and additive number theory, in particular in the study of Rogers-Ramanujan type identities [12]. By suitable variation of the q-analogue of Zeilberger's algorithm a computer-assisted investigation of Bailey chains is possible. This idea should be exploited systematically. (This subtask can be considered as a supplement to the former FWF project P7220 of the proposal author.) Investigations of this kind might also shed some light on open questions concerning positivity as, for instance, the Borwein conjecture [1].

(ii) Pfaff's method: Discussing shortcomings of Zeilberger's algorithm, Andrews recently suggested an alternative approach that goes back to Pfaff [3], [4], and [2]. In short, in order to prove (q-)hypergeometric function identities, one establishes recurrences similar to that what classically is called contiguous relations. The possibility of an efficient computer algebra implementation of Pfaff's method should be investigated. First steps towards an automatic treatment of contiguous relations have been made by Takayama [48], using noncommutative Groebner bases methods.

(iii) Hypergeometric series evaluation and Knuth-type identities: Recently Bill Gosper (via email letter) asked for a *systematic* evaluation of a certain nonterminating hypergeometric series. Gosper reported that all classical standard approaches (like contiguous relations) seem to fail on that instance; he only succeeded by using "matrices, theology, and plotting". The author of this proposal showed how a combination of Zeilberger's "fast" algorithm together with Petkovšek's algorithm "HYPER" succeeds in that particular example, and also in an example studied by R. Askey. From these experiences, a systematic investigation seems to be very promising. - Another achievement with respect to the use of algorithmic tools and in connection with the evaluation of nonterminating hypergeometric series is Paule's proof [19] of a combinatorial identity of completely new type, which was conjectured by D.E. Knuth in a study of a certain combinatorial problem. There is lots of evidence that a much richer class of Knuth-type identities exists; also it is to expect that those could be treated along similar lines.

5.4 Previous Work

Following the partition into subareas made in Section 5.3, we describe related previous work carried out in the group supervised by the author of this proposal.

5.4.1 Indefinite Summation Algorithms

In the context of his Ph.D. study [41] (advisor: P. Paule), Roberto Pirastu made an extensive study on the problem of indefinite *rational* summation, both in theory as well as in practice:

- R. Pirastu, *On Combinatorial Identities: Symbolic Summation and Umbral Calculus*, Ph.D. Thesis, RISC, J. Kepler University Linz, 1996 (115 pages).
- R. Pirastu, *A note on the minimality problem in indefinite summation of rational functions*, in: Proceedings of the Seminaire Lotharingien de Combinatoire, Saint-Nabor, J. Zeng (ed.), October 1993.
- R. Pirastu and K. Siegl, *Parallel computation and indefinite summation: a ||MAPLE|| application for the rational case*, J. Symbolic Computation **20** (1995), 603–616.
- R. Pirastu and V. Strehl, *Rational summation and Gosper-Petkovšek representation*, J. Symbolic Computation **20** (1995), 617–626.
- R. Pirastu, *Algorithms for indefinite summation of rational functions in Maple*, The Maple Techn. Newsletter **2**(1) (1995).

The thesis and all papers are available via WWW under the URL
http://info.risc.uni-linz.ac.at:70/1/people/rpirastu
The corresponding software, in particular, Maple implementations of the algorithms of Abramov and of Paule, can be picked up via WWW under the URL
http://info.risc.uni-linz.ac.at:70/1/archive/combinatorics/maple/rat-summation
A Mathematica version of Paule's algorithm for indefinite summation of rational functions, which is based on the greatest factorial factorization (GFF) concept, was implemented by C. Mallinger and is available upon email request to `Peter.Paule@risc.uni-linz.ac.at`. The corresponding paper, which also introduces the GFF concept in detail, is:

- P. Paule, *Greatest factorial factorization and symbolic summation*, J. Symbolic Computation **20** (1995), 235-268.

A survey article on indefinite summation and the GFF concept is provided by:

- P. Paule and V. Strehl, *Symbolic Summation - Some Recent Developments*, pp. 138–162 in: "Computer Algebra in Science and Engineering - Algorithms, Systems, and Applications", J. Fleischer, J. Grabmeier, F. Hehl, W. Kuechlin (eds.), World Scientific, Singapore, 1995.

As mentioned above, a prototype version of Karr's algorithm, written in the computer algebra system *Mathematica*, currently is carried out by K. Eichhorn. This work is done within a diploma thesis which is supervised by the proposal author. The corresponding software can be picked up via WWW under the URL
http://info.risc.uni-linz.ac.at:70/1/archive/combinatorics/mathematica/Karr
Eichhorn's implementation will serve as fundamental heuristic tool for further difference field investigations, i.e., for the extension problem and other related questions. Concerning the efficiency problem, i.e., the problem of avoiding complete factorization in Karr's approach, first steps have been made by the proposal author [17] using his concept of "greatest factorial factorization". In addition, one expects that this concept will play also an important role for studying difference equations related to more general summation contexts. For instance, the proposal author and Riese [21] showed that greatest factorial factorization can be extended in a direct manner to the q-case. A. Riese succeeded in carrying over GFF to the "bibasic" case and in solving the "bibasic" telescoping equation:

- A. Riese, *A generalization of Gosper's algorithm to bibasic hypergeometric summation*, Electronic Journal of Combinatorics **3** (1996) R19, 1–16.

A paper that presents a detailed discussion of the degree setting in Gosper's algorithm for the ordinary hypergeometric case (i.e., for computing a polynomial solution of Gosper's "key" difference equation) is:

- P. Lisonek, P. Paule and V. Strehl, *Improvement of the Degree Setting in Gosper's Algorithm*, J. Symbolic Computation **16** (1993), 243–258.

Finally we would like to point to a paper that introduces an approach to the (indefinite) symbolic summation problem along the fundamental notion of canonical form:

- P. Paule and I. Nemes: "A Canonical Form Guide to Symbolic Summation", (29 pages). To appear in: New Methodologies in Symbolic Computation Systems, A. Miola and M. Temperini (eds.), Springer Wien NewYork, 1997.

All papers of the proposal author are available via WWW under the URL
http://info.risc.uni-linz.ac.at:70/1/people/ppaule

5.4.2 Definite Summation Algorithms

M. Schorn and the proposal author came up with a Mathematica implementation of Zeilberger's "fast" algorithm which also introduces some nontrivial modifications and extensions:

- P. Paule and M. Schorn, *A Mathematica version of Zeilberger's algorithm for proving binomial coefficient identities*, J. Symbolic Computation **20** (1995), 673–698.

Meanwhile this implementation has become a standard reference; see, e.g., the book by Petkovšek, Wilf and Zeilberger [25].

The bottleneck problem of Zeilberger's "fast algorithm", i.e., the design of fast algorithms for solving linear systems of equations over rational functions, in the proposed research project will be attacked in several ways, namely by interpolation, parallelization, and also by employing modular approaches. First steps with respect to parallelization and p-adic arithmetic have been made by Limogenelli and Pirastu in the simpler case of linear systems over the *rationals* instead of *multivariate rational functions*:

- C. Limogenelli and R. Pirastu, *Exact solution of linear equation systems over rational numbers by parallell p-adic arithmetic*, in: Proc. CONPAR94-VAPP VI Linz, Springer LNCS 854, pages 313-323, 1994.
- C. Limogenelli and R. Pirastu, *p-adic arithmetic and parallel symbolic computation: an implementation for solving linear systems over rationals*, Computers and Artificial Intelligence **14** (1996), 35–62.

The research on nonminimal "Zeilberger orders" will be guided by two recent observations, independently made by the proposal author and V. Strehl, namely that certain "inverse transforms" might be responsible for this phenomenon. In this context, in particular in the q-case, also the effects of the proposal author's "creative symmetrizing" need further explanation. "Creative symmetrizing" has been introduced in

- P. Paule, *Short and Easy Computer Proofs of the Rogers-Ramanujan Identities and of Identities of Similar Type*, Electronic Journal of Combinatorics **1** (1994) R10, 1–9.

and discussed further in

- P. Paule and A. Riese, *A Mathematica q-Analogue of Zeilberger's Algorithm Based on an Algebraically Motivated Approach to q-Hypergeometric Telescoping* (30 pages). To appear in: Fields Proceedings of the Workshop "Special Functions, q-Series and Related Topics", organized by the Fields Institute for Research in Mathematical Sciences at University College, 12-23 June 1995, Toronto, Ontario.

The latter paper provides also a description of a Mathematica implementation of a q-analogue of Zeilberger's "fast" algorithm, carried out by A. Riese within a diploma thesis work supervised by Paule; it is based on a q-analogue of greatest factorial factorization. The Paule/Schorn implementation is available via WWW under the URL

http://info.risc.uni-linz.ac.at:70/1/archive/combinatorics/mathematica/PauleSchorn

In the near future it is planned to make also Riese's software available via WWW; at present his implementation can be obtained upon email request to `Peter.Paule@risc.uni-linz.ac.at`.

In case that Zeilberger's "fast" algorithm does not deliver the minimal recurrence despite a closed-form evaluation (e.g., a hypergeometric one) exists, Petkovšek's algorithm "HYPER" [40] computes the desired solution of the Zeilberger recurrence as a linear independent combination of hypergeometric sequences. An article that describes a q-analogue of Petkovšek's algorithm, i.e., for finding closed-form solutions of q-difference equations, is:

- S.A. Abramov, P. Paule and M. Petkovšek, *q-hypergeometric solutions of q-difference equations*, (20 pages). To appear in: Discrete Mathematics.

First results towards a systematic investigation of q-WZ pairs and dual identities have been achieved by using A. Riese's implementation; see the paper by Paule/Riese [21].

5.4.3 Definite Multisum Algorithms

There are various different approaches: (i) variation of the (Sister Celine) approach suggested by Wilf and Zeilberger [15]; (ii) approaches based on special purpose techniques, and (iii) general operator elimination methods. ad (i): Wegschaider within a diploma thesis work supervised by the author of this proposal, currently is developing a prototype implementation; for that he is using ideas of Verbaeten [54] for reducing the underlying linear system:

- K. Wegschaider, *Computer-Generated Proofs of Binomial Multi-Sum Identities*, Dipl.Thesis, RISC, J. Kepler University Linz. (Will be finished in March 1997.)

ad (ii): For doublesums an interesting matrix method approach, motivated by the Maple package GFUN [6], has recently been proposed by Strehl [52]. A remarkable, completely different approach was suggested by Schorn in Chapter 7 of his Diploma Thesis, which was supervised by Paule:

- M. Schorn, *Contributions to Symbolic Summation*, Dipl.Thesis, RISC, J. Kepler University Linz, 1995. (90 pages)

It is available via WWW under the URL

http://info.risc.uni-linz.ac.at:70/1/people/mschorn

ad (iii): Main tools are Gröbner bases methods for elimination in noncommutative operator algebra; see the following subsection.

5.4.4 Holonomic Function Identities

Work that treats the simple special case of holonomic sequences defined by linear difference equations with constant coefficients is

- I. Nemes and M. Petkovšek, *RComp: A Mathematica package for computing with recursive sequences*, J. Symbolic Computation **20** (1995), 745–754.

At present, I. Nemes is developing algorithms for symbolic solution of difference equations in his Ph.D. thesis supervised by Paule. Also under the supervision of Paule, a Mathematica package for handling holonomic functions and sequences in one variable has been implemented by C. Mallinger:

- C. Mallinger, *Algorithmic Manipulations and Transformations of Univariate Holonomic Functions and Sequences*, Dipl.Thesis, RISC, J. Kepler University Linz, 1996. (87 pages)

It is available via WWW under the URL
http://info.risc.uni-linz.ac.at:70/1/people/malling
In the case of more general classes, one has to solve the problem of elimination in noncommutative (operator) algebras like Weyl algebras; here noncommutative Gröbner bases methods play the most important role. First results in this direction have been achieved by Takayama [50]; concerning actual implementation, F. Chyzak and B. Salvy from INRIA-Paris made already very promising steps [10]. They developed their algorithms in the language of Ore algebras which has the additional advantage of universality (e.g., the ordinary case and the q-case are covered by the same overall setting). At the present stage no previous work has done in this direction at RISC. Nevertheless, concerning Gröbner basis theory for the ordinary commutative case, at RISC there is outstanding expertise and know-how available (e.g., in the SFB groups of B. Buchberger, F. Winkler, and H. Hong) from which the proposed "noncommutative research" will greatly benefit.

5.4.5 Combinatorial Identities Applications

Concerning *(i) Bailey Chains* we would like to mention explicitly the work of Paule which was carried out independently from that of Andrews; see also [12]:

- P. Paule, *Zwei neue Transformationen als elementare Anwendungen der q-Vandermonde Formel*, Ph.D. Thesis , University of Vienna, 1982. (93 pages, in German)
- P. Paule, *On Identities of the Rogers-Ramanujan Type*, Journal of Math. Anal. Appl. **107** (1985), 255–284.
- P. Paule, *A Note on Bailey's Lemma*, J. Comb. Th. (A) **44** (1987), 164–167.

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A paper that is related to both *(ii) Pfaff's method* and *(iii) Hypergeometric series evaluation and Knuth-type identities* is:

- P. Paule, *A Proof of a Conjecture of Knuth*, Experimental Mathematics **5** (1996), 83–89.

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5.5 Cooperations

5.5.1 TMR Network

The proposed research is closely related to a TMR-network proposal (EU Program: Training and Mobility of Researchers) the proposal author has submitted recently (No. ERB-4061-PL-97-0576). In case of its acceptance, (in average) one visiting researcher position would be assigned to each of the following teams that have agreed to participate: RISC-Linz (P. Paule), U. Erlangen (V. Strehl), INRIA-Paris (B. Salvy), U. Amsterdam (T. Koornwinder), RIACA-Eindhoven (A. Cohen), and U. Vienna (C. Krattenthaler). U. Ljubljana (M. Petkovšek) will be an associated node from the EU "third country" Solvenia. To most of these European partners the author of this proposal has established fruitful scientific contacts since long.

V. Strehl (U. Erlangen-Nürnberg) is one of the leading researchers in enumerative combinatorics and symbolic summation. He is co-organizer, together with D. Foata and A. Kerber, of the traditional Seminaire Lotharingien de Combinatoire and serves as co-editor of the accompanying new electronic journal. He is also editorial board member of the "Electronic Journal of Combinatorics" and of the "Maple Technical Newsletter". For many years there has been a strong research link between Strehl and the proposal author's group that resulted in several joint publications [2], [42], and [23]. R. Pirastu, who completed his Ph.D. thesis as an HCM fellow (Project No. ERBCHBICT930501) with the proposal author at RISC, did his diploma thesis on symbolic rational summation under the supervision of V. Strehl. Besides mutual visits in the framework of exchange programs, another joint international project of V. Strehl and the proposal author was the organization of the MSI-Cornell Workshop "Symbolic Computation in Combinatorics" in 1993; Strehl and the proposal author also edited the proceedings volume of this conference, see the JSC special issue [31]. Currently they are sharing the program committee chair for the 9-th International Conference on Formal Power Series and Algebraic Combinatorics (FPSAC'97), organized by Krattenthaler in July 1997 in Vienna.

B. Salvy (INRIA-Paris) is editorial-board member of the JSC (Journal of Symbolic Computation) and of the "Maple Technical Newsletter". He is author of Maple libraries for asymptotics, generating function analysis, manipulation of linear differential and recurrence equations. In addition, besides being member of the Maple Design Team, he is co-author of a book on Maple and author/co-author of articles in asymptotic analysis, computer algebra and analysis of algorithms. One of the significant contributions to holonomic function is the Maple package GFUN developed by B. Salvy and P. Zimmermann. (A Mathematica version carried out by C. Mallinger is cited above.) B. Salvy is member of a research group headed by Ph. Flajolet at INRIA-Paris. Both have been invited speakers at the 1993 Cornell workshop organized by the proposal author and Strehl. Of particular interest to the project is the work of this group concerning the algorithmic treatment of Ore polynomials which provide a common framework for algorithms in the area of summation, integration and q-summation. In 1994, the proposal author has been invited to visit INRIA; vice versa, B. Salvy and F. Chyzak (a Ph.D. student supervised by Salvy) visited RISC in 1995 and 1996. Besides the TMR project, further intensification of the scientific exchange is planned (e.g., AMADEUS).

T. Koornwinder (U. Amsterdam) is one of the leading experts in special functions and their q-analogues; also multivariable generalizations of these, associated with root systems; and interpretations of special functions in Lie groups and quantum groups. He is vice-chair of the SIAM Activity Group on Orthogonal Polynomials and Special Functions. Besides his manifold theoretical contributions to the field, T. Koornwinder has also good expertise with algorithms for evaluating hypergeometric sums, and with Maple programming. For instance, he came up with the first profound implementation of a q-analogue of Zeilbergers "fast" algorithm [51]. In addition, Koornwinder is one of the leading persons in the Askey Project, the new "Handbook of Special Functions" (successor of the Bateman Project). Besides the usual scientific exchange, the contact will be greatly intensified with respect to the envisioned electronic supplement of the Askey Project. For instance, the proposal author has been member of the international supervising board of the RIACA project (U. Eindhoven) "A computer implementation of the Askey-Wilson scheme" which was initiated by Koornwinder and carried out by Dr. R. Swarttouw during the first half of 1996; see `http://www.can.nl/~renes/index.html`.

C. Krattenthaler (U. Vienna) is one of the leading researchers in enumerative combinatorics and (q-)hypergeometric series. He is head of the combinatorics group at the Institut für Mathematik at the University of Vienna. In 1990, he received the best young researchers prize of the Austrian Mathematical Society. The needs of his work in enumerative combinatorics and (q-)hypergeometric series led him to develop the Mathematica packages HYP and HYPq, which are already powerful tools in identifying and manipulating (q-)binomial and (q-)hypergeometric series. The author of this proposal used his Mathematica package "hyp.m" as a tool for proving Knuth's conjecture [19]. Up to now the design of Krattenthaler's package is non-algorithmic; it provides a computer-assisted variant of the classical (q-)hypergeometric methodology. Nevertheless, especially in connection with summation and transformation of hypergeometric series this tool is of great practical value. For years there have been strong research links between Krattenthaler and the proposal author. Besides mutual visits, currently they cooperate in organizing the 9th FPSAC conference mentioned above.

M. Petkovšek (U. Ljubljana) is one of the leading researchers in difference equations and computer algebra. He is co-author (with Wilf and Zeilberger) of the book "A=B" [25] which has become *the* standard reference for the recent developments in the context of Zeilberger's breakthrough. For years there have been intensive scientific contacts, which besides mutual visits, resulted in the joint publications [16] and [25].

5.5.2 Other Scientific Contacts

Besides the close contacts to the researchers involved in the TMR-proposal, the author of this proposal since long keeps up intensive scientific exchange with many other leading researchers in the field.

For instance, a joint paper [5] resulted from a RISC visit of *G.E. Andrews* (PennState). He invited the proposal author to an inspiring PennState visit in 1994; in the same year Andrews served as a main speaker at the Cornell workshop mentioned above.

Another valuable scientific exchange we would like to mention is with *D.E. Knuth* (Stanford); it traces back to the RISC visit of D.E. Knuth in summer 1993. One offspring of this contact is the paper [19]; others can be found on pages 537 and 546 in the book [44].

For years there has been a fruitful scientific exchange with *H.S. Wilf* (Philadelphia) who visited the proposal author at RISC in 1995. One of the outcomes of this contact is the inclusion of the Paule/Schorn Mathematica implementation of Zeilberger's "fast" algorithm [55] in the electronic supplement to the book "A=B" [25].

There is also excellent scientific cooperation with both of Wilf's co-authors. M. Petkovšek (Slovenia), who in frame of an Austrian research fellowship spent a period of one month at RISC, already has been mentioned in connection with the proposed TMR network. In 1992 the first JSC special issue on "Symbolic Computation in Combinatorics" appeared; it was edited jointly by the proposal author and *D. Zeilberger* (Temple, Philadelphia), who also was mainspeaker at the Cornell workshop. Zeilberger invited Paule to be main speaker at the workshop "Special Functions, q-Series and Related Topics" held 1995 at the Fields Institute for Research in Mathematical Sciences in Toronto.

¿From 1984-1986 the author of this proposal had been a Humboldt fellow at *A. Kerber's* Lehrstuhl II at Bayreuth (Germany). There are still very strong links to the researchers at this Lehrstuhl (besides Kerber also to *R. Laue*); further intensification of the scintific contact (common theme: "algorithmic treatment of combinatorial identities arising from Polya theory") is planned.

Recently, *J. Borwein*, the director of the Center for Experimental and Constructive Mathematics at Simon Fraser University (Canada), suggested possible scientific cooperation. Several subtasks of the proposed joint research match perfectly manifold interests of both groups. In addition, P. Lisonek, who completed his Ph.D. [22] at RISC under the supervision of the proposal author, at present is holding a post doc position at Borwein's department.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

The main objective of the proposed research is mathematical foundation and design of computer algebra algorithms for symbolic summation and combinatorial identities. Also from the synergy of complementary expertise of other teams involved in the SFB project, major breakthroughs in theory as well as in applications are to be expected. The latter is meant also in the general sense that new algorithms, developed in the framework of the proposed research project, will significantly enhance the tool-box for computer-assisted problem solving in pure mathematics (besides combinatorics, also in number theory, special functions, etc.), computer science (e.g., analysis of algorithms), and physics (e.g., "partition function" computation).

In spite of the classical nature of the symbolic summation problem, one can say that Zeilberger's recent breakthrough gave the stimulus that had turned this problem field into a new, promising, and widely recognized subarea of symbolic computation. Due to the fact that the crucial new developments are only a few years old, a certain part of the proposed research deals with consolidation and documentation of research in this new area. However, the main part of the proposed research focuses on challenging new problems, mostly arising in the context of symbolic summation and holonomic functions; efficient algorithmic solutions would have a substantial impact on research in the application areas mentioned above.

More concretely, according to the partition into subareas that had been used in the previous sections, the project objectives can be described as follows.

1. Indefinite Summation Algorithms: Major project objectives are: (i) realization of a prototype implementation of Karr's algorithm (as a basis for further investigations); (ii) extension of Karr's algorithm in various directions (e.g., q-harmonic numbers, algebraic difference field extensions); (iii) modification of Karr's algorithm with respect to avoidance of complete factorization (relevant concerning efficiency!); (iv) design of indefinite summation algorithms for summand sequences that do not fit into the hypergeometric paradigm or into Karr's setting, respectively.

2. Definite Summation Algorithms: Major project objectives are: (i) explanation of the phenomenon of nonminimal "Zeilberger orders"; (ii) design of fast and efficient (also parallel) algorithms for the bottleneck of Zeilberger's "fast algorithm", i.e., for solving linear systems over rational functions; (iii) extension of Zeilberger's method to nonhypergeometric summand sequences (see, e.g., the recent results by Majewicz [25]); (iv) systematic exploitation of q-WZ theory, in particular q-WZ-duality.

3. Definite Multisum Algorithms: Here the major project objective is the design of efficient algorithms for (q-)hypergeometric multisum identities.

4. Holonomic Function Identities: Here the major project objective is the design of efficient algorithms for holonomic function identities as, for instance, for the automatic treatment of generating function identities like the "Hille-Hardy formula" for Laguerre polynomials [15].

5. Combinatorial Identities Applications: (i) Algorithmic study of Bailey-chain theory. (ii) Algorithmic treatment of contiguous relations for (q-)hypergeometric series (this relates to "Pfaff's method" recently introduced by Andrews). (iii) Algorithmic study of "Knuth-type" identities. (iv) The design of algorithms for solving difference equations. (vi) Algorithmic study of inverse relations.

6. Documentation: The proposed research is strongly motivated by practical demands and goes along with prototype implementations in computer algebra systems as Mathematica and Maple. Thus one of the project objectives is to set up an easily accessible electronic environment for: (i) the documentation of the results achieved, (ii) the software developed, and (iii) the motivating examples and applications.

5.6.2 Methods

1. Indefinite Summation Algorithms: The extension problem and other questions will be investigated after carrying out an appropriate prototype implementation of Karr's algorithm (in Mathematica). For the efficiency problem, i.e., the problem of avoiding complete factorization, first steps have been made by proposal author [17] based on his concept of "greatest factorial factorization". This concept that carries over also to the q-case and the "bibasic" case, could play also an important role for studying difference equations related to more general classes of summand sequences.

2. Definite Summation Algorithms: The bottleneck problem of Zeilberger's "fast algorithm", i.e., the design of fast algorithms for solving linear systems of equations over rational functions, will be attacked in several ways, namely by interpolation, parallelization, and also by employing modular approaches. This problem not only is a key problem in the context of definite summation, it can be also viewed as one of the standard problems in the field of *numeric-symbolic* computation. - The research on nonminimal "Zeilberger orders" will be guided by two recent observations, independently made by the proposal author and Strehl, namely that certain "inverse transforms" might be responsible for this phenomenon. In this context, in particular in the q-case, also the effects of Paule's "creative symmetrizing" need further explanation. Generally, the strategy for solving definite summation problems consists in combining various methods and approaches: the (q-)Zeilberger implementations [1] and [21]; difference equation solvers as, e.g., [25]; generating function procedures as, e.g.,[9]; and also noncommutative Gröbner bases methods (next subsection).

3. Definite Multisum Algorithms: Various different approaches will be followed: (i) that one taken by Wegschaider [1] (which consists in a "Verbaeten-variation" of the original Sister Celine approach suggested by Wilf and Zeilberger); (ii) special purpose techniques as suggested by Strehl [52] and Schorn [2]; and, most important, (iii) noncommutative Gröbner bases methods. (For the latter see the first steps made by Chyzak and Salvy [10].)

4. Holonomic Function Identities: One way to attack the problem of transforming holonomic theory into concrete algorithms is to restrict problem classes in such a way that special purpose methods apply; examples are: definite summation of (q-)hypergeometric sequences (here Zeilberger's "fast algorithm", based on Gosper's, applies) or particular (q-)hypergeometric multisums (which can be handled by methods briefly described above). In order to deal with sufficiently general classes, one is faced with the problem of elimination in noncommutative algebras like Weyl algebras. On this general level, noncommutative Gröbner bases methods play the most important role. As already pointed out, up to now no concrete work has been done at RISC in this direction. However, research in this direction, which is extremely promising as explained above, will be supplemented by outstanding expertise (with respect to the commutative case) of other SFB teams involved, e.g., the groups of B. Buchberger, F. Winkler, and H. Hong.

5. Combinatorial Identities Applications: (i) First steps towards a systematic investigation of Bailey chains and, more general, Bailey lattices [7] has already been made by A. Riese [43] by extending Zeilberger's "fast" algorithm in an appropriate way. The first results are very promising; nevertheless, lots of work remain to be done in theory as well as in practice. (ii) For the systematic algorithmic treatment of contiguous relations, noncommutative Gröbner bases methods play a prominent role; see item 4. (iii) The study of "Knuth-type" identities will follow the lines that were taken by the proposal author [19]. (iv) At present not too many tools for solving various types of difference or recurrence equations are to find in the standard computer algebra systems. To begin with, a systematic account of the state of the art should be made. This includes a bibliography on the theoretical literature (from recent to past, such as the books by Nörlund [28], Jordan [8] or Milne-Thomson [23]) as well as an account on algorithmic aspects (relevant work, existing implementations, etc.). On a more general level: investigation of Galois theory for difference equations. Important progress in this direction have been made recently by M. van der Put and M. Singer [27]. (v) From hypergeometric point of view, inverse relations between (q-)hypergeometric sequences (see, e.g., the tables compiled by Riordan [17]) are still not fully understood. Tools like Zeilberger's algorithm should be used to investigate the underlying mechanism in more detail. Of special interest, for instance, is the question whether for certain types of sequences the inverse relation could be computed in algorithmic manner. A first indication that this problem might be feasible is due to recent work of Milne and Bhatnagar [47].

6. Documentation: For documentation of the results achieved and of software developed, i.e., prototype implementations that were carried out for assisting the proposed research, an electronic environment, accessible also to the broad scientific community, will be installed in form of a project home page on the World Wide Web.

5.6.3 Programme and Schedule

The project objectives and research methods, which are described in the respective subsections, have been grouped into problem areas. The work plan is broken down accordingly. Of course, this splitting into subtasks has to be taken as a rough approximation.

Subtask 1: Indefinite Summation Algorithms

(a) Implementation of Karr's algorithm; research in connection with Karr's algorithm (extensions, factorization problem, relation to Gosper type approaches, etc.). (b) With respect to summation algorithms for sequences of nonhypergeometric type: exploitation of all possible approaches as, for instance, the use of algorithmic tools like Mallinger's package [9].

Subtask 2: Definite Summation Algorithms

(a) Detailed study of "Zeilberger orders". (b) Design of new and efficient algorithms for solving linear systems over rational function fields. (c) Extension of Zeilberger's method to nonhypergeometric summand sequences. (d) Systematic exploitation of q-WZ-pairs, in particular q-WZ-duality.

Subtask 3: Definite Multi-Sum Algorithms

(a) Refinement and extension of Wegschaider's approach (e.g., to triple-sums). (b) Investigation of special purpose methods proposed by Strehl and Schorn. (c) Implementation of noncommutative (Gröbner bases) elimination methods.

Subtask 4: Holonomic Function Identities

Systematic study of noncommutative (Gröbner bases) elimination methods.

Subtask 5: Combinatorial Identities Applications

(a) Algorithmic study of Bailey chain theory. (b) Algorithmic study of Pfaff's method (contiguous relations). (c) Extension of the class of "Knuth-type" identities. (d) Design of algorithms for solving difference equations. (e) Algorithmic approach to inverse relations.

Subtask 6: Documentation

Installation of an electronic WWW project home page.

The schedule and the chronological order for carrying out these subtasks 1 - 6 is given in the table of Section 5.8.

5.7 Integration with the SFB

The proposed research is well-integrated within the overall SFB. This is due to the following main reasons:

- *Proving and Solving* is also a central theme for symbolic summation and the automatic treatment of combinatorial identities. As already pointed out, the problem of *proving*, which in many instances is equivalent to closed-form evaluation or to finding canonical forms [20], will be transformed into problems of *solving*. This, for instance, means: solving linear systems of equations with rational function coefficients, finding (symbolic) solutions of difference equations, or finding (e.g., by applying Gröbner bases theory) certain operators in annihilating ideals arising in the context of certain noncommutative difference operator algebras and corresponding (left-)modules.

- *Symbolic-Numeric Computation* plays a fundamental role with respect to the bottleneck problem of Zeilberger's "fast algorithm", i.e., the design of fast algorithms for solving linear systems of equations over rational functions. Efficient algorithmic solutions to this problem will consist in a blend of numeric-symbolic methods as, for instance, interpolation, parallelization and modular approaches. Thus this bottleneck problem not only is a key problem in the context of definite (multi-)summation, it can be also viewed as one of the standard problems in the field of *numeric-symbolic* computation.

5.8 Detailed Budget

Project Personnel:

- A = Univ.-Doz. Dr. Peter Paule (proposal author and project coordinator)
- B = Dipl.-Ing. Axel Riese (post-doctoral researcher; he will finish his Ph.D. in fall 1997)
- C = Dipl.-Ing. Markus Schorn (Ph.D. student, paid as a 2/3-job)
- D = Dipl.-Ing. Kurt Wegschaider (Ph.D. student, paid as a 2/3-job)

Work Plan and Time Table: The work splits into Subtasks 1 - 6 as described in subsection 5.6.3. The chronical order in which the Subtasks will be carried out as well as the corresponding distribution of the project personnel A - D is given in the following table:

Subtask	Personnel	1st year		2nd year		3rd year	
		1 ... 6	7 ... 12	1 ... 6	7 ... 12	1 ... 6	7 ... 12
1	A, C						
2	A, B, C						
3	A, C, D						
4	A, B, D						
5	A, B						
6	B, C, D						

5.8.1 Requested Personnel

The costs for 1 post-doctoral researcher (B) and the costs for two Ph.D. students, (C) and (D), both paid as a 2/3 post-doc position are required.

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 2 workstations, which amounts to a total of **ATS 140.000,–** in the first year.
  The workstations serve as additional workplaces for the employees of this project.
- For time consuming codes, the powerful workstation of project P3 will be used.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 4
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	140.000	10.000	25.000				1.323.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	140.000	30.000	75.000				3.689.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 4

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Paule Peter, Dipl.-Ing. Dr. Univ.-Doz.	Computeralgebra	RISC	20%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 4

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Riese Axel, Dr.	Computeralgebra	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Schorn Markus, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Wegschaider Kurt, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Riese Axel, Dr.	Computeralgebra	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Schorn Markus, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Wegschaider Kurt, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Riese Axel, Dr.	Computeralgebra	RISC	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Schorn Markus, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
	100%	1	Wegschaider Kurt, Dipl.-Ing.	Computeralgebra	RISC	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 4

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe				Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 4

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 5: Coupled Field Problems: Advanced Numerical Methods and Applications to Nonlinear Magnetomechanical Systems

5.1 General Information

Title : Coupled Field Problems: Advanced Numerical Methods and Applications to Nonlinear Magnetomechanical Systems

Field of research : Systems of Coupled Partial Differential Equations, Magnetomechanical Field Problems, 3D Mesh Generation, Finite Element Method, Multilevel Methods, Domain Decomposition Methods, Parallelization, Pre- and Postprocessing, Modeling of Magnetomechanical Sensors and Actuators

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5.2 Abstract

The modeling of complex electromechanical systems often leads to coupled field problems involving the interaction of different systems of non-linear Partial Differential Equations (PDEs) in complicated 3D geometries. The complexity of these systems requires the development of efficient simulation tools working on powerful workstations as well as on workstation clusters and parallel computers. Roughly speaking, these simulation tools consist of

- preprocessing tools,
- the PDE solver, and
- postprocessing tools.

The subject of this project is the development, the analysis, the implementation and the application of advanced numerical methods for the solution of 3D non-linear, stationary and instationary (dynamic) coupled magnetomechanical field problems described by Maxwell's and Navier's systems of PDEs as well as the development of an advanced user surface including the handling of parallel processing. In the time-dependent case, this problem leads to the coupling of parabolic and hyperbolic PDE systems for defining the magnetic vector potential $\vec{A}$ and the displacement field $\vec{u}$ under suitable initial and boundary conditions as well as gauging condition for $\vec{A}$. In recent years, advanced numerical methods have been developed for 3D Maxwell's as well as for Lamè - Navier's equations separately, whereas the development and, especially, the analysis of similar methods for the coupled problems are at the very beginning. The usual approach to the solution of such problems consists in decoupling the field problems by an alternate iteration scheme. However, this decoupling can lead to a loss in efficiency of the corresponding numerical schemes, especially, in the presence of non-linearities and strong coupling terms. Therefore, new numerical schemes should avoid these losses in efficiency and should be based on hierarchical adaptive approximation and solver techniques including algebraic and hybrid multilevel solvers. The numerical solver together with appropriate pre- and postprocessing tools including automatic 3D mesh generators should enable us to simulate more and more complicated problems in advanced electromechanical applications.

5.3 State of the Art

Most of the results discussed in the literature are related either to the solution of stationary and non-stationary magnetical field problems or to the solution of static and dynamic elasticity problems. Unified approaches to coupled magnetomechanical problems are far less developed. Furthermore, the state of the art differs between the 2D and 3D case, between scientific computing and analysis, between conventional algorithms and parallel solvers, between application and real-life application.

Several approaches for the direct simulation of 2D magnetic and mechanical field problems on parallel computers have been proposed in the last 10 years. In particular, we refer to the work of the principal investigator and to the references given in his papers (see also next section) as well as to the annual conference (since 1987) on Domain Decomposition (DD) methods.

In contrast, time-dependent, non-linear, 3D magnetic and mechanical field problems are much more challenging. Very recently, several approaches to the mathematical formulation of 3D magnetic field problems have been discussed and analyzed [2, 10, 39, 57, 59, 15, 42]. The "State of the Art" in 3D magnetic field computations is reflected by the proceedings of the biennial "Conferences on the Computation of Magnetic Fields" (COMPUMAG) which are documented in the journal "IEEE Transactions on Magnetics". There, different techniques for 3D magnetostatics, in particular different gauging methods, are discussed (cf., e.g., [59, 52]). In fact, the systems of equations are solved by simple iterative (e.g., CG) methods taking hours of computing time [59]. There are, to the proposer's knowledge, still no papers about applying fast (i.e. optimal complexity) parallel solvers to the equations of 3D magnetostatics. 3D magnetic field problems have some special features. These features are related to the governing PDEs, to the non-linearity and, to the complex geometry of practical problems.

The combination of implicit time integration, Newton-type linearization and nested iteration should result in an efficient method provided that a good nested solver (e.g. based on DD-, MG-, or AMG-methods) for the arizing linear problems is available. The non-linearity arises in the ferromagnetic materials for Maxwell's equations. Such non-linearities can certainly be caught on some (sufficiently fine) coarse grid [30]. Stronger non-linearities, as arizing e.g. in the case of geometrical nonlinear mechanical problems, which will not be considered in this project, require more advanced linearization techniques (see [14] and the references cited there).

The parallel solution of such problems requires a special preparation phase (preprocessor) including tools for describing the geometry, the data of PDEs and the boundary and initial conditions as well as for distributing the data. The distributing tool based on DD will be provided by Project 12. There is a lot of literature on mesh generation and mesh refinement strategies, especially for 2D geometries. Concerning automatic 3D mesh generation, we refer to the survey [79] and to the more recent references given in [2, 17].

DD or DD based methods seem to be well suited for solving such problems. Important contributions to the development of non-overlapping DD solver techniques (preconditioners) have been made by M. Dryja [15, 17], J.H. Bramble, J.E. Pasciak, and A.M. Schatz [11], M. Dryja and O. Widlund [18], B. Smith [74] , O. Axelsson and P. Vassilevski [54], A. Quarteroni [1], P. Le Tallec [56], B.F. Smith, P. Bjørstad, and W. Gropp [4] and many others. We especially emphasize the works of Russian mathematicians of the Moscow School, Y.A. Kuznetsov et al. [48, 51], and of the Novosibirsk School, S.V. Nepomnyaschikh et al. [53, 54, 52, 10, 53]. The "State of the Art" is again quite well reflected by the proceedings of DD conferences, cf. [11, 12, 23, 19, 33, 40, 45, 61].

The main problems of the non-overlapping Dirichlet DD techniques are the construction of local (subdomain) Dirichlet problem preconditioners, of a suitable basis transformation and of a Schur complement preconditioner. The first problem is simple because every Dirichlet problem preconditioner can be used, e.g., multigrid preconditioners (cf., e.g., [6]). Major contributions to the second problem (the basis transformation) are based on norm-preserving extension ideas of S.V. Nepomnyaschikh [53, 54, 52, 10, 53] and their combination with multigrid techniques [10]. A lot of papers are devoted to the third topic, namely to the construction of Schur complement preconditioners [15, 17, 11, 74, 3, 12, 71, 69, 5]. Theoretically, both the overlapping DD in FEM and the non-overlapping DD are covered by a unified approach, the theory of Multiplicative and Additive Schwarz methods [18, 58, 55, 60, 82, 71, 83]. This approach allows to analyze global multigrid methods as well as hierarchical preconditioners, and BPX-type [12] preconditioners.

Although most of the ideas can be applied to three-dimensional (3D) as well as to two-dimensional (2D) problems, there are still many open questions, e.g., in the design of practically applicable Schur complement preconditioners, and, especially, questions related to special features of magnetomechanical systems.

One topic of this project will be the use of algebraic multilevel methods either as fast solver for the fine grid finite element equations, which can implemented in the reference standard f.e. code developed by the research group of R. Lerch, or as coarse grid (cross point) solver in a geometrical multigrid (domain decomposition) method. Algebraic multigrid methods were first proposed in the pioneered work [67] by J. Ruge and K. Stüben. Recently, there has been a revival of algebraic multigrid methods due to the rising computer resources as well as to new interesting ideas [2, 3, 51, 7, 66, 81, 21]. Even, in the engineering literature, very promising results concerning the solution of complicated structural mechanics problems by aggregation type AMG methods have been reported [10].

Especially the numerical simulation of coupled field problems as magnetomechanical systems is presently restricted to certain applications, which are allowed to be handled in 2D or with smaller meshes in 3D. Due to the high complexity of magnetomechanical systems, the presently available simulation algorithms urgently need an enhancement with respect to efficiency, in order to proceed to standard industrial design tools.
The above statement is also valid for the simulation of many other electromechanical and mechatronic components such as sensors and actuators. The full 3D simulation of micromachined electroacoustic microphones for example is not yet feasible at the moment due to the complexity of the related multi-field problem to be studied.

5.4 Previous Work

The **research group of the principal investigator** has collected considerable experience with design, analysis and implementation of advanced parallel solvers for static field problems in solid and structural mechanics as well as for quasistatic magnetic field problems in the case that these fields are not coupled.

In the linear case, *static mechanical field problems* can be described by, or derived from Navier-Lamé-system

$$-G\left(\nabla\cdot\nabla\vec{d}+\frac{1}{1-2\nu}\nabla\nabla\cdot\vec{d}\right) \quad = \quad \vec{f}_V \;\text{ in }\Omega \tag{2}$$

under appropriate boundary conditions on the boundary $\partial\Omega$ of the domain Ω, where $\vec{d}$ is the mechanical displacement vector, $\vec{f}_V$ the volume force, E the modulus of elasticity, ν Poisson's ratio, and G the shear modulus. In the survey paper [29] (see also the literature cited there), we have constructed and analysed optimal order and highly efficient parallel solvers for coupled boundary- and finite element equations approximating plane strain, or plane stress, linear elasticity boundary value problems in bounded and unbounded regions Ω. Advanced numerical solvers for *3D linear elasticity problems and structural mechanical problems* are currently studied within the research project **P10643-TEC** funded by the FWF. The main results of the project have been obtained on the following topics:

- Analysis of elastic multi-structures [78].
- Construction, analysis and implementation of stable discretizations and robust solvers, including multigrid solvers, for typical parameter dependent problems in structural mechanics [68, 73].
- Construction, analysis and implementation of a new non-conforming finite element method for Kirchhoff's plate bending problem (4th order PDE's) [68, 72].

- Fast solvers techniques for Signorini's and contact problems [69].

F. Kickinger developed an *Algebraic Multi-Grid (AMG)* method for scalar partial differential equations [46, 46]. This method was presented at the European Multi-Grid Conference *EMG96* [43]. Since then these results have been extended to 2D and 3D elasticity problems. In the first approach, standard block Gauss-Seidel smoothers were implemented. In order to improve the robustness, F. Kickinger and U. Langer proposed new smoothers called Global-Extraction Patch-by-Patch methods which can be easily parallelized [47].

Electromagnetical field problems are described by the Maxwell equations which lead in the magnetostatic case to

$$\mathbf{rot}\,\vec{\mathrm{H}} = \vec{\mathrm{J}}, \qquad \vec{\mathrm{H}} = \nu(|\vec{\mathrm{B}}|)\vec{\mathrm{B}}, \qquad \operatorname{div}\vec{\mathrm{B}} = 0 \tag{3}$$

with $\nu(|\vec{\mathrm{B}}|) = 1/\mu_0\mu_r(|\vec{\mathrm{B}}|)$ for nonlinear material, cf. [38]. Here, the magnetic field strength is denoted by $\vec{\mathrm{H}}$, the magnetic induction by $\vec{\mathrm{B}}$, and $\vec{\mathrm{J}}$ is the current density. Since (16) holds, we can introduce the magnetic vector potential $\vec{\mathrm{A}}$ by $\mathbf{rot}\,\vec{\mathrm{A}} = \vec{\mathrm{B}}$.

In the 2D case, only one component of the vector potential $\vec{\mathrm{A}}$ has to be considered and (2) gives formally

$$\begin{aligned} -\operatorname{div}\,(\nu(x, |\nabla u(x)|)\nabla u(x)) &= \mathrm{J}(x) + \frac{\partial \mathrm{H}_{0\mathrm{y}}(x)}{\partial \mathrm{x}} - \frac{\partial \mathrm{H}_{0\mathrm{x}}(x)}{\partial \mathrm{y}}, \quad x \in \Omega && (4)\\ u(x) &= 0, \quad x \in \partial\Omega && (5) \end{aligned}$$

with $\Omega \subset R^2$ as a bounded domain. The solution u is the z–component A_z of the vector potential $\vec{A} = (A_x, A_y, A_z)^T$. The component of the current density, which acts orthogonal to the cross-section being considered, is represented by $\mathrm{J}(x)$, whereas $\mathrm{H}_{0\mathrm{x}}$ and $\mathrm{H}_{0\mathrm{y}}$ stand for sources associated with permanent magnets that may occur and $\nu(.)$ denotes a coefficient depending on the material and on the gradient $|\nabla u(x)|$ (induction).

For this class of problems (2D case) a complete methodology has been developed and implemented. In particular this includes the following topics.

- *Analysis of optimal algorithms:* Preconditioners [30, 5, 8, 10, 27], DD-solvers [39, 29].
- *Implementation of algorithms:* FEMGP [62], FEMooBEM [28], Global and Robust Solvers [13].
- *Further extensions and applications:* DD-Preprocessing [9], FEM-BEM Coupling [29, 39], Applications [41, 13].

Considering (16) the situation becomes more complicated for 3D magnetic field problems. Introducing the Coulomb gauge $\operatorname{div}\vec{\mathrm{A}} = 0$ leads to

$$\mathbf{rot}\,\left(\nu\left(x, |\,\mathbf{rot}\,\vec{\mathrm{A}}|\right)\,\mathbf{rot}\,\vec{\mathrm{A}}\right) = \vec{\mathrm{J}}, \qquad \operatorname{div}\vec{\mathrm{A}} = 0.$$

These problems are currently analyzed within the research project **P11215-TEC** funded by the FWF. The following topics are part of current research activities.

- *Analysis and implementation of 3D magnetic field problems:* The exact mathematical formulation of the problem has been discussed and justified in [42]. A basic result of the paper is the definition of the underlying space which is $\mathbf{Y} := H_0(\,\mathbf{rot}\,;\Omega) \cap H(\,\operatorname{div}\,;\Omega)$.
- Based on these results, first algorithms for solving 3D magnetic field problems will be implemented as part of the software package *FEPP* [66].

The development of *automatic 3D mesh generators* was a further research topic of the projects mentioned above. The first mesh generator NETGEN developed by J. Schöberl [69] is based on the advancing front method, and allows us to triangulate two- and three-dimensional geometries. The second mesh generator NAOMI developed by F. Kickinger [17, 46] is based on a completely different technique, namely covering the domain by some uniform mesh and fitting the mesh to the boundary and interfaces locally.

The **research group of the co-investigator** has collected considerable experience with the *simulation of coupled magnetomechanical transducers (sensors and actuators).*
In magnetomechanical transducers a magnetic material is subject both to rigid motions and to elastic deformations, which in turn may strongly influence the magnetic field and thus the magnetic force distribution. Therefore, a modeling scheme must take into account the strong coupling of the magnetic and mechanical field quantities [65]. This feature is especially relevant for magnetomechanical actuators. Since in many technical applications magnetomechanical transducers are immersed in an acoustic fluid, the solid-fluid interaction has to be considered, too [36]. The coupling mechanisms between magnetic, mechanical and acoustic fields are described by means of the example of an acoustic power source as depicted in Fig. 3. The acoustic power source was optimized to generate high-intensive mechanical pulses for the non-invasive destruction of concrements in human kidneys and urinary tract. When the

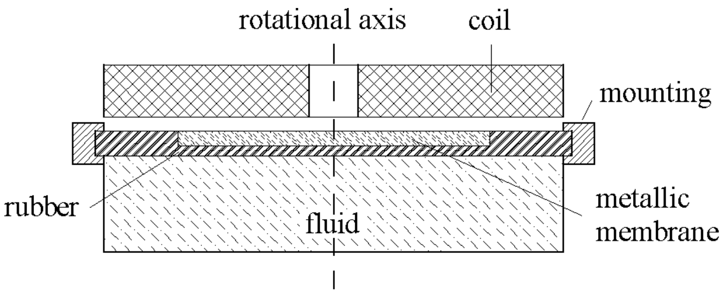

Figure 3: Schematic of an acoustic power source

slab coil is loaded by an electric current pulse, eddy currents are induced in the metallic membrane. The interaction between the eddy currents in the metallic membrane and the magnetic field results in a mechanical volume force acting on the membrane. Therewith, the metallic membrane-rubber structure is deformed and an acoustic pulse is radiated into the surrounding medium.

In the case of low frequencies (neglecting displacement current) magnetic systems with stationary and moving parts can be described by the following PDE

$$\begin{aligned} \nabla \times \left(\frac{1}{\mu} \nabla \times \vec{A} \right) &= -\gamma \left(\frac{\partial \vec{A}}{\partial t} + \nabla V \right) + \gamma \vec{v} \times (\nabla \times \vec{A}) \\ \vec{n} \cdot \vec{A} &= 0 \text{ auf } \Gamma_{\mathrm{e}} \ \times \ (0,T) \\ \vec{n} \times \frac{1}{\mu} \nabla \times \vec{A} &= 0 \text{ auf } \Gamma_{\mathrm{n}i} \ \times \ (0,T) \\ \vec{A}(\vec{r},0) &= \vec{A}_0 \ , \ \vec{r} \in \Omega \end{aligned} \tag{6}$$

In (6) $\vec{A}$ denotes the magnetic vector potential, μ the permeability , V the scalar electric potential, $\vec{v}$ the velocity and γ the conductivity. The term $\gamma\vec{v} \times (\nabla \times \vec{A})$ expresses the induced eddy current density in an

electric conductive body moving with velocity $\vec{v}$ in a magnetic field (motional emf). If the body under consideration can undergo elastic deformations, this term is bilinear with respect to the field quantities $\vec{A}$ and $\vec{d}$.
In the case of linear elasticity and isotropic materials, the dynamic behaviour of mechanical systems can be described by

$$\begin{aligned}
\rho \frac{\partial^2 \vec{d}}{\partial t^2} &= G \left(\nabla \cdot \nabla \vec{d} + \frac{1}{1-2\nu} \nabla \nabla \cdot \vec{d} \right) + \vec{f}_V \\
d_i &= d_{\Gamma i} \text{ auf } \Gamma_{\mathrm{e}i} \times (0,T) \\
\sigma_i &= \sigma_{\mathrm{n}i} \text{ auf } \Gamma_{\mathrm{n}i} \times (0,T) \\
\vec{d}(\vec{r},0) &= \vec{d}_0(\vec{r}) \ , \ \vec{r} \in \Omega \\
\frac{\partial \vec{d}(\vec{r},0)}{\partial t} &= \dot{\vec{d}}_0(\vec{r}) \ , \ \vec{r} \in \Omega
\end{aligned} \tag{7}$$

where $\vec{d}$ is the mechanical displacement, σ_i is the mechanical stress in direction i, $\vec{f}_{\mathrm{V}}$ the volume force, E the modulus of elasticity, ν Poisson's ratio, G the shear modulus and ρ the density.

The mechanical volume force due to a magnetic field of magnetic induction $\vec{B}$ (magnetic field intensity $\vec{H}$) acting on a body with current density $\vec{J}$ is given by

$$\vec{f}_V = \vec{J} \times \vec{B} = \left(-\gamma \frac{\partial \vec{A}}{\partial t} - \gamma \nabla V + \gamma \vec{v} \times (\nabla \times \vec{A}) \right) \times (\nabla \times \vec{A}) \, .$$

The equations governing the magnetic and mechanical field quantities are solved using a combined Finite-Element/Boundary-Element-Method (FEM-BEM) [37]. The stationary as well as the moving parts (rigid or elastic bodies) are discretized by finite elements and the open region between these parts by boundary elements. Therewith, the well-known problem of mesh distortion in pure finite element techniques due to moving parts can be avoided (Fig. 4). To circumvent the nonlinear system of

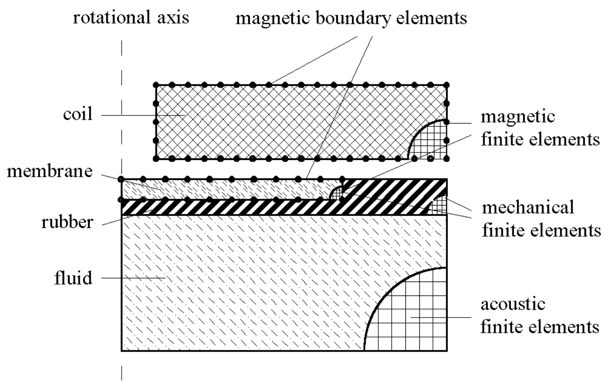

Figure 4: FEM-BEM discretization of the acoustic power source

equations resulting from a direct coupling of the magnetic and mechanical systems, the calculation of the magnetic forces is based on predictor values of the magnetic quantities. Therewith, a decoupling into a magnetic and mechanical matrix equation can be achieved. To ensure the strong coupling between the magnetic and mechanical quantities, a sophisticated Predictor/Multicorrector Algorithm [12] is used resulting in an efficient iteration between the two matrix equations within a single time step. Iterative solvers - GMRES (generalized minimum residual) and CGS (conjugate gradient squared) - have been adapted to solve these matrix system equations in a very fast way. The approach is currently limited by the assumption that the mechanical behaviour of the transducer is still subject to the theory of linear elasticity [50].

The above described simulation tool has been utilized to develop a special magnetomechanical sensor, shown in Fig. 5 [11]. This sensor is able to measure the thickness of PVC-walls within a range of 10mm to 30mm. The magnetic force generated by the permanent magnet presses the magnetic hollow ball

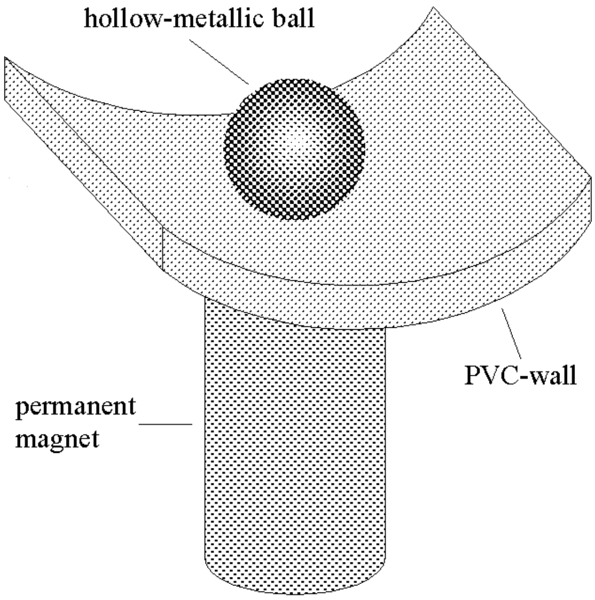

Figure 5: Permanent magnetic sensor for measuring the thickness of PVC walls.

against the PVC-wall, so that it can follow the guided movements of the permanent magnet. Therewith, according to the thickness of the wall, the metallic hollow ball influences the overall magnetic field which is measured by a hall sensor. The magnetomechanical sensor has been optimized with respect to maximum sensitivity.

5.5 Cooperations

Current cooperations with the research group of Prof. G. Wittum (ICA III) in Stuttgart and the SFB 393 (speaker Prof. A. Meyer) in Chemnitz will be continued and intensified.
Furthermore, there are cooperations with Siemens AG Erlangen and Munich in the following areas: ultrasound volume flow meters and sound emission from electromagnetic components such as high power transformers. In addition, an electrostatic micropump is simulated for the Fraunhofer Institut Munich.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

The project aims at a unified approach to the (parallel) solution of coupled magnetomechanical field problems, including the development of appropriate pre- and postprocessing tools, or the use of such tools partly developed in other projects, and the implementation of the software on powerful workstations as well as multiprocessor workstations, workstation clusters and parallel machines with distributed memory:

- *Preprocessing for Coupled Magnetomechanical Field Problems:*
  The preprocessing of magnetomechanical components asks for dedicated procedures, which allow the geometric modeling of complicated structures as well as the simultaneous handling of mechanical, electromagnetic and acoustic quantities. Furthermore, the recognition and automatic handling of certain interfaces, such as those between solids and fluids, should be available.
- *Mesh Generation and Refinement:*
  Improvement of the quality and efficiency of the 3D mesh generator NETGEN [69] including the handling of microstructures and the parallelization; Implementation of mesh refinement techniques; Handling of changing (rotating) geometries; Adapting the 3D mesh generator NAOMI [17, 46] developed in Project 6 for fluid-mechanical problems to the special needs in magnetomechanical field computation.
- *Algebraic Multigrid Solvers for PDE systems.*
  Extension of AMG methods to systems arizing from magnetomechanical field problems; Use of the AMG as solver for fine grid system, or as solver for a (sufficiently fine) coarse grid system in a geometrical multigrid method, resulting in a hybrid multigrid method; Parallelization of AMG.
- *(Parallel) Solvers for Instationary Coupled 3D Magnetomechanical Field Problems:*
  Development, analysis, and (C++) implementation of advanced parallel (local and global) multilevel solver for stationary and instationary coupled 3D magnetomechanical field problems; Error estimators; Adaptivity.
- *Postprocessing:*
  The postprocessing must allow the simultaneous handling and visualization of mechanical, electromagnetic and acoustic quantities. Therewith, it has to be considered that practical models exhibit meshes with more than 100.000 3D-elements.
- *Experimental Work:*
  For all simulations of magnetomechanical systems the input of relevant material parameters like the permeability tensor is necessary. Therefore, these quantities have to be determined experimentally.
- *Application and Evaluation:*
  The field of practical applications are:
  - acoustic power sources for medical applications (extracorporal lithotripsy)
  - sound emmision from electromagnetic equipment such as transformers, dc and ac motors
  - electromechanical microsystems (MEMS)
  - electromagnetic forming systems
  - electromagnetic distance sensors
  - electromagnetic loudspeakers

5.6.2 Methods

In the following, we outline our methodology for this project. The explanations follow the structure we used in the previous subsection.

- *Preprocessing for Coupled Magnetomechanical Field Problems:*
  The preprocessing of coupled field problems has to consider all mechanical and electromagnetical quantities. Therefore, dedicated input procedures have to be implemented which allow the input of

all these quantities as well as the corresponding material features. For geometric modeling special Euler-operators have to be implemented.

- *Mesh Generation:*
  The 3D tedrahedrial mesh generator NETGEN is based on the advancing front method. In the 2D version, we use a kind of harmonic extension of the boundary mesh in order to obtain meshes of high quality. One needs similar techniques in 3D. The parallelization will be based on domain decomposition obtained from *Project 12.* The 3D mesh generator NAOMI produces meshes locally fitted to the boundary and to interfaces. Microscales, arizing from the geometry and from the data of the PDE, will be resolved by a special density function. This mesh generator is of optimal complexity and can follow changing geometries by remeshing.

- *Algebraic Multigrid Solvers for PDE systems.*
  The AMG approach is based on matrix graph coarsening. The quality of AMG will be defined by the prolongation (restriction) and / or the smoother. Our main instrument for improving the AMG is the smoother, at least, for spd, or moderate non-symmetric problems. In the convection-diffusion case matrix-dependent prolongation (restriction) should be considered.

- *(Parallel) Solvers for Instationary Coupled 3D Magnetomechanical Field Problems:*
  Within a nested iteration scheme implicit time integration together with adaptive multilevel finite element solvers should result in an efficient solution technique.

- *Postprocessing:*
  For establishing an appropriate postprocessing, the implementation of dedicated procedures to evaluate certain interesting quantities such as the magnetic induction $\vec{B}$ from computed nodal vector potential $\vec{A}$ by $\mathbf{rot}\,\vec{A}$ is necessary. Furthermore, the handling of models with more than 100.000 3D-elements asks for the implementation highly efficient hidden line algorithms as well as procedures for the fast determination of isolines.

- *Experimental Work:*
  The experimental work is twofold:

  - The material parameters of the magnetic materials have to be measured in order to guarantee precise input data for the simulation. Therefore, the establishing of a dedicated measurement setup using a double yoke with one potential coil and one J-compensated coil is necessary.

  - Appropriate experiments have to be performed for the verification of the implemented computer modeling scheme. Therefore, a laser interferometer will be designed and built in order to precisely measure the deformations of transducers which are in the range of picometer to nanometer.

- *Application and Evaluation:*
  The implemented software will be tested for real life applications such as the precise simulation of the noise emission resulting from magnetic resonance equipment used in clinical environments. Furthermore, we have planned the simulation of electrodynamic loudspeakers in order to proceed the Computer Aided Design (CAD) of these devices. The CAD of these devices is not yet feasible due to a lack of appropriate numerical simulation tools. The simulation program will be also tested for an electromagnetic forming system as used in steel industry. The simulation of micromachined servo-acceleration sensors will also be performed. This fact is very important for the commercialization of these devices, since their design is still partly based on empirical trial and error.

5.6.3 Programme and Schedule

In the following, we divide the project into 9 overlapping phases, which are worked out by members of the basic staff (A) - (D), one interacting position between this project and Project 12 (J), one funded post doc (E), two funded Ph.D. students (F) - (G), and additional two diploma students (H) and (F) supported by the FWF via "kleiner Forschungsbeihilfe".

(1) Preprocessing for Coupled Magnetomechanical Field Problems.

(2) Mesh Generation.

(3) Algebraic Multigrid Solvers for PDE systems.

(4) Parallel Solvers Instationary Coupled Magnetomechanical Field Problems.

(5) Postprocessing.

(6) Experimental Work.

(7) Application and Evaluation.

(8) Supervision of (2), (3), (4).

(9) Supervision of (1), (5), (6), (7).

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12
(1)	D, G, H, J						
(2)	E, I						
(3)	E, I						
(4)	C, D, E, I						
(5)	D, G, H						
(6)	D, F						
(7)	D, F						
(8)	A						
(9)	B						

The symbols A, B, C, D, E, F, G, H, I and J are assigned to the following persons working on the corresponding problems:

A = O.Univ.-Prof. Dipl.-Ing. Dr. U. Langer (proposer of the project),

B = O.Univ.-Prof. Dipl.-Ing. Dr. R. Lerch (co-proposer of the project),

C = Dipl.-Ing.Dr. G. Haase (co-worker from the basic staff),

D = Dipl.-Ing.Dr. M. Kaltenbacher (co-worker from the basic staff),

E = **Dipl.-Ing. J. Schöberl** (applied full time post doc position),

F = **Dipl.-Ing M. Hirnschrodt** (applied doctoral position for a Ph.D. student paid as a 2/3-job).

G = **N.N.** (applied doctoral position for a Ph.D. student paid as a 2/3-job),

H = **N.N.** (applied support for a student via "Kleine Forschungsbeihilfe"),

I = **N.N.** (applied support for a student via "Kleine Forschungsbeihilfe"),

J = Dipl.-Ing. M. Kuhn (co-worker, full time post doc position applied in Project 12),

5.7 Integration with the SFB

This project is closely connected with *Project 8* and *Project 10* concerning the magnetic field computation and the structural mechanical part, respectively. In this project as well as in *Project 6*, (Parallel) Algebraic Multi-Grid (AMG) methods will be developed and applied to different field problems, including the field problems arizing in *Project 7, 8, 9, and 10.*

Especially in the 3D case, both, preprocessing and postprocessing of the data are indispensable. The need for both becomes even more evident for parallel computations. Here, the data have to be prepared for computations, e. g. for algorithms based on Domain Decomposition methods. This topic will be studied extensively in *Project 12.* One of the positions applied there is going to work on both subjects. In particular this involves the DD Preprocessing. The visualization of vector fields, especially of results produced by a parallel finite element code on a distributed memory machine, is the main topic in *Project 13.*

Another important part of the finite element code is the mesh generator, especially, for complicated 3D geometries, as well as remeshing and mesh refinement algorithms. The description and the precise handling of the geometry requires advanced symbolic techniques and visualization tools provided by *Projects 2-3* and *Project 13*, respectively.

5.8 Detailed Budget

5.8.1 Requested Personnel

As mentioned in Section 5.6.3, one full-time post doc position, two doctoral positions for Ph.D. students, which are paid as 2/3 job, and two "kleine Forschungsbeihilfen" for supporting the participation of diploma students in this project are required.

5.8.2 Computers and Experimental Equipment

We request funding for the following equipment:

- 1 powerful graphic workstation including special graphic software, which amounts to **ATS 300.000,–** in the second year.
  This workstation provides the working places for the post doc, and, at the same time, it is used for running time consuming codes and for graphical applications.

- 2 workstations, which amounts to a total of **ATS 140.000,–** in the first year.
  The workstations provide the working places for the two Ph.D. students applied for in this project. One of them is concerned with the development of the user surface and internal interfaces. The other one works on applications.

- 1 measurement equipment, which amounts to **ATS 409.117,–** in the first year.
  To provide the numerical simulation program with the necessary material characteristics (magnetization curve, hysterese loop) the following measurement equipment will be required:

component	description	price	
J-compensated coil	coil measuring the magnetic induction	S	32.760,00
potential-coil	coil measuring the magnetic field	S	31.500,00
fluxmeter 1	integrates the coil voltage to obtain the magnetic induction	S	100.464,00
fluxmeter 2	integrates the coil voltage to obtain the magnetic field	S	100.464,00
total:		S	265.188,00

  For the practical verification of the numerical calculation results of magnetic fields, measurement devices (listed below) will ne necessary.

component	description	price	
Gaussmeter model 9903	3-channel equipment for measuring the magnetic field	S	111.720,00
calibration magnet	permanent magnet for calibrating the Gaussmeter	S	8.353,00
Sensor 1	transversal sensor flexible	S	8.232,00
Sensor 2	axial sensor flexible	S	15.624,00
total:		S	143.929,00

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 5
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.268.000	549.117	10.000	25.000				1.852.117
2	1.268.000	300.000	10.000	25.000				1.603.000
3	1.268.000		10.000	25.000				1.303.000
Summe	3.804.000	849.117	30.000	75.000				4.758.117

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 5

Grundausstattung

Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Langer Ulrich, Dr., O.Univ.-Prof.	Numerische Mathematik	Mathematik	10%		1. Jahr	Univ.-Prof.	voll
Lerch Reinhard, Dr., O.Univ.-Prof	Elektrotechnik	Meßtechnik	20%		1. Jahr	Univ.-Prof.	voll
Haase Gundolf, Dipl.-Ing. Dr.	Numerische Mathematik	Mathematik	10%		1. Jahr	Univ.-Ass.	voll
Kaltenbacher Manfred, Dipl.-Ing. Dr.	Elektrotechnik	Meßtechnik	10%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 5

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Schöberl Joachim, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Hirnschrodt Michael, Dipl.-Ing.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Schöberl Joachim, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Hirnschrodt Michael, Dipl.-Ing.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Schöberl Joachim, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	Hirnschrodt Michael, Dipl.-Ing.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Elektrotechnik	Meßtechnik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 5

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Measurement Equipment	409.117		SFB	SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		SFB
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		SFB
Summe	409.117			Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Indigo2, R10000, 256 MB, 2 GB	300.000		SFB				
Summe	300.000			Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 5

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 6: Navier-Stokes Solver

5.1 General Information

Title : Navier-Stokes Solver

Field of research : Computational Fluid Dynamics

Principal investigators : Univ.-Doz. Dr. Walter Zulehner
Institute for Mathematics
Johannes Kepler University Linz

Co-investigator : Univ.-Prof. Dr. Ulrich Langer
Institute for Mathematics
Johannes Kepler University Linz

5.2 Abstract

Computational fluid dynamics is an important tool for engineers for designing products or analyzing and improving processes. Real life applications in engine development are the motivating background of this proposal. There is a companion project in cooperation with industry (AVL List GmbH), applied for support with the FFF (Forschungsförderungsfonds für die gewerbliche Wirtschaft), which concentrates on the development of software for grid generation, discretization and numerical solution of industrial flow problems for complex time dependent two-dimensional geometries.

Another important aspect of industrial flow is turbulence, whose numerical treatment is one of the topics of this proposal.

Turbulence is frequently modeled by so-called statistical turbulence models, which are based on the Reynolds-averaged Navier-Stokes equations. Several approaches of different complexity and different range of applicability have been suggested in literature.

All these statistical models have in common that a special treatment of near wall regions are necessary. Therefore special techniques in the grid generation are required for allowing to shift the boundaries in order to describe these near wall regions with the capability of a posteriori adaptation.

The discretization of the governing system will be basically done by a finite element technique whose stability for low Reynolds number flow is well established.

For high Reynolds number flow special stabilization techniques are to be included. One approach relies on stable finite volume schemes for the convective terms as they are well known for general conservation laws. The project will focus on possible combinations of mixed finite element and finite volume methods, or more generally speaking, of flux oriented discretizations which both work on the same grid.

Adaptive grid refinement strategies based on an a posteriori error estimator have to be included in order to improve the efficiency. Classical estimators are based on the residuals of the discretized equations and lead to norm estimates of the error. In connection with a turbulence model this could lead to a refinement strategy which prefers the near wall regions. For some interesting quantity which does not heavily depend on the behavior of the flow near a wall this might lead to an inefficient refinement strategy. A more promising technique for a class of problems including the laminar Navier-Stokes equations has been developed on the basis of a dual problem. This technique should be extended to turbulence models.

Efficient solution strategies for the resulting large scale system of discretized equations should be based on a multi-level approach. Solution techniques based on a partial decoupling of momentum and continuity equations has been used for quite a while. New theoretical investigations make clear how to construct such a method which is also suitable for a smoother in a multi-grid method. In the symmetric case (the Stokes problem) the success of the method rely on the property that the method is not expansive. In recent papers it was shown how this could be carried over to the general non-symmetric case which includes the Navier-Stokes equations provided one can keep the non-expansivity of the smoother.

Since in real life applications the coarse grid is already rather fine, an algebraic multigrid method is to be constructed to deal with the discretized equations as a black box method at this grid level.

5.3 State of the Art

Models

The standard governing equations for flow problems are the Navier-Stokes equations. Industrial flow is often turbulent, which, in principle, is believed to be incorporated in the standard Navier-Stokes equations. However, extremely fine grids are needed to resolve the occurring small eddies. This approach, the so-called direct numerical simulation (DNS), leads to prohibitively high cpu times and memory capacity for complex geometry.

A more practical alternative in this case are statistical turbulence models, which are based on the Reynolds-averaged Navier-Stokes equations. Several approaches of different complexity and different range of applicability have been suggested in literature, among which we concentrate on the widely used eddy viscosity models. In these models turbulent effects are taken care of by adding an extra term, the so-called eddy viscosity μ_t, to the laminar viscosity in the momentum equations. One of the most well-known models of this kind is the standard k-ε turbulence model, proposed by Launder and Spalding [20], where the eddy viscosity μ_t is expressed in terms of two further flow variables, the turbulent kinetic energy k and its dissipation rate ε, which satisfy two convection-diffusion type nonlinear partial differential equations.

Far off the walls and for high Reynolds-numbers this model is rather well-established. However, especially near the walls, modifications are necessary, see e.g. the survey by Patel et. al. [23].

A first approach is the use of wall functions, which explicitly describe the near wall behavior of the flow variables in dependence of the distance to the wall. The equations and/or the boundary and/or the boundary conditions are modified according to this near wall behavior, often with a priori information on the location of turbulent boundary layers, see e.g. Mohammadi, Pirroneau [21], page 15.

Another approach works with modified coefficients (depending on the distance to the wall and a turbulent Reynolds-number) in the k-ε model instead of the occurring empirical constants. These models do not need a priori information. One prominent model of this kind has been chosen for a recent benchmark initiative on numerical methods for incompressible turbulent flow, see Schäfer et.al. [27].

Analogous to the formulation in the description of this benchmark it is not the intention to evaluate the quality of a certain turbulence model. This research project is meant to be a contribution to the numerical solution of typical turbulence models. This should help to distinguish between the physical relevance and the numerical consequences of some proposed turbulence models.

In certain situations physical insight might help to overcome some of the known deficiencies of turbulence models by taking appropriate measures, in particular near the wall, which often do not allow the formulation of a consistent continuous model. The formulation of an continuous model, however, is an essential necessity, if one wants to automatize the solution process by adaptive grid generation and error control.

So the intention with respect to models is to fix typical turbulence models including models based on wall functions with a critical analysis of a possible continuous limit of these models.

Discretisation techniques

The two mostly used discretization techniques in this area of computational fluid dynamics are the finite element method and the finite volume method.

The stability of finite element methods for low Reynolds number flow is well understood, see Girault and Raviart [8].

For high Reynolds number flow special stabilization techniques are to be included. There are mainly two stabilization techniques in use.

One approach is SUPG (streamline upwind Petrov-Galerkin), a least-squares type stabilization technique, see e.g. Johnson [15], [31].

The second approach relies on stable finite volume schemes for the convective term as they are well known for conservation laws, see e.g. [19]. By some lumping technique this finite volume approach can be combined with a finite element approach for the remaining terms, see, e.g. Schieweck and Tobiska [28] and Feisterauer et. al. [7]. In these and other papers two types of grids are used, a primary grid and a secondary grid derived from the primary grid, for the two different discretization techniques.

This project will focus on possible combinations of mixed finite element and finite volume methods, or more generally speaking, of flux oriented discretizations which both work on the same grid. For this it is intended to use a hybrid (or hybridized) mixed finite element approach, see Brezzi and Fortin [3], which allow a combination with a finite volume method without lumping.

Adaptivity

Adaptive grid refinement strategies are especially necessary in the presence of turbulence models in order to automatically refine the grid near the boundary which is of great importance for the accuracy of the numerical approximation. These strategies help to improve the reliability and the efficiency of discretization methods. Several a posteriori error indicators or error estimator based on the residuals of the discretized equations, have been introduced for finite element methods for elliptic problems and the Stokes problem and lead to norm estimates of the error, see e.g. Verfürth [33].

Another promising technique has been developed on the basis of a dual problem, see e.g. Erikson and Johnson [6], Johnson et. al. [14] and, quite recently, Becker and Rannacher [1].

Recently, work has also been done on error indicators for finite volume methods, e.g. Sonar [30].

It is intended to extend the techniques to the Navier-Stokes equations with turbulence modeling.

Solvers

Grid generation itself often results in a hierarchy of grid. Moreover, adaptivity introduces additional levels of grids. Therefore, solution strategies for the resulting large scale system of discretized equations should be based on a multi-level approach.

Solution techniques based on a partial decoupling of momentum and continuity equations have been used for quite a while, see e.g. Patankar [22] for one of the classical approaches. They have been used and analyzed as smoothers in multi-grid methods, see Wittum [34], [35] and, more recently, Braess and Sarazin [2].

In the last paper it was shown for the symmetric case (the Stokes problem) that the success of the method relies on the property that the method is not expansive. In recent papers, see Reusken [25], Hackbusch [10], Ecker and Zulehner [5] it was shown how this could be carried over to the general non-symmetric case which includes the Navier-Stokes equations provided one can keep the non-expansivity of the smoother.

In a real life problem the starting grid is often already rather fine. Therefore either some coarsening strategies or pure algebraic multigrid strategies have been developed in this case, see [11], [36], [13], [4], [26], [32]. The methods have been primarily studied for elliptic problems. It is intended to extend these methods to the non-symmetric case and to the Navier-Stokes equations. The non-symmetric case could be successfully handled by some sort of matrix-dependent coarsening. The difficulty with the Navier-Stokes system is the appropriate dealing with different types of variables.

Along these lines the construction of an efficient smoothers is to be done.

5.4 Previous Work

In the last years automatic mesh generators have been developed for two- and three-dimensional geometries based on the advancing front technique, see Schöberl [29], and on local grid adaptation with micro scaling, see Kickinger [18], as well as grid generators for parallel machines, see Globisch [9].

From 1992 until 1995 Doz. Zulehner supervised a software development project on the numerical solution of the three-dimensional Navier-Stokes equations (including the Boussinesq approximation for natural convection, a temperature equation and the standard k-ε turbulence model) by a finite volume method on structured grids, see e.g. Hendorfer et. al. [12] and Preuer et. al. [24]. The project was financially supported by an industrial partner.

The group of Prof. Langer has extensive experience in geometric multi-grid methods, see Jung and Langer [16], Ecker and Zulehner [5], and first experience on algebraic multi-grid, see Kickinger [17].

5.5 Cooperations

Current international cooperations with the research group of Prof. G.Wittum (ICA III) in Stuttgart and the SFB 393 (speaker Prof. A. Meyer) in Chemnitz will be continued and intensified.

Within the framework of the partnership between the Charles University Prague and the University of Linz there has been a cooperation with the group of Prof. M. Feistauer for several years.

Since 1986 there has been a cooperation with AVL List GmbH (fluid dynamics department) on the basis of several smaller projects. Currently, a 2 years project on the numerical solution of the Navier-Stokes equations on time-dependent domains is applied for with the FFF (Forschungsförderungsfonds der gewerblichen Wirtschaft).

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

1. Reviewing and analyzing turbulence models. In particular, the consequences of the use of wall functions should be analyzed. The possibilities of the formulation of continuous models should be studied.
2. Development of a combined finite volume - finite element scheme for the Navier-Stokes equations extended by an eddy viscosity turbulence model.
3. Analysis of the numerical scheme for model problems
4. Development of an adaptive mesh generation technique on the basis of error estimators (residual based or with the help of a dual problem) for the Navier-Stokes equations including a turbulence model.
5. Construction and analysis of a geometric multi-grid method for the discretized equations with non-expansive smoothers.
6. Construction of an algebraic multigrid method for non-symmetric convection-diffusion equations
7. Construction of an algebraic multigrid method for the Stokes equations
8. Construction of an algebraic multigrid method for the Navier-Stokes equations
9. Integration of the geometric and algebraic multigrid method

5.6.2 Methods

ad 1. Survey articles will allow to extract the typical structure of widely used eddy viscosity turbulence models among which the model from the turbulent incompressible flow benchmark initiative, see [27] should be in any case. This opens the possibility of a comparison with other groups of numerical analysts. A carefully done limiting process (vanishing mesh size) for proposed discrete models with wall functions should reveal the possibility of the formulation of a consistent continuous model.

ad 2. Several known techniques how to combine the two discretization processes build the guideline of the intended new approach involving only one grid.

ad 3. Since a rigorous analysis of the method for the full models is very unlike to be successful, we will restrict the analysis to typical model problems such as a convection-diffusion problem and, for some part of the analysis, to the laminar Navier-Stokes equations. Finite volume methods will be interpreted as hybrid (or hybridized) mixed finite element methods, which will allow the application of the well-developed machinery of finite element analysis.

ad 4. Because of the complexity of the overall models one will be restricted to an at least partially heuristic approach for the construction of efficient error estimators along the lines of known estimators for some parts of the model equations.

ad 5. The principal construction of efficient smoothers is guided by the analysis in [2]. Complications are expected in carrying over the basic ideas to the general non-symmetric case although there is some hope, see [5].

ad 6. One approach is the separate treatment of the convection and the diffusion part taking into account the different behavior of these parts. Another strategy would be a type of matrix dependent coarsening technique.

ad 7. The starting point of the investigations could be a pressure correction strategy (Uzawa-like methods), where the known algebraic multigrid methods for elliptic problems could be used.

ad 8. It is intended to combine the techniques developed in the two previous steps (for convection-diffusion equations and the Stokes equations).

ad 9. If the geometric and the algebraic multigrid methods are available, the integration of the methods (algebraic multigrid at the coarse grid level, geometric multigrid for the refined grids) is straight forward.

5.6.3 Programme and Schedule

(1) Reviewing and analyzing turbulence models

(2) Construction of the mesh generator

(3) Construction and analysis of the discretization technique

(4) Construction of the error indicator/estimator

(5) Construction and analysis of a geometric multi-grid method and an efficient smoother

(6) Construction of an algebraic multigrid method for convection-diffusion equations

(7) Construction of an algebraic multigrid method for the Stokes equations

(8) Construction of an algebraic multigrid method for the Navier-Stokes equations

(9) Combining the algebraic and the geometric multigrid methods

(10) Supervision

The chronological order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12
(1)	C	■	■				
(2)	C	■	■				
(3)	D	■	■	■			
(4)	D, C			■	■		
(5)	D				■	■	■
(6)	E, C	■	■	■			
(7)	E, C		■	■	■		
(8)	E, C					■	■
(9)	C					■	■
(10)	A, B	■	■	■	■	■	■

The symbols A, B, C, D, and E are assigned to the following persons working on the corresponding problems:

A = Univ.-Doz.Dr. W. Zulehner (proposer of the project),

B = O.Univ.-Prof.Dr. U. Langer (proposer of the project),

C = Dipl.-Ing. F. Kickinger (applied full time post doc position),

D = N.N. (applied doctorial position for a Ph.D. student paid as a 2/3-job),

E = N.N. (applied doctorial position for a Ph.D. student paid as a 2/3-job),

5.7 Integration with the SFB

There is a natural link to Project 5, where coupled magneto-mechanical systems are considered which have some similarity to the Navier-Stokes system. This applies for the discretization methods as well as for the solvers, in particular, the black box algebraic multigrid method.

Visualization of the calculated vector and scalar fields is of great importance, in particular in 3D. So there is a strong link to Project 13, where efficient visualization tools are to be developed.

In the longterm perspective there will also be a link to Project 7, since very often the original motivation for studying direct industrial flow problems is an (inverse) design problem.

The development of software on a common platform keeps the door open for a parallelization of the code in an advanced stage of the SFB which will create links to Projects 5 and 8, where already parallelization techniques are in use and to Project 12 for the preprocessing part of domain decomposition parallelization concepts.

5.8 Detailed Budget

5.8.1 Requested Personnel

As mentioned in Section 5.6.3, one full-time post doc positions and two doctoral positions for Ph.D. students, which are paid as 2/3 job, are required for this project.

5.8.2 Computer Equipment

We request funding for the following equipment:

- 1 powerful graphic workstation including special graphic software, which amounts to **ATS 300.000,–** in the first year.
  This workstation provides the working places for the post doc, and, at the same time, it is used for running time consuming codes and for graphical applications.

- 2 workstations, which amounts to a total of **ATS 140.000,–** in the first year.
  The workstations provide the working places for the two Ph.D. students applied for in this project.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 6
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	440.000	10.000	25.000				1.623.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	440.000	30.000	75.000				3.989.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 6

Grundausstattung

Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Zulehner Walter, Dr. Univ.-Doz.	Numerische Mathematik	Mathematik	25%		1. Jahr	Univ.-Ass.	voll
Langer Ulrich, Dr., O.Univ.-Prof.	Numerische Mathematik	Mathematik	5%		1. Jahr	Univ.-Prof.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 6

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	<u>Kickinger Ferdinand, Dipl.-Ing.</u>	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	<u>N.N.</u>	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	<u>N.N.</u>	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Kickinger Ferdinand, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Kickinger Ferdinand, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Numerische Mathematik	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 6

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Indigo2, R10000, 256 MB, 2 GB	300.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	300.000			Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 6

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 7: Large Scale Inverse Problems

5.1 General Information

Title : Large Scale Inverse Problems

Field of research : Applied Mathematics

Principal investigator : Univ.-Prof. Dipl.-Ing. Dr. Heinz W. Engl
Institut für Industriemathematik
Johannes Kepler Universität Linz

5.2 Abstract

Inverse Problems are concernend with determining causes for a desired or an observed effect. Their importance in many application fields is growing. The mathematical formulation of inverse problems usually leads to ill-posed problems whose solution does not depend continuously on the data. This instability has to be treated by so-called regularization methods. The proposer and his group have contributed over the last years to the convergence theory of regularization methods for solving linear and especially nonlinear ill-posed problems. These rigorous theoretical results have been applied so far only to "toy problems". On the other hand, large scale inverse problems have been solved in many applications in science and industry, also in the proposer's group. In solving large-scale inverse problems, e.g., by iterative regularization methods, the cost of solving the direct problem and computing its gradient cannot be neglected. Therefore, it is the major aim of this project to develop theory-based methods for the optimal coupling between regularization methods and direct solvers for (mainly nonlinear) inverse problems where the corresponding direct problem involves partial differential equations. Related questions appear in shape optimization and will also be studied in this project.

5.3 Background

Inverse Problems are concerned with *determining causes for a desired or an oberserved effect*. From the applications point of view, two different motivations for studying inverse problems arise: First, one wants to *know* past states or parameters of a physical system. Second, one wants to find out how to *influence* a system via its present state or via parameters in order to *steer* it to a desired state in the future.

Strictly speaking, an inverse problem exists only in connection with the corresponding *direct problem*; it is mostly for historic reasons which of these two problems (usually the simpler one or the one which has been studied earlier) is called the direct problem and which one is called the inverse problem. However, if there is a real-world problem behind the mathematical problems studied, there is, in most cases, a quite natural distinction between the direct and the inverse problem: If one wants, e.g., to predict the future behaviour of a physical system from knowledge of its present state and the physical laws (including concrete values of all relevant physical parameters), one will call this the direct problem, while possible inverse problems are the determination of the present state of the system from future observations or the identification of physical parameters from oberservations of the evolution of the system (*parameter identification*).

If we symbolize the solution process of the direct problem by an operator F (the *forward operator*), then solving an inverse problem amounts to solving the operator equation

$$F(x) = y; \tag{8}$$

here, y denotes the data of the inverse problem, x its solution(s).

Before continuing with our abstract discussion, we want to give a few examples which will be relevant for our project:

Inverse Heat Conduction Problems: Here, x might be the initial temperature distribution in a domain, y the temperature distribution at some later time. Evaluating the forward operator F then amounts to solving a (linear or nonlinear) heat conduction equation with suitable boundary conditions and initial temperature x. Note that this operator is highly smoothing. Equation (8), considered as an equation for the unknown initial temperature x, is called the *backwards heat equation* and is a classical example for an *ill-posed problem* (see below). While the backwards heat equation is not of much practical relevance, there are a lot of other inverse problems connected with heat conduction equations that arise in many practical applications (see e.g. [5, 38, 63]).

Inverse Scattering Problems: In these types of problems, information about an unknown object (e.g., a scattering body, an inhomogeneity in a material, a potential) is to be recovered from measurements of wave fields scattered by this object. Let, e.g., x be a parametrization of the boundary of a body in $\mathbb{R}^2$ or $\mathbb{R}^3$ by which acoustic waves are scattered. If the incoming wave is time-harmonic, then the spatial part solves the Helmholtz equation in the exterior domain. The *direct scattering problem* then amounts to solving this equation and computing the *far-field pattern*, i.e., the direction-dependent component of the leading term in an expansion of the scattered field far away from the obstacle; the boundary conditions on the surface parameterized by x depends on the physical properties of the scattering object. An inverse scattering problem is then the determination of x, i.e., the location and shape of the scattering object, from measurements of the far-field pattern y. Again, the forward operator F (the *far-field operator*) is highly smoothing, the inverse scattering problem is ill-posed. A recent reference about inverse scattering problems is [12]; see also [68].

Parameter Identification Problems: It is a standard situation in science and engineering that a process to be described can be modelled by a (system of) partial differential equation(s), which contain(s) several parameters (constants, functions of space and/or time or even functions of the unknown solution). Some of these parameters might be accessible by direct measurements, while for others, this might not be the case. One then resorts to *parameter identification* from *distributed* or *boundary measurements* of the solution or of quantities derived from the solution. E.g., one might want to determine the (location-dependent) heat conductivity of a medium by heating the medium in a prescribed way and measuring the temperature development at locations distributed over the body or at sensors placed along the boundary of the body. In order to enforce uniqueness, one might have to use several such experiments, e.g., by using heat sources at different locations. Also, if available, one will use qualitative information about the unknown parameter, e.g., the fact that it might be piecewise constant (this situation appears frequently in practice, e.g., in nondestructive testing, cf., e.g., [30]). The operator F in (8) is the *parameter-to-solution-map*, i.e., it maps the parameter(s) x to the solution y of the partial differential equation. Solving (8) then amounts to determining the unknown parameter(s) from measurements of the solution of the partial differential equation in parts of the domain or of the boundary. Recent monographs on parameter identification in partial differential equations are [3] and [55].

Parameter identification appears also in connection with *homogenization* or *upscaling*, where one wants to determine an effective parameter, which is either smooth or defined on a coarse grid and produces a solution of a partial differential equation which is close to the solution of the same equation with a rapidly varying parameter which is measured on a much finer grid. Such problems appear e.g. in reservoir simulation, cf. [67]. Reservoir simulation and other geophysical applications are a major source for large-scale inverse problems (cf., e.g., [29]).

In this description, we concentrated on inverse problems where the corresponding direct problem involves solving a partial differential equation, since these will be problem classes which we will be concerned with within this project. Most of the problems described are nonlinear; note that even if the governing partial differential equation (e.g., in inverse scattering or in parameter identification) is linear the corresponding inverse problem is typically nonlinear. However, there are many more inverse problems of practical and mathematical interest, also linear ones; for a survey see e.g. [1, 4, 11, 19, 23, 45, 51, 54, 56, 60, 62, 76, 77].

As already mentioned, inverse problems are frequently *ill-posed*, i.e., their solution might not exist, might not be unique, and/or might not depend continuously on the data. Thus, if we replace (8) by

$$F(x) = y^\delta, \tag{9}$$

where y^δ denotes perturbed data with some given bound δ on the noise level

$$\|y - y^\delta\| \le \delta, \tag{10}$$

then solutions of (9), if they exist, need not at all be close to solutions of (8).

The class of methods one uses for dealing with the ill-posedness of inverse problems are *regularization methods*. There, one approximates the original ill-posed equation (8) by a parameter-dependent family of well-posed neighbouring problems, whose solutions are called *regularized solutions*; they depend on the *regularization parameter*, whose determination (in dependence of the noise level δ and other quantities) is one of the crucial problems in dealing with regularization methods. An (at least for the linear case) classical regularization method is *Tikhonov regularization*, where (8) is replaced by the regularized problem

$$\|F(x) - y^\delta\|^2 + \alpha\|x - x^*\|^2 \to \min\,, \tag{11}$$

where $\alpha > 0$ is the regularization parameter and x^* is an a-priori guess for the unknown solution of the inverse problem. For the theory of Tikhonov regularization for linear problems see [44]; the ground work for its theory for the nonlinear case has been laid in [25, 66, 74], where stability and convergence (for appropriate choices of the regularization parameter α) are proven and convergence rates are derived (also with respect to finite-dimensional approximations of the forward operator F and of the unknown x). The problem of convergence rates is particularly difficult: for ill-posed problems (even linear ones), convergence for any regularization method can be arbitarly slow (cf. [73]); convergence rates can only be shown under a-priori conditions of the type

$$x_0 - x^* \in R(F'(x_0)^*), \tag{12}$$

where F' denotes the Fréchet derivative, and x_0 the exact (unknown) solution. Since, as mentioned above, F is frequently a smoothing operator, *source conditions* like (12) can usually be interpreted as smoothness conditions on the difference between the a-priori guess and the exact solution, related to the smoothing properties of the (derivative of the) forward operator. For Tikhonov regularization, if α is chosen proportional to the noise level δ, one can show that regularized solutions converge to the exact solution with the rate $O(\sqrt{\delta})$ if (12) holds. However, the information if a source condition actually holds or not is usually not available, so that one needs parameter choice strategies that yield optimal convergence rates without explicitely needing information of the type (12). For a large class of regularization methods for linear problems, such *order optimal parameter choice strategies* have been developed in [20], for Tikhonov regularization for nonlinear ill-posed problems in [72].

While for linear problems, Tikhonov regularization is a reasonable method also for practical problems, it is much more difficult to apply to nonlinear problems, since in general, the functional in (11) is not convex, so that its minimization is difficult. Therefore, iterative methods seem to be an attractive alternative; there, the index where the iteration is stopped plays the role of the regularization parameter. If that index is not chosen carefully, i.e., if one iterates too far, then the noise propagation takes over and destroys all information contained in the regularized solution. Thus, the analogue of parameter choice rules for Tikhonov regularization is the appropriate design of *stopping rules*. For linear inverse problems, the theory of iterative methods is well developed, since recently also for nonlinear iteration methods for solving linear ill-posed problems like the conjugate gradient method ([46]). For nonlinear ill-posed problems, the development of a rigorous theory (e.g., concerning convergence, convergence rates at stopping rules) of iterative regularization methods has just begun. Methods studied include the *nonlinear Landweber iteration* ([49])

$$x_{k+1}^\delta = x_k^\delta + F'(x_k^\delta)^*(y^\delta - F(x_k^\delta)), \tag{13}$$

and Newton-type methods like *Levenberg-Marquardt method* [47]

$$x_{k+1}^\delta = x_k^\delta + [F'(x_k^\delta)^* F'(x_k^\delta) + \alpha_k I]^{-1} F'(x_k^\delta)^* (y^\delta - F(x_k^\delta)) \tag{14}$$

and the closely related *regularized Gauß-Newton method* [2, 10]

$$x_{k+1}^\delta = x_k^\delta + [F'(x_k^\delta)^* F'(x_k^\delta) + \alpha_k I]^{-1} [F'(x_k^\delta)^* (y^\delta - F(x_k^\delta) + \alpha_k (x^* - x_k^\delta)]. \tag{15}$$

The rigorous theory of regularization methods for nonlinear inverse problems has so far been only applied (in the sense that all assumptions could in fact be verified) to "toy problems" like parameter identification for simple elliptic problems in one or two space dimensions. On the other hand, both Tikhonov regularization and iterative regularization methods have successfully been applied to many real-world inverse problems, but without convergence proofs, e.g., the nonlinear Landweber iteration has proved to be quite successful for inverse scattering problems (see [48]), the same is true for Newton-type methods (see e.g. [69] and [52]). It is the need to close this gap between toy problems where rigorous theory can be applied and real-world large-scale problems where the methods work in practice that motivates this project. This is in the spirit of the subtitle "proving – solving" of the whole SFB.

While most of the work in this project will focus on inverse problems, we also want to investigate related questions in shape optimization, where one wants to determine the shape of an object (within constraints) in such a way that a given criterion, e.g., the volume (and hence the weight) is minimized. Usually, the governing equations come from continuum mechanics, e.g., from elasticity, the constraints involve both the geometry and quantities that appear as solutions of these equations, e.g., stresses. For a survey about shape optimization see e.g. [50]. At least on the surface, there are some similarities between inverse and shape optimization problems, which is also why they were treated at the same conference by SIAM ([32]): one wants to determine a cause (the optimal shape) for a desired effect (minimal weight) under various constraints. However, there are essential differences: while in inverse problems, uniqueness is usually desired, this is generally not the case in shape optimization. Also, convergence of approximate solutions is usually not of importance, but only convergence of the resulting values of the objective functionals. Nevertheless, the similarities between inverse problems and shape optimization problems when designing efficient algorithms seem to justify to include shape optimization problems to some extent into this project.

5.4 Previous Work

Prof. Engl and his group have worked on inverse problems for more than ten years. A recent outcome of this work is the monograph [23].

Until about 1988, the group of Prof. Engl has worked on linear ill-posed problems, starting with [16] and extending to the development of an order optimal parameter choice strategy ([20]) as mentioned above. Also, regularization by projection has been studied (cf., e.g., [17, 18, 33, 34]). The first step into nonlinear problems was the thesis by Andreas Neubauer (under the direction of Prof. Engl) on Tikhonov regularization of ill-posed linear operator equations with convex constraints, which led to the publications [64, 65]. A major application of linear ill-posed problems in physical chemistry in connection with time-resolved fluorescence is reported about in [59].

¿From about 1988 on, basic research in inverse problems in Prof. Engl's group centered around nonlinear inverse problems. The work on Tikhonov regularization mentioned in the last section ([25, 72]) was applied to various nonlinear inverse problems (e.g., [9, 37, 39, 40, 70, 71]). Using the tools developed for treating Tikhonov regularization of nonlinear ill-posed problems, the widely-used maximum entropy method was analyzed in [26, 27, 57]. As already mentioned in the previous section, current research in Prof. Engl's group centers around the theory of iterative methods for nonlinear inverse problems. In addition to the references already given, the thesis by Barbara Blaschke [7], cf. also [8], where Newton-type methods are treated, should be mentioned.

Parallel to basic research, a lot of inverse problems from industry have been treated in Prof. Engl's group (cf., e.g., [28, 35, 36, 43, 58]). These industrial problems frequently motivated theoretical investigations (cf., e.g., [6, 24, 31]).

In shape optimization, we have not contributed to the theoretical literature. However, we have developed software for shape optimization, coupling a tailored SQP-method with a black-box direct solver from NASTRAN; this software has been developed for AVL List GmbH (Graz, supported by the Austrian Forschungsförderungsfonds für die gewerbliche Wirtschaft), an engineering company cooperating with most major car producers; see [41, 53, 61, 75]. The design of this software involved problems of optimal coupling of the optimization software with the direct solver as we want to treat them in this project for inverse problems.

Hence, we think to have both theoretical and practical expertise sufficient for this project in the field of inverse problems and at least extensive practical experience in the field of shape optimization.

As already mentioned above, Prof. Engl's group has cooperated with industry, especially in the fields of inverse problems and shape optimization, in the last decade. This cooperation was partly financed via the Christian Doppler Forschungsgesellschaft. Partner companies for major projects included VOEST Alpine Stahl Linz GmbH, VOEST Alpine Industrieanlagenbau GmbH, AVL List GmbH, AMAG (Ranshofen), Zumtobel Licht GmbH (Dornbirn), HILTI AG (Liechtenstein) and Ford Motor Company. Although the work proposed in this project is basic research, it will, if successful, also strengthen our competence for further industrial cooperations.

5.5 Cooperations

As can be seen from the publications already quoted, Prof. Engl and his group have cooperated with leading researchers in the field of inverse problems like M. Z. Nashed (University of Delaware), [42], C. W. Groetsch (University of Cincinnati), [22], P. Manselli and S. Vessella (Universita di Firenze), [6] and [31], K. Kunisch (Universität Graz), [72], R. S. Anderssen (CSIRO, Canberra), [71] V. Isakov (Wichita State University), [24], W. Rundell (Texas A & M University), [39], M. Yamamoto (Tokyo University), [40], M. Klibanov (University of North Carolina), [9]. In addition to these cooperations documented in joint publications, Prof. Engl and some of his coworkers have given numerous invited talks at conferences on inverse problems all over the world. Prof. Engl has been the main organizer of two conferences on inverse problems in Austria (for the proceedings see [21, 38]); he has organized a conference on inverse problems and optimal design in industry for SIAM (in cooperation with ECMI, see [32]) and co-organizes (with D. Colton, A. Louis and W. Rundell) a conference series on inverse problems for SIAM (in cooperation with GAMM); see [29]. Together with A. Louis and W. Rundell, Prof. Engl chaired a conference on inverse problems in medical imaging and nondestructive testing in Oberwolfach in February 1996 ([30]). Prof. Engl is on the Editorial Board of *Inverse Problems*, the leading journal in the field.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives and Methods

As mentioned in Section 5.3, Tikhonov regularization consists of minimizing the functional in (11), where F is the forward operator. This minimization process needs information about F'. The conditions for convergence rates involve also the adjoint of F'.

If F describes a large-scale problem, then each evaluation of F and, more so, of F' is quite costly. On the other hand, as long as the iterative method for minimizing the functional in (11) is still far away from the minimum, it is not necessary to compute F and/or F' with high accuracy. A first aim of this project is to systematically derive criteria how to choose the accuracy in computing F and/or F' in such a way that the total effort of computing a minimizer of the functional in (11) is minimized. For toy problems, where the evaluation of F is cheap, this question is not so relevant; however, for large-scale problems, it is. We want to deal with problems where the evaluation of F involves the solution of a (linear or nonlinear) partial differential equation in two or three space dimensions. Note that if we are dealing with a parameter identification problem, the parameter-to-solution map F is nonlinear even if the partial differential equation containing the parameter x is linear. Concrete classes of methods which we want to use for evaluating F include multigrid and domain decomposition methods. For parameter identification problems as they arise in nondestructive testing, where one frequently knows a-priori that the unknown parameter is piecewise constant and one has to identify "only" the interfaces along which the values of the parameter change, domain decomposition methods seem to be quite appropriate to evaluate F and F'. However, during each iteration for minimizing the functional in (11), these interfaces change, so that also the domains in the domain decomposition method have to been changed accordingly in each iteration. When using multigrid methods, the grids will also have to change adaptively in each step of the iteration used for minimizing the functional in (11); the number of levels can be used to control the accuracy of computing F and F' as needed for the minimization. For inverse scattering problems, the method for computing F and F' will be a boundary element method.

As long as the regularization parameter $\alpha > 0$ is kept constant, we are still dealing with a well-posed problem. The major complication comes from the fact that in the end, we want to design our algorithms in such a way that as the noise level δ tends to zero, the regularized solutions tend to the exact solution of the underlying inverse problem with optimal rate of convergence in terms of δ. This will involve an order-optimal choice of the regularization parameter α like the one discussed in [72]; such a parameter choice always involves the solution of a nonlinear equation containing the norm of some type of residual of the equation (8) and of its linearization; this nonlinear equation again has to be solved iteratively in order to determine an optimal regularization parameter; in this iteration, the remarks made above concerning the necessary accuracy of computing F and F' again apply. The final aim is to choose all parameters involved (regularization parameter, discretization level of x, accuracy of computing F and F') in such a way that, for given data and noise level, an optimal regularized solution can be computed in minimal time.

As mentioned in Section 5.3, iterative methods are a promising alternative for Tikhonov regularization for solving nonlinear inverse problems. In the iterative methods described in Section 5.3, F, F' and its adjoint have to be evaluated in each step. In the Levenberg-Marquardt and the Gauß-Newton methods, Tikhonov regularization of the linearized problem appears in each step. Thus, all the questions discussed above for nonlinear Tikhonov regularization appear again like the questions how to compute F and F' in an efficient way and how to choose the accuracy in these computations depending on the *outer iteration*, i.e., the iteration for solving the inverse problem.

The Levenberg-Marquardt and the Gauß-Newton methods involve in each step, as mentioned, linear Tikhonov regularization and hence the inversion of a linear operator. This step can be replaced by an iterative method for the approximate solution of the linearized problem, which we will call the *inner iteration*. This leads e.g. to the *iteratively regularized Gauß-Newton method*. Preliminary results concerning this method have been obtained in [7], the theory of these methods is currently under investigation in our FWF-project P10866-TEC. In the proposed project, we want to use iterative methods containing an outer iteration (for the nonlinear inverse problem) and an inner iteration (for the linearized problem, which is also ill-posed) for large-scale problems. Here, we will emphasize questions like how to control the necessary accuracy for the direct solvers (using the classes of direct solvers mentioned above) and how to design stopping rules both for the outer and for the inner iteration in such a way that the total effort of computing an optimal regularized solution is minimized. In our opinion, methods of this type can be thought of as analogues to cascadic algorithms ([14]) for the ill-posed situation.

In addition to iteratively regularized Gauß-Newton methods, also other Newton-type methods will be investigated. It seems to be promising to combine our methods for analyzing iterative algorithms for solving ill-posed problems with Deuflhard's theory of Newton's method based on affine covariance (see e.g. [15], [13]).

In shape optimization, we want to deal with similar questions. The analogy to the problems described above is the following one: there is also an outer iteration loop, namely the minimization of the objective functional; depending on the method used for minimization, in each step of this outer iteration one has to solve a "direct problem", namely the field equations (e.g., from continuum mechanics) and also adjoint equations for computing gradient information about the objective functional. Again, the accuracy of solving these direct problems should be controlled by the outer iteration as mentioned above. If the field equations are nonlinear, a further iteration process for solving these nonlinear equations appears. All these processes have to be coupled in an optimal way. We have experience with this question in connection with the SQP-method as outer iteration and (linear and nonlinear) elasticity for the direct problem; however, this experience is only on the practical level and should be supplemented by some theory (again in the sense of "proving – solving") in this project. In addition to NASTRAN, which we have used as direct solver so far, we plan to use, as with our inverse problems, domain decomposition and multigrid methods for our direct solvers.

5.6.2 Programme and Schedule

We base this schedule on the personnel capacity applied for, namely one postdoc (Dr. Barbara Blaschke), two doctoral students (Dipl.-Math. Hohage and Dipl.-Math. Pfau), and two diploma students.

In the *first year*, Dr. Blaschke will concentrate on developing a theoretical framework for the coupling of parameter identification with domain decomposition and multigrid methods; Hohage will investigate the theoretical foundation of iterative methods applied to inverse scattering problems. Since the far-field-operator F is highly smoothing, the condition (12) will be much too restrictive and will hence have to be adapted in such a way that one obtains at least logarithmic convergence rates in terms of the noise level. Pfau will work on the optimal coupling of the outer and the inner iteration in shape optimization with NASTRAN as direct solver.

In the *second year*, Blaschke will concentrate on developing and implementing optimal algorithms in the sense described above for parameter identification in large-scale partial differential equations from distributed measurements using domain decomposition and multigrids as direct solvers. Hohage will develop optimal Newton-type methods for two- and three-dimensional inverse scattering problems, where boundary elements will be used as direct solvers. Pfau will develop a theoretical framework for the optimal coupling of multigrid and domain decomposition methods with SQP as outer iteration for shape optimization.

In the *third year*, Blaschke will continue her work in the direction of parameter identification from boundary measurements. Hohage and Pfau will implement and evaluate their algorithms.

In all three years, the diploma students will support the work outlined above by test implementations in order to enable the researchers to check theoretical hypotheses numerically. They will (together with the researchers) also import symbolic methods from Project Area I to our project with the aim of automatically generating Fréchet derivatives and adjoints. One of these diploma students will work with Blaschke and Hohage on inverse problems, the other with Pfau on shape optimization.

It is quite natural that this schedule can only be considered to be tentative, the direction of research and the emphasis put on different aspects might be changed dynamically depending on our successes (or failures) and on developments in the international scientific community.

5.7 Integration with the SFB

From the proposed work, it is quite clear that we have to and will closely cooperate with the group of Prof. Langer in all aspects involving the coupling of direct solvers with our methods for solving inverse problems. Thus, cooperation with Projects 5 and 8 will be quite intensive. Of course, also the link with Project 9 is quite intensive. It should be emphasized that Project 9 concentrates more on the "inverse" aspects of parameter identification, while the current project concentrates on the efficient coupling of inverse and direct solvers.

Our project will benefit from the projects in Project Area I in various ways: first, we will need methods from symbolic computation for computing derivatives and adjoints of our forward operators, which are implicitely defined by various partial differential equations. Then in all our problems, especially in shape optimization, we will meet various constraints. It will be investigated if the methods to be developed in Project 2 might help to remove or simplify some of these constraints in a preprocessing step.

As mentioned in Section 5.3, source conditions like (12) are essential for convergence rates; their verification and interpretation in concrete cases has always been a major effort. For error estimates, estimates on the norm of solutions of (12) are needed. We will investigate if the formal proof methods to be developed in Project 1 can be used to verify and interprete these source conditions and maybe also to derive these estimates. We admit that at the moment these links to Project Area I might be considered speculative.

It can be expected that Project 11 might also involve ill-posed problems, so that our general expertise in this field might provide a link to that project. Furthermore, it is obvious that we will need and use the graphical tools to be developed in Project Area III.

In summary, we are convinced that our project is well embedded into the whole SFB.

5.8 Detailed Budget

5.8.1 Requested Personnel

As outlined in Section 5.6.2, the work proposed in this project requires at least one postdoc, two doctoral students and two diploma students.

At the time this proposal is made, we plan to hire the following persons for these positions:

Dipl.-Ing. Dr. Barbara Blaschke should be employed as postdoc; she has finished her PhD under the direction of Prof. Engl in the field of iterative methods for nonlinear inverse problems and is currently employed as postdoc in the FWF-Project P10866-TEC. From May 1996 on, she will be on maternity leave. If the SFB is approved, she will return to work within the proposed project. Her position in Project P10866-TEC will then be filled by somebody else. There will be enough people available, since we continuously educate diploma students in the field of nonlinear inverse problems.

The two positions for doctoral students will be filled by Dipl. -Math. Thorsten Hohage and Dipl. - Math. Ralf Uwe Pfau. Thorsten Hohage did his diploma thesis at Universität Göttingen under the direction of Prof. Kress in the field of iterative methods for inverse scattering problems, Ralf Uwe Pfau graduated from Universität Karlsruhe in Technomathematics, working on a joint project between mathematics and electrical engineering. Both are currently employed at the Institut für Industriemathematik supported by the Christian Doppler Forschungsgesellschaft. Because of that, a doctoral student salary (S 328.000,– per year) is needed for both of them to keep their current salary. Since Dipl.-Math. Pfau is currently working on an industrial project involving shape optimization, he is well qualified for the theoretical work proposed in this project. He might have to continue with his industrial project in the framework of the Christian Doppler Laboratory, employed on a full-time postdoctoral salary because of his industrial work. If funded through this project for his theoretical research, he might have to continue his industrial project in the Christian Doppler Laboratory; in that case, his doctoral student's salary would be supplemented by the Christian Doppler Laboratory.

The two diploma students to be supported by the project would be selected at the time the project actually starts.

For the schedule of the proposed work, see section 5.6.2.

5.8.2 Equipment

We request funding for the following equipment:

- 1 powerful graphic workstation for 500.000.– in the first year (this graphic workstation will also be used by project P9). The graphic workstation is used for time consuming codes and graphical applications of projects 7 and 9
- 2 workstations totalling 140.000.– in the first year. The workstations serve as additional workplaces for the employees of this project.

costs

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications of each participant of this project can be found in Appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 7
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.268.000	640.000	10.000	25.000				1.943.000
2	1.432.000		10.000	25.000				1.467.000
3	1.596.000		10.000	25.000				1.631.000
Summe	4.296.000	640.000	30.000	75.000				5.041.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 7

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Engl Heinz, Dr. O.Univ.-Prof.	Industriemathematik	Industriemathematik	20%		1. Jahr	Univ.-Prof.	voll
Stangl Christoph, Dipl.-Ing. Dr.	Industriemathematik	Industriemathematik	20%		1. Jahr	Univ.-Ass.	voll
Landl Gerhard, Dipl.-Ing. Dr.	Industriemathematik	Industriemathematik	20%		1. Jahr	VB I/a	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 7

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Blaschke Barbara, Dipl.-Ing. Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Hohage Thorsten, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
	100%	1	Pfau Ralf Uwe, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Blaschke Barbara, Dipl.-Ing. Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
	100%	1	Hohage Thorsten, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Pfau Ralf Uwe, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Blaschke Barbara, Dipl.-Ing. Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
	100%	1	Hohage Thorsten, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
	100%	1	Pfau Ralf Uwe, Dipl.-Math.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI										
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Industriemathematik	Industriemathematik	100%		1. Jahr	FB	voll
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	500%	5								

Tabelle 17 c

Aufstellung der beantragten Geräte Projektteil 7

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Octane, R10000, 256 MB, 4 GB	500.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	500.000			Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 7

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 8: Hierarchical Methods for Simulation and Optimal Design with Applications to Magnetic Field Problems

5.1 General Information

Title : Hierarchical Methods for Simulation and Optimal Design with Applications to Magnetic Field Problems

Field of research : Finite Element Methods, Domain Decomposition Methods, Multilevel Methods, Nonlinear Constrained Mixed-Integer Optimization, Optimal Design, Magnetic Field Problems

Principal investigator : Univ.-Prof. Dr. Ulrich Langer
Institute of Mathematics
Johannes Kepler University Linz

Co-investigator : Dipl.-Ing. Dr. Ewald Lindner
Institute of Mathematics
Johannes Kepler University Linz

5.2 Abstract

The subject of this project is the development, analysis and implementation of numerically efficient algorithms for solving optimal design problems arising, e. g., in magnetostatics. The project aims at a unified treatment of direct simulation and optimization based on hierarchical methods.

The development of both numerical algorithms and the power of hardware components during the last few years enables us today to solve direct simulation problems with some 100.000 unknowns in seconds. However, most of the practical problems are inverse or are given implicitly by a functional which is to be optimized. Here, we are concerned with the latter case, for which until now no efficient numerical methodology exists.

Our approach aims at a uniform algorithm involving both, direct simulation and optimization, instead of just using some direct simulation within an optimization algorithm. The application of hierarchical methods seems to be the right approach if optimal algorithms are sought. Here, nested algorithms similar to nested Newton iterations in the nonlinear case allow only a few iterations on finer grids whereas most of the iterations are realized on coarser grids where the solution of the direct problem is cheap.

Nevertheless, the development of such unified algorithms requires the experience in the field of direct simulation. In the 2D case, the project concentrates on the adaptation of existing algorithms to hierarchical optimization methods, whereas in the 3D case, direct solvers and their components as, e.g., preconditioners, have to be developed and analyzed. Additionally, optimal design problems cause the need for handling parameter-dependent geometries. Thus, new flexible data structures describing the geometry have to be defined. Moreover, in order to construct efficient algorithms, inter-grid transfer operators have to be defined. Such operators are applied, e.g., to compute good initial guesses on updated grids from computed intermediate solutions on previous grids. Furthermore, adaptive strategies based on error estimates should be applied in order to reduce the total complexity of the discrete problems.

Parallel computers offer the opportunity to speed up the solution of direct problems which is indispensable with respect to optimization. 2D applications have shown that Domain Decomposition (DD) methods or methods based on DD data partitions are well suited for this purpose in the field of magnetostatics. That is why a DD data decomposition as discussed in Project 12 has to be seen as part of the overall solution process.

Computer aided optimal design of electromagnetic machines (e.g. electric motors) is the ultimate aim of practical applications. There is a great variety of design parameters affecting the machine. For computations these design parameters have to be defined explicitly. The same yields for the objectives. Each evaluation of the model of the electromagnetic machine results in solving a nonlinear problem on its magnetic field, i.e., numerically solving a nonlinear partial differential equation. Some kind

of postprocessing will be necessary to compute the objective function from the magnetic field. Both tasks, direct simulation and postprocessing are of high complexity in real applications. That is why a hierarchical and unified approach with respect to optimization is necessary.

The first step lying at hand will be combining an optimization code **OPTI** [5, 6] with the fast simulation code **FEPP** [66] aiming at the development of an efficient package for optimal design of parameters in models for electromagnetic machines.

However, the crucial goal of this proposal is the development of new and much faster methods based on

- the hierarchical coupling of simulation and optimization by a "Multilevel–Nested–Iteration" and
- the parallelization of the coupled method.

The development of parallel algorithms for solving nonlinear problems for magnetic fields and their implementation on massively parallel computers is currently supported by the Austrian Research Fund FWF under a grant given to the principal investigator. The results of that project may be harnessed for parallelizing the hierarchically coupled methods to be newly developed in this proposal.

5.3 State of the Art

Most of the results discussed in the literature are either related to direct simulation or optimization. A unified approach involving both parts seems to be new. Furthermore, the state of the art differs between the 2D and 3D case.

Several approaches for the direct simulation of 2D nonlinear magnetic field problems have been proposed. In particular we refer to the work of the research group of the principal investigator (see next section) and the broad literature on efficient numerical methods for nonlinear potential equations (see [16, 70, 63]). The application of such fast algorithms to optimal design problems has been considered less extensively. Instead, stand-alone-optimization which simply applies some direct simulation procedure has been discussed [5, 6].

In contrast, 3D magnetic field problems are much more challenging. Here, even the correct mathematical formulation of the problem has been discussed controversely in the past. Very recently several approaches have been discussed and analyzed [2, 10, 59, 15, 42].

The "State of the Art" in 3D magnetic field computations is reflected by the proceedings of the biennial "Conferences on the Computation of Magnetic Fields" (COMPUMAG) which are documented in the journal "IEEE Transactions on Magnetics". There, different techniques for 3D magnetostatics, in particular different gauging methods, are discussed (cf., e.g., [59]). In fact, the systems of equations are solved by simple iterative (e.g., CG) methods taking hours of computing time [59].

There are less papers on the application of fast (i.e. optimal complexity) parallel solvers to the equations of 3D magnetostatics than in 2D. 3D magnetic field problems have some special features. These features are related to the describing PDEs, to the non-linearity and to the complex geometry in real-life problems.

DD methods or methods based on DD data partitioning seem to be well suited for solving such problems. Important contributions to the development of non-overlapping DD techniques have been made by M. Dryja [17], J.H. Bramble, J.E. Pasciak, and A.M. Schatz [11], M. Dryja and O. Widlund [18], O. Axelsson and P. Vassilevski [54], A. Quarteroni [1], P. Le Tallec [56], B.F. Smith, P. Bjørstad, and W. Gropp [4] and many others. We especially emphasize the works of Russian mathematicians of the Moscow School, Y.A. Kuznetsov et al. [51], and of the Novosibirsk School, S.V. Nepomnyaschikh et al. [52, 10, 53]. The "State of the Art" is again quite well reflected by the proceedings of DD conferences, cf. [23, 33, 45, 61].

The main problems of the non-overlapping Dirichlet DD techniques are the construction of local (subdomain) Dirichlet problem preconditioners, of a suitable basis transformation and of a Schur complement preconditioner. The first problem is simple because every Dirichlet problem preconditioner can be used, e.g., multigrid preconditioners. Major contributions to the second problem (the basis transformation) are based on norm-preserving extension ideas by S.V. Nepomnyaschikh [52, 10, 53] and their combination with multigrid techniques [10]. A lot of papers are devoted to the third topic, namely to the construction of Schur complement preconditioners [17, 11, 3, 12, 71, 69, 5]. Theoretically, both the overlapping DD in FEM and the non-overlapping DD are covered by a unified approach, the theory of Multiplicative and Additive Schwarz methods [18, 55, 71]. This approach allows to analyze global multigrid methods as well as hierarchical preconditioners, and BPX-type [12] preconditioners. Although most of the ideas can be applied for three-dimensional (3D) problems as well as for two-dimensional (2D) ones, there are still many open questions, e.g., in the construction of practically applicable robust Schur complement preconditioners.

Considering smooth nonlinear constrained optimization problems there has been little progress in the past years. Of course, there has been progress if we consider the state given in [44] essentially by Powell [58] or compare [21, 6, 7]. After proving superlinear convergence of the Quasi-Newton Method (cf. Schittkowski [65]) modifications consider either different approaches in the line search (e.g. Rustem [64]), modifications in the update formulae (e.g. Contreras and Tapia [14]) or exploiting the structure of the objective (e.g. Huschens [43] which might be of importance to this project). See also Facchinei and Lucifi [20].

In the case of nonsmooth unconstrained optimization there has been significant progress in the past years, see e.g. Kiwiel [49, 50], Schramm and Zowe [68], Facchinei [19], and for of global and superlinear convergence Qi [60], Pang and Qi [57], and Fukushima and Qi [22]. For the beginning of this project a nonsmooth objective will probably be of now or low importance. A significant speedup of algorithms for nonlinear optimization may be gained by the use of Automatic Differentiation so that one prevents calculating finite differences for approximating the arising gradients, see, e.g., Griewank [25].

5.4 Previous Work

The research group of the principal investigator has collected considerable experience with direct simulation especially for magnetic field problems. These problems are described by the Maxwell equations which read in the magnetostatic case

$$\mathbf{rot}\,\vec{\mathrm{H}} = \vec{\mathrm{J}}, \qquad \vec{\mathrm{H}} = \nu(|\vec{\mathrm{B}}|)\vec{\mathrm{B}}, \qquad \mathrm{div}\,\vec{\mathrm{B}} = 0 \tag{16}$$

with $\nu(|\vec{\mathrm{B}}|) = 1/\mu_0\mu_r(|\vec{\mathrm{B}}|)$ in the nonlinear model, cf. [38]. Here, the magnetic field strength is denoted by $\vec{\mathrm{H}}$, the magnetic induction by $\vec{\mathrm{B}}$, and $\vec{\mathrm{J}}$ is the current density. Since (16) holds, we can introduce the magnetic vector potential $\vec{\mathrm{A}}$ by $\mathbf{rot}\,\vec{\mathrm{A}} = \vec{\mathrm{B}}$.

In the 2D case, only one component of the vector potential $\vec{\mathrm{A}}$ has to be considered and 5.4 gives formally

$$-\mathrm{div}\;(\nu(x, |\nabla u(x)|)\nabla u(x)) \;=\; \mathrm{S}(x) + \frac{\partial \mathrm{H_{0y}}(x)}{\partial \mathrm{x}} - \frac{\partial \mathrm{H_{0x}}(x)}{\partial \mathrm{y}}, \quad x \in \Omega \tag{17}$$

$$u(x) \;=\; 0, \quad x \in \partial\Omega \tag{18}$$

with $\Omega \subset R^2$ is a bounded domain. The solution u is the z–component A_z of the vector potential $\vec{A} = (A_x, A_y, A_z)^T$ introduced in the Maxwell equation. The component of the current density, which acts orthogonal to the cross-section being considered, is represented by $\mathrm{S}(x)$, whereas $\mathrm{H_{0x}}$ and $\mathrm{H_{0y}}$ stand for sources associated with permanent magnets that may occur and $\nu(.)$ denotes a coefficient depending on the material and on the gradient $|\nabla u(x)|$ (induction).

For this class of problems (2D case) a complete methodology has been developed and implemented. In particular this includes the following topics.

- *DD Preprocessing.* For the two dimensional case there exists a complete numerical software package including the preprocessor *ADDPre* [9] and the parallel code FEM⊗BEM [28] for solving partial

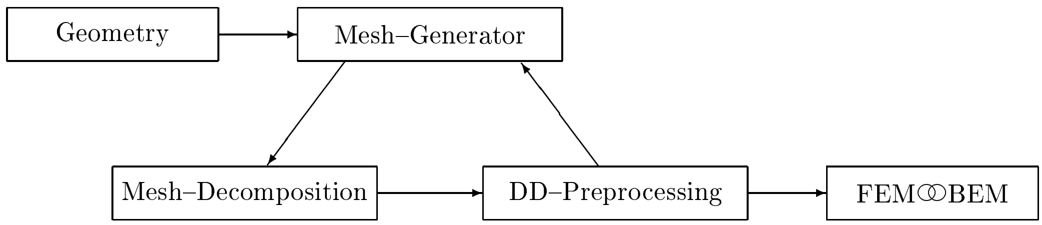

Figure 6: The components of the 2D Domain Decomposition preprocessor.

differential equations arising in magneto-statics. Examples can be found, e. g., in [29, 13]. Figure 7 shows the interactions between the components of the preprocessor which delivers, finally, the input for the parallel DD code FEM∞BEM. The results of numerous numerical experiments, including tests of several strategies of data decompositions have to be analyzed and extended for the much more challenging 3D case.

- *Analysis of Asymptotically Optimal Solvers.* Preconditioners [30, 8, 10, 27] which are the main components of DD-solvers [39, 29] have been analyzed in several papers. Thus, for this class of problems, optimal or almost optimal solvers with high parallel efficiency have been proposed. The preconditioners can be adapted to special difficulties of the problem yielding robust solvers. Both, DD-solvers and parallelized global solvers based on a DD-data structure have been investigated.

  Additionally, nonlinear problems have been solved by using nested Newton methods. Here, the solution starts on coarser grids in order to obtain 'good' initial solutions on finer meshes. As a result only very few Newton iterations are required on finer meshes [36, 37].

- *FEM-BEM Coupling.* In order to model exterior problems correctly the coupling of Finite and Boundary Element Methods has been investigated [29, 39]. Fast parallel solvers based on DD have been constructed. Applications can be found in [41, 13]. Boundary Element methods have been investigated in [13].

- *Implementation of Algorithms.* During the past years several algorithms based on multilevel and DD approaches have been implemented for solving magnetostatic problems. FEMGP [62] is a sequential FEM code, whereas FEMooBEM [28] is a parallel solver for coupled FEM-BEM equations. Besides DD-methods also global solvers have been implemented [13].

- *3D Tools.* For the 3D case, two advanced mesh generators, *NETGEN* [67] and *NAOMI* [17, 48], are available. They work for a wide range of 3D objects and produce unstructured meshes. These meshes are the basis for 3D Finite Element calculations using the numerical software package *FEPP* [66], which can solve problems arising, e. g., in structural mechanics. The extension of these codes, e. g., to wider classes of problems as magnetic field calculations, is the topic of current research activities.

Considering (16) the situation becomes different for the 3D case. Introducing the Coulomb gauge $\operatorname{div} \vec{\mathrm{A}} = 0$ leads to

$$\mathbf{rot}\ (\nu\,(x, |\,\mathbf{rot}\,\mathbf{u}|)\ \mathbf{rot}\,\mathbf{u}) = \mathbf{f}, \qquad \operatorname{div}\mathbf{u} = 0.$$

These problems are currently analyzed within the research project P11215-TEC funded by the FWF. The following topics are part of current research activities.

- *Analysis and Implementation of 3D Magnetic Field Problems.* The exact mathematical formulation of the problem has been discussed and justified in [42]. A basic result of the paper is the definition of the underlying space which is $\mathbf{Y} := H_0(\mathbf{rot}\,;\Omega) \cap H(\mathrm{div}\,;\Omega)$. Based on these results, first algorithms for solving 3D magnetic field problems will be implemented as part of the software package *FEPP* [66].

- *3D Mesh Generators.* As a first step towards 3D computations two mesh generators, NETGEN [67] and NAOMI [17, 46, 48] have been developed. Nevertheless, an advanced tool for the 3D preprocessing which works similar to the 2D case has to be developed. The latter is part of Project 12.

The co-investigator was formerly member of a task group that concentrated on nonlinear constrained optimization, also large scale optimization, with applications especially in the field of hydro power generation (see [1, 2]). During the past years the co-investigator already spent some time on optimization codes for the optimal design of three-phase asynchronous motors. This work was done in cooperation with an Austrian company based on simplified calculations for the magnetostatic problem (see [5, 6]). The problem was formulated as a nonlinear box-constrained mixed-integer problem. During this problem we considered:

- *Objective.* Specifying what an optimal motor is.
  In the above mentioned project the monetary value of certain characteristic quantities is considered. Due to special regulations in the contracts between the company and the purchaser of the motors all nonlinear inequality constraints were also included in the objective by their monetary value. However, this is no penalty approach.

- *Evaluability.* The Quasi-Newton-Method had to be modified so that the governing field equations are well defined and may be evaluated for each set of parameters selected. I.e., infeasible points of the optimization code are only acceptable as far as the governing PDEs still make sense. For this problem this might imply a check for geometric plausibility.

- *Constraints.* So far only box constraints are considered explicitly, inequality constraints are considered by their monetary equivalent due to special regulations in the contract in the above mentioned project (cf. *Objective*).

5.5 Cooperations

This project is concerned with the development and implementation of parallel algorithms. The group of Prof. G. Wittum (ICA III) in Stuttgart has great experience in the field of parallelization. In particular well suited data structures (DDD tool) have been developed. Existing cooperations will be continued in the field of parallelization.

In 2D magnetic field computations coupled FE–BE discretizations have been used successfully. In 3D, the implementation of boundary element methods is much more challenging. In particular the approach using wavelets turns out to be a complex task of its own. That is why a close cooperation with several groups working in this subject is desired. We mention the groups of Prof. W.L. Wendland in Stuttgart, Prof. C. Schwab in Zürich, Prof. R. Schneider in Chemnitz and Prof. O. Axelsson in Nijmegen.

The research groups of the principal investigator of this project and Prof. A. Meyer in Chemnitz work together in the field of parallel algorithms for many years. Additionally, there are several contacts to researchers working within the SFB 393 (speaker Prof. A. Meyer). This close cooperation will be continued and intensified.

The task group "Numerical Analysis and Optimization" has been in tight contact with Prof. A. Griewank (Scientific Computing, TU Dresden, formerly Argonne National Laboratory) who is one of the experts in Automatic Differentiation which is to be used in this project.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

The project aims at a unified approach to optimal design problems in magnetostatics. Both, direct simulation and optimization are to be considered as one unified algorithm. In particular a nested approach seems to be very promising with respect to an efficient solver for 3D problems. With respect to this ultimate goal, the solution of optimal design problems in 3D, the current project is concerned with the following objectives.

- *Preprocessing.* In a first step the problem has to be defined. In particular characteristic quantities, design parameters, and constraints have to be described in a meaningful way. For the direct simulation based on DD methods, a special (geometrical) preprocessing as described above for the 2D case is required.

- *Parameter-dependent Geometries.* During the process of optimizing the design of some device, direct problems with varying geometries have to be solved. Both, discrete parameters, e.g. the number of slots, and continuous parameters, e.g. the diameter of the rotor, have to be considered. This freedom with respect to geometrical data requires a new approach with respect to the internal representation of the devices. The numerical algorithms have to be adapted to this situation. This involves several components, as, e.g., the mesh generator and the solver itself. So, after adapting the mesh to the new geometry, a new initial solution may be obtained from the previous solution living on the old mesh. Here, new recovery techniques are required.

- *Direct Simulation.* The direct simulation of electromagnetic field problems is the basis for any optimization algorithm. For the 3D case, algorithms of optimal complexity for solving magnetostatic problems have to be constructed and implemented. This task involves the construction of preconditioners and their theoretical justification.

  For the 2D case several algorithms of optimal complexity are now available. These algorithms have to be adapted to the methodology to be developed in this project.

- *Hierarchical Optimization.* We will consider nonlinear constrained mixed-integer optimization problems, where the number of discrete parameters used at once for optimization is low and may explicitly described by the set of all feasible discrete points. For each feasible discrete point we then have to solve a nonlinear constrained continuous optimization problem where each evaluation of the objective and/or of the constraints is equivalent to the solution of the governing field equations. The optimal solution of the total problem, i.e. the mixed-integer optimization problem, is then obtained by comparing the optimal values of all continuous problems generated before via the set of all feasible discrete points. We will investigate the optimal complexity in combining direct simulation and optimization, modelling of nonlinear inequality constraints and their impact on evaluability of field equations.

- *Postprocessing.* For the optimal design of the considered magnetic field problem characteristic quantities have to be displayed but also the solution of the governing field equation as such.

  Since the direct simulation results in computing the magnetic (or electric) field only, some postprocessing for computing the characteristic quantities is required.

- *Parallelization.* Parallelization is a powerful tool for speeding up calculations. In our case two options for parallelization are at hand: parallel optimization and parallel simulation. In the first case, the sequential calls of the direct solver, e.g., during discrete optimization may be performed in parallel. This approach seems to be suited especially if only a few processors are available. Nevertheless a well adapted strategy in order to get a good load balance is required. In the case that numerous processors (e.g. at least 16) are to be used it seems to be more advantageous to apply a parallel direct solver, e.g., based on Domain Decomposition methods.

Both options should be considered for implementation. The goal is to design algorithms of good scalability and high parallel efficiency. Thus, low communication effort within the algorithms is one of the objectives. Additionally an approach allowing well balanced distributions is required.

- *Application and Evaluation.* The project aims at the solution of optimal design problems of "real life" devices. The algorithms should work robust with respect to complex geometries. Several examples of applications should be presented. Since during the project several approaches will be proposed, the different performance results are to be documented. For example, the different strategies for parallelization mentioned above, should be analyzed with respect to differing applications and differing computer architectures being used.

5.6.2 Methods

In the following we outline our methodology for this project. The explanations follow the structure we used in the previous subsection.

- *Preprocessing.* We plan a list of characteristic quantities, design parameters, and constraints, from which the actual formulation of the optimization problem is compiled. When solution of equations over the real numbers is available from Project 2 some constraints also will be eliminated in the preprocessing step. In case of use of Automatic Differentiation we will generate the code for the derivatives.

  Project 12 is concerned with the DD preprocessing for 3D problems. Thus there will be a close interaction between these projects. The modular design of the software will guarantee the transfer of results between the different projects.

- *Parameter-dependent Geometries.* In order to solve optimal design problems it is necessary to change the geometry of the object being modelled accordingly to the change of the design parameter. That is why a parameter dependent description of the geometry is required. Two cases have to be considered: discrete and continuous parameters. In an initial approach, the first case could be tackled offline. That is, we could think of completely different devices which are to be modelled. Then, in some preprocessing (cf. Project 12) we produce the geometrical description of all these devices. The results of the direct simulation for all these subproblems are compared for optimization purposes. In the case of continuous parameters we aim at an online adaptation of the geometry. So, small changes of parameters, e.g., diameters, may cause an adaptation of the existing mesh only. On the other hand, major changes of parameters may require a remeshing of the problem. At all stages the correctness of the proposed geometry has to be justified. Intergrid transfer operators have to be defined in order to transfer old intermediate solutions to the updated grids to obtain a good initial guesses.

- *Direct Simulation.* Domain Decomposition methods turned out to be well suited for simulating 2D magnetic field problems. In particular complex geometries which are typical for these applications can be modelled in a robust way. Thus, it seems to be promising to generalize the ideas to the 3D case. Project 12 is concerned with the DD Preprocessing for the 3D case. Thus, the initial geometrical description of the problem including the definition of subdomains will be available.

  In the 2D case, existing algorithms have to be adapted to the new approach of nested hierarchical optimization. In particular, new methods for transferring data between different meshes, i.e., between different levels of a hierarchy and between meshes of different geometries caused by changes of parameters, have to be developed. In the new context of hierarchical optimization, existing components (preconditioners) of the algorithm may turn out to be less or more efficient. Even new ideas may be necessary. Adaptive mesh refinement based on a-posteriori error estimates are to be applied. New error estimators which are designed according to the objectives under consideration may have to be designed.

In order to obtain an efficient optimization code, optimal rules for parameter choices have to be defined. This involves, for example, to determine the accuracy required for the result of the direct simulation. Similar to the nested Newton approach, the optimal choice of the stopping criterion can lead to a considerable reduction in computation time.

In the 3D case, efficient and robust DD solvers have to be developed. Here, ideas from the 2D case have to be generalized. The basis for any calculation is the DD Preprocessing tool which is to be developed in Project 12.

As in the 2D case, Boundary Element methods are well suited for modelling the exterior problem which may be essential in certain applications. If possible, results of other research groups who are concerned with the implementation of wavelet based algorithms should be used. A stand-alone implementation of such algorithms seems to be far beyond the scope of this project.

- *Hierarchical Optimization.* In this beginning of the total project we will only consider such mixed-integer optimization problems that there is only a small number of feasible discrete points. Hence, each feasible discrete point generates an optimization problem with continuous variables only. In principle we will use the Quasi-Newton Method for these nonlinear constrained optimization problems. However in contrast to Quasi-Newton Methods, if possible, each iteration point of the optimization code should be a feasible point as for real world problems each generated iteration point of the optimization code should be able to be realized. At the first glance this additional feature seems to be fulfilled by obeying box constraints. Then the optimal solution of the mixed-integer problem is simply determined by comparing the optimal values of the objective of the continuous problems generated by all feasible discrete points. Branch and bound methods are not applicable as the governing field equations will make no sense in case the discrete parameters might have a noninteger value. For saving computing time we will test Automatic Differentiation, basically the software package ADOL-C [26].

  The crucial point to efficiency with respect to the optimization code will be combining estimation on the error in the solver for the field equations (PDE-solver like DD methods) with the information on a stationary point for the continuous optimization problem. As long as the iteration point of the optimization code is no stationary point we do not have to solve the field problem with a high accuracy. The more the iteration point of the continuous optimization problem will fulfill the first order Kuhn-Tucker conditions the more accurate we will solve the governing PDEs. We will have to investigate the qualitative (and quantitative) behaviour of the objective with respect to the continuous design parameters. As mentioned in *Parameter-dependent Geometries* we will investigate how to make best (maybe optimal) use of the information of the intermediate solution of the old grid (i.e. for the old iteration point of the optimization code) for solving the new, i.e. next, continuous problem with the new grid. Predictor/corrector methods will be considered.

- *Postprocessing.*

  Crucial for defining an objective relevant to real world problems is to define relevant characteristic quantities. For this purpose we will also cooperate with Project 5.

  After solving the direct field problem the above mentioned characteristic quantities have to be calculated from the magnetic (or electric) field. Here, recovery techniques, e.g., for computing derivates numerically, have to be applied.

  The visualization of data is carried out in close cooperation with Project 13.

- *Parallelization.* For many formulations of optimal magnetic field machines there arise discrete parameters. In many of these cases the set of all feasible discrete points may be totally enumerated and the total number of all feasible points is not too large. So in this case no approximative algorithms for obtaining the optimal discrete parameters in reasonable computing time have to be applied. In this case we obtain a set of continuous problems. For each of them the field problem has to be solved separately. These tasks can then be performed completely in parallel.

Several parallel algorithms for the direct simulation in 2D are now available. DD or DD-based methods seem to be well suited to solve such problems. This class of solvers involves DD methods as well as parallel global methods, e.g., multigrid. Algorithm of optimal complexity and high parallel efficiency have been designed. These experiences have to be used to modify existing algorithms in order to implement them in some optimization process maintaining the parallel performance of the algorithm.

In the case of parallel direct simulation of 3D problems lots of data are generated during the computations. These data must be handled and compressed such that they can be interpreted in a meaningful way. A full collection of these data within some optimization may slow down the whole algorithm considerably. That is why new methods for compressing these data have to be applied. Alternatively, functionals which describe important properties of the device could be defined. Thus, the evaluation of the quality of the device would be simplified to the computation of such a functional.

The opportunity to parallelize either the optimization part or the direct simulation ensures a greater flexibility of the algorithm. Thus it can be well adapted to the actual hardware environment. The optimal way of parallelization will, of course, also depend on the problem under consideration.

- *Application and Evaluation.* In order to test the algorithms several test examples have to be defined. For the 2D case a class of examples exists. For these problems, design parameters have to be defined.

  For the 3D case, new problems have to be established in close cooperation with Projects 12 and 5.. The different choices of preconditioners and their performance should be analyzed.

5.6.3 Programme and Schedule

In the following we divide the project into 8 overlapping phases, which are worked out by members of the basic staff, one interacting position between this project and Project 12, two additional scientists, and two research students (FB).

(1) Definition of flexible data structures describing the geometry, in particular concerning potential design parameters in optimal design applications. Implementation of parameter-dependent geometrical data structures. DD Preprocessing.

(2) Preprocessing, involving the definition of data structures and the definition of objectives. Selecting objective, constraints, specifying actual design parameters and constraints. Postprocessing of the field solution for the use in the objectives.

(3) Development of a unified approach concerning solver and optimization. Analysis and implementation of hierarchical optimization in 2D. Adaptation of 2D solvers.

(4) Implementation of new DD solvers in 3D. Development and analysis of preconditioners.

(5) Parallelization of optimization and direct simulation.

(6) Definition and realization of applications. Evaluation of the algorithms.

(7) Supervision of (1) – (6).

(8) Supervision of (1) – (3), (5), (6).

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year 1 ... 6	1st year 7 ... 12	2nd year 1 ... 6	2nd year 7 ... 12	3rd year 1 ... 6	3rd year 7 ... 12
(1)	C, D, E, F, G	▬	▬				
(2)	E, H	▬	▬				
(3)	E, H	▬	▬	▬	▬	▬	▬
(4)	F, G	▬	▬	▬	▬	▬	▬
(5)	C, D, E, F			▬	▬	▬	▬
(6)	E, F, G, H					▬	▬
(7)	A	▬	▬	▬	▬	▬	▬
(8)	B	▬	▬	▬	▬	▬	▬

The symbols A, B, C, D, E, F, G and H are assigned to the following persons working on the corresponding problems:

A = O.Univ.-Prof.Dr. U. Langer (proposer of the project),

B = Dipl.-Ing.Dr. E. Lindner (co-proposer of the project),

C = Dipl.-Ing.Dr. G. Haase (co-worker from the basic staff),

D = Dipl.-Ing. M. Kuhn (co-worker, full time post doc position applied in Project 12),

E = N.N. (applied doctoral position for a Ph.D. student paid as a 2/3-job),

F = N.N. (applied doctoral position for a Ph.D. student paid as a 2/3-job).

G = N.N. (applied support for a student (FB) via "Kleine Forschungsbeihilfe"(FB).

H = N.N. (applied support for a student (FB) via "Kleine Forschungsbeihilfe"(FB).

5.7 Integration with the SFB

The outcome of this project has to be considered as part of an overall solution process of partial differential equations, in particular of magnetic field problems. Here, we are concerned with the numerical core of a software package, i. e. with the implementation and justification of efficient numerical algorithms.

Especially in the 3D case, both, preprocessing and postprocessing of the data are indispensable. The need for both becomes even more evident for parallel computations. Here, the data have to be prepared for computations, e. g. for algorithms based on Domain Decomposition methods. This topic has been discussed extensively in Project 12. One of the positions applied there is going to work on both subjects. In particular this involves the DD Preprocessing, cf. Project 12.

On the other hand the postprocessing of the huge amount of data generated especially by parallel algorithms is very important and is necessary for interpreting results.

An explicit solution of nonlinear constraints over real numbers (Project 2: Doz. Hong), i.e. substitution of certain continuous variables, will fasten the optimization code by reducing the number of continuous variables. For checking geometrical plausibilities we will use the methods developed in Project 3.

Project 5 is concerned with similar classes of problems. Thus there is a strong interaction between the two projects concerning both software components and practical applications. In Project 7 (Inverse Problems) similar problems are considered, discretized and then solved by the SQP Method whereas in Project 8 we treat problems with a finite number of finite dimensional design parameters by the QN Method. The integration of all components and a unified treatment is one of the main goals of this SFB.

5.8 Detailed Budget

5.8.1 Requested Personnel

As mentioned in Section 5.6.3, two doctoral positions for Ph.D. students, which are paid as 2/3 job, and two "Kleine Forschungsbeihilfen" for supporting the participation of diploma students in this project are required.

5.8.2 Computers and Experimental Equipment

We request funding for the following equipment:

- 1 workstation, which amounts to a total of **ATS 70.000,–** in the first year.
  The workstation provides the working place for one of the Ph.D. students applied for in this project. One of them is concerned with the development of the 2D optimization codes and applications.
- Upgrade of 1 workstation (SUN Ultra) from 128MB to 512MB main memory, which amounts to a total of **ATS 100.000,–** in the first year.
  This workstation provides the working place for one of the Ph.D. students applied for in this project. At the same time, it is used for running time consuming codes (3D applications) and for graphical applications.

  The workstation to be upgraded has been funded by the FWF under the grant P 11215-TEC given to the principal investigator.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 8
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	776.000	170.000	10.000	25.000				981.000
2	776.000		10.000	25.000				811.000
3	776.000		10.000	25.000				811.000
Summe	2.328.000	170.000	30.000	75.000				2.603.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 8

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Langer Ulrich, Dipl.-Ing. Dr., O.Univ.-Prof.	Numerische Mathematik und Optimierung	Mathematik	10%		1. Jahr	O.Univ.-Prof.	voll
Haase Gundolf, Dipl.-Ing. Dr., Univ.-Ass.	Numerische Mathematik und Optimierung	Mathematik	10%		1. Jahr	Univ.-Ass.	voll
Lindner Ewald, Dipl.-Ing. Dr., Univ.-Ass.	Numerische Mathematik und Optimierung	Mathematik	25%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 8

1.Jahr
Ergänzungsausstattung
Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.										
Mag./DI	100%	1	<u>N.N., Dipl.-Ing.</u>	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	<u>N.N., Dipl.-Ing.</u>	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	<u>N.N.</u>	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
	100%	1	<u>N.N.</u>	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	400%	4								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.										
Mag./DI	100%	1	N.N., Dipl.-Ing.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N., Dipl.-Ing.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	400%	4								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.										
Mag./DI	100%	1	N.N., Dipl.-Ing.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N., Dipl.-Ing.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.	100%	1	N.N.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
	100%	1	N.N.	Numerische Mathematik und Optimierung	Mathematik	100%		1. Jahr	FB	voll
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	400%	4								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 8

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
384 MB Speichererweiterung für FWF-Workstation	100.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	100.000			Summe	70.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 8

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 9: Estimation of Discontinuous Parameters in Differential Equations

5.1 General Information

Title : Estimation of Discontinuous Parameters in Differential Equations

Field of research : Inverse Problems

Principal investigators : Univ.-Doz. Dipl.-Ing. Dr. Otmar Scherzer and
o. Univ.-Prof. Dipl.-Ing. Dr. Heinz Engl
Institute for Industrial Mathematics
Johannes Kepler University Linz

5.2 Abstract

In many practical problems governed by differential equations one in principle knows the type of equation but not the explicit values or forms of the parameters. E.g., if one considers heat conduction in a material occupying a three-dimensional domain Ω whose temperature is frozen at the boundary, the temperature distribution u after sufficiently long time can be modelled by the heat equation

$$\begin{aligned} -\nabla.(a(x,y,z)\nabla u) &= f(x,y,z)\,, \quad (x,y,z) \in \Omega\,, \\ u &= 0\,, \qquad\qquad \text{on } \partial\Omega\,, \end{aligned}$$

where f denotes internal heat sources and a is the (spatially varying) heat conductivity. One can try to identify the parameter a from internal measurements of the temperature u or from overdetermined boundary measurements.

Of particular interest are problems, where the parameter a is discontinuous, e.g., if materials with different conductivity occur in the problem above. Another interesting parameter identification problem is the estimation of locally varying source terms (a known and a possibly discontinuous function f is to be determined in the heat equation.

Parameter identification problems belong to the class of *nonlinear inverse problems* and they are ill-posed, i.e., the solution does not depend continuously on the data. Therefore, some *regularization techniques* have to be applied to solve such problems in a stable way numerically.

In the literature, Tikhonov regularization is a well known method for solving parameter identification problems in a stable manner. Recently iterative methods such as Landweber iteration and Gauss-Newton method were shown to stabilize ill-posed problems if they are combined with an appropriate stopping rule. For all these methods good results (reasonable convergence rate) are obtainable if the exact solution a (of the heat equation) is smooth.

It is the aim of this project, to develop new regularization methods and their efficient numerical realizations in the case of parameters with singularities (e.g. discontinuous functions).

5.3 State of the Art

General nonlinear inverse problems may be formulated as the solution of nonlinear operator equations

$$F(a) = y\,. \tag{19}$$

Here a denotes the unknown (searched for) parameter and y denotes the (measured) data. For a few monographs treating inverse problems and their numerical solution we refer to Colton and Kress [11], Engl, Hanke and Neubauer [15], Hofmann [20], Isakov [21], and Louis [25].

There are essentially two different approaches in treating nonlinear ill-posed problems: The first is to use nonlinear regularization techniques and the second is to linearize the nonlinear problem and to combine this step with regularization techniques for linear ill-posed problems, where the analysis is much further advanced than for nonlinear problems.

In both cases, one distinguishes between continuous and iterative regularization methods. The most well known continuous regularization method is *Tikhonov regularization*, where the exact solution of problem (19) is approximated by a minimizer a_α^δ of the problem

$$\|F(a) - y^\delta\|^2 + \alpha\|a - a_0\|^2 \to \min\,, \quad a \in \mathcal{D}(F)\,, \tag{20}$$

where $\alpha > 0$, $y^\delta \in Y$ is an approximation of the exact right-hand side y of problem (19) and $a_0 \in X$ plays the role of an initial guess of the solution. The role of Tikhonov regularization to stabilize parameter estimation problems has been studied in, e.g., [9, 10, 24]. Stability and convergence of Tikhonov regularized solutions, x_α^δ, for general nonlinear problems have been treated in [36]. Convergence rates for general nonlinear problems have been presented more recently in [16, 29].

The choice of the regularization (penalty) term ($\|a - a^*\|^2$ in (20)) essentially influences the quality of the approximation a_α^δ. The square of a Hilbert space norm has the advantages that the penalty term is differentiable (good for minimization algorithms) and that a convergence analysis is possible via Hilbert space techniques. However, such a penalty term frequently yields approximations where discontinuities are smeared out.

Acar and Vogel [1] analyzed a Tikhonov-like regularization method based on total variation, i.e.,

$$\|F(a) - y\|^2 + \alpha \int_\Omega |\nabla a(t)|\, dt \to \min \tag{21}$$

for the problem of denoising ($F = I$) and deblurring (F linear, compact). This variant has the advantage that it enhances sharp features in a, which is useful, e.g., in image reconstruction (cf. [13, 32]). A technical difficulty is the non-differentiability of the penalty term. To solve this minimization problem in a stable way iterative methods are used [7, 3].

An alternative approach to Tikhonov regularization are iterative regularization methods such as Landweber iteration, i.e.,

$$a_{k+1}^\delta = a_k^\delta - F'(a_k^\delta)^*(F(a_k^\delta) - y^\delta)\,, \tag{22}$$

or regularized Gauss-Newton method, i.e.,

$$a_{k+1}^\delta = a_k^\delta + (F'(a_k^\delta)^* F'(a_k^\delta) + \alpha_k I)^{-1}[F'(a_k^\delta)^*(y^\delta - F(a_k^\delta)) + \alpha_k(a^* - a_k^\delta)]\,. \tag{23}$$

The analysis of these methods is well understood in abstract Hilbert space settings [7, 2, 2]. Note that the nonlinear operator F has to be Fréchet differentiable. For the problem of identifying a in the heat equation this is not the case for an arbitrary discontinuous parameter.

5.4 Previous Work

Both proposers have contributed to the field of regularization methods for linear and nonlinear ill-posed problems. Convergence and convergence rates results for Tikhonov regularization can be found in [16, 11, 22], similar results for the nonlinear Landweber iteration and the regularized Gauss-Newton method (suggested by Bakushinskii [2]) have been developed recently in [7, 2]. Heinz Engl is coauthor of a new book on inverse problems [15]. Contributions to total variation regularization were given by Otmar Scherzer in [3, 13, 10].

5.5 Cooperations

Some Cooperations have been made in the field of inverse problems with well known researchers leading to several publications; see the reference list of both proposers.

5.6 Objectives, Methods, Program and Schedule

5.6.1 Objectives

1. Development of problem adapted penalty terms in Tikhonov-like methods, especially suited for the estimation of discontinuous parameters in differential equations
2. Efficient numerical minimization of the Tikhonov-like functionals developed in 1.
3. Adaption of well known iterative methods such as Landweber iteration and regularized Gauss-Newton method to the parameter estimation problem in the case of discontinuous parameters.

5.6.2 Methods

For the approximate solution of (19) we intend to study Tikhonov-like regularized solutions, i.e., minimizers of functionals of the form

$$\|F(x) - y\|^2 + \alpha G(x)\,. \tag{24}$$

The operator G should be chosen such that minimizer of (24) optimally enhances the desired features of the solution (19).

We intend to study two different prototypes of operators G:

1. $G(x) = \|x\|^2_{H^s}$, where s is a positive (not necessarily integer) constant. In many practical applications it is realistic to assume that a parameter to be reconstructed is piecewise smooth, and thus is an element of the Sobolev space H^s, where $0 < s < \frac{1}{2}$. Since standard theorems on stability and convergence of regularizing techniques require the function to be reconstructed to be an element of $D(G)$, the H^s–norm is expected to be a reasonable regularization norm for reconstructing piecewise discontinuous parameters.

   For $G(x) = \|x\|^2_{H^s}$ it is well–known that for a Fréchet–differentiable operator F the minimizer of (24) can be characterized by the first order optimality condition, i.e., it satisfies

   $$F'(x)^*(F(x) - y) + \alpha x = 0\,, \tag{25}$$

   where $F'(x)^*$ denotes the adjoint of the Fréchet–derivative of F as an operator of H^s into L^2. If $s < \frac{1}{2}$, then the explicit form of the Fréchet–derivative may be extremely difficult to derive and therefore it might be preferable in practical applications to directly minimize (24) (this approach is also relevant if the operator F is not differentiable) with an iterative technique or to use a finite element approach to solve (25), i.e., to solve

   $$(F(x) - y, F'(x)v)_{L^2} + \alpha(x, v)_{H^s} = 0\,, \tag{26}$$

   for an appropriate space of Ansatz–functions for which the inner product $(x, v)_{H^s}$ can be evaluated efficiently.

   Based on (26) we intend to study different numerical algorithms for minimization of (24) like *gradient type methods*

   $$-(F(x_k) - y, F'(x_k)v)_{L^2} + (1 - \alpha_k)(x_k, v)_{H^s} = (x_{k+1}, v)_{H^s}\,. \tag{27}$$

This iteration scheme requires in each iteration the calculation of x_k from its finite element coefficient. In general, the evaluation of the $(.,.)^2_{H^s}$ is computationally extremely expensive. For wavelets–functions the inner product can be calculated efficiently (see e.g. [12, 26]), which motivates to use Wavelet–functions for the efficient implementation of (27).

Gradient type methods (like (27)) are known to be slowly convergent and thus we intend to study further on other iterative regularization algorithms like the Gauss Newton method

$$x_{k+1} = x_k - (\alpha_k I + F'(x)^* F'(x))^{-1} (F'(x_k)^*(F(x) - y) + \alpha(x_k - x_0)) \ . \tag{28}$$

In concrete applications (27) and (28) have to be implemented on a finite dimensional subspace defined by a family of Ansatz functions. For ill-posed problems a reasonable reconstruction very much depends on the choice of the space of Ansatz–functions, and its dimension. If the number of linearly independent components is too large, then the iteration scheme (27) or (28) may lack stability. On the other hand if the dimension of the subspace it too small, then the iteration yields poor reconstructions. To overcome the difficulty for choosing the appropriate number of independent Ansatz–functions we intend to study cascadic algorithms (see e.g. [4, 3]) based on (27), (28), which combined with appropriate stopping criteria allow to determine the optimal number of Ansatz–functions (see [14]). In order to implement cascadic algorithms for the solution of nonlinear ill–posed problems efficiently there has to exist a family of nested subsets $\{X_n\}$ which satisfy, that each element on a lower scale can be efficiently represented in a higher scale, which makes wavelets particularly interesting for cascadic algorithms for the solution of nonlinear ill–posed problems.

We note that parameter estimation problems with discontinuous parameters, which we have in mind to solve with the techniques described above, are rather different to problems which are usually solved with Wavelet functions, like in signal–and image processing, data compression .... In all these applications data of the image is available more or less directly, and not attained from some indirect measurements (which is represented in our approach by the nonlinear operator F).

2. An alternative approach is to study regularization terms $G(x) := \int_\Omega g(x(t), \nabla x(t))$, where g is a function, which is not necessarily smooth. A challenging approach for recovering discontinuous parameters, which has been considered recently in the literature is bounded variation regularization, which is $g(x(t), \nabla x(t)) = |\nabla x(t)|$. In [27] several suggestions for enhancing different features (edges, corners, poles) in images in the context of denoising are given. These selective smoothing techniques are based on anisotropic diffusion. For denoising images Morel and Solimini noted the strong similarity between anisotropic diffusion and penalized least squares problems (which can be interpreted as regularization techniques). An important issue of selective smoothing techniques is that specified details of images can be enhanced.

   Regularization techniques with nonlinear penalty terms are extremely challenging from a point of convergence analysis, since the minimization (in the infinite dimensional setting) has to be formulated in appropriate function spaces. New enhancing techniques lead to probably new function spaces on which the minimization has to be performed. The space of functions of bounded variation enhances sharp features in images. The space of functions with derivatives of bounded variation was found to enhance sharp details in derivatives of images efficiently which makes it a practically important tool for studying parameter estimation problems (see [13]). The space of functions with derivatives of bounded variation seems not to have been studied in the literature before and therefore the functional analytic background (like general embedding theorems or trace theorems for Sobolev spaces) are missing.

   We intend to analyze nonlinear penalty terms, which are motivated from image enhancing techniques with nonlinear diffusion processes, to parameter estimation problems with discontinuous parameters, and to study efficiency of these methods in practical applications.

For bounded variation regularization several minimization algorithms have been proposed [23, 22, 8, 17, 5, 7]. All these algorithms circumvent the minimization of the bounded variation functional, i.e., the minimization of

$$\|F(x) - y^\delta\|^2 + \alpha \int_\Omega |\nabla x| \,. \tag{29}$$

The main arguments in the above cited papers for considering modified minimization functionals are to make the modified minimization problem attractable to iterative algorithms: Chambolle and Lions [5] study an algorithm, which is **globally** convergent to the minimizer of the modified functional.

A further argument for considering modified minimization algorithms instead of (29) arises from stability issues, which are associated with the minimizers of (29). If G is linear like in (27), then stability of the minimizers of (19) can be proven with respect to the norm specified by the operator G, i.e., in the concrete example considered above with respect to the H^s–norm. The same is not true for BV–regularization, where stability only holds with respect to a L^p–norm, in which the space of functions of bounded variation can be compactly embedded. This is a mayor drawback of bounded variation regularization, since stability of the minimizers is relatively poor. On the other hand it can be shown analytically that discontinuities of a piecewise constant functions (without noise) can be resolved **exactly** with bounded variation regularization – a property, which no other regularization technique studied so far seems to have. This property seems to make BV–regularization techniques extremely suitable for parameter estimation problems, when the main objective is to estimate locations of different materials exactly. Numerical algorithms for (29) (or some modifications) are difficult to analyze, which is partly due the fact the functional to be minimized might not be differentiable and moreover the operator F will be a smoothing operator.

For the actual minimization of (29) a cascadic algorithm has been considered in [6]: There the functional in (29) is replaced by a scale of modified (differentiable) functionals, which in the limiting case correspond with (29). Each modified functional can be minimized by solving a (highly) nonlinear partial differential equation. In [6] the scale of the minimization problem is updated according to some discrepancy principle in order to optimally simulate bounded variation minimization. We intend to study cascadic algorithms for the efficient minimization of (29) (and functionals with other nonlinear penalty terms, which are suitable for enhancing desired features of the parameter to estimate), since these technique allows to determine the optimal trade off between the level of stability (i.e., the level of the approximation by differentiable functionals) and convergence (i.e. the quality of the reconstruction).

Since the BV–regularized solution can be approximated by the solution of a (integro–) differential equation, we intend to use multi–grid methods for the efficient approximate minimization of the BV–functional (29). We expect that also for other Tikhonov–like functionals, which are motivated from nonlinear diffusion processes, multi–grid methods for the efficient solution can be applied.

The similarity of the approach discussed in [6] to the cascadic algorithms for the linear regularization techniques described above will be the basis to study further on combinations of both techniques, especially to combine efficiently the appropriate space of Ansatz–functions with the appropriate level of approximation of the functional with nonlinear non–differentiable penalty terms.

5.6.3 Program and Schedule

(1) Analysis of penalized least squares problems with linear regularization terms for parameter estimation problems with discontinuous parameters and their effective numerical implementation using Wavelet functions

(2) Investigation of nonlinear penalty terms (motivated from diffusion processes) and their applicability to parameter estimation problems with discontinuous parameters

(3) Efficient numerical implementation of regularization methods with nonlinear penalty terms developed in (2)

(4) Combination of the methods developed in (2) and (1), e.g., to use Wavelet Ansatz–functions for the regularization methods developed in (3), comparison of the methods for practical applications.

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12	1 . . . 6	7 . . . 12
(1)	A, B						
(2)	C						
(1)	D						
(2)	E						
(3)	C, E						
(4)	D						

The symbols A, B, C, D, and E are assigned to the following persons working on the corresponding problems:

A = Doz. Dr. O. Scherzer (proposer of the project),

B = Prof. Dr. H. W. Engl (proposer of the project),

C = N.N. (applied full time post doc position),

D = Dipl.-Ing. E. Radmoser (applied doctoral position for a Ph.D. student paid as a 2/3-job),

E = Dipl.-Ing. Kindermann (applied doctoral position for a Ph.D. student paid as a 2/3-job)

5.7 Integration with the SFB

Ito and Kunisch [23, 22] discovered that bounded–variation regularization is closely related to a Signorini–problem (for a detailed exposition on the Signorini–problem see e.g. the book of Glowinski [18]) – problems of this type are relevant in project [P6]. As mentioned above, bounded variation regularization for deblurring and denoising of images can be simulated by (highly) nonlinear partial differential equations. For the effective solution of these partial differential equations we intend to use multi–grid methods, which are also a central point in the projects [P7,P8]. Moreover, the effective implementation of methods developed in 1. will require the effective evaluation of the operators F, F', and F'^*, which gives again links to the project of [P7].

5.8 Detailed Budget

Personnel: For the comprehensive project activities one full time researcher (on a PhD level) and two part time researchers (PhD students) will be needed additionally to the project leaders. The full time researcher should have a strong background in nonlinear functional analysis and partial differential equations. The two part time researchers will work on linear regularization techniques with the motivation to apply the results developed for linear techniques to nonlinear regularization techniques. It can be expected that both PhD students will receive the PhD within the first project year, and that they will get a full position afterwards.

5.8.1 Computer and Experimental Equipment

In addition to the powerful graphics workstation applied for in project 7 (which will also be used in project 9), we reqeust

- 3 graphic workstations totalling 210.000,– in the first year. The workstations serve as additional workplaces for the employees of this project.

5.8.2 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.3 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 9
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	210.000	10.000	25.000				1.393.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	210.000	30.000	75.000				3.759.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 9

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Engl Heinz, Dipl.-Ing., O.Univ.-Prof.	Industriemathematik	Industriemathematik	5%		1. Jahr	O.Univ.-Prof.	voll
Scherzer Otmar, Dipl.-Ing. Dr., Univ.-Doz.	Industriemathematik	Industriemathematik	25%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 9

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Kindermann Stefan, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
	100%	1	Radmoser Esther, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Kindermann Stefan, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
	100%	1	Radmoser Esther, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	N.N., Dr.	Industriemathematik	Industriemathematik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Kindermann Stefan, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
	100%	1	Radmoser Esther, Dipl.-Ing.	Industriemathematik	Industriemathematik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 9

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe				Summe	210.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 9

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 10: Structural Dynamics of Elasto-Plastic Multi-Body Systems: Integrated Symbolic and Numerical Computations

5.1 General Information

Title : Structural Dynamics of Elasto-Plastic Multi-Body Systems: Integrated Symbolic and Numerical Computations

Field of research : Computational Mechanics

Principal investigator : Univ.-Prof. Dipl.-Ing. Dr. Hans Irschik
Institut für Mechanik und Maschinenlehre
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5.2 Abstract

The main intent of the present proposal is the extension of the existing computational experience to elasto-plastic multi-body systems. The main idea is to create such "smart" programs which can perform a preliminary analysis of the multi-body system in question, so called object-oriented programs. That means that the mechanical behaviour of the component bodies should be characterized by hierarchical classes of objects. Standard mechanical bodies as rods, plates etc. should be implemented in connection with various inelastic strain-stress relations. The program should be "intelligent" enough to choose the suitable computational strategy for solving the elasto-plastic problem of the whole multi-body system. Inelastic part of the strain is treated as a source of eigenstrains in linear elastic bodies, so that an analytical formulation of the elastic solids can be applied to the physically non-linear problems. Special attention will be paid to the use of finite element method with exact stiffness matrix. The efficiency of the approach will be increased by means of the linear concept of the influence numbers and modal matrix, since they will be computed before the main calculation. These concepts of the linear analysis are to be consistently applied to dynamics of elasto-plastic multi-body dynamics. Another challenging problem is the prevention of uncontrolled high frequency vibrations in engineering structures which affect small sensitive elements of the complex structures, e.g. microprocessors, controllers etc. Special approaches will be proposed for the prediction of high-frequency vibrations in complex structures since the conventional well-established methods of structural analysis, such as finite element method, substructure synthesis method etc. are not suitable because of high computing cost.

The local principle in structural dynamics which is obtained by the group and is a sophisticated generalisation of multi-body dynamics, allows one to decompose engineering structures into substructures and provides one with the governing equation for each substructure and the imposed constraints. Various methods, among them symbolic computation, FE-, BE-, integral approaches, are applied for modelling the dynamics of each structural member. Structural members of conventional geometry and classical mechanical objects like rods and plates, will be handled by applying symbolic computation. Nonlinear effects, internal material damping and local low contact rigidity can be taken into account by means of the eigenstrains or self-stresses. Dynamics of structural members of the complicated form will be settled down by means of FE-analysis or another numerical methods. Consequently, integral methods will be applied in the high frequency domain and the results obtained will be matched to the those at low frequencies. In this case the global description of the engineering structures will be obtained for any broad band dynamic loading. The proposed project is expected to provide the user with a very flexible, mighty, object-oriented and multi-purpose software which results in considerable reduction of the computing cost.

5.3 State of the Art

Computational methods of structural mechanics mainly follow two main streams: Multi-Body Dynamics (MBD) and Finite Element (FE) Analysis.

In the classical formulation, a MBD-system is assumed to consist of an ensemble of rigid bodies connected by massless interconnecting elements, like springs, dampers etc. The constitutive relations of these interconnecting elements are usually taken to be of the linear elastic or linear viscoelastic type. Non-linearity comes into the play by means of the equations of motion of the rigid component bodies undergoing large transplacements and by the set of kinematical constraints between these bodies. Such a modelling is suitable for the simulation of the overall dynamic behaviour of mechanisms built up from relatively stiff elements. Nowadays, MBD analysis represents a standard tool for the approximate computational analysis of dynamically loaded structures in various fields of engineering, such as robotics, machine dynamics, automotive structures, for control engineering and also in earthquake engineering. Because of the comparatively low number of degrees of freedom to be considered in rigid body dynamics, the standard method of MBD is to obtain the non-linear equations of motion of the single bodies and of the ensemble by means of symbolic matrix algebra, see e.g. the books of Wittenburg [1], Nikravesh [2] and Schiehlen [3]. The computational effort accompanied by the ensembling of a relatively large number of rigid bodies can be decreased by a problem-oriented choice of the mechanical co-ordinates and by the use of special methods of kinematics and analytical mechanics like Kane's equations. For some recent state-of-the art reports, see eg. Angeles et al. [4], Seabra Pereira and Ambrosio [5], and Stadler [6].

In FE-analysis, deformable bodies, usually without any rigid-body-degree-of-freedom, are considered, where the dynamic or static equations are set up and solved numerically. Because FE analysis in its classical form is mainly devoted to the realistic prediction of strains and stresses in the high-strength regions of engineering structures, a detailed modelling has to be performed, discretizing and transforming the problem to a dynamic system with a large number of degrees of freedom. Non-linearity comes into the play both, due to the non-linearity of the kinematic equations and due to physical non-linearity like visco-plasticity or damage. Note an obvious relationship between FEM and MBD, where in the former case the deformable body is subdivided into a number finite elements, while in the latter one the mechanism is built up from a number of rigid bodies. State-of-the-art in engineering applications of FEM is discussed in the monographs [7] - [15].

Due to the high number of degree-of-freedoms encountered in FE-formulations, the computionally efficient as well as accurate time-integration of non-linear dynamic problems by FEM remains a field of up-to-date research, especially for physically non-linear problems, in the domain of high-frequencies and for non-linear wave propagation. Special methods like sub-structuring and modal condensation often have to be applied in practical computations in order to keep the computational effort reasonable when dealing with non-linear dynamic equations produced by FEM codes. For engineering applications of the FEM codes see, eg., [16] - [21].

Since it is a scope of the present project to include physical nonlinearities into flexible MBD, inelastic constitutive modelling will be reviewed in some detail below. Even with no inertia effects taken into account are the phenomena associated with the loading and unloading processes in plasticity still a challenge for computational mechanics and are also problematic with respect to the realistic choice of the constitutive relations. Hardening in metals of all kinds during the first few cycles followed possibly by ductile damage or the phenomenon of low cycle fatigue need to be properly modeled. Thermal shock loading or high temperature waves may produce dynamic processes and plastic deformations. Impacting a structure or shaking it severely produces time variant plastic zones where mechanical energy is dissipated and localized transient temperature fields change the material properties and cause thermal stresses in addition to the load stresses. The implementation of these effects remains a challenging field of research in FE-analysis.

In solid mechanics, the analyses of linearized thermo-elasticity were upon the first to be successfully reformulated in the sense of the general multiple field approach of applied mathematics. Considering the isothermal Hookean body as the background structure with imposed thermal strains, quite naturally a two-field theory is constructed by the inspection of the generalized Hooke's law. In the classical theory, the fields are coupled only by the prescribed boundary conditions. Taking into account the dissipation of dynamic compressibility, the source term in Fourier's law of heat conduction is proportional to the rate of dilatation, cf. Chadwick [22], yields an extra volume coupling of the two strain fields. When high temperature technology of machinery promoted the development of thermal stress analysis, special theories were developed based on thermal Green's functions, e.g., of a hot spot type, cf. Melan and Parkus [23], and for non-stationary fields with an extension to include elastic-plastic material behavior, Parkus [24]. At the same time the method of particular thermoelastic solutions (with simplified boundary conditions) was developed at the expense of the complicated isothermal analysis which has to be solved to account for the full set of boundary conditions. However, the latter strategy may be considered as a first step towards a multiple field theory. A review is provided by Ziegler and Irschik [25]. Also the dummy load concept of structural thermo-elasticity should be mentioned here, Boley and Weiner [26]. It was not until Maysel's formula [27], [28] became known, - with a novel derivation by the twofold application of the principle of virtual work, and hence, the isothermal Green's function of the background structure enters the analysis together with an auxiliary isothermal problem, Parkus [29], Ziegler [30], - that the two-field analysis of thermo-elasticity was fully understood and recognized as the optimal way of analysis. An extension of Maysel's formula to include inertia in dynamic problems is straightforward when keeping the auxiliary problem unchanged, i.e., when considering the static Green's function, Irschik and Ziegler [31]. The output of a low order modal analysis of linear structural vibrations is commonly improved by separating the quasi-static response and by expanding the remaining dynamic solution in a modal series. In linear thermo-elasticity, originally, Boley and Barber [32] considered the dynamic effects of rapid heating by splitting the solution into the quasi-static and the dynamic parts. The quasi-static deformations, that are due to the distortions of the background structure, quite naturally define the plastic drift. The latter represents the instantaneous permanent deformation, and in the case of shake-down of the structure also the remaining plastic deformations. The dynamic Green's function, if readily available for a given background structure, may be more convenient, and the two-field theory is easily adapted, Fotiu et al. [33]. Multiple field theories of nonlinear waves solely rely on dynamic Green's functions, Irschik and Ziegler [34].

Plastic strains may be imposed on the elastic background structure and the generalized Hooke's law suggests a three-field theory, however, with an apriori volume coupling present through the nonlinear constitutive relations. A concise general formulation of the dynamic coupled thermoelastic-viscoplastic ini value problem for the case of infinitesimal deformations can be taken from the review by Allen [35]. The monograph of Parkus [24] was the first resembling non-stationary thermal stress problems including inertia effects and extending the linear theory to elastic-plastic material behaviour. During the last decade, increasing attention has been paid in the literature to the dynamic elastic-plastic and elastic-viscoplastic behavior of structures, see the reviews of Jones [36] and Ohno [37]. A review, emphasizing the coupling between the mechanical and the thermodynamic processes in inelastic solids under dynamic or quasi-static conditions, has been more recently presented by Allen [35]. Various inelastic constitutive relations and their applications to some thermomechanical processes involving phase transformations are discussed by Inoue [38]. The microstructural aspects of the mechanics of solids in the thermodynamic framework together with methods for the numerical analysis of the resulting equations have been outlined by Lemaitre and Chaboche [39]. An introduction into the quasi-static formulations of nonlinear thermo-mechanics including finite element applications has been presented by Sluzalec [40]. The mathematical theory of plasticity and fracture as opposed to the physical theory of these fields has been discussed in the thermomechanical framework by Maugin [41]. Isothermal dynamic models for structural plasticity have been presented by Stronge and Yu [42].

Ductile damage contributes to the inelastic strain (that is non compatible in the background material) not only during loading but also in the unloading process, see Kachanov, Lemaitre [43]. A formulation suitable for multiple-field theories has been developed by Fotiu [44].Coupling of the linear and nonlinear strain fields through the damage process has been exploited by Dafalias [45]. For a review on microme-chanical foundations of dynamic plasticity with application to damaging structures, see Fotiu, Irschik, Ziegler [46]. The above discussion of the state-of-the-art in inelastic constitutive modelling follows closely the recent review of Irschik and Ziegler [8] on dynamic processes in structural thermo-viscoplasticity.

During the last decade, the Boundary Element Method(BEM) has proven to represent a computationally advantageous alternative to FEM. Starting from some weak formulations of the mechanical boundary-initial value problem likewise to FEM, the idea of BEM is to transform the field equations to boundary integrals the solution of which is solved by numeric integration. The treatment of singular kernels in the integrals, the application of regularization techniques and the mapping of boundary elements to standardized master elements, however, can be conveniently performed by symbolic computation. In BEM one eventually ends with a set of unknowns located at or referred to the boundary, instead of subdividing the structure into numerous finite elements. While the number of unknowns is thus decreased with respect to FEM, a number of drawbacks have to be encountered, e.g. domain integrals occurring in case of non-homogeneous, anisotropic, non-linear or inelastic bodies. The application of BEM to dynamic non-linear problems remains an open field of recent research in the literature. An relationship between BEM and MBD analysis may be seen in the fact that unknown boundary values are used as unknowns in BEM, while it is often convenient in MBD to work with coordinates of joints located at the surface of the rigid body. For the state-of-the-art in engineering applications of BEM see [48] - [53]. With respect to the present project, however, a conceptually important feature of BEM is the fact that dynamic Green's functions serve as the kernels of the underlying boundary or domain integrals, see Melnikov [54] for a state-of-the-art review. Hence, a quite natural link is provided to the inelastic multiple-field modelling referenced above.

Recently, an increasing amount of work has been devoted in the literature to the development of small strain elastic multi-body system dynamics, see the monographs [55] - [58]. These formulations extend MBD to the deformable coordinates of linear elastic systems, utilizing classical formulations of dynamics like the Newton-Euler equations and Lagrange's equations in connection with some analytical predecessors of FEM like the Ritz-Galerkin method. FE analysis is applied for the flexible component bodies in [59]. An projection method has been developed in [60] and [61]. The application of various geometrically nonlinear rod theories for MBD has been discussed in [62] and [63]. Geometrically nonlinear FE-analysis of the component bodies has been performed in [64]. A substructure synthesis method has been presented in the context of flexible MBD in [65]. Both, numeric and symbolic computation have been utilized for flexible MBD in [66]. Modal analysis solution techniques for elastic mechanism have been discussed in [67]. Assumed mode methods for flexible MBD have been applied in [68], while mixed-interface analysis of flexible MBD has been performed in [69]. It is thus seen that recent contributions to multi-body systems made of an ensemble of linear elastic bodies quite natural parallels the developments for FEM in physically non-linear problems. An object-oriented computational approach for flexible MBD has been introduced by Anantharaman, cf. [70]. A state-of-the-art on object oriented modelling and design is presented in monograph [71].

The above cited work refer to flexible motions in the lower frequency domain. A FEM-type or BEM type discretization is limited by the time-step necessary for an accurate integration of the dynamic system of discretized equations. Roughly speaking, this time step should be not larger than a reasonable percentage of the shortest natural period of the highest linear elastic mode to be modelled. FEM and flexible MBD thus is restricted to the modelling of vibrations in the low-frequency domain. The further problem which therefore will be tackled in the project is the high frequency response of engineering structures. All the high-tech objects are actually multi-body systems which are assembled from small-size elements. The products of the modern technology present one of the most important applications of the multi-body theories to practice. Potential danger of existence of uncontrolled high frequency vibrations in modern complex structures arises from the fact that high frequency vibration affect small sensitive elements of the complex structures, e.g. microprocessors etc. Special approaches are needed for the prediction of high-frequency vibrations in complex structures. Attempts of precise description of high frequencies of actual structures fail, since too many vibration modes are excited in the structure. The conventional methods of structural analysis, such as FEM, substructure synthesis method etc. are not directly applicable. A fine finite-element mesh is required to model short wavelength deformations of higher normal modes. Modern "smart" structures are very small and sensitive to external loading especially to high frequency part of the excitation spectrum. The reason is that the control processes are very sensitive to high frequencies. Apart from the computing costs an excessive number of degrees of freedom produces insuperable difficulties in analysis of obtained results.

Dynamic behaves of the structures or shortly high frequency dynamics, cf. [72] is a new and very rapidly developing branch of science. Among the problem this dynamics deals with the modelling of the modern engineering structures is the most challenging one. Attempts to pedantically describe all details and peculiarities of real structures are doomed to failure for the following reasons. Firstly, at higher frequencies, the existence of many inherently uncontrolled factors plays a principle role. Review papers by Ibrahim [73] and Fahy [74] give a very deep insight into the problem of uncertainties in dynamics. In structural dynamics, uncertainties arise from stiffness, mass and damping fluctuations caused by variations in material properties as well as variations resulting from manufacturing and assembly. The latter factor causes vagueness in the boundary conditions for each structural member since the high-frequency dynamic properties of joints between structural members are especially uncertain. Secondly, the essential heterogeneity and presence of complicated secondary systems have to be taken into account. Thirdly, even if it were possible to obtain an "exact" boundary-value problem in which all the complexity of the structure was taken into account and we could solve this problem, the very interpretation of this "exact" result would present great difficulty. The reason for this is that the field of vibration of real engineering structures is a very complicated function of time and spatial coordinates since a great many modes are excited in the structure. Summarising, one can say that the blind extension of conventional methods of modal analysis to higher frequencies at the expense of computational cost reaches a deadlock because the results become unreliable and "indigestible". Surprisingly, structural dynamicists "act" as if the methods and approaches of the traditional vibration theory are limitless, i.e. as if these methods may be extended to arbitrarily high frequencies. No such fundamental restriction as "axiom" of physics, which is "there is always a cut-off" often seems to exist in the modern structural dynamics. Another typical feature of complex structures is that all modern structures are weakly coupled. Any engineering structure is in fact an assembly of substructures attached to one another or to the framework only at several points. As a result, the complex structures possess such low global dynamic rigidity that only the first, the second and seldom the third global resonances are observed in such structures. Beyond the region of these few global resonances the vibrations localise within the structural members or groups of structural members. This phenomenon is known as strong vibration localization or normal mode localization and was first mentioned by Mandelstamm, 1929 [75]. A detailed survey of the phenomena of mode localization in structures can be found in the review papers by Hodges and Woodhouse [76], Ibrahim [73], Li and Benaroya [77] and Benaroya [78]. Several representative studies are also worth mentioning, e.g. Pierre and Dowell [79], Cornwell and Bendiksen [80], Pierre and Cha [81] - [83], Ariaratnam and Xie [84] and Langley [85]. As shown in these papers, the phenomenon of mode localization occurs not only for disordered assemblies of weakly coupled subsystems, but also for nearly periodic structures like bladed-disk assemblies and truss structures. This effect has also been observed in solid-state physics, e.g. the metallic conductivity is reduced because of localization of the electron eigenstates, the so-called Anderson localization effect, 1958 [86].

On the other hand, the review of the literature in structural dynamics suggests that present-day analytical methods are too idealised and do not adequately reflect the inherent complexity of structures. Complex engineering structures are often taken to consist of a few structural members of well-studied shapes (shells, beams, plates etc.) otherwise lumped-mass models are applied. The consideration of secondary systems, that is controllers, devices, rigs ec. is commonly avoided in the literature. This avoidance is even more surprising taking into account the fact that the secondary systems can comprise the major portion of the structural members of a unit.

A break-through in the field of high frequency dynamics has been done in the seventies and eighties, see monograph of Lyon [87] and state-of the-art papers [88] - [90]. It has been observed that traditional methods of vibration theory fail at progressively higher frequencies and another approaches have been proposed. It has been shown that the energetic, see [91] - [109] and integral, see [110] - [118] approaches are the most suitable for the description of the engineering structures at high frequencies. For the project proposed the integral description appears to be very perspective. The idea of the integral description is as follows. Actually one is interested in the dynamics of the few structural members that are vibration sensitive. A spatially smooth function which is viewed as the displacement of the primary structure is sought for the whole structure that is integral description whereas dynamics of the particular structural members of interest is performed either by analytical or numerical methods of mechanics. In other words a very sophisticated application of the dynamic condensation method is applied. The substantiation for this method which is called locality principle in structural dynamics as well as some examples of its applications is found in [119] - [125]. This idea provides the main motivation for the project and link the methods of high frequency dynamics and numerical methods.

5.4 Previous Work

With respect to numerical computations, a BEM utilizing Green's functions of finite domains has been developed and applied to various static and dynamic structural problems in Refs. [126] - [132]. The principle of virtual work, a weak formulation of the boundary-value problems of structural mechanics, has been related to BE-formulations for elastic and inelastic problems in [133]. The proper use of Green's functions and modal analysis for BE- formulations of geometrically and physically non-linear structural vibrations have been proposed and presented in [134] - [136].

The use of linear concepts like Green's functions and modal analysis for non-linear problems has been made possible by analogy between the inelastic and non-linear strains and sources of selfstress or eigenstrains acting upon a linear elastic back-ground structure. This elastic multiple-field theory has been referenced in some detail in the previous section. The importance of eigenstrains in elastic problems mainly stems from their application in thermoelasticity. A sate-of-the-art report on Maysel's formula of thermoelasticity has been provided in [25]. In Maysel's formula, thermal stresses are related to the isothermal problem of stresses produced by dummy force loadings. Thus the concept of influence or Green's functions quite naturally comes into the play by using concentrated actions as dummy loadings. The application of Maysel's formula has been extended to dynamic problems including inelastic strains in [3]. The thermodynamic and micromechanical foundation of the proposed eigenstrain analogy for elasto-viscoplastic and damaging, deteriorating materials has been studied in [46], [138], [139]. A review of the numerical aspects of the eigenstrain analogy for physically as well as for geometrically non-linear structural vibrations has been given in [31]. Dynamic processes in structural thermo-viscoplasticity have been reviewed in [140]. Various special problems of vibrations of elasto-plastic, viscoplastic and damaging structures have been treated in [33], [141] - [148]. The dynamic interaction between vibrating elasto-viscoplastic structures and fluids has been studied in [5]. Multi-layered composite elastoplastic vibrations of structures using second order theory have been treated in [6]. The method has been extended to dissipative and elasto-plastic wave-propagation in [34], [151]. Large amplitude vibrations of beams, plates and shells have been studied in [1] - [157].A review on vibrations of multi-layered composite structures including large amplitude vibrations has been presented in [4].

An efficient algorithm for the time-integration of non-linear dynamic systems resulting from FE-computations for rotordynamic problems has presented in [159]. This method has been applied to dynamic systems with a variable mass in [160], [161]. A new version of the substructure method for large non-liner dynamical systems generated by FEM has been developed in [162]. This method again utilizes Green's functions and modal analysis of a linear elastic back-ground system.

The above referenced preliminary work mostly refers to numerical computations. Special emphasis has been devoted to accuracy and convergence of the numerically obtained solutions of non-linear problems. Following Ernst Mach's principle of analogy in natural philosophy, this is achieved by means of the cited analogy to linear mechanical back-ground problems. Hence, the numerical solution of the non-linear problem may be understood as a semi-analytic solution of the adjoint background structure by analogy. The thermodynamic and micromechanical foundation of this analogy has been studied in [46], [138] - [140], where it has been shown that the analogy reflects nothing else than the very physical nature of the problem at the microscale. Due to the semi-analytical type of the computations, symbolic computation has been used frequently in the above referenced preliminary work. Fore a purely symbolic previous work, see [163], where a structural element has been treated within the framework of Eric Reissner's famous sixth and eight-order theories of plates.

Mechanical properties of the engineering structures at high frequencies as well as the rational approaches which are applicable to describe the dynamics of the structures in the aforementioned domain received considerable attention in the previous papers of the members of the group. It has been shown that at high frequencies the engineering structures behave like mechanical systems with a continuous spectrum of natural frequencies and considerable spatial decay, cf. [90], [110], [112] - [114], [122]. For these reasons, for high frequency vibration the structure appears to be a heavily damped infinite body. In contrast to this, at low frequencies the structure has a discrete spectrum of natural frequencies. That is that in principle different approaches have to be applied at low and high frequencies. The problem of how to combine the conventional description of a system at low frequencies with the recently obtained approaches at high frequencies has been successfully solved in [110]. Paper [117] has realized the idea of the FE-description at low frequencies with the integral description at high frequencies. The success of such a modelling allows us to develop this idea and to combine FE-modelling with symbolic computation at low frequencies, on the one side, and the integral description with numerical modelling, on the other side.

The secondary systems of the engineering structures have been shown to act as dynamic absorbers on the primary structure which in the case of high modal overlap provides considerable spatial absorption of high frequency vibration, cf. [90], [110], [112] - [114], [122]. The secondary systems, which are predominantly sensitive electrical and mechanical equipment, "smart" structures etc. may be affected or even damaged, since they absorb vibrational energy at their natural frequencies. This provides the main motivation for considering the high-frequency dynamics of complex structures. Various application to numerous mechanical systems, e.g. engines, spacecrafts, nuclear power plants, electromechanical systems, robots are discussed in papers [165] - [174]. The broad variety of the engineering structures which have been successfully studied permits to hope that the methods developed are of the basic character and may be applied to any mechanical, electromechanical and mechatronical system.

5.5 Cooperations

The principle investigator and his group is closely co-operating with Professor Ziegler (Technical University of Vienna) in the field of nonlinear structural vibrations, and with Professor Palmov and Professor Belyaev (St. Petersburg Technical University) in the field of high frequency vibrations. Since 1993, Professor Belyaev serves as a guest professor at the University of Linz and as an active member of the group. These co-operations are documented in numerous joint publications and they shall be even further intensified in the course of the project, especially the co-operation with Professor Palmov, Professor Belyaev and their co-workers in St. Petersburg. Among others, further co-operations take place with Prof. Zyzkowski (Polish Academy of Science, University of Krakov) in the field of inelastic damping of vibrations, Prof. Hetnarski (Rochester Polytechnical Institute) in the field of thermal stresses, Prof. Librescu and Prof. Heller (Virginia Politechnical Institute) in the field of structural vibrations, Prof. Elishakoff (Florida Atlantic University) in the field of random vibrations, Prof. Vakakis (University of Illinois at-Urbana-Champaign) and Prof Shaw (State University of Michigan at East Lansing) in the field of high-frequency vibrations. The principle investigator and his group have given numerous invited talks on structural dynamics, among them a Hauptvortrag at the GAMM-Tagung 1992 in Leipzig. The principle investigator has organized the Special Session "Non-Linear Dynamics" at the 10th European Conference on Earthquake Engineering, Vienna 1994, and he has co-organized a Mini-Symposium on "Homogenization Techniques" at the GAMM-Tagung 1996 in Prague. Currently he is organizing the Symposium "Mechanics of Smart Structures" at the 35th Annual Technical Meeting of the Society of Engineering Science, 1998.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives and Methods

The interconnection of MBD and FEM analysis represents a marriage a'la mode. In various fields of engineering, like automotive structures, robotics, aeronautics and astronautics, in civil-engineering and in biomechanics one often has to deal with an ensemble of flexible bodies connected by more or less flexible joints. So far, mainly due to restrictions in computer hardware, but also due to a lack of efficient algorithms for a realistic modelling of those structures, only linear elastic components with small deformations have been implemented in flexible MBD systems so far. As has already mentioned before, the problem becomes intractable at high frequencies because of the large amount of the modes excited and the necessity of very fine FE-meshes in order to model short wave deformation.

There is an immense practical need, however, for including physical and geometrical non-linearities in the modelling of the flexible component bodies. Computational simulations of crash-tests for automotive structures, or the simulation of a realistic dynamic behaviour of historical monuments under the action of strong-motion earthquakes, to mention only two examples, bring up the necessity of modelling the component bodies within the non-linear range of deformation.

The main intent of the proposed project is the demand of the high quality of the scientific computations aimed in the algorithmic realisation of such codes as well as their numerical efficiency. The aim of the proposed project is to make use of own experience with the simulation of nonlinear vibrations of singular structural members, see previous work, for the development of algorithms and computer codes for flexible MBD at inelastic deformations. In order to reach the highest efficiency, that is to make use of the merits of the symbolic computations and keep the computational cost on the maximal low level, an "imaginary decomposition" of the structure has to be performed. The components of the structure should have such simple geometric forms that the conventional theories of structural dynamics can be applied. In this case, closed-form solutions may be obtained for each member of the structure and the solution obtained may be considered to be the basic solutions for the component bodies of these particular forms. The considerations therefore will be restricted to the straight bars, beams, rods in torsion, plates etc. Similarly, the interconnections between the elements are realized only in form of classical types joints and pins. The theory of elastic behaviour of such structural members is well developed and can be extended to the presence of imposed distributions of eigenstrains in a straight forward manner, the results being obtained by symbolic computation with relative ease.

Inelastic material behaviour of the structural components eventually will be modelled as it has been done in the previous papers of the group. A single structural member will be represented in the form of a linear elastic background element with imposed dynamic actions which will be modelled by means of the either given external loads or yet unknown distributions of eigenstrains. When FE or BE formulations are applied to such "large" finite elements, then exact convolution integral formulations are obtained and can be evaluated symbolically, where dynamic Green's functions serve as the kernel of the convolution integrals. Eventually, exact stiffness matrices and consistent mass matrices, normal modes, dynamic influence functions for the imposed forces and for eigenstrains as well as influence functions for the quasi-static parts of the solutions will be derived and will serve as describing basic functions.

Following the philosophy of object-oriented programming, these basic functions, characterizing the mechanical behaviour of the separate structural components and connecting elements, will be grouped into classes of objects, and the corresponding hierarchy within the classes will be performed for the sake of factoring out common properties. It will be studied and shown how to combine the classified objects in order to get the whole engineering structure, that is how to impose the kinematic constraints between the component bodies. Solving the problem of the "assembling" the whole structure from the elements, classical principles of MBD will be utilized. These approaches will be critically worked out and modified in such direction that the self-stress analogy will be used in order to allow one to take into account the non-linear material behaviour of the parts of the structure. Briefly speaking, multi-body dynamics will be modified and developed for the case of the imposed eigenstrains. The computer code C++ will be used for the object-oriented language, however use will be made of the translation possibility of the symbolic computation to the above mentioned code. This sort of programming together with the symbolically-obtained basic properties of the structural members should lead to the considerable increasing of the numerical efficiency. It is easy to understand that there exist many ways of the object-oriented modelling, i.e. the merits and shortcomings of each possibility are to be discussed. The governing equations for the whole system, a non-linear dynamic system of ordinary differential equations, should be integrated by means of a time step integration schema. Especially important is the analysis of the influence of the particular non-linear material law of a single component on the dynamic characteristics of the structure. In elasto-viscoplasticity, constitutive equations are formulated as a set of mostly stiff non-linear ordinary differential equations in time for certain characteristic internal variables. These internal variables are connected to the eigenstrains used in the afore mentioned analogy, again by differential relations. In order to keep the complexity of the algorithms to be developed low, the integration of the symbolically obtained equations of motion shall be performed, where possible, together with the integration of the constitutive equations for the eigenstrains. Implicit integration schemes have to be used in general, where the above referenced previous own experience shall be utilized. Various types of inelastic materials shall be implemented via their constitutive equations. This shall be done again using the strategy of object-oriented programming. In the first stage of the development of the inelastic flexible MBD system, only geometrically linearized deformations shall be studied. Systems made of only few components with a rather localized plastic zone due to impact shall be studied as benchmark problems in detail. The advantages of substructuring shall be introduced in an object-oriented manner. Large amplitude vibrations of the component members shall be treated later on.

Use will be made of the principle of locality in structural dynamics which has already been discussed and successfully applied in the previous papers of the group. The mighty of the principle may be easily understood since the principle provides us with mathematical substantiation of the decomposition in structural mechanics. According to this principle, the engineering structure can be decomposed into substructures, and the principle provides us with the governing equation for each substructure and the imposed constraints. Now, when the structure is decomposed, one can apply various methods for the modelling their dynamics of each elements. Some elements, especially elements of simple geometry and classical mechanical objects like rods and plates, may be handled by applying symbolic computation to conventional methods of mechanics. Any complication, e.g. internal material damping, nonlinear effects, local low contact rigidity can be taken into account by means of the eigenstrains or self-stresses. Dynamics of structural members of the complicated form will be settled down by means of FE-analysis or another numerical methods. As mentioned before, all numerical procedures as well classical methods of structural dynamics become inefficient or even fail at higher frequencies. Consequently, integral methods will be applied in the high frequency domain and the results obtained will be matched to the those at low frequencies. In this case the global description of the engineering structures will be obtained for any broad band dynamic loading.

Summarising, the proposed project provides the user with a very flexible and mighty approach which is highly object-oriented and multi-purpose at the same time.

5.6.2 Programme and Schedule

The following schedule refers to the personnel capacity applied for, namely one postdoc, two doctoral students , and two diploma students.

In the *first year*, the post doc will concentrate on developing eigenstrain– based constitutive models of elasto-plastic and elasto-viscoplastic materials in a form suitable for an implementation in the inelastic flexible MBD code to be developed. Special emphasis shall be laid on the models shall be classified and implemented according to the special needs of time-integration of the non-linear constitutive equations, and special benchmark problems of vibrations of single component members with a finite spread of inelastic zones shall be studied in some detail.

Meanwhile, the doctoral students will concentrate on the development of describing functions for the component flexible background members and joints in the presence of eigenstrain, such as exact stiffness matrices and consistent mass matrices, normal modes, dynamic influence functions for the imposed forces and for eigenstrains as well as influence functions for the quasi-static part of the solutions. Especially, the influence of normal forces according to the theory of second order, and the influence of shear and rotatory inertia, both shall be included as complicated effects into the dynamic modelling of component structures in the presence of eigenstrain. As further extension of the catalogue of structural members, multi-layered structures shall be considered.

In the *second year*, the post-doc will concentrate on efficient time-integration of the equations of motion when the inelastic constitutive equations are included. Various integration methods known from elastic flexible MBD systems shall be tested with respect to their suitability in the presence of dynamic sub-systems characterizing eigenstrains produced by inelastic strains. Furthermore, the postdoc shall start with an computational application of integral formulations to component members in the high frequency domain and the inelastic results obtained should be matched to the those at low frequencies.

The doctoral students will study and implement various formulations of assembling the flexible component members in the presence of eigenstrain to MBD systems in an object-oriented manner, and the resulting computer-codes shall be tested with respect to computational efficiency using some benchmark problems with few flexible bodies known from the literature on elastic MBD.

In the *third year*, the post doc will continue his work on high-frequency vibrations in the direction of more complex structures with advanced constitutive equations including material damage. With respect to the domain of lower frequencies, he will deal with an implementation of his results on non-linear constitutive modelling to the flexible MBD-system in the presence of eigenstrain. He also will study the recent advances of sub-structure synthesis on inelastic flexible MBD.

The doctoral students will deal with the algorithmic implementation of the latter results in an object-oriented manner to the flexible MBD system and with an optimization of the computer codes developed. Moreover, they will co-operate with the post doc in matching the results of the low frequency and the high-frequency computations for the sake of global description of the MBD system for broad band dynamic loading.

In all three years, the diploma students will support the work outlined above by various test computations and programming work. One of these diploma students will concentrate on computational aspects of the flexible MBD system, the other on the computational application of the locality principle and of integral formulations in the higher frequency domain.

It is understood that this schedule can only be considered to be tentative, where the emphasis put on different aspects may change continuously, depending on the experience gained and on new developments in the literature.

5.7 Integration with the SFB

From the proposed work, it is quite obvious that we will cooperate with the group of Prof. Engl in the aspects of deriving the distributions of eigenstrain characterizing the inelastic behaviour of structures. This will be because in both, our low and high frequency computations, we start from integral equations of the convolution type, where the computation of eigenstrains corresponding to the real physically non-linear behaviour may be considered as an indirect problem.

It is also clear that the cooperation with Professor Langer and his co-workers should be rather intensive, since inelastic MBD systems so far suffered from a lack of efficient numeric solvers, and since our project will utilize FE techniques.

We hope that our project should gain a high benefit from the projects 1 and 2, since we will need methods of efficient symbolic computation in all of the stages of our computations, especially for introducing the non-linear kinematic constraints and for the decisions to be automatically performed in the process of assembling the component structures to an ensemble of inelastic bodies.

Last but not least, it can be well recognized in MBD there is an urgent need of using the graphical tools to be developed in Project Area III.

In summary, it is anticipated that our project is well embedded into the whole project.

5.8 Detailed Budget

5.8.1 Requested Personnel

As outlined in Section 5.6.2, the work proposed in this project requires at least one postdoc, two doctoral students and two diploma students.

At the time this proposal is applied for, we plan to hire the following persons for these positions:

Dipl.-Ing. Dr. Walter Brunner should be employed as postdoc; he has finished his PhD under the direction of Prof. Irschik in the field dynamic elasto-plastic solid-fluid interaction. Dr. Brunner is outstanding expert in the field of computational mechanics and he is well qualified for the theoretical work and computational work proposed in this project. As a member of his father's group consulting engineers in Steyr, he is currently successfully working on various industrial projects.

The two positions for doctoral students will be filled by Dipl.-Ing. Markus Hochrainer and Dipl.-Ing. Harald Bürbaumer. Dipl.-Ing. Markus Hochrainer has performed his diploma thesis under the direction of Prof.Irschik in the field vibrations of composite shells, while Dipl.-Ing. Harald Bürbaumer has performed his diploma thesis under the direction of Prof.Irschik in the field of thermal stresses in shells. Both doctoral students currently are finishing a master's curriculum at the University of Loughborough, UK.

The two diploma students to be supported by the project would be selected at the time the project actually starts.

For the schedule of the proposed work, see section 5.6.2.

5.8.2 Equipment

We apply for one high-performence Unix-Workstation and two working places according to the computer plan of the whole SFB. These are needed for all implementations where software from other projects, especially from the groups of Prof. Buchberger, Prof. Langer and Prof. Engl is needed. It is emphasized that computations at the very frontier of Computational Mechanics will have to be developed and tested in the project, where the existing hardware of the institute can only be used in a limited way.

5.8.3 Funds for Travel to Scientific Cooperations and to Conferences

Funds for guest scientists, especially for a further intensification of the co-operation with Professor Palmov and Professor Belyaev and for other costs like software and publication costs are contained in the coordination project.

5.8.4 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.5 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.8.6 Curriculum Vitae and Bibliography

The curriculum vitae and list of publications of each participant of this project can be found in Appendix

5.9 Curriculum and Bibliography

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 10
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	540.000	10.000	25.000				1.723.000
2	1.148.000		10.000	25.000				1.183.000
3	1.148.000		10.000	25.000				1.183.000
Summe	3.444.000	540.000	30.000	75.000				4.089.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 10

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungsstätte (Institut)	% Arbeitszeit für Projekt	beratend	Anfang im SFB	Beschäftigungsverhältnis	Beschäftigungsausmaß
114	115	116	117	118	119	120	121
Irschik Hans, Dipl.-Ing. Dr., O.Univ.-Prof.	Technische Mechanik	Mechanik	20%		1. Jahr	Univ.-Prof.	voll
Holl Helmut, Dipl.-Ing. Dr., Univ.-Ass.	Technische Mechanik	Mechanik	10%		1. Jahr	Univ.-Ass.	voll
Baldinger Martin, Dipl.-Ing., Univ.-Ass.	Technische Mechanik	Mechanik	10%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 10

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Brunner Walter, Dipl.-Ing. Dr.	Technische Mechanik	Mechanik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Bürbaumer Harald, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
	100%	1	Hochrainer Markus, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Brunner Walter, Dipl.-Ing. Dr.	Technische Mechanik	Mechanik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Bürbaumer Harald, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
	100%	1	Hochrainer Markus, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Brunner Walter, Dipl.-Ing. Dr.	Technische Mechanik	Mechanik	100%		1. Jahr	PostDoc	voll
Mag./DI	100%	1	Bürbaumer Harald, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
	100%	1	Hochrainer Markus, Dipl.-Ing.	Technische Mechanik	Mechanik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 10

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Octane, 256 MB, 2 GB	400.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	400.000			Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 10

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 11: Title will be announced later

5.1 General Information

Title : Title will be announced later

Field of research : Will be announced later

Principal investigator : N.N.
Institute of Mathematics
Johannes Kepler University Linz

5.2 Abstract

This project is reserved for a later application by the successor to the chair for mathematics with emphasis on analysis (Institute for Mathematics). **Herewith the SFB applies for the possibility that the successor to the chair for mathematics can apply for this project immediately after accepting the call.**

Project 12: Sophisticated Data Distribution Systems

5.1 General Information

Title : Sophisticated Data Distribution Systems

Field of research : Computer Graphics and Parallel Processing

Principal investigator : Univ.-Prof. Dr.-Ing. Jens Volkert
Systems Programming Institute
Johannes Kepler University Linz

Co-investigator : Univ.-Prof. Dr. Ulrich Langer
Institute of Mathematics
Johannes Kepler University Linz

5.2 Abstract

The subject of this project is the development of a sophisticated data distribution system for parallel unstructured mesh computations and, in particular, for Domain Decomposition (DD) solvers which put additional requirements onto the decomposition. In this sense, the subject is part of an overall solution process of partial differential equations (pde) continuing with the topics discussed in projects 5 and 8.

Nowadays computations with large unstructured meshes are performed on parallel computers because of size considerations and computational requirements. Using distributed memory machines the user is faced with the non-trivial problem of data distribution. Meshes must be partitioned across the local memories of the processors in such a way that a good load balancing is achieved and interprocessor communication is kept minimal. The situation is even more complicated if DD solvers are to be applied, since the definition of "well shaped" subdomains is required additionally.

It is known that optimization of these issues involves the solution of NP-complete problems [8], so up to now researchers have developed heuristics that yield reasonable, yet suboptimal results [14, 16, 24, 29]. Using virtual shared memory machines data distribution is also relevant since a good distribution promotes data locality and so improves overall performance. The decision about the efficiency of a distribution is hard to find because it depends on several factors, including the suitability of a distribution algorithm for the given mesh, the problem to be solved, and the target computer. Thus the data distribution procedure is not a fully automatic, but an interactive process, which should be supported by appropriate tools. With such a tool the application user can create and evaluate several distributions and determine the best one for his or her purpose.

The result of our research is a software environment that allows the user to create efficient distributions of graph-based data structures (including unstructured 2D and 3D meshes) easily and quickly. Based on such a distribution, a DD-data structure, which serves later on as input for parallel computations, can be generated. Furthermore the environment offers enough flexibility in order to provide seamless combination with problem solving environments for parallel scientific computations, such as with those developed in projects 5 and 8.

The key to efficient data distributions is the integration of state-of-the-art distribution algorithms into the environment. On the one hand we will integrate some efficient algorithms developed by other researchers, on the other hand we have located deficiencies in some of today's best algorithms and we will develop alternative algorithms which give better results for certain classes of graphs.

The most important contributions to simplicity of the data distribution process are a user-friendly graphical user interface and a flexible and extensible input/output interface. Graphical front-ends for the best available distribution algorithms allow easy and fast creation of distributions, which is essential for experiments. Results will be stored in a distribution workspace where they can be evaluated by means of graphical displays. The displays are based on distribution quality metrics and use colored 3D charts in order to give the user a first estimation on how efficient a given parallel application will behave with a

given distribution. Furthermore all distributions in the workspace can be compared graphically in order to find the best one at a glance. The graphical displays are based on distribution quality metrics. Since the variety of unstructured mesh computations and parallel computer architectures makes the definition of universal quality metrics impossible, we will examine the applicability of known metrics for different applications and parallel computers, and investigate new metrics that consider characteristics of recent parallel numerical codes and so yield more accurate estimations.

In particular, numerical algorithms based on DD methods require a decomposition into "well shaped" subdomains rather than a simple distribution of the mesh. The generation of reasonable decompositions of domains into subdomains, especially in the case of complicated, i. e., non-convex, geometries, requires new ideas. The visualization and evaluation of the decompositions generated automatically are of major importance. A new kind of DD preprocessing which defines subdomains based on the partition of the mesh will be necessary. Hereby, the requirements originating from the numerical point of view may influence considerably the criteria for evaluating a decomposition. The availability of a 3D Domain Decomposition preprocessor would allow us to choose from a wide range of numerical algorithms including global parallelized solvers, DD solvers or even solvers applying coupled finite element - boundary element discretizations.

In order to provide seamless combination with problem solving environments the data distribution system requires a modular software architecture with maximum flexibility. We plan to exploit the facilities of dynamic linking in today's operating systems in order to allow the user to configure the system with selected components that are composed to a running system at program startup. User-specific components will be built upon pre-defined components that offer object-oriented programming interfaces and so provide customization with minimum effort.

In a case study we will combine the environment with *NETGEN* [26] and *FEPP* [25], a problem solving environment developed in projects 5 and 8. Since the numerical algorithms benefit from services provided by a data distribution system at several stages, they represent an ideal experimental platform. During this case study we will develop several special-purpose functions for *NETGEN* and *FEPP*. The result will be a user-friendly environment for generating DD-data for complex geometries which are the input for DD solvers for partial differential equations in two and especially in **three** dimensions running on massively parallel computers. Experiences gained through this case study will be brought back into our environment and so promote its flexibility for further applications.

5.3 State of the Art

Up to the present only few data distribution systems have been developed that integrate a number of distribution algorithms with graphical evaluation facilities.

TOP/DOMDEC [5] is regarded as a state-of-the-art mesh partitioning environment. It offers algorithms for initial partitioning of graphs and for non-deterministic optimization of graph partitions. Optimization of partitions can be based on various single or combined quality metrics. The system does not support separate mapping of partitions to machine topologies. It shows partitions by drawing mesh elements with different colors and provides partition evaluation by means of various metrics. These cover also computations on data structures that are derived from the mesh representation, for example, stiffness matrices. From today's point of view, most algorithms provided by TOP/DOMDEC are obsolete, because since 1993 several better algorithms have been developed. This is not a drawback of the system itself since algorithms can be replaced. Although based upon IRIS GL, the evaluation displays are of quite poor quality. For example, the interconnectivity map is a monochrome 2D display, which hides valuable information from the user (e. g., message sizes or hop numbers). Finally, evaluation of partitions does not consider the processor topology of the given target computer.

DecTool [3] is a tiny data distribution tool and part of the *ELLPACK* [15] environment. It offers several built-in algorithms for partitioning of graphs and mapping of partitions to arbitrary machine topologies. Partitions can be shown in two and three dimensions and even altered by means of mouse operations. From today's point of view, DecTool's algorithms are partially obsolete. Unlike

TOP/DOMDEC, DecTool does not support replacement of algorithms since they are statically linked to the tool. The partition display is quite simple since it is implemented upon X11 directly. View manipulation is not supported, evaluation facilities are missing.

DDT (Domain Decomposition Tool) [6] is a very simple data distribution tool. It has six built-in algorithms that are not comparable with today's distribution algorithms. The tool also lacks arbitrary view manipulation and provides very limited evaluation facilities.

All the tools mentioned above are applied to given meshes and generate a partition of these meshes, which is not sufficient if subdomains, as they are required for DD algorithms, are to be defined. The latter task has only been solved for the 2D case [9] and for simple 3D model problems. Thus, completely new methods for defining subdomains which fulfill additional regularity requirements have to be established.

5.4 Previous Work

In the last years the research group of the principal investigator collected considerable experience with data visualization [27], data distribution for parallel processing, and the combination of both topics [19]. Previous work focussed primarily on graphical support for data-parallel programming languages, which offer facilities for explicit data distribution. Thus we are familiar with visualization concepts and techniques for distributed data structures and we will apply them to unstructured meshes in this project.

GDDT (*Graphical Data Distribution Tool*) [4] is a prototypical tool for source-based visualization of distributed data structures at the level of data-parallel programming languages, such as High-Performance-Fortran (HPF) [7]. It also offers visual programming facilities by allowing interactive and graphical specification of distributed data structures and automatic source code generation. Finally, due to the importance of visualization of run-time information, the tool provides an open interface to external compilation systems [2] and run-time environments. A few visualization tools are provided that utilize data gained from this interface.

Development of GDDT started within the scope of the project *CEI-PACT* (working package 1, GZ: 308.927), so the current version supports the HPF predecessor *Vienna Fortran* [30]. Since this language covers a superset of HPF's facilities, the tool may also be used for visualization of HPF data structures. GDDT's tool palette can be split up into three interacting groups:

- *Specification Tools.* At the computational space level data structures and their distributions can be specified interactively. The *data structure editor* (DSE) provides a workbench for the Vienna Fortran programmer allowing him or her to create program-units, parameters, distribution types, processor shapes and data arrays by means of a sensible combination of text and graphics editors. Fine-tuning of distributions is supported by the *value editor*, which allows modification of parameter array values (e. g., by means of the *block size ruler*).

- *Exploratory Tools.* This category considers both source text, compile-time and run-time information and supports facile navigation in large data arrays and processor shapes. A number of tools allows fast and easy exploration of *mapping relationships* between computational space and processor space. Array representations can be scaled, translated, rotated and sliced. Mapping relationships can be shown at the level of single array elements, element groups, slices or distribution blocks. Besides source text information also compiler-generated information such as overlap descriptions can be shown and modified. In addition to static facilities a dynamic display is provided where sequences of distributions can be replayed by an *animator tool.* This tool can also be supplied with run-time information gained from GDDT's external interface.

- *Estimation Tools.* Assessment of data distributions takes place at the processor space level and is supported by a few graphical displays showing the effects of a data distribution on load distribution and inter-processor communication before the program run [6].

  The *data load diagram* and the *overlap communication display* produce meaningful representations which facilitate perception of patterns, relationships and anomalies. Both processor loads and communication volume are shown by means of bar heights. Considerable differences in heights indicate inefficiency due to load imbalance and processor idle times respectively. Both displays are scalable with respect to processors by means of a slicing facility.

On the other hand, the co-investigator has collected considerable experience with DD preprocessing in several projects:

- *DD Preprocessing in 2D.* For the two dimensional case there exists a complete numerical software package including the preprocessor *ADDPre* [9] and the parallel code FEM⊗BEM [10] for solving partial differential equations arising in magneto-statics and linear elasticity. Examples can be found, e. g., in [11, 13]. Figure 7 shows the interactions between the components of the preprocessor

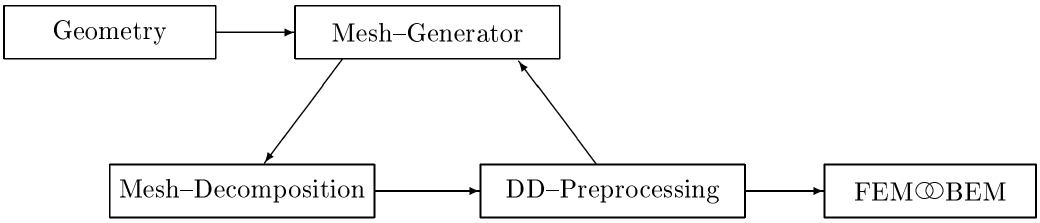

Figure 7: The components of the 2D Domain Decomposition preprocessor.

  which delivers, finally, the input for the parallel DD code FEM⊗BEM. The results of numerous numerical experiments, including tests of several strategies of data decompositions have to be analyzed and extended for the much more challenging 3D case.

- *3D Tools.* For the 3D case, two advanced mesh generators, *NETGEN* [26] and *NAOMI* [17], are available. They work for a wide range of 3D objects and produce unstructured meshes. These meshes are the basis for 3D Finite Element calculations using the numerical software package *FEPP* [25], which can solve problems arising, e. g., in structural mechanics. The extension of these codes, e. g., to wider classes of problems as magnetic field calculations, is the topic of current research activities.

5.5 Cooperations

Current cooperations with the research group of Prof. G. Wittum (ICA III) in Stuttgart and the SFB 393 (speaker Prof. A. Meyer) in Chemnitz will be continued and intensified.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

This section describes objectives of the project that are concerned with general functions of the environment. Additional objectives relating to the cooperation with the research group of projects 5 and 8 are detailed in Section 5.7.

- *Visualization of arbitrary graph structures.* A basic facility is the visualization of two- and three-dimensional graphs given in various formats. The environment will support a range of popular mesh formats, among them the file format of *MSC/NASTRAN* [21], a finite element package with many element types, and the the formats being used by the sofware packages NETGEN, NAOMI and FEPP developed in projects 5 and 8. Additional formats will be supported whenever test meshes in these formats are available. Users shall be able to configure the environment with their custom mesh formats without having to re-build the whole environment.

- *Implementation of a Distribution Methodology.* The environment prescribes a data distribution methodology to the user that consists of two steps: partitioning and mapping.

  Partitioning decomposes the input graph into a number of subgraphs where the subgraphs should be equal in size and the boundaries between subgraphs should be minimum. This step is entirely machine-independent and yields a partition. During *mapping* the partition graph is mapped to the topology of a given parallel computer such that adjacent subgraphs of the partition graphs are placed to adjacent processors in the parallel computer. Without a careful mapping event good partitions may cause message transfer delays and network congestion on several parallel computers. In order to promote efficiency on *all* computers, a machine-dependent mapping should be applied to a partition [28]. In this proposal the combination of a partition with a mapping is referred to as a *distribution*.

  The environment shall offer several state-of-the-art algorithms for partitioning and mapping. The partitioning algorithms include developments of other researchers (such as *Chaco* [14], *Jostle* [29], *Metis* [16] and *Scotch* [24]) and own developments. The mapping algorithms include the popular *CPE* heuristic [12], which supports hypercubes and 2D and 3D mesh/torus architectures. The ongoing development of partitioning and mapping algorithms, which is driven by the development of parallel unstructured mesh applications, and rapid changes in parallel hardware technology pose additional requirements to our data distribution environment: flexibility and modularity. Similar to mesh formats, algorithms must be replaceable if they are obsolete or inappropriate for the given application or target computer. On the other hand, algorithms shall be integrated in the environment seamlessly such that they are easy to use. This is an important issue since most algorithms offer numerous options for fine-tuning.

- *DD Adaptation.* The DD solvers discussed in projects 5 and 8 are based on locally uniform properties, including material coefficients, of the pde. Thus, changes of such properties imply an a-priori "material"-based decomposition of the geometric domain. The special situation, that any further partition is only admissible if it is a sub-partition of the a-priori given decomposition, brings about several new requirements for the partitioning algorithm in order to finally obtain a load balanced decomposition. These requirements include, e. g., the decomposition into arbitrary numbers of subdomains. These special features related to DD methods are not realized by existing tools, which only work for certain numbers of subdomains (powers of 2) and do not take into account changing properties of the pde.

  Additionally, advanced DD based numerical algorithms require a decomposition into "well shaped" subdomains rather than just a distribution of a given mesh. Starting with a mesh-based decomposition we look for a decomposition into subdomains which guarantees load balanced numerical calculations. The tool which is to be developed should determine automatically smooth subdomain interfaces, which then define the subdomains. In general, this problem does not have a unique solution so that an interactive evaluation of admissible solutions may be advantageous, i. e., the visualization of the results is indispensable. Furthermore, the task involves the reduction of the full 3D refinement information to 2D-data attached to the interfaces. These information has to be sufficient for the parallel mesh generator, such that it can reproduce qualitatively the full 3D mesh which has to be conform across the subdomain boundaries.

- *Exploration and evaluation of distributions.* Our environment shall provide exploration and evaluation of mesh distributions and DD partitions through graphical displays. The displays use 3D color graphics in order to visualize distribution quality metrics, which give users an accurate estimation about the *efficiency* of a distribution and so lets them find the most suitable algorithms for their applications and their parallel computers in shortest time. Existing data distribution systems provide only facilities for the evaluation of single distributions. With our environment the user shall be able to compare several distributions with respect to a given metric in one picture and so shall be able to choose the best distribution at a glance.

5.6.2 Methods

In the following we outline our methodology for this project. The explanations follow the structure we used in the previous subsection.

- *Visualization of arbitrary graph structures.* This task can be divided into three subtasks: development of appropriate visualization techniques, definition of a general-purpose internal representation for arbitrary graphs, and realization of the visualization. Concerning the first subtask we will use a technique that associates graph entities, i. e., vertices and edges, with *properties*. For example, the number of edges incident to a graph node may be such a property. Property values are drawn by means of different sizes or different colors. The visualization of a graph with respect to given properties shows the distribution of property values across the whole graph in one picture. If a property corresponds to a distribution quality metric, the user can easily detect bottlenecks in a given distribution.

  The internal representation of graphs must be general enough to cover various mesh types. For this, an object-oriented design shows promising. On the other hand, it must lead to low-overhead and light-weighting objects structures in order to ensure efficiency of the environment when large meshes are processed. On the contrary, objects must store enough information to allow efficient graph visualization and distribution evaluation. In order to reach these goals preliminary developments, i. e., prototypes, must be evaluated and re-designed repeatedly.

  The actual visualization facilities must be realized through the use of a powerful graphics standard. On the one hand, such a standard provides high-level building blocks, which simplify implementation work, on the other hand it promotes portability across computers with different graphics capabilities. We intend to use *OpenGL* [23] since implementations are available in hardware and software form. So the environment can be used with high-end and low-end workstations.

- *Implementation of a Distribution Methodology.* An environment that claims to offer state-of-the-art algorithms for partitioning and mapping must exhibit a modular architecture since in the area of distribution algorithms fast progress is made and obsolete algorithms must be replaced with better ones. Furthermore, users might want to customize the environment with their favorite algorithms instead of working with an overloaded, monolithic environment. In order to reach the goal of modularity we plan to exploit facilities of today's operating systems, primarily *dynamic linking*, which is used to build complex software systems from several simple components at program startup or runtime. For this, each third-party algorithm will be equipped with a small interface that allows the environment to identify such a component at startup and to plug it in at the right location. This interface must be easy to understand, such that developers are willing to integrate their algorithms into the environment.

  A drawback of all available partitioning and mapping algorithms is the lack of appropriate user interfaces. Although they offer a variety of options, for example, different bisection or refinement strategies, they supply the user only with command line interfaces. Such interfaces are inappropriate for the use in an environment where users should be able to make quick experiments and incremental changes in order to create good results in shortest time. Thus we will define graphical user interface standards for partitioning and mapping algorithms, which are based on dialog windows containing lists, pop-up menus, checkboxes and push buttons. Each interface consists of a general part and a specific part. The general part ensures a uniform appearance of the user interfaces, the specific part provides user interface elements for algorithm-specific facilities. This separation has two advantages: through the uniform appearance users become familiar with algorithms earlier, and developers can build upon a standard and must make only algorithm-specific adaptations. Finally, we will validate our standards through the implementation of user interfaces for all currently available partitioning and mapping algorithms, including Chaco, Jostle, Metis, Scotch and CPE.

- *DD Adaptation.* In order to meet the requirements to the input data of DD algorithms, several modifications and extensions of state-of-the-art algorithms for mesh partitioning are necessary.

  For the 2D case, we have developed heuristics like moving front techniques, shifting of the cutting value defining the partition within the Recursive Spectral Bisection algorithm (RSB) [1] and other algorithms, which allow arbitrary decompositions of complex geometries. These ideas have to be generalized and new methods have to be established for the more complex 3D case. Here, non-convex geometries, which may lead to disconnected subdomains, and the validation of the admissibility of a decomposition may cause serious problems.

  Besides the modification and extension of existing mesh partitioners the DD adaptation brings up a completely new task – the definition of subdomains. Here, the goal is to define a load balanced decomposition into regular subdomains, where each subdomain is defined by a minimum number of smooth boundary faces. A face is called smooth, if there exists a simple transformation mapping the face onto a plane reference face. Such simple surface elements could be described, e. g., by B-splines.

  We look for a minimum number of faces describing a subdomain since it guarantees the smoothness of the subdomains. The latter has great impact on the performance of DD solvers, especially on the construction and behavior of interface preconditioners for the Schur-complement. Without this restriction, i. e., for global parallel solvers, it would be sufficient to generate a partition of the mesh. In contrast, DD methods offer a wider choice of both, discretization methods, e. g., coupling of finite and boundary element methods, and solution methods.

  The generation of DD-data involves, additionally, the definition of reduced refinement information attached to the interfaces. These refinement data have to be defined such that the parallel mesh generator discretizes each subdomain in a desired way. In particular, the mesh generated in parallel has to be load balanced and conform across the subdomain boundaries.

  We conclude, that the generation of DD-data is a complex task which brings up new requirements compared to simple mesh partitioning. Furthermore, the goal of generating subdomains instead of mesh partitions may change the criteria for evaluating the quality of mesh partitions.

- *Exploration and evaluation of distributions.* Distributions that have been created by available algorithms can be explored and evaluated by means of graphical displays. The displays visualize various distribution quality metrics, either together with the mesh or in separate charts. In order to produce usable estimations, quality metrics must consider several factors, including characteristics of the application code and properties of the parallel computer. The variety of mesh applications and parallel computer architectures make this kind of performance prediction become a difficult task [28].

  At first we will design exploration and evaluation displays that visualize known quality metrics, for example, the average number of cut edges between the subgraphs that a partition defines. Through the association of such metrics with the graph representation (as properties, as previously mentioned) we obtain a flexible exploration display, where users can detect bottlenecks easily and quickly. Although this methodology looks straight-forward, it must be noted that quality metrics as described above are partially complex, such that they are difficult to visualize in appropriate ways. Furthermore all these metrics are only useful in connection with *explicit* mesh computations [5], i. e., computations that are directly concerned with mesh elements, vertices or edges. Examples of such nodewise or edgewise computations are molecular dynamics codes [4] and computational fluid dynamics codes [22], respectively. Besides explicit computations, which are generally quite simple, there are *implicit* mesh computations. They are not directly concerned with mesh entities but with a derived data structure, for example, a matrix. Distributions for such computations are difficult to rate because of the variety of equation solver strategies (direct or iterative, differently for the interior and the interface system) and analysis methods (static or dynamic, linear or non-linear).

Thus, in the second part we will investigate representative distribution quality metrics for important implicit computations, where we need close cooperation with developers of such application codes, for examples, members of other projects. During these cooperations and during the development of evaluation facilities for explicit computations we will collect valuable experiences in order to define useful quality metrics for implicit computations and to visualize them through appropriate graphical displays.

5.6.3 Programme and Schedule

In the following we divide the project into six overlapping phases, which are worked out by members of the basic staff and three additional scientists.

(1) Analysis of the problem domain: unstructured mesh applications with explicit and implicit computations, distribution algorithms, mesh types and widely-used mesh formats (C–F). Investigation of appropriate quality metrics for implicit computations using experiences from cooperations and measurements (C, D).

(2) Design of the system architecture: definition of replaceable components (besides mesh formats and distribution algorithms) (D). Implementation of component concept, which should be portable across several operating systems (E).

(3) Design of a generic internal representation for arbitrary mesh types (D). Implementation of mesh readers for the NASTRAN, NETGEN and NAOMI data formats (E, F). Implementation of the internal representation and evaluation with large meshes through runtime and memory measurements (E). Design of the graphical user interface standard for third-party partitioning and mapping algorithms (D). Implementation of the standard with specific extensions for all available algorithms (Chaco, Jostle, Metis, Scotch and CPE) (E). Extension of one or more distribution algorithms for consideration of an a-priori given decomposition corresponding to changing properties of the pde (e. g., materials) (F).

(4) Development of visualization techniques for exploration and evaluation displays. Implementation of the techniques via user interface prototypes and evaluation of the prototypes (including re-designs) (D, E).

(5) Development of a DD preprocessing tool which generates DD data (partitions) from distributed meshes. Coupling of *NETGEN* and *NAOMI* with the environment and evaluation through application (F).

(6) Evaluation of the entire environment with various unstructured mesh applications involving explicit computations and DD applications (D, E, F). Evaluation of the distribution evaluation displays (D, E) and revision of quality metrics for implicit computations and development of appropriate displays (D, E).

(7) Supervision of (1), (2), (3), (4), (6) – (A).

(8) Supervision of (5), (4), (3) – (B).

The chronical order of the plan of work as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 ... 6	7 ... 12	1 ... 6	7 ... 12	1 ... 6	7 ... 12
(1)	C – F						
(2)	D, E						
(3)	D, E, F						
(4)	D, E						
(5)	F						
(6)	D, E, F						
(7)	A						
(8)	B						

The symbols A, B, C, D, E and F are assigned to the following persons working on the corresponding problems:

A = O.Univ.-Prof.Dr. J. Volkert (proposer of the project),

B = O.Univ.-Prof.Dr. U. Langer (co-proposer of the project),

C = Dipl.-Ing. R. Koppler (co-worker from the basic staff),

D = Dipl.-Ing. S. Grabner (applied full time post doc position),

E = N.N. (applied doctoral position for a Ph.D. student paid as a 2/3-job),

F = Dipl.-Ing. M. Kuhn (applied full time post doc position).

5.7 Integration with the SFB

The software environment we will develop has to be considered as a part of an overall solution process of partial differential equations. So, this project and the work of projects 5 and 8 share a number of facilities. Parallel numerical algorithms, in particular DD methods, require as input the decomposition of the data describing the problem. The performance of the algorithms depends heavily on the quality of the decomposition with respect to attributes as geometric regularity of the subdomains, load balance after parallel mesh generation and the mapping between subdomains and processors. That means, a high-quality preprocessing, including visualization and evaluation of the results, is very important if DD methods are to be applied and it is, in this sense, an equally rated part of the solution process. One of the project goals is the seamless combination of both, single components and the general-purpose environment with the numerical software developed in projects 5 and 8. The interactions promote the flexibility and applicability of the software to be developed.

Development in cooperation with projects 5 and 8 will focus on the following aspects:

1. *Processing of three-dimensional meshes.* With the help of our environment enhanced visualization of 3D meshes and 3D mesh distributions will be feasible. For this, we will develop an I/O module for our environment that understands the mesh formats and geometry describing formats used by *NETGEN*, *NAOMI* and *FEPP*. As a result, users of these numerical software packages can exploit all visualization capabilities provided by our environment.

2. *Efficient distribution of meshes.* Currently mesh distribution in ADDPre is performed by applying the RSB partitioning algorithm [1]. The original algorithm was extended in order to consider material boundaries such that one processor does not compute solution values for more than one material.

   From today's point of view the RSB algorithm must be regarded as obsolete since it suffers from high computing times and the produced partitions are of low quality compared to the results of state-of-the-art algorithms. Since we have access to some of the best algorithms available today, we will extend one of them such that it considers material boundaries during partitioning. The implementation will be enhanced with a graphical front-end and integrated in our environment.

3. *DD Preprocessing.* While the conversion of triangular meshes into DD-data can be performed by a quite simple algorithm in the 2D case, the conversion process from tetrahedral meshes into DD data, i. e., the 3D case, is much more complex. Such algorithms are based on advanced computer graphics.

The results of this cooperation will enhance both *FEPP* and our environment. The combination of both environments yields a powerful system for solving partial differential equations on 3D unstructured meshes. A working session with this system could look as follows:

1. Load the initial decomposition, possibly just the description of the geometry of a given problem, into *NETGEN*.
2. Let *NETGEN* create a tetrahedral mesh from the given data.
3. Use our environment to graphically explore the tetrahedral mesh and to create an efficient distribution for the given parallel application code and the given target computer. For this purpose the distribution additionally considers material boundaries.
4. Use the DD preprocessor to create a refined domain decomposition from the given tetrahedral mesh.
5. Go to step 2 until quality of domain decomposition is satisfactory.
6. Start parallel application (e. g., parallel version of *FEPP*): send subdomains to processors, let them create meshes and compute solution in parallel. Efficiency of the parallel computation is promoted by the use of state-of-the-art partitioning algorithms augmented with the DD adaptation. The extended algorithms consider characteristics of the given application and thus help to utilize the parallel resources optimally.

5.8 Detailed Budget

5.8.1 Requested Personnel

As mentioned in Section 5.6.3, two full-time post doc positions and one doctoral positions for some Ph.D. student, which is paid as 2/3 job, are required for this project.

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 1 powerful graphic workstation including special graphic software, which amounts to **ATS 400.000,–** in the first year.
  For visualization purposes and interface development a high quality graphic is recommanded. Additionally, the distribution algorithms require high computational power.

- 2 workstations, which amounts to a total of **ATS 140.000,–** in the first year.
  These workstations serve as additional workplaces for the employees of this project.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighboring countries, we request a budget of **ATS 25.000,– per year**. This will cover the cost for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 12
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.312.000	540.000	10.000	25.000				1.887.000
2	1.312.000		10.000	25.000				1.347.000
3	1.312.000		10.000	25.000				1.347.000
Summe	3.936.000	540.000	30.000	75.000				4.581.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 12

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Volkert Jens, Dr.-Ing., O.Univ.-Prof.	Systemprogrammierung	Informatik	30%		1. Jahr	O.Univ.-Prof.	voll
Koppler Rainer, Dipl.-Ing., Univ.-Ass.	Systemprogrammierung	Informatik	10%		1. Jahr	Univ.-Ass.	voll
Langer Ulrich, Dipl.-Ing. Dr., O.Univ.-Prof.	Numerische Mathematik	Mathematik	5%		1. Jahr	O.Univ.-Prof.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 12

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungsstätte (Institut)	% Arbeitszeit für Projekt	beratend	Anfang im SFB	Beschäftigungsverhältnis	Beschäftigungsausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Grabner Siegfried, Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
	100%	1	Kuhn Michael, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Grabner Siegfried, Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
	100%	1	Kuhn Michael, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Grabner Siegfried, Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
	100%	1	Kuhn Michael, Dipl.-Ing.	Numerische Mathematik	Mathematik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 12

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Octane, SI Grafik, 128 MB, 2 GB	400.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	400.000			Summe	140.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge
Projektteil 12

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000				
Summe	10.000	Summe	25.000	Summe		Summe	

Project 13: High Performance Visualization of High-Dimensional Data

5.1 General Information

Title : High Performance Visualization of High-Dimensional Data

Field of research : Visualization: acceleration of rendering, parallelization of algorithms, steering; monitoring and steering of simulation

Principal investigators : Univ.-Prof. Dr. Jens Volkert
Systems Programming Institute
Johannes Kepler University Linz

5.2 Abstract

Visualization is one of the main components of scientific computing. Usually, huge datasets of vectors and scalar functions in 3D-space have to be handled. In many cases these data are time dependent and therefore their change over time must be visualized by animations. In conventional visualization packages some often used methods are not efficiently enough implemented to generate visualizations and/or animations of such data volumes within a reasonable time frame. One main goal of this project is to solve or at least to reduce this problem. Several approaches will be investigated: the use of novel results from computer graphics research (image based rendering) to accelerate the visualization of data, the parallelization of time-consuming visualization algorithms and the automatic steering of the image quality during the generation. In a second part of the project the obtained results will be integrated in the visualization environment GRAPE. The benefit of using an existing environment is the availability of current algorithms. Additionally, we will add a monitor, which will not only support the simultaneous execution of simulation and visualization on parallel hardware, but will also utilize the steering of both.

5.3 State of the Art

In order to understand computer simulations of complex phenomena faster, several visualization techniques have emerged as favourites for analysis of large datasets: function-mapped surfaces, function-mapped cutting planes, and iso-surfaces are widely used for viewing scalar values [40]. The favourites for analysis of vector fields are particle traces and topology extractions. The major limitation of current visualization systems are the relatively low bandwidth of information from the workstation to the human, the inability to view or even modify the accuracy of the rendering, the inability to match the human cognitive capabilities, and the ineffectiveness of visualizing high dimensional data. Efforts to overcome such limitations are under investigation in certain fields of visualization. One way to accelerate the rendering or the creation of animations is the use of expensive high-end graphics supercomputers. Another possibility is to improve existing algorithms for software solutions to speed-up the generation of images and/or animations. In the domain of visualization as well as in the field of rendering several interesting approaches exist:

Wellner and Mencl [41] propose an algorithm for the visualization of scattered data, where one is often faced with the problem of finding the nearest neighbours of a data site. This is often the case in an advanced stage of the visualization process, where several data structures have been created during runtime. To take advantage of this previously allocated data structure, they propose an algorithm for determining the k nearest neighbours in a triangulated point set. As a benefit, this algorithm dynamically computes exactly as many neighbours as necessary for the specific application and does not assume a particular kind of triangulation.

De Leeuw, Post, and Vaatstra [38] describe how to model turbulent flow using spot noise. They describe several methods, which utilize spot noise texture to visualize turbulent flow modelled in this way. With spot noise the separate fields are combined in one visualization, which shows both data fields and how they are related in an intuitively clear way. Different aspects of turbulent flow can be shown using different mappings.

One of the best methods for the visualization of two dimensional vector fields is the method of line integral convolution [1]. Here an input texture (usually white noise) is filtered along the curved stream line segments of a vector field. The big advantage of this technique is that it is able to depict directional information at high spatial resolutions.

One of the bottlenecks in these visualization methods is that the run time of conventional rendering is proportional to the number of geometric primitives shown. Ning and Hesselink [39] are conducting research on techniques to improve insight into the accuracy of rendering methods. Although their main effort is on reducing the number of polygons to increase rendering speeds for a certain accuracy, a major benefit is that the viewer gains insight into the rendering accuracy. Helman and Hesselink [36], and Globus, Levit, and Lasinski [35] extract the topology of vector fields in order to create scenes with the essence of the flow field.

A recent development in computer graphics are image based rendering methods where the performance depends mainly on the number of pixels generated. The central idea is to cache rendered images for objects for further reuse. These cached images are known as impostors [15, 14, 2]. They can be used to display the background of the scene in more detail without too much cost in performance. If the object's position in relation to the view point has not changed significantly for the next frame, the impostor can be reused. This exploits the fact that drawing one textured polygon (the impostor) is much cheaper than redrawing an object on modern graphic workstation and PC's [27, 26]. Combining impostors into a hierarchy leads to a system, which allows the rapid display of very large scenes [18, 2], which is discussed in more detail in the following section on previous work.

When multiresolution modelling is used for geometric objects for the benefit of quality vs. speed tradeoffs during rendering, memory and transmission demands are doubled with straight-forward approaches. However, when exploiting the hierarchical nature of this approach detailed model approximations can be encoded as the difference to coarse approximations, thereby avoiding the double memory requirements. The approach is also superior to discrete level of detail approaches as a virtually unlimited number of levels of detail is available. Schmalstieg et al. [21] have shown that the approach is both efficient for storing as well as for transmitting geometric models.

With the help of new algorithms visualization and rendering can be sped-up and new insight into the datasets under investigation can be achieved. In Wijk et al. [30] three methods for visualizing 3D flows are discussed: implicit stream surfaces, turbulent particle animation, and probe flow. The first two methods can be used to get a global impression of the flow. On the other hand probing the flow allows the user to investigate a local flow field in detail, including the local flow velocity and its gradient.

Spray rendering [31] provides a framework for creating and experimenting with different visualization techniques. The name spray rendering is derived from the metaphor of using a virtual spray can to paint datasets. Varying the type of paint in the can highlights data in different ways. This technique can be also applied to flashlights and probes.

While new algorithms are one solution to accelerate visualization and rendering, research is also conducted in parallelizing certain methods. Werner and Lang [42] propose a hierarchical splatting technique, which they parallelized on a distributed memory parallel machine to speed-up the calculations. The algorithm works with a distributed non-equidistant orthogonal dataset. It distributes most of the work to the parallel nodes to achieve high-quality rendering of high-resolution 3D datasets. The data fields remain unchanged so that the algorithm could use shared memory access to a distributed numerical code. The nodes render their individual data space independently and generate their own sub-images. The final image is composited by a parallel overlaying procedure.

In the context of distributed rendering on both distributed memory computers and workstation clusters the problem of transferring geometric models from one computational node to another is also a potential bottleneck. Instead of brute force transmission of geometric models it pays to compress geometry before transmitting it. Deering [2] has shown that lossy compression reduces storage and transmission times by a factor of 6 to 10 with unnoticeable losses in image quality.

An aspect of transmitting images in a distributed environment is that the quality of the transmitted images can be adapted to the available communication resources. The system starts by sending a coarse approximation of the image, which conveys a quick first impression to the user. Then the system progressively refines the transmitted image until the full version can be reconstructed at the receiver side. This transfer can be interrupted at any time. For time or resource critical applications the same system can be adapted to transfer the best possible image under the given constraints. Other work in this area includes [13, 16, 28].

In the literature also algorithms and techniques are investigated as well, which help the user interact with the visualization insofar as the scientist can define arbitrary cutting planes or handle 3D datasets. Jones and Chen [37] propose operations to speed-up cutting for displaying surface interiors. In many applications it is necessary for a user to interactively perform cutting operations on a volume dataset in order to see different parts of the data and to get an insight on the calculations performed in the interior of a volume. Jones and Chen propose a method for implementing such operations, together with a direct surface rendering algorithm, with a glimpse on real time cutting.

DiscMC is an interactive system for fast fitting of iso-surfaces to volume data [34]. It adopts a discretized fitting algorithm that considerably reduces the number of polygons generates by a Marching Cubes-scheme while having shorter runtimes. The extracted surfaces are composed of polygons lying within a finite number of incidences, thus allowing simple merging of output facets into larger coplanar triangular facets. A pyramidal representation of the volume dataset was adopted to speed-up iso-surface fitting, by avoiding empty volume traversal, and to support multiple level of resolution fitting.

Research is being conducted by van Dam et al. at Brown University [33] on an effective interface for manipulating, sculpting, and viewing of 3D objects. NASA Ames [32] researchers work on a single visual environment for all tasks involved in fluid dynamic simulations so that the user does not have to change environments between the preprocessing, simulation, and analysis task.

Several visualization packages are commercially available, which support some of the methods mentioned above. Well known packages are GRAPE, AVS, and Khoros. The performance of the rendering techniques used by these systems depend largely on the graphics hardware used or on the size of the datasets being processed.

Whatever computations or visualizations are performed, the amount of time necessary for these operations introduces some problems. First, the interaction between the user and the program is delayed. Therefore a way of informing the user about the current state of the calculations has to be incorporated at any time one needs information about the status of the calculations. Second, parameters might have to be adopted during the simulation according to the visual feedback given by the visualization. Steering capabilities are necessary, which enable users to supervise and dynamically control the computation of an ongoing simulation.

One approach is described in [29]. An architecture for a steering system called CSE is proposed. It is a modular approach for a computational steering environment. The kernel of the architecture is designed to be simple, yet flexible. All higher level system functionality is pushed into modular components outside the kernel, called satellites. These satellites, which are small tools for steering or receiving data, are built around the so called data manager. It implements the interface to the ongoing simulation, where all of the communication between the tools or the user, respectively, and the simulation has to take place.

5.4 Previous Work

Previous work in the department in the scope of this project can be classified as follows:

- Optimized rendering methods for large scenes. Several rendering methods have been developed:
  - Due to the limited resolution of raster displays it is possible to substitute less detailed models for distant objects as the viewer will not be able to discern the difference. To exploit this

fact a method for the automatic simplification of polygonal geometry has been investigated [1]. It computes multiple geometric simplifications (termed levels of detail - LOD's) for each object. The method utilizes a cluster tree to identify object features depending on size. A level of detail is then generated by choosing a horizontal layer in the tree and reconstructing the corresponding polygons. By repeating this process for multiple layers several levels of detail are created, each with a decreasing number of polygons and thereby reduced rendering cost. For distant objects a coarse level of detail can be displayed, while for near objects a fine level of detail is used.

- A method of dynamically generated impostors [2] was introduced. Complex objects are replaced by textured partially transparent polygons. Once generated an impostor for an object is reused until the viewpoint has moved significantly. From the geometric configuration of viewpoint and object criteria can be derived, which allow to judge when the image on the impostor will fail to match the appearance of the object. As an impostor is much cheaper to draw on current graphics hardware this approach allows to replace many objects in a scene with impostors resulting in large savings in rendering time.

  For large scenes with millions of objects a similar number of impostors would be needed. To avoid the overhead of drawing that many textured polygons the three dimensional hierarchical image cache has been developed [2]. Here space is subdivided into a hierarchy of voxels. For each voxel an image of it's contents are rendered into an impostor. By rendering the impostors for the subvoxels the impostors for higher levels are created. This allows to replace large distant parts of a scene by a few impostors thereby again reducing the rendering time significantly.

- One restriction of the impostor concept is that impostors fail for objects, which touch or occupy intersecting regions of space. As impostors are flat they cannot capture the subtle geometric detail of the three-dimensional surface of the depicted object. As a result one impostor is always in front or behind another, which may not be how the depicted objects are set up in space. To remove this restriction nailboards [18] have been proposed. By additionally storing a reduced version of the impostors' depth information multiple impostors can be composited without errors. Another advantage of this approach is that it also works for scenes with dynamic objects.

• Progressive transmission as proposed in [21] fulfills a range of requirements arising for geometry models to be used in distributed rendering. It offers not just a few discrete levels of detail as previously proposed methods but a very large range of selectable detail, which can be used to tune the rendering process to the available rendering capabilities. Incremental transmission and decoding effectively saves storage and bandwidth requirements as only the difference to the next coarser representation is encoded. In addition not only one level of detail can be chosen for one object but different object parts can be rendered with the detail maximizing the image quality for the current viewing conditions.

• Scientific visualization — classification and new approaches. This research activity was focused on flow field display. An extension of Haber's model [43] of the visualization process was developed [45]. Its transformational steps filtering, visualization mapping, and rendering were classified by several methods. These classifications were applied to both well-known and newly developed visualization approaches. Especially, a new scheme called DD-classification distinguishes different visualization methods by the dimension of the domain of data represented by a single abstract visualization object (AVO). ¿From these investigations a new visualization method has been derived, which allows to simultaneously display up to four scalar and one vector quantity in 3D-space. The display is based on the mapping of physical properties to spatial, temporal, structural and optical properties of compound AVOs consisting of spheres, arrows, surfaces, streamline, and cylinders. Filtering functions defined by location or data value allow a selection of displayable data. In the visualization, mapping and rendering phases the data are transferred into combination-AVOs (e.g sphere-arrow-glyphs, cylinder-arrow-glyphs), iso-surface-arrow-AVOs or iso-surface-streamline-AVOs giving insight into the topological structure of flow fields. Based on AVS a flow visualizer was implemented. All these techniques and their application to fluid dynamics data were investigated [45].

- Volume rendering using supercomputers [44]. Volume rendering [46] is one of the most important techniques for the visualization of scalar volume data. It has been proved that in many cases these methods give better insight than other approaches (e.g.[47, 48]). In early papers on volume rendering modelling aspects were preferred. Later on research concentrated on the development of efficient algorithms. This aspect is especially important because already relatively small data sets demand highest computing power for rapid image generation. This feature is one reason why volume rendering is not used as widely as it corresponds to its ability. Most implementations have been done on vector machines and on MIMD machines with distributed memory architecture. Both kinds of computers offer highest processing power, so the development of specialized algorithms holds great potential.

  At the department two new algorithms created on locally available hardware platforms have been implemented. As a further improvement two possible combinations of both methods have been investigated. The resulting combination of parallel and vectorized algorithms promise improved performance on parallel machines with vector nodes. Since corresponding hardware was not available no actual implementations and runtime measurements could be conducted. However, the expected performance was estimated. Furthermore a proposal for a hardware solution was given.

- For the parallelization of global illumination simulations a parallel visibility calculation method was developed [6, 4, 5]. Resolving visibility is one of the core problems in rendering. The presented parallel visibility method was designed for massively parallel machines. The internal structure of the algorithm allows to adapt the method to the available number of processors and memory restrictions.

- A completely different project deals with monitoring and debugging of parallel programs. The indispensible result of this research is the Monitoring And Debugging environment MAD [7], which will be in the scope of the SFB. MAD allows to customize the amount of data generated. Afterwards the generated data can be used either for error detection — with special emphasis on communication errors and race conditions — or for performance analysis of communication bottlenecks [2].

5.5 Cooperations

- A cooperation with the developers of GRAPE at the universities Bonn and Freiburg will be started. First contacts have already been made.

- The ACPC group of Prof. Dr. Peter Zinterhof in Salzburg will serve as a consultant for compression techniques.

5.6 Objectives, Methods, Programme and Schedule

5.6.1 Objectives

The main goal of this work is to supply other projects in the scope of the SFB with an efficient visualization environment, which will help the user to interpret results obtained by simulation.

The data to be visualized consist of three dimensional geometry and an associated mesh. Multiple values (scalars and vectors) are computed at each mesh point. As most simulations are performed for dynamic events the data are additionally defined for multiple time steps. In the scope of the SFB meshes with several million nodes are used. Therefore efficient visualization methods are needed. Animations of time dependent data consume considerable processing time and must be accelerated significantly with improved methods. Current visualization package are not adequate for this purpose.

- *Visualization environment.* The well-known GRAphics Programming Environment (GRAPE [49]; developed by the Sonderforschungsbereich 256, Universities Bonn and Freiburg) will be used to include all the capabilities of this system. We will integrate the methods, which will be developed by the other activities of this project. Furthermore, GRAPE will be extended to provide the user with additional features.

  The user will be able to steer the visualization as well as the simulation itself. This will be of interest especially in case of time-consuming computations. Typical examples for such interactions are changing the value of a parameter, which controls a refinement procedure, interrupting the simulation to investigate the situation, and to decide how long the run should be continued, changing the quality of the output with respect to the contents of the images or changing the time interval where new frames will be produced.

  Several projects will use parallel hardware, therefore the environment has to manage interactions between the simulation and the visualization, e. g. the collection and the distribution of data from and to the processes.

  The extension will be designed in such a way that a link to other visualization systems like AVS will be possible.

- *Fast rendering methods for large datasets.* The user of visualization tools is interested in images, which are good enough to extract all the information he needs. Furthermore the period for the generation of an image ought to be as short as possible. Frequently, the datasets to be visualized are so huge that even high speed graphics hardware is not able to render them within an acceptable amount of time. It should be mentioned that in a distributed environment the situation is even more challenging as communication plays an important role. Thus, methods have to be used, which reduce the amount of data to be rendered and/or transported. The degree of reduction ought to be automatically fixed. Since there does not exist one method that helps in all these cases. Several approaches must investigated and compared. Of course, the method must preserve important information.

  It should be mentioned that some of these methods will also help in case of visually cluttered images. Such an effect can be caused by too much information, even when the rendering hardware is able to generate the image within the desired time frame.

- *Parallelization of visualization algorithms.* As parallel machines or networks of graphics workstations are used to speed-up the simulation, it is obvious to utilize these resources for the visualization process, too. Especially the generation of animations for time dependent data consumes considerable computing power, therefore parallel and/or distributed visualization methods are needed. Even in cases without time constraints some algorithms are time-consuming to such a degree that parallelization is desirable.

- *Integration of novel and design of new visualization methods.* During the last years a lot of papers have been published describing new methods for the visualization of data gained by scientific computation. These methods have to be investigated and integrated if they promise good results with respect to the demands of the SFB. One of the main concerns of this project is to improve these algorithms and to derive new ones in order to accelerate the visualization process, especially during simulation runtime.

- *Integration of MAD.* This task is not part of this SFB project, but we have in mind to integrate the existing MAD environment. It will help to find communications bottlenecks or bugs in parallel simulation programs.

5.6.2 Methods

The same structure as in the previous subsection will be used in the following paragraphs. We assume that the simulation runs in parallel. Of course this is not a necessary condition but it simplifies the explanations.

- *Visualisation environment.* In order to get the desired behaviour a monitor will act as a link between simulation and visualization. This monitor has to consist of a central master process and a number of distributed slave processes. Each slave is attached to one of the distributed processes of the simulation task and is responsible for the communication (data and steering information) between simulation and monitor. This part is independent from the utilized visualization system and it is assumed that MPI is used for parallelization of the simulation program. A special GRAPE object will be used for the communication with the central master process. It serves as an interface between the monitor and GRAPE. It will be easy to realize the interconnection to another visualization system by adding a corresponding interface.

  A state-of-the-art graphical user interface (GUI) will be part of the monitoring system. The communication with the user interface of GRAPE will be done via a GDI (graphical data interface).

  The modularity of the design is self-evident. For reasons see project P12.

- *Fast rendering methods for large datasets.* In order to attack the problem of very large datasets, which are to be rendered or transported, several methods will be realized.

  - Parallelizing the visualization mapping. If the set of AVOs (abstract visualization object) is much smaller than the original information, the calculation of the mapping in parallel will reduce the amount of data to be transported to the output device and will reduce the rendering time, too. For example, this approach will help if particle tracing is used (see also parallelization of visualization algorithms).
  - Coarse images. The information will be reduced by downsizing. This method works well except that — too quickly — all details are lost leading to missinterpretation of images. Giving the rendering algorithm control of this speed vs. quality trade-off allows to achieve the best possible quality in the available time frame.

    In the context of parallel rendering progressive image transmission is utilized. The general idea of progressive image transmission is to transfer the image in successively better approximations. Using these techniques images are transferred between processors until the chosen time frame has been exceeded, whereupon the image compression is aborted. This combination allows to transfer the images with the best quality possible while retaining the advantages of a fixed frame rate.
  - Reducing the number of frames per time unit. Especially, when visualization and simulation are executed simultaneously, this will be acceptable as the output is only used for controlling purposes or the frames are interpolated afterwards to get a movie.
  - Image based rendering methods. In case of time variant results image based rendering methods can reduce the rendering effort. To exploit the potential of this technique for dynamic datasets the rendering method has to check the dataset for changes over time. In regions with significant changes previously generated images cannot be utilized. In "quiet" regions, where little changes occurred, previous images can be reused resulting in reduced rendering time. An important aspect is that the applied criterion also takes into account the visual change

in the rendered image. If this change is too large, the whole image has to be re-rendered. Therefore this research topic concentrates on methods to quantify, which changes in the data will result in a visible change in the visualization. An improvement will be the analysis of the data beforehand images will be generated, which show details only in "complicated" regions. In this context a new combination of volume rendering methods with image based rendering methods is proposed. The advantage of this approach is that image based rendering methods consume resources proportional to the number of pixels in the final image and are (largely) independent of the number of geometric primitives.

  - For the reduction of bandwidth requirements for parallel and distributed visualization compression methods for images, general data, and geometry will be considered.
  - In order to get the best solution research will focus on methods, which strategies automatically choose among different rendering methods, and different communication strategies (raw data, images, compression methods) to adapt the rendering time to the available resources and network bandwidth.

- *Regions of main interest.* The aim is to avoid images, which show unrelevant data. Regions, where values to be displayed change only gradually, need not be displayed in full detail if viewed from the distance. Full detail is only needed if the viewpoint is sufficiently close. On the other hand "complicated" regions with rapid changes in the data can be highlighted by showing more detail, which will guide the user to these regions. A visualization system based on these concepts will allow a faster analysis of relevant scientific data.
- *Parallelization of visualization algorithms.* All time-consuming visualization methods used by other projects in the scope of the SFB will be considered for potential parallelization. Some of the promising algorithms will be implemented. At least three parallel algorithms will be realized: a volume rendering method, the construction of cutting planes in huge unstructured meshes, and a particle tracer. For the implementation MPI will be used.
- *Integration of novel methods and design of new visualization methods.* Several visualization methods will be integrated: e.g. implicit stream surfaces [30], volume rendering techniques [44], spray rendering [31], and the use of probes [30]. A new class of combining AVOs (abstract visualization object) [45] will be tested. Naturally, the search for new methods is part of this project. New visualization methods for three dimensional vector fields will be based on recent work dealing with the visualization of two dimensional streamlines. A generalization of this work will be utilized to generated images of three dimensional flow fields. This will be done by applying techniques from volume rendering to flow field visualization.

5.6.3 Programme and Schedule

The work program consists of the following activities:

(1) *Design and implementation of monitoring and steering components.* The incorporation of monitoring facilities within the scientific simulation requires the design of an interface between the application and the visualization. Special care has to be taken to allow parallel and distributed systems as target platforms. The monitoring tool will be implemented on the basis of MPI, allowing to observe the simulation and to control the transmission of data between the simulation and GRAPE. On the other hand steering capabilities will be implemented, which allow the user to tune parameters of the simulation during runtime.

(2) *Downsizing of images and progressive transmission methods for images.* For parallel and distributed visualization algorithms, which transfer (partial) images, the communication time is proportional to the bandwidth consumed. If the bandwidth is not sufficient, it is sensible to transfer the best

possible image in the time frame given by either the frame rate (user determined or real time) or the simulation step duration. Therefore an algorithm calculating the amount of data, which can be transferred, has to be developed.

(3) *Combination of image based rendering and hierarchical splatting.* In this task we will implement and test a combination of hierarchical splatting and a three dimensional image cache. The hierarchical splatting approach [12] renders three dimensional scalar fields and can be seen as an early attempt of applying image based rendering to visualization algorithms. This activity generalizes the hierarchical splatting approach for general scalar fields.

(4) *Application of image based rendering to vector field visualization and iso-surface rendering.* Based on the experience gained in the previous activity, the application of image based rendering to visualization algorithms for three dimensional vector fields is done by utilizing suitable impostors. A different approach to three dimensional data visualization are iso-surface algorithms. In this activity image based rendering algorithms are adapted to this important class of visualization techniques.

(5) *Image based rendering for parallel machines.* In order to accelerate parallel rendering the three dimensional hierarchical image cache developed at GUP-Linz will be implemented on a distributed shared memory machine.

(6) *Realization of a new visualization method, which avoids cluttered images.* Contrary to activity (2) the work in the scope of this activity analyses a static dataset based on it's visual appearance. Methods are developed, which analyse the data to identify regions with uniform data values and regions with rapid changes. By grouping the uniform data and displaying less detail in these regions visual clutter can be avoided. For "interesting" regions, where the data change rapidly, the full details are to be shown to visually "guide" the viewer towards these regions.

(7) *Distributed visualization on workstation clusters.* In the case of distributed simulations it is useful to investigate distributed visualization algorithms. Because the data is already spread over several workstations distributed algorithms can process the data in parallel without an inefficient data collection and re-distribution step.

(8) *Automatic adaption of rendering to time and network constraints.* Research in this activity concentrates on achieving the optimum visualization performance on a given platform under current load conditions. To achieve this goal the algorithms automatically choose among the available techniques (image based rendering, level of detail, parallel/distributed rendering, compressed images, progressive image transfer) to generate the best possible image within a given time frame. The algorithms also adapt to varying conditions such as network load.

(9) *Research of visualization methods for three dimensional vector fields.* Based on a thorough study of visualization methods for two dimensional vector fields new methods for three dimensional vector fields will be realized. One such approach will be based on recent work on the visualization of two dimensional streamlines.

(10) *Supervision.*

The workplan of this project is based on the following table of activities. The chronological order of the plan as well as the provided participation of the co-workers involved in the project is given in the following table:

Activity	Personnel	1st year		2nd year		3rd year	
		1 ... 6	7 ... 12	1 ... 6	7 ... 12	1 ... 6	7 ... 12
(1)	F,D,A,S						
(2)	B,G1						
(3)	E,C						
(4)	E,C						
(5)	E,C,A						
(6)	B,F						
(7)	E,C,A						
(8)	E,C,A						
(9)	B,G2						
(10)	A						

The symbols A, B, C, D, E, F, G and S are assigned to the following persons working on the corresponding problems:

A = O.Univ.-Prof. Dr. J. Volkert (proposer of the project, 10%),

B = Dr. W. Stürzlinger (applied for a PostDoc position),

C = Dipl.-Ing. G. Schaufler (co-worker from the basic staff, 10%),

D = Dipl.-Ing. D. Kranzlmüller (co-worker from the basic staff, 15%),

E = N.N. (applied doctorial position for a Ph.D. student paid as a 2/ 3-job),

F = N.N. (applied doctorial position for a Ph.D. student paid as a 2/ 3-job),

G1 = guest (work contract): specialist for progressive transmission methods,

G2 = guest (work contract): specialist for vector fields,

S = student assistance, paid by research aiding and work contracts.

5.7 Integration with the SFB

Each group in the scope of the SFB will benefit from our visualization research. The efficiency of the visualization methods will be crucial, especially for projects producing huge datasets by simulation. These are all projects dealing with numerical algorithms (P6 to P11).

For projects 5, 6, and 8, which use parallel algorithms, the intended visualization environment will also simplify the interaction between simulation and visualization. Particularly, the simultaneous execution of both simulation and visualization will be necessary in order to investigate intermediate simulation results. In this context, the capability to steer the simulation as well as the quality of the visualization will be helpful.

Conversely, our group needs the feedback from the other projects so that we can improve our visualization techniques as well as the whole environment.

5.8 Detailed Budget

5.8.1 Requested Personnel

As mentioned before, one full-time post doc position (S 492.000/year) and two doctoral positions for Ph.D. students, which are paid as 2/3 job (S 328.000/year), are required for this project.

5.8.2 Computer and Experimental Equipment

We request funding for the following equipment:

- 1 powerful high end graphics workstation including special graphics software, which amounts to **ATS 600.000,–** in the first year. The project is strongly connected with the graphical pre- and postprocessing of huge data arrays incoming from projects P5 - P10.
- 3 workstations, which amount to a total of **ATS 210.000,–** in the first year.
  The workstations serve as additional workplaces for the employees of this project.

5.8.3 Materials

For the funding of materials such as paper, transparencies etc., we request an amount of **ATS 10.000,– per year**.

5.8.4 Travel Support

For travel within Austria or to neighbouring countries, we request a budget of **ATS 25.000,– per year**. This will cover the costs for communication with external researchers and for presentations at conferences, workshops, and meetings in this geographical area.

5.9 Curriculum and Bibliography

The curriculum vitae and a list of publications for each actually known participant of this project can be found in appendix A.

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5.10 Tables

Tabelle 16
Übersicht über die bisherige und die beantragte Förderung
von Projektteil 13
(wichtig: siehe Hinweise zur Antragstellung !)

Jahr	PeK	GeK	MaK	ReK	PuK	SoK	WV	Summe
105	106	107	108	109	110	111	112	113
bisher								
-4								
-2								
-1								
Summe								
beantragt								
1	1.148.000	810.000	10.000	25.000		50.000		2.043.000
2	1.148.000		10.000	25.000		50.000		1.233.000
3	1.148.000		10.000	25.000		50.000		1.233.000
Summe	3.444.000	810.000	30.000	75.000		150.000		4.509.000

Tabelle 17 a
Aufstellung des eingesetzten Personals für
Projektteil 13

Grundausstattung
Personaleinsatz (sämtliche Beteiligte einschließlich P-Leiter)

Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
114	115	116	117	118	119	120	121
Volkert Jens, Dr.-Ing., O.Univ.-Prof.	Systemprogrammierung	Informatik	10%		1. Jahr	O.Univ.-Prof.	voll
Schaufler Gernot, Dipl.-Ing.	Systemprogrammierung	Informatik	10%		1. Jahr	Univ.-Ass.	voll
Kranzlmüller Dieter, Dipl.-Ing.	Systemprogrammierung	Informatik	15%		1. Jahr	Univ.-Ass.	voll

Tabelle 17 b
Aufstellung des beantragten Personals für
Projektteil 13

1.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungsstätte (Institut)	% Arbeitszeit für Projekt	beratend	Anfang im SFB	Beschäftigungsverhältnis	Beschäftigungsausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Stürzlinger Wolfgang, Dipl.-Ing. Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

2.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Stürzlinger Wolfgang, Dipl.-Ing. Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

3.Jahr

Ergänzungsausstattung

Personalbedarf

Übersicht			Aufschlüsselung: nicht besetzte Stellen in Klammer, neu beantragte Stellen unterstrichen							
beantragte Stelle	% DV (bzw.FB)	Summe	Name, akad. Grad Dienstgrad	engeres Fachgebiet	Forschungs-stätte (Institut)	% Arbeits-zeit für Projekt	beratend	Anfang im SFB	Beschäftigungs-verhältnis	Beschäftigungs-ausmaß
122	123	124	125	126	127	128	129	130	131	132
V.Ass.	100%	1	Stürzlinger Wolfgang, Dipl.-Ing. Dr.	Systemprogrammierung	Informatik	100%		1. Jahr	Postdoc	voll
Mag./DI	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
	100%	1	N.N.	Systemprogrammierung	Informatik	100%		1. Jahr	Doktorand	voll
FB Mag./DI										
FB Diplom.										
MTA										
MTF										
CTA										
TA										
Ingenieur										
Mechaniker										
Laborant										
Summe	300%	3								

Tabelle 17 c
Aufstellung der beantragten Geräte Projektteil 13

1.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
SGI Octane, SSI-Grafik, 256 MB, 4 GB	600.000			SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
				SGI O2, R5000PC, 64 MB, 2 GB, 17"	70.000		
Summe	600.000			Summe	210.000		

2.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

3.Jahr

Geräte über 100.000,00 ÖS Anschaffungswert (inkl. MWST)				Geräte unter 100.000,00 ÖS Anschaffungswert (inkl. MWST)			
Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort	Gerätebezeichnung	Summe (inkl. MWST)	Code	Aufstellungsort
133	133a	133b	133c	134	134a	134b	134c
Summe				Summe			

Tabelle 17 d
Aufstellung des beantragten Materials, der Reise- und sonstigen Kosten sowie der Werkverträge

Projektteil 13

1.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000	Software Development	50.000		
Summe	10.000	Summe	25.000	Summe	50.000	Summe	

2.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000	Software Development	50.000		
Summe	10.000	Summe	25.000	Summe	50.000	Summe	

3.Jahr

Material Auflistung	Betrag	Reisekosten Auflistung	Betrag	Sonstige Kosten Auflistung	Betrag	Werkverträge über 100.000 ÖS Auflistung Empfänger	Betrag
135	135a	136	136a	137	137a	138	138a
EDV- und Büromaterial	10.000	Besuch von Kooperationspartnern und Tagungen	25.000	Software Development	50.000		
Summe	10.000	Summe	25.000	Summe	50.000	Summe	

6 Entwurf der Ordnung für den SFB

ENTWURF

Ordnung

für den SFB

Numerical and Symbolic Scientific Computing

§*1. Trägeruniversität des SFB "Numerical and Symbolic Scientific Computing"* – im folgenden kurz SFB genannt – im Sinne der Richtlinien des FWF ist die Johannes Kepler Universität Linz.

§*2. Aufgaben des SFB:*

1. Betreiben von Forschung auf dem Gebiet des Wissenschaftlichen Rechnens.
2. Publikation der wissenschaftlichen Ergebnisse.
3. Einbindung von wissenschaftlichen Arbeitsgruppen außerhalb des SFB in ausgewählten Problemstellungen gemäß Abs. 1 (in Form von Kooperationen auf nationaler und internationaler Ebene) mit dem Ziel, die Lösung dieser Problemstellungen entscheidend voranzutreiben.
4. Funktion als Ansprechpartner für andere universitäre oder außeruniversitäre Arbeitsgruppen betreffend die in Abs. 1 genannten Problemstellungen.
5. Ausbildung von wissenschaftlichem Nachwuchs für die im SFB vertretenen Fachgebiete.
6. Aufklärung der Öffentlichkeit über Forschungsziele und Ergebnisse zur Information und Weiterbildung.

§*3. Mitglieder des SFB:*

1. Mitglieder des SFB sind WissenschaftlerInnen, die sich zur Mitarbeit am SFB während des laufenden Abschnittes verpflichtet haben und zusätzlich entweder
   - Leiter eines Projektes *(principal investigator)* sind, oder
   - stellvertretender Leiter eines Projektes *(co-investigator)* sind, oder die
   - Funktion des Sprechers, des Stellvertretenden Sprechers oder des Finanzbeauftragten innehaben.
2. Über Aufnahme und Ausschluß von Mitgliedern während des laufenden Abschnittes entscheidet der Vorstand des SFB mit einfacher Mehrheit, nach Anhörung der Mitgliederversammlung. Bei Stimmengleichheit zählt die Stimme des Vorsitzenden doppelt.

§*4. Mitarbeiter des SFB:*

1. Mitarbeiter des SFB können nur WissenschaftlerInnen sein, die sich zur Mitarbeit am SFB während des laufenden Abschnittes verpflichtet haben.

2. Über Aufnahme und Ausschluß von Mitarbeitern während des laufenden Abschnittes entscheidet die Mitgliederversammlung des SFB mit einfacher Mehrheit. Zu Beginn des laufenden Abschnittes sind WissenschaftlerInnen, welche die Voraussetzung gemäß Abs. 1 erfüllen, automatisch Mitarbeiter des SFB.

§*5. Gremien des SFB:*

1. Gremien des SFB sind der *Vorstand* (executive board) und die *Mitgliederversammlung* (council) des SFB (im folgenden kurz MV genannt).
2. Der Vorstand besteht aus 5 Mitgliedern des SFB. Alle Mitglieder des SFB gehören der Universität Linz an.

   Zu den Mitgliedern des Vorstandes zählen:

   - der Sprecher
   - der stellvertretende Sprecher

   Der Vorstand kann einen Finanzbeauftragten bestellen, der dann mit beratender Stimme dem Vorstand kooptiert wird.
3. Vorsitzender des Vorstandes ist der Sprecher des SFB.
4. Die MV besteht aus den Mitgliedern. Der/Die SekretärIn des SFB gehöhrt der MV mit beratender Stimme an.
5. Die MV muß mindestens zweimal pro Jahr einberufen werden. Eine Sitzung der MV ist auf jeden Fall einzuberufen, wenn dies von mindestens 2/3 der Mitglieder der MV schriftlich gefordert wird. Die Einladung zu einer Sitzung der MV hat 7 Tage vor der Sitzung schriftlich zu erfolgen.

§*6. Wahlen:*

1. Die MV wählt die Mitglieder des Vorstandes unter Beachtung von § 5 Abs. 2, nach Einbringen von Wahlvorschlägen (5 Vorstandsmitglieder beim Sprecher des SFB) eine Woche vor der Wahl.
2. Der Vorstand wählt den Sprecher des SFB, seinen Stellvertreter und den Finanzsprecher aus seiner Mitte. Der Sprecher gehört der Universität Linz an. Vorsitzender für die Wahl ist das dienstälteste Mitglied des Vorstandes.
3. Der Sprecher des SFB und sein Stellvertreter sind automatisch auch Vorsitzende der MV.
4. Die Funktionsperiode des Sprechers und seines Stellvertreters ist die Dauer des laufenden Abschnittes.

§*7. Beschlußerfordernisse:*

1. Für die Beschlußfähigkeit der Gremien des SFB ist die Anwesenheit von mindestens der Hälfte der Mitglieder des Gremiums notwendig.
2. Ein Antrag gilt als angenommen, wenn mindestens die Hälfte der anwesenden Mitglieder des Gremiums zustimmt.

3. Bei Wahlen gilt ein Vorschlag (Person) als gewählt, wenn auf ihn (sie) die Stimmen von mindestens der Hälfte der anwesenden Mitglieder entfallen. Bei Stimmengleichheit findet eine Stichwahl statt. Bleibt diese ohne Ergebnis, zählt die Stimme des Vorsitzenden doppelt.

4. Stimmübertragungen an Gremienmitglieder sind möglich.

§8. Pflichten der Mitglieder und Mitarbeiter des SFB:

1. Mitglieder und Mitarbeiter des SFB sind verpflichtet, in dem im Antrag für den laufenden Abschnitt angegebenen Umfang an den Projektteilen des SFB mitzuarbeiten. Im Rahmen dieser Verpflichtung haben sie die Arbeiten im SFB insgesamt zu fördern und insbesondere an der Betreuung des wissenschaftlichen Nachwuchses, an der Verwaltung und an der Öffentlichkeitsarbeit des SFB mitzuwirken.

2. Mitglieder von Gremien des SFB sind verpflichtet, an den Sitzungen dieser Gremien teilzunehmen. Mitglieder und Mitarbeiter des SFB sind verpflichtet, am Kolloquium des SFB teilzunehmen.

§9. Aufgaben des Vorstandes:

1. Anhörung der MV vor Entscheidungen über Aufnahme und Ausschluß von Mitgliedern während des laufenden Abschnittes sowie vor neuer Abschlußperiode.

2. Antragstellung an die MV betreffend Aufnahme bzw. Ausschluß von Mitarbeitern des SFB.

3. Antragstellung an die MV betreffend die Zuweisung von Finanzmitteln, Personal und Ressourcen an die einzelnen Projektteile.

4. Durchführung der internen Evaluierung des SFB. Über die Ergebnisse der Evaluierung ist der MV zu berichten.

5. Organisation des *SFB Kolloquiums.* Aus dem Kreis der Mitglieder des SFB ist ein Koordinator für das Kolloquium zu bestellen. Das Kolloquium dient der gegenseitigen Information, Beratung und Unterstützung sowie der internen Evaluierung. Bei Bedarf sind zusätzlich interne Workshops zur Förderung der Zusammenarbeit zwischen einzelnen Projektteilen einzurichten.

§10. Aufgaben des Sprechers des SFBs:

1. Der Sprecher vertritt den SFB nach außen. Er kann einzelne Mitglieder des SFB mit der Vertretung des SFB gegenüber jenen Universitätsgremien und anderen Institutionen bevollmächtigen, welchen sie angehören.

2. Der Sprecher leitet das Sekretariat des SFB und führt die Dienstaufsicht über den/die SekretärIn des SFB.

§11. Aufgaben der MV:

1. Die MV entscheidet in Angelegenheiten gemäß §9 Abs. 2 und 3, wobei gegebenenfalls existierende Richtlinien des FWF zu berücksichtigen sind. Bei Angelegenheiten gemäß §9 Abs. 3 ist Rücksicht auf den dem laufenden Abschnitt zugrundeliegenden Antrag zu nehmen. Für Angelegenheiten gemäß §9 Abs. 2 ist für einen gültigen Beschluß die Zustimmung von mindestens 2/3 der anwesenden Mitglieder der MV erforderlich.

2. Abwahl von Mitgliedern des Vorstandes bzw. Abwahl des Vorsitzenden der MV mit 2/3–Mehrheit im Falle der Nichterfüllung der jeweiligen Verpflichtungen.

3. Für einzelne Angelegenheiten kann die MV ihre Entscheidungskompetenzen an den Vorstand oder einzelne Vorstandsmitglieder delegieren.

4. Die MV beschließt eine Geschäftsordnung für die Gremien des SFB. Bis zur Verabschiedung einer Geschäftsordnung für die Gremien des SFB gilt die Geschäftsordnung des Fakultätskollegiums der Technisch-Naturwissenschaftlichen Fakultät (TNF) der Johannes Kepler Universität Linz sinngemäß.

7 Entwurf des speziellen Memorandums

Entwurf

des

speziellen Memorandums

zur Einrichtung und Förderung des Spezialforschungsbereiches

Numerical and Symbolic Scientific Computing

geschlossen zwischen der

Johannes Kepler Universität Linz
(Trägerhochschule)

und dem

Fonds zur Förderung der wissenschaftlichen Forschung

in Absprache und mit dem Einverständnis von
BMWV
dem Land Oberösterreich
der Stadt Linz

zur Kenntnis an die beteiligten Forschungsstätten

Forschungsinstitut für Symbolisches Rechnen (RISC)
Institut für Elektrische Meßtechnik
Institut für Industriemathematik
Institut für Mathematik
Institut für Mechanik und Maschinenlehre
Institut für Systemprogrammierung

Linz, d. xx. xx. 199x

Inhaltsverzeichnis

§1. Allgemeines

Die Unterzeichner des speziellen Memorandums erklären, daß sie die Grundsätze und die Definition des Förderungsprogrammes "Spezialforschungsbereiche" (im folgenden "SFB") kennen und akzeptieren, so wie sie im Rahmenmemorandum festgelegt sind, geschlossen am 29. 1. 1993 zwischen BMWV, FWF und ÖRK.

Die Unterzeichneten geben in diesem Memorandum die **Absichtserklärung ab, für die gesamte Laufzeit des SFB** die in diesem Memorandum festgehaltenen **Aufgaben im Rahmen ihrer Kompetenzen und Möglichkeiten wahrzunehmen**, gemäß den im Rahmenmemorandum festgelegten Grundzügen der Aufgabenverteilung bei der Finanzierung und Durchführung von SFB.

Die Unterzeichneten erklären, daß sie im Rahmen ihrer Kompetenzen und Möglichkeiten eine plangemäße und konsequente Umsetzung der in diesem Memorandum abgegebenen Absichtserklärungen anstreben werden.

Die Unterzeichneten akzeptieren, daß die Einhaltung der Absichtserklärungen im Rahmen der Begutachtung des Ergebnisberichtes und des allfälligen Fortsetzungsantrages nach Ablauf der jeweiligen Antragsperiode evaluiert wird und eine offensichtliche Nichteinhaltung zur Einstellung der Förderung des SFB führen kann.

§2. Laufzeit des SFB

Der SFB "Numerical and Symbolic Scientific Computing" ist für eine Laufzeit von 10 Jahren konzipiert.
Der erste Antragszeitraum umfaßt 3 Jahre.
Rechtzeitig vor Ablauf dieser Frist ist gemeinsam mit dem Fortsetzungsantrag für die nächste Förderungsperiode ein Ergebnisbericht vorzulegen. Ob, in welcher Form und für wie lange der SFB weitergefördert wird, hängt von dem Ergebnis der Begutachtung und der Entscheidung des Kuratoriums des FWF ab. Das Kuratorium des FWF beschließt über die Fortführung oder Einstellung des SFB aus wissenschaftlichen und/oder organisatorischen Gründen.
Die Unterzeichneten erklären, für die Laufzeit des SFB "Numerical and Symbolic Scientific Computing" den verbindlichen Charakter der Beschlüsse des Kuratoriums des FWF anzuerkennen.

§3. Umfang des SFB

Dem SFB stehen für die Antragsperiode personelle und materielle Mittel aus dem Bereich der Trägeruniversität und der beteiligten Forschungsstätten in dem Ausmaß zur Verfügung, wie im Antrag unter Punkten 1, 2 und 4 angegeben ist.
Personelle und materielle Mittel aus der vom FWF finanzierten Ergänzungsausstattung stehen dem SFB für die Antragsperiode - vorbehaltlich der Bereitstellung der erforderlichen Mittel durch den Gesetzgeber - in dem Ausmaß zur Verfügung, wie im Bewilligungsschreiben aufgrund der Entscheidung des Kuratoriums des FWF angegeben.

Personelle und materielle Mittel durch Zuwendungen des BMWV, bzw. der Stadt stehen dem SFB in dem Ausmaß zur Verfügung, wie die unter §4 dieses Memorandums abgegebenen Absichtserklärungen gemäß den Kompetenzen und Möglichkeiten der betreffenden Institutionen erfüllt werden können.
Personelle und materielle Mittel aus sonstigen Quellen stehen dem SFB in dem im Antrag unter Punkt 2 angegebenen Umfang in dem Ausmaß zur Verfügung, wie die entsprechenden Abkommen (EU-Projekte, etc.) verwirklicht werden können.

Die Unterzeichneten erklären, bei Erfüllung der Absichtserklärungen das ebendort für den SFB vorgesehene Forschungs- und Förderungspotential tatsächlich und ausschließlich für den SFB zur Verfügung zu stellen.

Die Institutsvorstände halten fest, daß der SFB für sie ein Schwerpunktprogramm darstellt und somit sichergestellt ist, daß Ressourcen in ihrem Bereich zunehmend für den SFB genutzt werden.

Modifikationen des Umfanges können für jeweils die nächste Antragsperiode vorgenommen werden aufgrund von Fortsetzungsanträgen, deren Begutachtungsergebnissen und Entscheidungen (Vorgaben, Auflagen) seitens des Kuratoriums des FWF.
Für Zuwendungen aus der Ergänzungsausstattung des FWF in der jeweils nächsten Antragsperiode gilt als Ausgangpunkt die unter §5 dieses Memorandums festgehaltene Vorgabe.

§4. Aufgabenverteilung

4.1. Mitglieder und Mitarbeiter/innen des SFB

Die Mitglieder und Mitarbeiter/innen laut Ordnung des SFB erklären ihre Absicht, ihre Arbeitskapazität im antragsgemäßen Ausmaß für die gesamte Laufzeit des SFB zur Verfügung zu stellen.
Die Mitglieder und Mitarbeiter/innen akzeptieren, daß das Arbeitsausmaß, das sie für den jeweiligen Antragszeitraum gemäß den Förderungsvertrag für den SFB zugesagt haben, für den FWF als bindend gilt und entsprechend bei der Beurteilung der Forschungsergebnisse berücksichtigt werden wird.

Änderungen dieser Zusagen müssen von den Gremien des SFB anerkannt und im Ergebnisbericht berücksichtigt werden.

Die Mitglieder und Mitarbeiter/innen des SFB erklären, die Ordnung des SFB und die Entscheidungen der Gremien zu akzeptieren.
Die Mitglieder und Mitarbeiter/innen erklären weiters, die für die Durchführung der Forschungsarbeiten und die Verwendung von Förderungsmitteln geltenden Richtlinien des FWF mit den SFB-spezifischen Zusätzen einzuhalten.

4.2. Forschungsstätten

Die Forschungsstätten erklären ihre Absicht, das unter **Punkt 1 und 4 des Antrages** angegebene, bzw. aufgrund der Bewilligung des FWF für den SFB aus Mitteln der Grundausstattung notwendige Forschungspotential in personeller und materieller Hinsicht (siehe §3) und im antragsgemäßen Ausmaß für die gesamte Laufzeit des SFB zur Verfügung zu stellen. Durch die unten angegebenen Maßnahmen werden sich die Forschungsstätten bemühen, während der Laufzeit den in den SFB eingebundenen Anteil der Grundausstattung zu erhöhen.

Die Forschungsstätten erklären ihre Absicht, den unter **Punkt 2 des Antrages** angegebenen und nach Entscheidung des Kuratoriums des FWF modifizierten Bedarfsüberblick für den SFB in personeller und materieller Hinsicht in die künftige Dienststellen-, Raum- und Budgetplanung miteinzubeziehen und hier die Erfordernisse des SFB vorrangig zu berücksichtigen. In diesem Zusammenhang wird die Trägeruniversität einen Verteilungsschlüssel für ordentliche und außerordentliche Dotationen entwickeln, der eine vorrangige Berücksichtigung des SFB gewährleistet.

Die Forschungsstätten erklären ihre Absicht, allfälligen Änderungen im Umfang des SFB, wie sie sich aufgrund von Fortsetzungsanträgen, deren Begutachtungsergebnissen und Entscheidungen (Vorgaben, Auflagen) seitens des Kuratoriums des FWF ergeben, Rechnung zu tragen.

Die Forschungsstätten nehmen ausdrücklich zur Kenntnis, daß sich die Finanzierung von personeller Ergänzungsausstattung seitens des FWF gemäß §5 dieses Memorandums festgehaltenen Vorgabe in der nächsten Antragsperiode reduziert. Die Forschungsstätten erklären ihre Absicht, die Übernahme dieses Personals in die Forschungsstätten im größtmöglichen Ausmaß anzustreben.

4.3. Fonds zur Förderung der wissenschaftlichen Forschung (FWF)

Der FWF erklärt seine Absicht - vorbehaltlich der Bereitstellung der erforderlichen Mittel durch den Gesetzgeber -, die Ergänzungsausstattung für den SFB in der jeweiligen Antragsperiode in dem Ausmaß zu finanzieren, wie es die aufgrund der Begutachtungsergebnisse des Antrages (Fortsetzungsantrages) getroffene Entscheidung des Kuratoriums vorsieht.

Der FWF wird den SFB laufend in organisatorischen Fragen beraten und nach Möglichkeit unterstützen, um eine reibungslose Durchführung der Forschungsarbeiten zu begünstigen.

Weiters führt der FWF das Begutachtungsverfahren des Ergebnisberichtes und des Fortsetzungsantrages durch, sowie die Überprüfung der widmungsgemäßen und richtlinienkonformen Verwaltung und Verwendung der Förderungsmittel durch den SFB.

4.4. Bundesministerium für Wissenschaft und Verkehr (BMWV)

Das BMWV nimmt die Einrichtung des SFB "Numerical and Symbolic Scientific Computing" an der Johannes Kepler Universität Linz zustimmend zur Kenntnis.

Das BMWV erklärt seine Absicht, gemäß den im Rahmenmemorandum festgehaltenen Grundsätzen den SFB bei

- Berufungen
- Dienstpostenvergabe
- Raumausstattung
- Personalausstattung
- Geräteausstattung
- Sachausstattung und
- Umbauten für Geräteinstallationen

nach Maßgabe der budgetären Möglichkeiten zu unterstützen.

Das BMWV nimmt in diesem Zusammenhang den unter **Punkt 2 des Antrages** angegebenen Bedarfsüberblick zur Kenntnis.
Im Sinne des geschlossenen Rahmenmemorandums wird sich das BMWV bemühen, den angesprochenen Bedarf zum ehestmöglichen Zeitpunkt in größtmöglichen Umfang zu decken.
Insbesondere bekräftigt das BMWV im Sinne des Rahmenmemorandums seine Absicht, die Forschungsstätten nach Möglichkeit bei der Zuteilung zusätzlicher Dienstposten im Hinblick auf die Erfüllung der unter §5 angegebenen Vorgabe vorrangig zu berücksichtigen.

Weiters wird seitens des BMWV die Absicht erklärt, im Rahmen der budgetären Möglichkeiten die Finanzzuteilungen an den SFB in einem Ausmaß zu erhöhen, das dem Ausmaß der inneruniversitären Umschichtungen an ordentlichen und außerordentlichen Dotationsmitteln für den SFB entspricht.

4.5. Landesregierung des Landes Oberösterreich

Die Landesregierung des Landes Oberösterreich nimmt die Einrichtung des SFB "Numerical and Symbolic Scientific Computing" zustimmend zur Kenntnis. Seitens der Landesregierung wird die Absicht erklärt, den SFB in dem aufgrund des Beschlusses des Landtages vom .... in Aussicht gestellten Ausmaß zu unterstützen.

4.6. Stadtverwaltung der Stadt Linz

Die Stadt Linz nimmt die Einrichtung des SFB "Numerical and Symbolic Scientific Computing" zustimmend zur Kenntnis. Seitens des Stadtsenates wird die Absicht erklärt, den SFB in dem aufgrund des Beschlusses des Senates vom .... in Aussicht gestellten Ausmaß zu unterstützen.

4.7. Sonstiges

Keine Angaben.

§5. Vorgabe für die Finanzierungsstruktur der nächsten Antragsperiode

Gemäß der Finanzierungsstruktur bei Spezialforschungsbereichen müssen die Forschungsstätten während der Laufzeit des SFB anstreben, vornehmlich kostenintensives Personal aus der Ergänzungsausstattung in die Struktur der Forschungsstätten zu übernehmen.

Da der SFB "Numerical and Symbolic Scientific Computing" mit einem hohen Personalstand aus der Grundausstattung startet und in der Anfangsphase eine relativ geringe Zahl von Mitarbeitern als Ergänzungsausstattung zusätzlich beantragt, ist es plausibel, daß es nur zu einer geringfügigen Personalrücknahme für die nächste Antragsperiode kommen kann, wenn man weiterhin von einem geförderten Projekt sprechen möchte. Es wird daher für die nächste Antragsperiode eine Reduktion des Personalstandes in der Ergänzungsausstattung beim wissenschaftlichen Personal um 2 Stellen in Aussicht gestellt. Zum Erhalt der Leistungsfähigkeit von SFBs ist als allgemeine Maßnahme seitens des BMWV die Schaffung eines Stellenpools in Aussicht genommen, aus dem in Forschungsstätten Stellen befristet zur Verfügung gestellt werden, gebunden an besondere Leistungsnachweise der betreffenden Institution.

§6. Universitäts-Organisationsgesetz

Bei einer Änderung des Universitäts-Organisationsgesetzes werden die Bestimmungen des Memorandums dem dann geltenden Organisationsrecht anzupassen sein.

Unterzeichnende des Entwurfes des speziellen Memorandums:

Für die Trägeruniversität

....
der Rektor

Datum: ....

....
der/die Dekan(e)

Datum: ....

für den SFB

....
der Sprecher

Datum: ....

A CVs and Publications of Participating Scientists

CURRICULUM VITAE

Name: Martin Baldinger

Date and Place of Birth: 19 December 1969, Grieskirchen, Austria

Nationality: Austria

Home Address: Etzingerstr. 1, A-4084 St. Agatha, Austria

Affiliation: Institute of Mechanics and Machine Design
Johannes Kepler University Linz
Altenbergerstr. 69, A-4020 Linz, Austria
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www-Page: http://mechatonik.uni-linz.ac.at/institute/TMGM/baldinger.html

Title: Univ.-Ass.

Education:

1989:	High School Diploma (Matura)
1990 - 1995:	Studied Mechatronics at University of Linz, graduated to Dipl.-Ing.

Employment:

1996 - :	Assistant, Inst. of Technical Mechanics, University of Linz

Societies and Activities:

Member, Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)

Publications:

[1] M. Baldinger, Aufbau und Modellierung des Labormodelles balancierter Balken mit gleitendem Wagen, Diplomarbeit 1995.

CURRICULUM VITAE

Name: Alexander K. Belyaev

Date and Place of Birth: 13. August 1953, Kamchatka, Russia

Nationality: Russia

Home Address: Prandtauerstr. 22, A-4040 Linz, Austria

Affiliation: Institute of Mechanics and Machine Design
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www-Page: http://mechatronik.uni-linz.ac.at/institute/TMGM/belyaev.html

Title: Univ.-Dozent Dr.

Education:

1960 - 1970:	Physical-Mathematical School Nr. 239 in St. Petersburg, with distinction
1970 - 1976:	Studied Dynamics and Strength of Machines at the Polytechnical Institute in Leningrad, graduated with distinction to Dipl.-Ing.
1979:	Degree of Doctor in Physics and Mathematics at the Polytechnical Institute in Leningrad
1988:	Habilitation for Mechanics at the Polytechnical Institute in Leningrad

Employment:

1979 - 1986:	Assistant at the Department of Mechanics and Control Processes, Polytechnical Institute in Leningrad
1986 - present time:	Univ.-Docent at the Department of Mechanics and Control Processes, State Technical University of St. Petersburg, former Polytechnical Institute in Leningrad.
1988 - 1989:	Sabbatical leave at Institut für Allgemeine Mechanik, Technical University of Vienna.
1991:	Visiting Professor at Institute of Mechanics, University of Innsbruck.
1992 - 1993:	Research Fellow of the Alexander von Humboldt Foundation at Institute of Technical Mechanics, Technical University of Braunschweig.
1993 - 1995:	Visiting Professor at Institute of Technical Mechanics and Foundation of Machine Design, Johannes Kepler University of Linz.
1995 - 1996:	Senior Researcher of the FWF-Project P09533-TEC "Micromechanics of the Dynamic Processes in the Viscoplasticity", Institute of Technical Mechanics and Foundation of Machine Design, Johannes Kepler University of Linz.
1996 - present time:	Visiting Professor at Institute of Mechanics and Machine Design, Johannes Kepler University of Linz.

Selected Project Experience:

1979 - 1988:	eight projects for Soviet outer space industry
1995 - 1996:	FWF-Project P09533-TEC 'Micromechanics of the Dynamic Processes in the Viscoplasticity'

Prize:

1993:	Thomas A. Jaeger Prize of the International Association for Structural Mechanics in Reactor Technology.

Societies and Activities:

- Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)
- Society of Interaction of Mathematics and Mechanics (ISIMM)

Publications:
Some 80 papers in English, German and in Russian. The list of 10 recent related papers is enclosed.

[1] A.K.Belyaev, Vibrational state of complex mechanical structures under broad-band excitation. Int. Journal of Solids and Structures, 1991, 27, No. 7, pp. 811-823.

[2] A.K.Belyaev, Dynamical simulation of high-frequency vibration of extended complex structures. Int. Journal Mechanics of Structures and Machines, 1992, 20, No. 2, pp 155-168.

[3] A.K.Belyaev, High-frequency vibration of extended complex structures. Int. Journal of Probabilistic Engineering Mechanics, 8, 15-24, 1993.

[4] A.K.Belyaev and N.J.Krutzik, Localization of high-frequency vibrations of secondary systems of power plants. Acta Mechanica, 1994, 102, No. 1, pp. 1-10.

[5] A.K.Belyaev, Vibrational conductivity approach to high-frequency dynamics. Int. J. Nuclear Engineering and Design, 1994, 150, No 2-3, pp. 281-286.

[6] V.A.Palmov, E.Brommundt and A.K.Belyaev, Stability analysis of drillstring rotation. International Journal Dynamics and Stability of Systems, 1995, 10, No. 2, pp. 99-110.

[7] A.K.Belyaev and H.J.Pradlwarter, Wide-band random vibration in members of complex structures. International Journal of Solids and Structures, 1995, 32, No. 24, pp. 3629-3641.

[8] P.Fischer, A.K.Belyaev and H.J.Pradlwarter, Combined integral and FE analysis of broadband random vibration in structural members. Probabilistic Engineering Mechanics, Vol. 10, No.4, 1995, pp. 241-250.

[9] A.K.Belyaev and V.A.Palmov, Thermodynamic derivation of heat conduction equation and dynamic boundary value problem for thermoelastic materials and fluids. Acta Mechanica, Vol. 114, 1996, pp. 27-37.

[10] A.K.Belyaev and H.Irschik, Non-linear waves in complex structures modelled by elastic-viscoplastic stochastic media. International Journal of Non-Linear Mechanics, Vol. 31, No. 5, pp. 771-777, 1996.

CURRICULUM VITAE

Name: Barbara Blaschke

Date and Place of Birth: November 4, 1969, Linz

Nationality: Austria

Home Address: Kürnbergblick 1, A-4040 Puchenau, Austria

Affiliation: Institute for Industrial Mathematics
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WWW-Page: http://www.indmath.uni-linz.ac.at/

Title: PhD

Education:

1988:	High School Diploma (Matura)
1988 - 1993:	Studied Technical Mathematic in Linz, graduated to Dipl.-Ing.
1996:	Ph.D. (Dr. techn.) in Mathematics (Linz), Thesis topic: Some Newton type methods for the regularization of nonlinear ill–posed problems (referees: Heinz W. Engl, Linz; Ulrich Langer, Linz)

Employment:

since 1995:	Research Assistant at the Chair for Industrial Mathematics, Universitdt Linz, currently funded via FWF project 10866.

Selected Project Experience:

1995 - 1996:	Project "Direct and inverse initial–boundary value problems for parabolic differential equations" funded by the Jubiläumsfonds der österreichischen Nationalbank, Project 5391
since 1996:	Project "Quasi–Newton methods for nonliner ill–posed problems" of the FWF, Project 10866

Publications:

B. Blaschke: *Quasi-Newton Verfahren für partiell separable Funktionen*, Diploma Thesis, Institut für Mathematik, Johannes Kepler Universität Linz, June 1993.

B. Blaschke, H.W. Engl, W. Grever, M. Klibanov: *An application of Tikhonov regularization to phase retrieval*, to appear in: Nonlinear World, 1997.

B.Blaschke, A. Neubauer, O. Scherzer: *On convergence rates for the iteratively regularized Gauss-Newton method*, to appear in: IMA Journal of Numerical Analysis, 1997.

B.Blaschke, H.W. Engl: *Regularization methods for nonlinear ill–posed problems with applications to phase reconstruction*, to appear in: H.W. Engl, A.K. Louis, W.Rundell, eds., Inverse Problems in Medical Imaging and Nondestructive Testing, Springer, Vienna–New York, 1997.

B. Blaschke: *Some Newton type methods for the solution of nonlinear ill–posed problems*, PhD Thesis, Johannes Kepler Universität Linz, 1996.

B. Blaschke: *Some Newton type methods for the solution of nonlinear ill–posed problems*, submitted.

B. Blaschke: *A posteriori parameter choice strategies for some Newton type methods for the regularization of nonlinear ill–posed problems*, submitted.

B. Blaschke: *On convergence rates of some iterative regularization methods for an inverse problem for a parabolic equation connected with continuous casting of steel*, submitted.

CURRICULUM VITAE

Name: Walter Brunner

Date and Place of Birth: 25. April 1968, Steyr

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Home Address: Hofergraben 25/4, A-4400 Steyr, Austria

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Title: Lekturer

Education:

1986:	High School Diploma (Matura)
1986 - 1991:	Studied Civil Engineering, graduated to Dipl.-Ing., Technical University of Vienna
1994:	Ph.D. (Dr. techn.) in Technical Mechanics, University of Linz

Employment:

1991 - 1995:	Assistant, Inst. of Technical Mechanics, University of Linz
1996 - :	Consulting engineer in Steyr

Societies and Activities:

- Member, Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)

Publications:

Diplomarbeit: Allgemeines Verschiebungsgrößenverfahren für Stäbe mit stetig veränderlichem Querschnitt unter Berücksichtigung der Stabverkürzung durch Ausbiegung nach Theorie I. und II.Ordnung. Institut für Baustatik, TU Wien, 05/1991.
Dissertation: Dynamische Interaktion von Flüssigkeiten mit elasto-viskoplastischen Konstruktionen. Institut für Mechanik und Maschinenlehre, Johannes-Kepler Universität Linz, 10/1994.

Some 12 papers in English and German. The list of 10 recent related papers is enclosed.

[1] Brunner, Walter; Irschik, Hans.: An Efficient Algorithm for Elasto-Viscoplastic Vibrations of Multi-Layered Composite Beams Using Second-Order Theory, Nonlinear Dynamics 6, 1994, pp. 37-48.

[2] Brunner, Walter; Irschik, Hans.: Inelastic beams excited by earthquakes: Dynamic fluid-solid interaction, Structural Dynamics - Eurodyn'93, Moan et al. (eds), A.A.Balkema, Rotterdam, 1993, pp. 33-39.

[3] Brunner, Walter: Anwendung des Reduktionsverfahrens auf die Fließzonentheorie II.Ordnung (Application of the Transfer-Matrix Approach to Second Order Theory of Yielding Zones in Beams), ZAMM 74, 1994, T 154-T155.

[4] Brunner, Walter; Irschik, Hans.: Dynamic interaction of inelastic structures and fluids, Archives of Mechanics, Engineering Transactions 1-2/94, 1994., pp. 181-194.

[5] Brunner, Walter: Zur Substrukturtechnik bei der dynamischen Interaktion von inelastischen Konstruktionen mit Flüssigkeiten (On Substructure-Technique for Dynamic Interaction of Inelastic Structures with Fluids), ZAMM 75, 1995, S247-S248.

[6] Brunner, Walter: A Time Domain Formulation for the Dynamic Interaction between Fluid and Inelastic Solids, Proc. 10th European Conference on Earthquake Engineering, Vienna, Austria, 1994.

[7] Brunner, Walter; Irschik, Hans; Ziegler, Franz.: Blast-Type Loading of Elastic-Plastic Containers, Proc. ASME/JSME PVP Conference, Honolulu, Hawaii, 1995.

[8] Brunner, Walter; Irschik, Hans; Klauser, R.; Kletzmayr, J.; Sturm, I.; Woloszczuk, W.; Kovarik, J.: Neoral - An New Microemulsion Formula of Cyclosporine A : Interpatient Pharmacokinetic Variability in Renal Transplant Recipients.

[9] Brunner, Walter; Adam, Christoph.: Comparison of Beam and Plane Stree Theories for Inelastic Structures, Proc. ICES-95.

[10] Brunner, Walter; Irschik, Hans; Schlacher, Kurt.: Symbolic Computation of the Transistion Matrix for Cylindrical Bending of Plates According to Reissner's Eight-Order Theory, Proc. ICES-95.

CURRICULUM VITAE

Name: Bruno Buchberger

Date and Place of Birth: October 22, 1942, Innsbruck (Austria)

Nationality: Austria

Home Address: Loeschfeld 6, A-4232 Hagenberg, Austria

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www-page: http://www.risc.uni-linz.ac.at/people/buchberger

Title: O.Univ.Professor

Education:

1960:	High School Diploma (Matura)
1960 - 1966:	Studies in Mathematics at Univ. Innsbruck
1966:	Ph.D. in mathematics, Univ. Innsbruck
1973:	Habilitation in mathematics, University of Innsbruck

Employment:

1964 - 1968:	Programmer, systems programmer, mathematical consultant, University of Innsbruck, Computer Center.
1966 - 1974:	Assistant, University of Innsbruck, Dept. of Computer Science.
1974 - :	Full professor of mathematics (theoretical computer science), University of Linz (Austria).
1979 - 1981:	Dean of the School of Technical Sciences, University of Linz.
1987 - :	Founder and chairman of the Research Institute for Symbolic Computation, University of Linz.
1989 - :	Founder and director of the Software-Park in Hagenberg.
1993:	Founder of the College (Fachhochschule) for Software Engineering in Hagenberg.
1996:	Founder of the College (Fachhochschule) for Media Technology and Design in Hagenberg.
1970 - 1996:	numerous visiting appointments in international research centers (see "International cooperation").

Selected Project Experience:

1993 - 1995:	BMWF project CEI-PACT, parts of tasks WP4, WP5. Cooperation between several research institutes in Austria, Czech Republic, Slovakia and Hungary).
1989 - 1991:	FWF project P06931-PH. Parallel languages for symbolic computation.
1989 - 1992:	ESPRIT BRA project: MEDLAR. Mechanizing Deduction in the Logics of Practical Reasoning.
1990 - 1992:	FWF project: Grvbner Bases: theory and applications.
1991 - 1996:	FWF project: Parallel Symbolic Computation on Shared Memory Machines
1993 - 1995:	BMWF project PARAGRAPH (parallel computational geometry). Cooperation with Dept. Computer Graphics, University of Linz (Prof. Volkert) and Research Institute for Software Technologies, University of Salzburg (Prof. Zinterhof).
1993 - 1995:	International project: Hybrid Evolutionary Programming Techniques: Integration of Symbolic Computation with Neural Networks and Genetic Programming. Sponsored by: Japanese Ministry of Science in the frame of the Real World Computing Program (RWCP).
1985 - 1996:	In addition, numerous (about 20) software development projects with the Austrian industry on CAD, NC and robot off-line programming, tunnel construction, window production etc. with a total volume of approx. 15 mio ATS.

Societies and Activities:

- Member of ACM, German Chapter of ACM, EATCS, AISB,
  GI, DMV, DVMLGM (Germany),
  ÖGI, ÖMG, ÖGAI (Austria).
- Secretary ACM SIGSAM (1982 - 1984).
- 1996: Appointed Chairman of the Joined Mathematics and Informatics Section of the Academia Europea.
- Founder and co-editor (with G. Collins): "Texts and Monographs in Symbolic Computation", Springer NY – Vienna, Vol. 1 - 7 appeared.
- Founder and Editor-in-Chief (1985 - 1995): international Journal of Symbolic Computation (Academic Press). Also special issue editor: 1988, 1995.
- Member of the editorial board: Advances in Mathematics and Artificial Intelligence, Journal for Universal Computer Science, Applied Algebra and Error Correcting Codes, Electronic Journal on Combinatorics and Computer Algebra.
- Organizer (with F. Winkler), "RISC-Linz Special Year on Gröbner Bases", March 1997 – February 199
- Program Chairman: EUROCAL 85 Conference on Computer Algebra, ICME 5 Conference '84 (Adelaide), Section Computer Algebra, DMV Fall School on Computer Algebra 1988 (Düsseldorf; jointly with J. Davenport), Conference on "Applicable Algebra" '89 (Oberwolfach; jointly with T. Beth and H. Lüneburg), Conference on "Computer Algebra" '91 (Dagstuhl; jointly with F. Schwarz), CONPAR 94 - VAPP VI (Linz).

- Program Committee Member: EUROCAM 82 (Marseille), EUROCAL 83 (London), MIMI 84 (Bari), ÖGAI 85 (Vienna), CADE 86 (Oxford), CAAP 87 (Pisa), RTA 87 (Karlsruhe), ICALP 87 (Karlsruhe), EUROCAL 87 (Leipzig), ICALP 90 (Warwick), DISCO 90 (Capri), Expert Systems in Engineering 90 (Vienna), PARCELLA 90 (Berlin) , ACPC 91 (Salzburg), ICALP 92 (Vienna), MEGA 92 (Nice), DISCO 93 (Gmunden), AMAST 96 (Munich) , IMACS 96 on Computer Algebra (Hagenberg), CADE 96 (Boston), ACPC 96 (Klagenfurt), AI and Mathematics (Steyr).
- Referee for the following journals: Zentralblatt für Mathematik, ÖMG Bulletin, Theoretical Computer Science, Computing, ACM TOMS, Applicable Algebra and Error Correcting Codes, IEEE Transactions on Computers, Acta Informatica, Mathematics of Computation.
- Reviewer for: US National Science Foundation, Austrian Science Foundation, German Science Foundation, Science Foundation of the Netherlands, European Commission (ESPRIT Basic Research Action).
- Referee for numerous conferences on computer algebra, symbolic computation, computational logic, etc.

Scientific Cooperations:

- 1970-1971 Sabbatical year as a fellow at the Joint Institute for Nuclear Research in Dubna (Moscow), Laboratory of Computing Technique.
- 1982: 6 months, Visiting Professor, University of Delaware, Dept. of Computer Science.
- 1982: 2 months, Visiting Professor, University of Wisconsin - Madison, Dept. of Computer Science.
- 1983: 1 month, Visiting Researcher, University of Genova (Italy), Dept. of Mathematics.
- 1984: 1 month, Visiting Researcher, University of Leipzig (GDR), Mathematical Center.
- 1986: 2 months, Visiting Researcher, University of Delaware, Dept. of Computer Science.
- 1986: 2 months, Consultant, Soft Warehouse, Honolulu (Hawaii).
- 1986: 2 months, Visiting Researcher, Ohio State University, Dept. of Computer Science.
- 1987: 2 months, Visiting Researcher, RIKEN Institute and ICOT Institute, Tokyo (Japan).
- 1991: 1 month, Visiting Professor, University of Pisa, Computer Science Dpt.
- 1996: 1 month, Visiting Professor, Australian National University, Canberra, CSIR Institute (head: Professor Michael Mc Robbie)
- 1996: 1 month, Visiting Fellow, Wolfram Research International, Urbana-Champaign, USA.
- 1996: 2 months, Visiting Researcher, University of Tsukuba, SCORE Lab, (head: Professor Tetsuo Ida).
- 1997: 1 month: Visiting Researcher, University of Tsukuba, SCORE Lab, (head: Professor Tetsuo Ida) and Hiroshima University, Computer Science Dept. (head: Tadao Ichikawa).

Publications: Besides the following books [10] [12] [1] and scientific papers [2] [3] [4] [5] [6] [7] [8], [9], [11], [13], the author has published 60 more refereed papers on symbolic computation, computational logic, computer algebra, constructive algebraic geometry, and parallel computation, and also presented 95 colloquium lectures in universities and at conferences around the world, among them 37 invited main lectures at international conferences.

[1] B. Buchberger. Mathematics: An Introduction to Mathematics Integrating the Pure and Algorithmic Aspect. Lecture Notes in the Form of a Mathematica Notebook, RISC Institute, Austria. Springer, Vienna. in preparation as a book.

[2] B. Buchberger. *On Finding a Vector Space Basis of the Residue Class Ring Modulo a Zero Dimensional Polynomial Ideal (German).* PhD thesis, University of Innsbruck, Math.Dept., 1965.

[3] B. Buchberger. An Algorithmical Criterion for the Solvability of Algebraic Systems of Equations (German). *Aequationes mathematicae*, 4(3):374–383, 1970.

[4] B. Buchberger. A Theoretical Basis for the Reduction of Polynomials to Canonical Forms. *ACM SIGSAM Bull.*, 10(3):19–29, 1976.

[5] B. Buchberger. Gröbner-Bases: An Algorithmic Method in Polynomial Ideal Theory. In N.K. Bose, editor, *Multidimensional Systems Theory*, pages 184–232. Reidel Publishing Company, Dodrecht, 1985.

[6] B. Buchberger. History and Basic Features of the Critical-Pair/Completion Approach. In *Rewrite Technique and Applications, Dijon, May 1985*, LNCS 202, pages 1–45. Springer, 1985. invited paper.

[7] B. Buchberger. Symbolic computation: Computer algebra and logic. In F. Baader and K.U. Schulz, editors, *Frontiers of Combining Systems*, Applied Logic Series. Kluwer Academic Publishers, 1996. to appear.

[8] B. Buchberger. Chapter: Symbolic computation (german). In G. Pomberger and P. Rechenberg, editors, *Handbuch der Informatik*. Birkhaeuser, Munich, 1997. to appear.

[9] B. Buchberger, G. E. Collins, and B. Kutzler. Algebraic Methods in Computational Geometry. *Annual Reviews in Computer Science*, 3:85–119, 1988.

[10] B. Buchberger, G. E. Collins, and R. Loos. *Computer Algebra - Symbolic and Algebraic Computation*. Springer, Wien, New York, 1982. Russian edition 1986, Mir Publishing Company.

[11] B. Buchberger and J. Elias. Using Gröbner Bases for Detecting Polynomial Identities. A Case Study on Fermat's Ideal. *Journal of Number Theory*, 41(3):272–279, 1992.

[12] B. Buchberger and F. Lichtenberger. *Mathematics for Computer Science I - The Method of Mathematics (German).* Springer, Berlin, Heidelberg, New York, 1981. 2nd Edition.

[13] B. Buchberger and R. Loos. Chapter: Algebraic simplification. In B. Buchberger, G. E. Collins, and R. Loos, editors, *Computer Algebra - Symbolic and Algebraic Computation*, pages 11–44. Springer, Vienna, New York, 1982.

CURRICULUM VITAE

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Date and Place of Birth: 21 February 1972, Steyr

Nationality: Austria

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Education:

1991:	High School Diploma (Matura)
1992 - 1996:	Studied Mechatronics at University of Linz, graduated to Dipl.-Ing.
1996 - 1997:	MSc. Mechatronics and Optical Engineering, Loughborough University

Employment:

1991:	CNC Programmierer

Societies and Activities:

- Member, Austrian Biological Society (ABS)

CURRICULUM VITAE

Name: Heinz W. Engl

Date and Place of Birth: March 28, 1953, Linz

Nationality: Austria

Home Address: Wolfauerstraße 80, A-4040 Linz, Austria

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WWW-Homepage: http://www.indmath.uni-linz.ac.at/www/staff/engl.html

Title: o.Univ.-Prof. (full professor of industrial mathematics)

Education:

1971:	High School Diploma (Matura)
1971:	Third Prize, International Mathematical Olympia, CSSR
1971 – 1975:	Studied Technical Mathematic in Linz, graduated to Dipl.-Ing.
1977:	Ph.D. (Dr. techn.) in Mathematics (Linz), degree awarded sup auspiciis praesidents rei publicae; thesis topic: Fixed point theorems for random operators on stochastic domains (referees: Hansjörg Wacker Linz; M.Z. Nashed, University of Delaware; A.T. Bharucha-Reid, Wayne State University, Detroit)
1979:	Habilitation for mathematics, Johannes Kepler Universität Linz

Employment:

1972 – 1975:	Teaching Assistant at the Chairs for Operations Research and for Numerical Analysis, Universität Linz
1976 – 1981:	Universitätsassistent, Institut für Mathematik, Universität Linz
1976/77 :	Assistant at the School of Mathematics, Georgia Institute of Technology, USA
1978/79 :	Visiting Assistant Professor, Department of Mathematics, University of Delaware, USA
1980/81:	Visiting Professor, Universität Klagenfurt (Austria)
1981 – 1988:	Associate Professor (außerordentlicher Universitätsprofessor), Universität Linz
Summers of 1986 and 1989:	Visiting Fellow, Center for Mathematical Analysis, Australian National University, Canberra

1986/87:	Visiting Professor at Universität Klagenfurt (Austria)
since 1981:	Several times on short lists for professorships in Germany, Switzerland and Austria
since July 1988:	Full Professor (ordentlicher Universitätsprofesser) for Industrial Mathematics, Johannes Kepler Universität Linz
1988/89:	Visiting Professor, University of Vienna
1994:	Call to a Chair for Applied Mathematics at Universität Kaiserslautern (Germany), declined
since 1995:	Dean of the College of Science and Engineering, Johannes Kepler Universität Linz
since 1996:	Owner of MathConsult GmbH

Selected Project Experience:

1984 – 1989:	Special Research Program S 32/03 of the FWF (Ill-Posed Problems with Industrial Applications)
1990 – 1992:	FWF-Project P7869-PHY "Regularization of Nonlinear Ill-Posed Problems" (together with Karl Kunisch)
1993 – 1995:	Participant of the EU-Project "Mathematics as an Industrial Resource" (HCM-Network; Austrian part financed via FWF-project P09647-PHY "Mathematics as an Industrial Resource".)
since July 1992:	Head of the Christian Doppler Laboratory for Mathematical Modelling and Numerical Simulation; current budget exceeding 3 Mio ATS per year
1995 – 1996:	Project 5391 , funded by Jubiläumsfonds der Österreichischen Nationalbank (Austrian National Bank)
since Sept. 1996:	FWF-Project P10866-TEC "Nonlinear Ill-posed Problem"
1992 – 1997:	Project "Optimization of Problems in Structural Mechanics" co-financed by the Austrian Forschungsförderungsfonds für die gewerbliche Wirtschaft and AVL List GmbH (Graz)
	various projects directly with industry in Austria and abroad

Societies and Activities:

- Member, American Mathematical Society (AMS)
- Member of the Board of GAMM
- Head of the Upper Austrian Section of the Austrian Mathematical Society (ÖMG)
- Member of the Board and 1994 – 1996 President of ECMI
- Founder and Editor-in-Chief of *Surveys on Mathematics for Industry* (Springer, Wien/New York)
- Member of the Editorial Board of *Inverse Problems*

- Member of the Editorial Board of *Mathematical Modelling and Computational Experiment* (Moscow)
- Member of the Editorial Board of ZAMM
- Former member of the Editoral Boards of Zeitschrift für *Operations Research, Series B*, and of *Computing*
- Member of the Board (Kuratorium) of the FWF

Scientific Cooperations: see Project 7, Chapter 5.5

Publications: Editor of six books, author of two monographs on inverse problems and of one text book on integral equations; 101 publications in scientific journals and proceedings, among them 75 original papers. Selected recent 10 publications (see also the references given for Project 7):

H. W. Engl and M. Hanke and A. Neubauer, *Regularization of Inverse Problems*, Kluwer, Dordrecht, 1996.

A. Binder and H. W. Engl and S. Vessella, Some inverse problems for a nonlinear parabolic equation connected with continuous casting of steel: stability estimates and regularization, *Numer. Funct. Anal. Optim.*, 11:643-672, 1990.

H. W. Engl and W. Grever, Using the L-curve for determining optimal regularization parameters, *Numer. Math.*, 69:25-31, 1994.

H. W. Engl and C. W. Groetsch, A higher order approximation technique for restricted linear least-squares problems, *Bull. of the Austral. Math. Soc.*, 37:121-130, 1988.

H. W. Engl and M. Hanke, An optimal stopping rule for the nu-methods for solving ill-posed problems using Christoffel functions, *J. Approx. Theory*, 79:89-108, 1994.

H. W. Engl and G. Hodina, Uniform convergence of regularization methods for linear ill-posed problems, *J. of Comp. and Appl. Math*, 38:87-103, 1991.

H. W. Engl and V. Isakov, On the identifiability of steel reinforcement bars in concrete from magneto-static measurements, *European J. Appl. Math.*, 3:255-262, 1992.

H. W. Engl and K. Kunisch and A. Neubauer, Convergence rates for Tikhonov regularization of nonlinear ill-posed problems, *Inverse Problems*, 5:523-540, 1989.

H. W. Engl and G. Landl, Convergence rates for maximum entropy regularization, *SIAM J. Numer. Anal.*, 30:1509-1536, 1993.

W. Grever and A. Binder and H. W. Engl and K. Mörwald, Optimal cooling strategies in continuous casting of steel with variable casting speed, *Inverse Problems Engrg.*, 2:289-300, 1996.

O. Scherzer and H. W. Engl and K. Kunisch, Optimal a-posteriori parameter choice for Tikhonov regularization for solving nonlinear ill-posed problems, *SIAM J. Numer. Anal.*, 30:1796-1838, 1993.

[1] G. Anger. *Inverse Problems in Differential Equations.* Akademieverlag, Berlin, 1990.

[2] A. B. Bakushinskii. The problem of the convergence of the iteratively regularized Gauß-Newton method. *Comput. Math. Math. Phys.*, 32:1353–1359, 1992.

[3] H. Banks and K. Kunisch. *Parameter Estimation Techniques for Distributed Systems.* Birkhäuser, Boston, 1989.

[4] J. Baumeister. *Stable Solution of Inverse Problems.* Vieweg, Braunschweig, 1987.

[5] J. Beck, B. Blackwell, and C. S. Clair. *Inverse Heat Conductions.* Wiley, Sussex, 1985.

[6] A. Binder, H. W. Engl, and S. Vessella. Some inverse problems for a nonlinear parabolic equation connected with continuous casting of steel: stability estimates and regularization. *Numer. Funct. Anal. Optim.*, 11:643–672, 1990.

[7] B. Blaschke. *Some Newton type methods for the solution of nonlinear ill-posed problems.* PhD thesis, Johannes Kepler Universität Linz, 1996.

[8] B. Blaschke and H. W. Engl. Regularization methods for nonlinear ill-posed problems with applications to phase reconstruction. to appear in: H. W. Engl, A. K. Louis, W. Rundell, eds., Inverse Problems in Medical Imaging and Nondestructive Testing, Springer, Vienna-New York, 1997.

[9] B. Blaschke, H. W. Engl, W. Grever, and M. V. Klibanov. An application of Tikhonov regularization to phase retrieval. *Nonlinear World*, to appear, 1997.

[10] B. Blaschke, A. Neubauer, and O. Scherzer. On convergence rates for the iteratively regularized Gauß-Newton method. *IMA Journal of Numerical Analysis*, 1997. to appear.

[11] F. Bloom. *Ill-Posed Problems for Integrodifferential Equations in Mechanics and Electromagnetic Theory.* SIAM, Philadelphia, 1981.

[12] D. Colton and R. Kress. *Inverse Acoustic and Electromagnetic Scattering Theory.* Springer, Berlin, 1992.

[13] P. Deuflhard. Global inexact Newton methods for very large scale nonlinear problems. *Impact of Comp. in Sc. and Eng.*, 3:366–393, 1991.

[14] P. Deuflhard. Cascadic conjugate gradient methods for elliptic partial differential equations. Algorithm and numerical results. In D. Keyes and J. Xu, editors, *Proceedings of the 7th International Conference on Domain Decomposition Methods*, pages 29–42, Providence, 1993. AMS.

[15] P. Deuflhard and G. Heindl. Affine invariant convergence theorems for Newton's method and extensions to related methods. *SIAM J. Numer. Anal.*, 16:1–10, 1979.

[16] H. W. Engl. Necessary and sufficient conditions for convergence of regularization methods for solving linear operator equations of the first kind. *Numer. Funct. Anal. Optim.*, 3:201–222, 1981.

[17] H. W. Engl. On least-squares collocation for solving linear integral equations of the first kind with noisy right-hand side. *Boll. Geodesia Sc. Aff.*, 41:291–313, 1982.

[18] H. W. Engl. Regularization by least-squares collocation. In P. Deuflhard and E.Hairer, editors, *Numerical Treatment of Inverse Problems in Differential and Integral Equations*, pages 345–354, Boston, 1983. Birkhäuser.

[19] H. W. Engl. Regularization methods for the stable solution of inverse problems. *Surveys on Mathematics for Industry*, 3:71–143, 1993.

[20] H. W. Engl and H. Gfrerer. A posteriori parameter choice for general regularization methods for solving linear ill-posed problems. *Appl. Numer. Math.*, 4:395–417, 1988.

[21] H. W. Engl and C. W. Groetsch, editors. *Inverse and Ill-Posed Problems.* Academic Press, Orlando, 1987.

[22] H. W. Engl and C. W. Groetsch. A higher order approximation technique for restricted linear least-squares problems. *Bull. of the Austral. Math. Soc.*, 37:121–130, 1988.

[23] H. W. Engl, M. Hanke, and A. Neubauer. *Regularization of Inverse Problems.* Kluwer, Dordrecht, 1996.

[24] H. W. Engl and V. Isakov. On the identifiability of steel reinforcement bars in concrete from magnetostatic measurements. *European J. Appl. Math.*, 3:255–262, 1992.

[25] H. W. Engl, K. Kunisch, and A. Neubauer. Convergence rates for Tikhonov regularization of nonlinear ill-posed problems. *Inverse Problems*, 5:523–540, 1989.

[26] H. W. Engl and G. Landl. Convergence rates for maximum entropy regularization. *SIAM J. Numer. Anal.*, 30:1509–1536, 1993.

[27] H. W. Engl and G. Landl. Maximum entropy regularization of nonlinear ill-posed problems. In V. Lakshmikantham, editor, *Proceedings of the First World Congress of Nonlinear Analysts*, pages 513–525, Berlin, 1996. de Gruyter.

[28] H. W. Engl and T. Langthaler. Control of the solidification front by secondary cooling in continuous casting of steel. In H. W. Engl, H. Wacker, and W. Zulehner, editors, *Case Studies in Industrial Mathematics*, pages 51–77, Stuttgart/Dordrecht, 1988. Teubner/Kluwer.

[29] H. W. Engl, A. K. Louis, and W. Rundell, editors. *Inverse Problems in Geophysical Applications.* SIAM, Philadelphia, 1996.

[30] H. W. Engl, A. K. Louis, and W. Rundell, editors. *Inverse Problems in Medical Imaging and Nondestructive Testing.* Springer, Wien, New York, 1997.

[31] H. W. Engl and P. Manselli. Stability estimates and regularization for an inverse heat conduction problem in semi-infinite and finite time intervals. *Numer. Funct. Anal. Optim.*, 10:517–540, 1989.

[32] H. W. Engl and J. McLaughlin, editors. *Inverse Problems and Optimal Design in Industry.* Teubner, Stuttgart, 1994.

[33] H. W. Engl and A. Neubauer. On projection methods for solving linear ill-posed problems. In A. Vogel, editor, *Model Optimization in Exporation Geophysics*, pages 73–92. Vieweg, 1987.

[34] H. W. Engl and A. Neubauer. Convergence rates for Tikhonov regularization in finite-dimensional subspaces of Hilbert scales. *Proc. Amer. Math. Soc.*, 102:587–592, 1988.

[35] H. W. Engl and A. Neubauer. On an inverse problem from magnetostatics. In W. L. Hogarth and B. J. Noye, editors, *Computational Techniques and Applications: CTAC-89*, pages 3–15, Washington, D.C., 1990. Hemisphere Publ.Comp.

[36] H. W. Engl and A. Neubauer. Reflector design as an inverse problem. In M. Heiliö, editor, *Proc. of the Fifth European Conference on Mathematics in Industry*, pages 13–24, Stuttgart, 1991. Teubner.

[37] H. W. Engl and A. Neubauer. Convergence rates for Tikhonov regularization of implicitely defined nonlinear inverse problems with an application to inverse scattering. In S. Kubo, editor, *Inverse Problems*, pages 90–98, Atlanta, 1993. Technology Publ.

[38] H. W. Engl and W. Rundell, editors. *Inverse Problems in Diffusion Processes.* SIAM, Philadelphia, 1995.

[39] H. W. Engl, W. Rundell, and O. Scherzer. A regularization scheme for an inverse problem in age-structered populations. *J. Math. Anal. Appl.*, 182:658–679, 1994.

[40] H. W. Engl, O. Scherzer, and M. Yamamoto. Uniqueness and stable determination of forcing terms in linear partial differential equations with overspecified boundary data. *Inverse Problems*, 10:1253–1276, 1994.

[41] H.W. Engl, L. Holzleitner, and K. Mahmoud. Optimum structural design using MSC/NASTRAN and sequential quadratic programming. *Computers and Structures*, 52:437–447, 1994.

[42] H.W. Engl and M. Z. Nashed. New extremal characterizations of generalized inverses of linear operators. *Jour. Math. Anal. Appl.*, 32:566–586, 1981.

[43] W. Grever, A. Binder, H. W. Engl, and K. Mörwald. Optimal cooling strategies in continuous casting of steel with variable casting speed. *Inverse Problems Engrg.*, 2:289–300, 1996.

[44] C. W. Groetsch. *The Theory of Tikhonov Regularization for Fredholm Equations of the First Kind.* Pitman, Boston, 1984.

[45] C. W. Groetsch. *Inverse Problems in the Mathematical Sciences.* Vieweg, Braunschweig, 1993.

[46] M. Hanke. *Conjugate Gradient Type Methods for Ill-Posed Problems.* Longman Scientific & Technical, Harlow, Essex, 1995.

[47] M. Hanke. A regularization Levenberg-Marquardt scheme with applications to inverse groundwater filtration problems. Preprint 283, Universität Kaiserslautern, and submitted, 1996.

[48] M. Hanke, F. Hettlich, and O. Scherzer. The Landweber iteration for an inverse scattering problem. In K. W. Wang et al., editors, *Proceedings of the 1995 Design Engineering Technical Conferences Vol. 3 Part C*, pages 909–915, New York, 1995. ASME.

[49] M. Hanke, A. Neubauer, and O. Scherzer. A convergence analysis of the Landweber iteration for nonlinear ill-posed problems. *Numer. Math.*, 72:21–37, 1995.

[50] J. Haslinger and P. Neittaanmäki, editors. *Finite Element Approximation for Optimal Shape Design: Theory and Applications.* John Wiley & Sons Ltd., Cichester, 1988.

[51] B. Hofmann. *Regularization for Applied Inverse and Ill-Posed Problems.* Teubner, Leipzig, 1986.

[52] T. Hohage. Newton-Verfahren beim inversen Neumann-Problem zur Helmholtz-Gleichung. Master's thesis, Universität Göttingen, 1996.

[53] L. Holzleitner. *Domain Optimization in Linearized Elasticity with the Finite Element Package MSC-NASTRAN.* PhD thesis, Johannes Kepler Universität Linz, 1996.

[54] J. Honerkamp. Ill-posed problems in rheology. *Rheol. Acta*, 28:363–371, 1989.

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[63] D. A. Murio. *The Mollification Method and the Numerical Solution of Ill-Posed Problems.* Wiley, New York, 1993.

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[65] A. Neubauer. Tikhonov regularization of ill-posed linear operator equations on closed convex sets. *J. Approx. Theory*, 53:304–320, 1988.

[66] A. Neubauer. Tikhonov regularization for nonlinear ill-posed problems: optimal convergence and finite-dimensional approximation. *Inverse Problems*, 5:541–557, 1989.

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[71] O. Scherzer, H. W. Engl, and R. S. Anderssen. Parameter identification from boundary measurements in a parabolic equation arising from geophysics. *Nonlinear Anal.*, 20:127–156, 1993.

[72] O. Scherzer, H. W. Engl, and K. Kunisch. Optimal a-posteriori parameter choice for Tikhonov regularization for solving nonlinear ill-posed problems. *SIAM J. Numer. Anal.*, 30:1796–1838, 1993.

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[76] A. N. Tikhonov and V. Arsenin. *Solutions of Ill-Posed Problems.* Wiley, New York, 1977.

[77] A. N. Tikhonov, A. Goncharsky, V. Stepanov, and A. Yagola. *Numerical Methods for the Solution of Ill-Posed Problems.* Kluwer, Dordrecht, 1995.

CURRICULUM VITAE

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Title: none

Education:

1983:	High School Diploma (Matura)
1983 - 1991:	Studies in Computer Science, Johannes Kepler University Linz
1991:	Diploma (Computer Science), Johannes Kepler University Linz

Employment:

1988:	Student assistent, Institute of Systems Theory and Information Technology, Johannes Kepler University Linz
1990 - 1991:	Student assistent, Institute of Computer Science, Johannes Kepler University Linz
1991 - 1995:	Assistant, Institute of Computer Science, Johannes Kepler University Linz
since 1996:	Research assistent, Institute of Computer Science, Johannes Kepler University Linz

Selected Project Experience:

since 1991:	Development of a the debugging environment MAD (Monitoring And Debugging) for distributed memory machines [17] including the monitoring tool EMU (Event Monitoring Utility) [4], the visualization tool ATEMPT (A Tool for Event Manipulation) [7] and the parallel simulation tool PARASIT [15].
1992 - 1995:	Development of GDDT [1, 4, 5]

Scientific Cooperations:

- Institute for Software Technology and Parallel Systems, University of Vienna

- Institute of Statistics and Computer Science, University of Vienna
- Institute of Computer Science, TU Munich
- Institute od Computer SCtructures and Operating Systems, University Hannover

Publications:

[1] W. Burger and S. Grabner. Eine homogene Software-Umgebung fuer Machine Vision. In A. Pinz, editor, *Wissensbasierte Mustererkennung*, volume 49 of *Schriftenreihe OeAGM*, Vienna, 1989. R. Oldenbourg Verlag.

[2] S. Grabner. Das Hough Verfahren zur Detektion linearer Strukturen mit hierarchischer Realisierung im Bildraum. Master's thesis, Institute of Systems Theory and Information Technology, Johannes kepler University Linz, 1991.

[3] S. Grabner and R. Koppler. GDDT - A Graphical Data Distribution Tool. In Klaus Ecker and Joerg Apsel, editors, *Proc. ICOLE '94 Workshop*, pages 98–113, Lessach, September 1994.

[4] S. Grabner and D. Kranzlmueller. Monitoring for Detecting Bugs and Blocking Communication. In *CONPAR 94 - VAPP VI*, Linz, Austria, Sept. 1994.

[5] S. Grabner, D. Kranzlmueller, and J. Volkert. ATEMPT - A Tool for Event Graph Manipulation. In *Proc. Workshop on Parallel Processing*, Lessach, Austria, Sept. 1994.

[6] S. Grabner, D. Kranzlmueller, and J. Volkert. Debugging of Concurrent Processes. In *Proc. Euromicro PDP '95 Workshop*, San Remo, Italy, Jan. 1995.

[7] S. Grabner, D. Kranzlmueller, and J. Volkert. Debugging Parallel Programs using ATEMPT. In *Proc. HPCN '95*, Springer LNCS, Milano, Italy, May 1995.

[8] S. Grabner and J. Volkert. A Debugger for Distributed Memory Machines. In *Proc. Workshop on Parallel Processing*, Lessach, Austria, Sept. 1993.

[9] S. Grabner and J. Volkert. Debugging Parallel Programs via Event Graph Manipulation. In *Proc. First Vector and Parallel Processing Workshop*, Porto, Portugal, Sept. 1993.

[10] S. Grabner and J. Volkert. Debugging Parallel Programs via Event Graph Manipulation. *Computer Systems in Engineering*, 6(4/5):443 – 450, 1995.

[11] R. Kolmhofer and S. Grabner. A nCUBE – CONVEX Batch Attachment. In *Proc. CONVEX Worldwide User Group Conference*, Richardson/Dallas, TX, March 1993.

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[13] R. Koppler, S. Grabner, and J. Volkert. Visualization of Distributed Data Structures for HPF-like languages. *Scientific Programming, special issue High Performance Fortran Comes Of Age*, 6(1):115–126, Spring 1997.

[14] D. Kranzlmueller, A. Christanell, S. Grabner, and J. Volkert. Control and Data Flow Analysis for Parallel Program Debugging. In *Proc. of VECPAR '96*, Porto, Portugal, Sept. 1996.

[15] D. Kranzlmueller, S. Grabner, and J. Volkert. Combining the Benefits of Error-Debugging and Performance Evaluation. In *Proc. PCAT '94 Conference*, pages 79 – 88, Wollongong, Australia, Nov. 1994.

[16] D. Kranzlmueller, S. Grabner, and J. Volkert. Message Passing Visualization with ATEMPT. In *Proc. of PARCO '95 Conference on Parallel Computing*, pages 653–656, Gent, Belgium, Sept. 1995.

[17] D. Kranzlmueller, S. Grabner, and J. Volkert. Race Condition Detection with the MAD Environment. In *Proc. of PART'95 Conference on Parallel and Real-Time Systems*, pages 160–166, Fremantle, Australia, Sept. 1995.

[18] D. Kranzlmueller, S. Grabner, and J. Volkert. Abstractions Mechanisms for Debugging Massively Parallel Programs. In *Proc. of Massively Parallel Computing Systems, MPCS '96*, Ischia, Italy, May 1996.

[19] D. Kranzlmueller, S. Grabner, and J. Volkert. Debugging Massively Parallel Programs with ATEMPT. In *Proc. of HPCN Europe Conference*, pages 806–811, Brussels, Belgium, Apr. 1996.

[20] D. Kranzlmueller, S. Grabner, and J. Volkert. Event Graph Visualization for Debugging Large Applications. In *Proc. of SIGMETRICS Symposium on Parallel and Distributed Tools, SPDT '96*, pages 108–117, Philadelphia, PA, May 1996.

[21] D. Kranzlmueller, S. Grabner, and J. Volkert. Monitoring Strategies for Hypercube Systems. In *Proc. of 4th EUROMICRO Workshop on PDP*, pages 486–492, Braga, Portugal, Jan. 1996.

[22] D. Kranzlmueller, S. Grabner, and J. Volkert. The Tools of the Monitoring And Debugging Environment. In *Proc. of 2nd European School of Computer Science, ESPPE'96*, pages 169–172, Alpe d'Huez, France, Apr. 1996.

[23] D. Kranzlmueller, R. Koppler, S. Grabner, Ch. Holzner, and J. Volkert. Parallel Program Visualization with MUCH. In L. Boeszoermenyi, editor, *ACPC'96 - Parallel Computation, Proc. of the 3rd Int'l ACPC Conference*, LNCS 1127, pages 148–160, Klagenfurt, Austria, September 1996. Springer Verlag.

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Education:

1981:	High School Diploma (Matura)
1983 - 1988:	Studies in Mathematics and Physics at TU Karl-Marx-Stadt
1988:	Dipl.-Lehrer (Matura, Ma/Ph), TU Karl-Marx-Stadt
1986 - 1990:	Studies in Technical Mathematics at TU Karl-Marx-Stadt
1990:	Dipl.-Ing. (Germany: Dipl.-Math.), TU Karl-Marx-Stadt
1993:	Dr.techn. (Germany: Dr.rer.nat.), TU Chemnitz

Employment:

1986 - 1988:	Student assistant, Institute of Mathematics, TU Karl-Marx-Stadt
1988 - 1993:	Research assistant, Institute of Mathematics, TU Karl-Marx-Stadt/Chemnitz
1993 - :	Assistant, Institute of Mathematics, JKU Linz

Selected Project Experience:

1992 - :	Development of parallel iterative solvers for partial differential equations based on Domain Decomposition algorithms
1993 - :	Data partitioning for parallel computers
1994 - 1996:	FEM calculations and visualization

Publications:

[1] Gundolf Haase. An incomplete factorization preconditioner based on a non-overlapping domain decomposition data distribution. In *Proceedings of the Euro-Par'97*, Lecture Notes in Computer Sciences, Heidelberg, 1997. Springer. accepted for publication.

[2] Gundolf Haase. Multilevel extension techniques in domain decomposition preconditioners. In *DD9 Proceedings*. John Wiley and Sons Ltd., 1997.

[3] Gundolf Haase. Hierarchical extension operators plus smoothing in domain decomposition preconditioners. *Applied Numerical Mathematics*, 23(3):327–346, May 1997.

[4] Gundolf Haase, Bodo Heise, Michael Jung, and Michael Kuhn. FEM⚭BEM - a parallel solver for linear and nonlinear coupled FE/BE-equations. Report 94-16, DFG-Schwerpunkt "'Randelementmethoden"', University of Stuttgart, 1994.

[5] Gundolf Haase and Ulrich Langer. The non-overlapping domain decomposition multiplicative Schwarz method. *Inter. J. Computer Math.*, 44:223–242, 1992.

[6] Gundolf Haase and Ulrich Langer. Domain decomposition vs. adaptivity. In M. Křížek, P. Neittaanmäki, and R. Stenberg, editors, *Finite Element Methods : Fifty Years of the Courant Element*, volume 164 of *Lecture Notes in Pure and Applied Mathematics*, pages 243 – 258, New York, Basel, Hong Kong, 1994. Marcel Dekker, Inc. ISBN 0-8247-9276-9.

[7] Gundolf Haase, Ulrich Langer, and Arnd Meyer. The approximate Dirichlet decomposition method. part I,II. *Computing*, 47:137–167, 1991.

[8] Gundolf Haase, Ulrich Langer, and Arnd Meyer. Domain decomposition preconditioners with inexact subdomain solvers. *J. of Num. Lin. Alg. with Appl.*, 1:27–42, 1992. (Preprint 192, TU Chemnitz, 1991).

[9] Gundolf Haase, Ulrich Langer, and Arnd Meyer. Parallelisierung und Vorkonditionierung des CG-Verfahrens durch Gebietszerlegung. In *Parallele Algorithmen auf Transputersystemen*, Teubner-Scripten zur Numerik III, Stuttgart, 1992. Teubner. Tagungsbericht der GAMM-Tagung, 31. Mai-1. Juni 1991, Heidelberg.

[10] Gundolf Haase, Ulrich Langer, Arnd Meyer, and S. V. Nepomnyaschikh. Hierarchical extension operators and local multigrid methods in domain decomposition preconditioners. *East-West J. Numer. Math.*, 2(3):173–193, 1994.

CURRICULUM VITAE

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Title: Univ.-Ass.

Education:

1980:	High School Diploma (Matura)
1985 - 1990:	Studied Mechatronics at University of Linz, graduated to Dipl.-Ing.

Employment:

1982 - 1985:	Training of apprentices for telecommunication fitter
1985 - 1990	Telecommunication fitter by Post und Telegraphenverwaltung in Linz
1995 - :	Assistant, Inst. of Technical Mechanics, University of Linz

Societies and Activities:

Member, Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)

Publications:

[1] K. Hagenauer, Modellierung eines magnetostriktiven Aktors für den Entwurf einer linearen optimalen Regelung, Diplomarbeit 1995.

[2] K. Hagenauer und H. Irschik, Eine Analogie für vorgekrümmte schubelastische Platten mit eingeprägter Temperaturkrümmung, eingereicht zur Veröffentlichung in ZAMM,[77], 1997.

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Title: Dipl.-Ing.

Education:

1989:	High School Diploma (Matura)
1990 - 1996:	Studies in Mathematics at Univ. Linz
Nov. 1996:	Dipl.-Ing. (Mathematics), Univ. Linz
	(RISC-Linz price for "Best Diploma Thesis of the Year")
1996 -	Ph.D. studies in Mathematics at RISC-Linz

Employment:

Selected Project Experience:

Societies and Activities:
Scientific Cooperations:

Publications: I plan to publish [1] together with Doz. Dr. F. Winkler.

[1] E. Hillgarter and F. Winkler. Points on algebraic curves and the parametrization problem.

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1991:	High School Diploma (Matura)
1992 - 1996:	Studied Mechatronics at University of Linz, graduated to Dipl.-Ing.
1996 - 1997:	MSc. Mechatronics and Optical Engineering, Loughborough University

Employment:

1991 - 1992:	Fa. Schwarzmueller, Hanzing

Societies and Activities:

- Member, The Institute of Electrical and Electronics Engineers (IEEE)
- Member, Verein Deutscher Eisenhüttenleute (VDeh)

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Education:

1986:	First Prize, State Competition in Mathematics, Hessia
1988 - 1989:	Exchange Stundent at Liberty High School, Washington, USA
1991:	High School Diploma (Abitur)
1991 - 1993:	Studied Mathematics and Physics in Marburg
1991 - 1996:	Scholarship by Studienstiftung des Deutschen Volkes
1993 - 1996:	Studied Mathematics and Physics in Göttingen
1996	Graduated to Dipl.-Math.

Employment:

1995 - 1996:	Teaching Assistant at the Chair for Numerical and Applied Mathematics, Universität Göttingen
since 1996:	Assistant at the Institut for Industrial Mathematics, Universität Linz, financed via the Christian Doppler Laboratory for Mathematical Modelling and Numerical Simulation

Publications:

T. Hohage, Newton-Verfahren beim äusseren Neumann-Problem zur Helmholtz-Gleichung, Diploma Thesis, Göttingen 1996.

CURRICULUM VITAE

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Education:

1982:	High School Diploma (Matura)
1982 - 1987:	Studies in Mechanical Engineering, graduated to Dipl.-Ing., Technical University of Vienna
Linz	

Employment:

1987 - 1991:	Researchengineer at the VOEST Alpine Industrieanlagenbau
1991 - :	Assistant, Inst. of Technical Mechanics, University of Linz

Societies and Activities:

- Member, Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)
- Referee for Mechanical Systems and Signal Processing (MSSP)

Publications:

Diplomarbeit: Parameteruntersuchung zur Abgrenzung der Anwendbarkeit eines Berechnungskonzeptes für erdbebenbeanspruchte Tankbauwerke. TU Wien, 138 Seiten, 50 Seiten Programmbeilage, 1987.
Mit dem gleichen Titel auch publiziert als: Heft ILFB 1/87 der Berichte aus dem Institut für Leichtbau und Flugzeugbau der TU Wien, ed: Rammerstorfer, F.G.; S.138, 1987.
Dissertation: Ein effizienter Algorithmus für nichtlineare Probleme der Strukturdynamik mit Anwendungen in der Rotordynamik. Universität Linz, S. 239, 1995.
Mit dem gleichen Titel auch publiziert als: Reihe C - Technik und Naturwissenschaften, Universitätsverlag Rudolf Trauner, Linz,1995. (ISBN 3-85320-769-3)

Some 24 papers in English and German. The list of 10 recent related papers is enclosed.

[1] Holl, Helmut J.; Scheidl, Rudolf; Schwaha, Karl L.: A Mathematical Model for the Calculation of Cooling Criteria for Round Bloom. Proceedings of the Fourth European Conference on Mathematics in Industry, ECMI Vol. 6, 29. Mai - 2. Juni 1989, eds: Wacker, Hj.; Zulehner, W.; Strobl, 97-108, Teubner Verlag, 1989. (ISBN 3-519-02175-7)

[2] Camplin, J.Mark; Herbertson, Joe; Holl, Helmut J.; Whitehouse, Paul; Guthrie, Roderick I.L.; Han, J.W.; Hasan, M.: The Application of Mathematical and Water Modelling in the Selection of Tundish Design for the Proposed Combicaster at BHP Whyalla. Proceedings of the Sixth International Iron and Steel Congress, Vol. 3 - Steelmaking I, Nov. 1990, ed: ISIJ, Nagoya, 207-214, 1990. Reprinted in: Tundish Metallurgy Volume II, Vol. 9201-72-0029, 41-48, (1992).

[3] Humer, Franz; Eidinger, Helmut; Holl, Helmut J.: Konstruktive Lösungen für den Kokillenbereich von Hochleistungsanlagen. IV. Symposium des Stranggießens, Miskolc, 1990.

[4] Holl, Helmut J.; Irschik, Hans: A Substructure Method for the Transient Analysis of Nonlinear Rotordynamic Systems Using Modal Analysis. Proceedings of the 12th International Modal Analysis Conference, 31. J n. - 3. Feb. 1994, eds: DeMichele, D.J.; Society for Experimental Mechanics; Honolulu, 1638-1643, 1994. (ISBN 0-912053-44-5)

[5] Holl, Helmut J.: Transient Analysis of Earthquake Excited Nonlinear Rotordynamic Systems Using Modal Analysis. Proceedings of the 10th European Conference on Earthquake Engineering, Vol. 2, 28. Aug. - 2. Sept. 1994, ed.: Duma, G.; Wien, 1223-1228, A.A.Balkema Rotterdam, 1995. (ISBN 90-5410-530-5).

[6] Ziegler, Franz; Irschik, Hans; Holl, Helmut J.: Spherical Elastic-Plastic Waves. Journal of Vibration and Control, Vol. 1, Nr. 3, ed.: Nayfeh, A.H.; 345-360, Sage Science Press, 1995. (ISSN 1077-5463)

[7] Holl, Helmut J., Irschik, Hans: Ein Mehrzweck-Versuchsaufbau zum Studium von Schwingern mit zwei Freiheitsgraden, parametererregter Schwingungen und der Schwingungstilgung. Österreichische Ingenieur- und Architektenzeitschrift ÖIAZ 141, Heft 4, 153-156, 1996. (ISSN 0721-9415)

[8] Holl, Helmut J.; Belyaev, Alexander K.; Irschik, Hans: Simulation of the Duffing-Oscillator with Time-varying Mass By a BEM in Time. Proceedings of the Third International Conference on Computational Structures Technology, Advances in Boundary Element Methods, Vol. G, ed.: Topping, B.H.V.; 21. - 23. August 1996, Budapest, 113-120, 1996. (ISBN 0-948749-46-6)

[9] Holl, Helmut J.: Zur numerischen Stabilität bei der Partitionierung von Bewegungsgleichungen. ZAMM, Vol. 77 (submitted) , 1997. (ISSN 0044-2267)

[10] Holl, Helmut J.: A Time-Integration Algorithm for Time-varying systems with Non-classical Damping Based on Modal Methods. Proceedings of the 15th International Modal Analysis Conference, 3. - 6. Feb. 1997, eds: Wicks, A.L. ; Society for Experimental Mechanics; Orlando, 1558-1564, 1997. (ISBN 0-912053-53-4) (ISSN 1046-6770)

Patent:
AT 3414/87 (DE 3840448 A1)
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1988 - 1990:	Ph.D. in Computer Science (Computer Algebra) at Ohio State Univ, USA
1986 - 1988:	M.S. in Computer Science (Computer Algebra) at Ohio State Univ, USA
1975 - 1979:	B.S. in Physics (Particle Physics) at Seoul National Univ, Korea

Employment:

1990 - Date	Universität VertragsAssistant at Univ, Linz.
1990 - 1990	Research Assistant at Ohio State Univ, USA.
1989 - 1990	Instructor at the Ohio State Univ, USA.
1988 - 1989	Researcher at Applied Information and Technologies. Columbus, Ohio, USA.
1987 - 1988	Research Assistant at Ohio State Univ, USA.
1986 - 1987	Computer Consultant at Ohio State Univ, USA.
1985 - 1986	Computer Programmer at Ohio State Univ, USA.
1979 - 1980	Computer Programmer at Korean National Security Organization, Korea.

Selected Project Experience:

- Parallel Computer Algebra
  Central European Initiative (CEI)
  2 years (1994)
  Principal Investigator.

- Constraint Solving (ACCLAIM)
  European Community and Austrian Science Foundation (ACCLAIM).
  2 years (1993)
  Principal Investigator.

- Parallel Symbolic Computation
  Austrian Science Foundation, (S-5302-PHY)
  2 years (1993)
  Principal Investigator.

- Device (Transistor) Simulation
  Digital Equipment Cooperation, Austria (EERP AU-021).
  1 year (1991)
  Principal Investigator.

Professional Societies:

- Vice-President of ACM SIGSAM: Symbolic and Algebraic Manipulation.
- Nonminated for President of ACM SIGSAM for 1997-1999.
- Member of ACM
- Member at Large of ISSAC Steering Committee: One of three persons who choose the general chair and the program chair of ISSAC each year.

Editor of Journals/Issues:

- An editor of Journal of Symbolic Computation (JSC).
- Guest editor for a special issue of the journal *Mathematics and Computers in Simulation* on *Non-standard Application of Computer Algebra*. To appear in 1997.
- Guest editor for a special issue of the *Journal of Symbolic Computation* on *Quantifier Elimination and Applications*. To appear in 1997.
- Guest editor for a special issue of the *Journal of Foundation of Computer Science* on *Algebraic Constraint Solving*. To appear in 1997.
- Guest editor for a special issue of the *Journal of Symbolic Computation* Vol 21. No 4-6. 1996 on *Parallel Algebraic Computation*.
- Guest editor for a special issue of the *Annals of Mathematics and Artificial Intelligence* Vol 13. No 1,2. 1995 on *Algebraic Approaches to Geometric Theorem Proving*.
- Guest editor for a special issue of the *Computer Journal* Vol 36, No 5. !993 on *Computational Quantifier Elimination*.

Organization of International Conferences:

- General Chair of the International Symposium on Parallel Symbolic Computation (PASCO'97).
- Vice Program Chair for the International Symposium on Symbolic and Algebraic Computation (ISSAC'97).
- Co-Chair of the symbolic computation section of the European Conference on Parallel Computation (EURO-PAR'97).
- Program Committee Chair of the IMACS conference on Applied Computer Algebra (IMACS-ACA'96).
- Tutorial Chair for the International Symposium on Symbolic and Algebraic Computation (ISSAC) 1996.

- Program Committee Chair of The First International Symposium on Parallel Symbolic Computation (PASCO'94).

Organization of International Workshops/Schools:

- Co-chair for the workshop (AAGR 92) on Algebraic Approaches to Geometric Reasoning.
- Organizer and lecturer of the summer school (QEschool 92) on quantifier elimination.

Invited Lectures at International Conferences

- Approximate Quantified Constraint Solving. IMACS/GAMM International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics (SCAN-95).
- Algorithmic Quantifier Elimination. International Conference on Symbolic and Algebraic Computation (ISSAC-95).
- Numeric-Symbolic Method for Quantified Constraint Solving. (SCAN-95).
- Methods for Non-linear constraint solving (CCL-95).
- Problem Solving by Quantifier Elimination. International Conference on Logic Programming and Automated Reasoning (LPAR'94).
- The Design of SACLIB/PACLIB Kernels. International Symposium on Design and Implementation of Symbolic Computation Systems. (DISCO'93).
- Hilbert 16th Problem by CAD. Symposium on Quantifier Elimination and Cylindrical Algebraic Decomposition, Schloss Hagenberg, Austria. (QECAD'93).
- Can Symbolic Computation be parallelized? International Symposium on Massively Parallel Programming Models, Berlin, Germany. (MPPM'93).
- Efficient Method for Analyzing Topology of Plane Algebraic Curves. International IMACS symposium on Symbolic Computation, IMACS-SC 93, Lille France.
- Tutorial on Non-linear Constraint Solving. WCLP-92 Marseille, France.

Refeering for Journal and Conferences

- Numerous journals and conferences (over 50) in mathematics, logic, computer science.

Scientific Cooperations:

- University of Vienna, Austria (Zima, Fahringer)

  We have carried out two joint research project: CEI-PACT, FWF Schwer-punkt on parallel computation. In particular, we have been developing volume computation methods for their automatic parallelizing compiler for Vienna Fortran.

- University of Passau, Germany (Weispfenning)

  We have provided our software to them and they integrate it to their software in solving some large non-trivial problems.

  We have been also carrying out joint research on how term orderings (in Groebner basis) behave under composition.

- University of Marseilles, France (Colmerauer):

  We have been developing efficient real algebraic constraint solvers for constraint logic programming languages, under the European Union project ACCLAIM.

- University of Renne, France (Roy)

  We have been developing efficient solvers for real algebraic constrains under the European Union project POSSO.

- University of Santander, Spain (Recio, Gonzales-Vega)

  We have been developing efficient solvers for real algebraic constrains under the European Union project POSSO.

- University of Prague, Czeck (Liska)

  We have been applying the theory/software of real algebraic constraints for the stability analysis of partial differential equations and their numerical schemes.

- University of Linkoping, Sweden (Jirstrand)

  We have provided our software to them. They have been applying it to various problems arising from non-linear control system design.

- University of Patras, Greece (Ioakimidis)

  We have helped them to solve various problems arising mechanical engineerings.

- University of Glasgow, England (Loidl)

  We have been studying how to parallelize quantifier elimination method using functional languages (Haskell).

- University of Delaware, USA (Collins, Brown)

  Collins was a faculty at RISC until June of 1996. Since Collins joined University of Delaware, we have been continuing joint research in improving the method of cylindrical algebraic decomposition.

- University of Kent, USA (Wang)

  We have been sharing various software tools for parallelizing symbolic computations algorithms (in particular quantifier elimination).

- University of Nex Mexico, USA (Steinberg, Robidoux)

  We have been applying the theory/software of real algebraic constraints for the stability analysis of partial differential equations and their numerical schemes.

Publications (Refereed Journals and Conferences):

[1] G. E. Collins and H. Hong. Partial cylindrical algebraic decomposition for quantifier elimination. *Journal of Symbolic Computation*, 12(3):299–328, sep 1991.

[2] H. Hong. An improvement of the projection operator in cylindrical algebraic decomposition. In *International Symposium of Symbolic and Algebraic Computation (ISSAC-90)*, pages 261–264. ACM, 1990.

[3] H. Hong. *Improvements in CAD–based Quantifier Elimination.* PhD thesis, The Ohio State University, 1990.

[4] H. Hong. Heuristic search strategies for cylindrical algebraic decomposition. In *Proceedings of Artificial Intelligence and Symbolic Mathematical Computing, Springer Lecture Notes in Computer Science 737*, pages 152–165, 1992.

[5] H. Hong. Non-linear real constrains in constraint logic programming. In *International Conference on Algebraic and Logic Programming, Springer Lecture Notes in Computer Science 632*, pages 201–212, 1992.

[6] H. Hong. Simple solution formula construction in cylindrical algebraic decomposition based quantifier elimination. In *International Conference on Symbolic and Algebraic Computation ISSAC-92*, pages 177–188, 1992.

[7] H. Hong. An efficient method for analyzing the topology of plane real algebraic curves. *Journal of Mathematics and Computers in Simulation*, 1993. Accepted in 1993 and to appear in 1996.

[8] H. Hong. Efficient method for analyzing topology of plane real algebraic curves. In *Proceedings of IMACS-SC 93, (Lille, France)*, June 1993.

[9] H. Hong. Heuristic search and pruning in polynomial constraint satisfaction. *The Annals of Mathematics and AI*, 1993. To appear in 1996.

[10] H. Hong. Parallelization of quantifier elimination on a workstation network. In *Proceedings of AAECC 10 (Puerto Rico), Springer Lecture Notes in Computer Science 673*, pages 170–179, 1993.

[11] H. Hong. Quantifier elimination for formulas constrained by quadratic equations. In *International Conference on Symbolic and Algebraic Computation ISSAC-93*, pages 264–274. ACM, July 1993.

[12] H. Hong. Quantifier elimination for formulas constrained by quadratic equations via slope resultants. *The Computer Journal*, 36(5):440–449, 1993.

[13] H. Hong. Risc-clp(real): Constraint logic programming over real numbers. In F. Benhamou and A. Colmerauer, editors, *Constraint Logic Programming: Selected Research*. MIT Press, 1993.

[14] H. Hong. Risc-clp(cf): Constraint logic programming over functions. In *Logic Programming and Automated Reasoning (LPAR'94)*, July 1994.

[15] H. Hong. Topology analysis of plane algebraic curves by a hybrid method: Numeric, interval, and algebraic. In *Interval 94, St. Petersburg*, pages 109–114, March 1994.

[16] H. Hong. Approximate quantifier elimination. In *Proceedings of SCAN'95*, 1995. Invited Talk.

[17] H. Hong. The exact region of stability for maccormack scheme. *Computing*, 1995. To appear.

[18] H. Hong. Generic quantifier elimination. In *Proceedings of IMACS-ACA'95*, 1995.

[19] H. Hong. Implicitization of curves parameterized by generalized trigonometric polynomials. In *Proceedings of Applied Algebra, Algebraic Algorithms and Error Correcting Codes (AAECC-11)*, pages 285–296, July 1995.

[20] H. Hong. The exact stability region of the maccormack scheme for the scalar advection equation. *Applied Mathematics Letters*, 9(4):99–101, 1996.

[21] H. Hong. Groebner basis under composition i. *Journal of Symbolic Computation*, 1996. To appear.

[22] H. Hong. Groebner basis under composition ii. In *Proceedings of ISSAC 96 (International Symposium on Symbolic and Algebraic Computation)*, pages 79–85. ACM, 1996.

[23] H. Hong. Implicitization of nested circular curves. *Journal of Symbolic Computation*, 1996. To appear.

[24] H. Hong. Subresultant under composition. *Journal of Symbolic Computation*, 1996. To appear.

[25] H. Hong and H. W. Loidl. Parallel computation of modular multivariate polynomial resultants on a shared memory machine. In B. Buchberger and J. Volkert, editors, *The proceedings of CONPAR 94–VAPP VI, Springer LNCS 854.*, pages 325–336. Springer Verlag, September 1994.

[26] H. Hong and A. Neubacher. Approximate quantifier elimination. In *Proceedings of IMACS-ACA'96*, 1996.

[27] H. Hong, A. Neubacher, and W. Schreiner. The design of the saclib/paclib kernels. In Alfonso Miola, editor, *The proceedings of DISCO-93*, pages 288–302. Springer Verlag, September 1993.

[28] H. Hong, A. Neubacher, and W. Schreiner. The design of the saclib/paclib kernels. *Journal of Symbolic Computation*, 19:111–132, 1995.

[29] H. Hong and J. Rafael Sendra. Computation of variant results. In B. Caviness and J. Johnson, editors, *Quantifier Elimination and Cylindrical Algebraic Decomposition, Texts and Monographs in Symbolic Computation*. Springer Verlag, 1993. Accepted in 1993, and to appear in 1995.

[30] H. Hong and V. Stahl. Safe start region by fixed points and tightening. In *The proceedings of Scientific Computing, Computer Arithmetic and Validated Numerics*, September 1993.

[31] H. Hong and V. Stahl. Safe start region by fixed points and tightening. *Computing, (Archives for Informatics and Numerical Computation)*, 53(3-4):323–335, 1994.

[32] H. Hong and V. Stahl. Bernstein form is inclusion monotone. *Computing*, Vol. 55(1):43–53, 1995.

[33] W. Schreiner and H. Hong. The design of the paclib kernel for parallel algebraic computation. In Jens Volkert, editor, *Second International ACPC Conference, LNCS 734*, pages 204–218, Gmunden, Austria, 1993. Springer.

[34] W. Schreiner and H. Hong. A new library for parallel algebraic computation. In Richard F. Sincovec et al., editors, *Sixth SIAM Conference on Parallel Processing for Scientific Computing*, pages 776–783, Norfolk, Virginia, March 22–24, 1993. SIAM.

[35] W. Schreiner and H. Hong. Paclib — a system for parallel algebraic computation on shared memory computers. In Hussein M. Alnuweiri, editor, *Parallel Systems Fair at the Seventh International Parallel Processing Symposium*, pages 56–61, Newport Beach, CA, April 14, 1993. IPPS '93.

CURRICULUM VITAE

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Title: O.Univ.-Prof. (full professor of technical mechanics)

Education:

1969:	High School Diploma (Matura)
1970 – 1977:	Studied Civil Engineering, graduated to Dipl.-Ing.
1983:	Ph.D. (Dr. techn.) in Civil Engineering, with excellence, thesis topic: Application of Green's Function Method to Thin Elastic Plates by Boundary Integral Equations (referees: F. Ziegler, E. Mudrak, Technical University of Vienna)
1986:	Habilitation for Mechanics, Technical University of Vienna

Employment:

1970 – 1978:	Structural Engineer
1978 – 1988:	Universitätsassistent, Institut für Allgemeine Mechanik, Technical University of Vienna
1988 – 1991:	Assistenzprofessor, Institut für Allgemeine Mechanik, Technical University of Vienna
since July 1991:	Full Professor (ordentlicher Universitätsprofessor) of Technical Mechanics, Johannes Kepler Universität Linz
since 1996:	Vice-President of Research, Johannes Kepler Universität Linz

Selected Project Experience:

1986 – 1989:	Senior Researcher in the Research Program "Erdbebenlasten im Zeit- und Frequenzbereich" of the FWF Stuctural Dynamics
1993 – 1997:	FWF-Project P09533-TEC "Micromechanics of Dynamic Processes in Viscoplasticity" (together with F.Ziegler)
1978 – up to now:	Various projects directly with industry in Austria and abroad

Societies and Activities:

- Member, American Society of Mechanical Engineers
- Member, American Institute of Aeronautics and Astronautics
- Member, Int. Association for Structural Control
- Member, Gesellschaft für Angewandte Mathematik und Mechanik
- Member, Society for the Interaction of Mathematics and Mechanics
- Member, Euromechanics Society
- Member, European Association for Structural Control, Co-chairman of working Group: Mechatronics
- Member, Österreichisches Nationalkommittee für Angewandte und Theoretische Mechanik
- Member, OGE
- Member, Österreichischer Ingenieur-und Architektenverein
- Member of the Advisory Board of Acta Mechanica
- Member of the Board (Senat) of the Christian Doppler Gesellschaft

Prizes:

1988 :	Kardinal Innitzer Förderungspreis für Naturwissenschaften
1988 :	Förderungspreis der Stadt Wien für Technische Wissenschaften
1996 :	F. Schweppe Best Paper Award (together with K. Schlacher, A. Kugi), Int. Conf. Uncertain Structures, Miami

Scientific Cooperations:
see Project 10, Chapter 10.5

Publications:
Author of about 150 publications in scientific books, journals and proceedings. Selected recent 10 publications (see also the references given for Project 10):

[1] R. Heuer, H. Irschik. Multi-Modal Approach for Large Natural Flexural Vibrations of Thermally Stressed Plates. *Non-Linear Dynamics*, 1:449-458, 1990.

[2] P. Fotiu, R. Heuer, H. Irschik, F. Ziegler. Nonlinear Flexural Vibrations of Layered Plates. *Int.J.Solids Structures*, 29:1813-1818, 1992.

[3] H. Irschik, F. Ziegler, P.Fotiu. Extension of Maysel's Formula to the Dynamic Eigenstrain Problem. *J. Mechanical Behavior of Materials*, 5:5966, 1993.

[4] H. Irschik. On Vibrations of Layered Beams and Plates. (Hauptvortrag GAMM-Tagung Leipzig) *ZAMM*, 73:T34 - T 45, 1993.

[5] W. Brunner, H.Irschik. Dynamic Elasto-Viscoplastic Solid-Fluid Interaction. *Eng. Transactions,* 42:181-194, 1994.

[6] W. Brunner, H. Irschik. Multi-Layered Composite Beams Using Second-Order Theory. *Non-Linear Dynamics*, 6:37-48, 1994.

[7] P. Fotiu, H. Irschik, F. Ziegler. Modal Analysis of Elastic-Plastic Vibrations by Integral Equations. *Eng. Analysis with Boundary Elements,* 14:81-97, 1994.

[8] H. Irschik, F. Ziegler. Dynamic processes in structural thermo–viscoplasticity. *Applied Mechanics Reviews* , 301–315, 1995.

[9] A. K. Belyaev, H. Irschik. Non-linear waves in complex structures modelled by elastic-viscoplastic stochastic media. *International Journal of Non-Linear Mechanics*, 31:771-777, 1996.

[10] H. Irschik, F.Ziegler. Maysel's formula generalized for piezoelectric vibrations: Application to thin shells of revolution. *AIAA Journal*, 34:2402-2405, 1996.

CURRICULUM VITAE

Name: Tudor Jebelean

Date and Place of Birth: 1 December 1955, Timişoara (Romania)

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Home Address: Raiffeisenstr. 1, 4232 Hagenberg, Austria

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Title: Assistenzprof. Univ.

Education:

1974:	High School Diploma (Matura)
1975 - 1979:	Studies in Informatics at Univ. Timişoara
1979:	MSc (Informatics), Univ. Timişoara
1990 - 1994:	Ph.D. studies in Computer Science at Univ. Linz
1994:	Ph.D. (Computer Science), Univ. Linz

Employment:

1979:	Programmer, "Astra" Arad, Romania
1980 - 1986:	Programmer, Univ. Timişoara
1986 - 1990:	Assistant-Prof., Univ. Timişoara
1990:	Visiting Researcher, T.U. Delft, Netherlands
1990 - 1994	Research Assistant, RISC, Univ. Linz
1994 - 1997	Assistant-Prof., RISC, Univ. Linz

Selected Project Experience:

1990 - 1991:	RISPEL (implementation of a functional language for knowledge-based systems
1990 - 1994:	Systolic Multiprecision Arithmetic (PhD project)
1991 - 1993:	Parallel Symbolic Computation (FWF S5302-PHY
1993 - 1994:	POSSO (Polynomial System Solving) ESPRIT BRA 6846
1994 - 1997:	Principal investigator, Multiple Precision Arithmetic on Parallel Architectures (FWF P10002-MAT)
1997 - :	Theorema (automatic theorem proving in natural deduction style)

Societies and Activities:

- Member in IEEE Computer Society and ACM.
- Secretary of the Hyper-G Consortium (http://hgc.org)
- Referee for the following journals: J. Symbolic Computation, ACM Trans. on Mathematical Software, IEEE Transactions on Computers, Journal of VLSI Signal Processing.
- Reviewer for the European Comission (programme INFO 2000).
- Referee for the conferences: ACPC 91, ICALP 93, DISCO 93, ASAP 93, ASAP 94, ACPC 95, FPLA 95, HICSS-29, ISSAC 95, IPPS 96, AAECC-12.

Scientific Cooperations:

- European Research Project "POSSO", with universities at Pisa, Bath, Paris (VI), Nice, Genova, Santander, Hagen, Stockholm.

Publications: About 25 technical reports, unrefereed publications and talks, as well as 24 refereed publications in journals and at international conferences on computer algebra, systolic computations, cellular automata, and formal language theory. Few representative papers are: [2], [4], [3], [5], [6], [8], [7], [1].

[1] B. Buchberger, T. Jebelean, F. Kriftner, M. Marin, E. Tomuţa, and D. Văsaru. An Overview of the *Theorema* Project. In *ISSAC'97 - International Symposium on Symbolic and Algebraic Computation.* ACM Press, July 1997.

[2] T. Jebelean. Bilinear automata. *Studii şi Cercetări Matematice*, 42(1):19–29, 1990.

[3] T. Jebelean. A generalization of the binary GCD algorithm. In M. Bronstein, editor, *ISSAC'93: International Symposium on Symbolic and Algebraic Computation*, pages 111–116, Kiev, Ukraine, July 1993. ACM Press.

[4] T. Jebelean. An algorithm for exact division. *J of Symbolic Computation*, 15(2):169–180, February 1993.

[5] T. Jebelean. A double-digit Lehmer-Euclid algorithm for finding the GCD of long integers. *J of Symbolic Computation*, 19:145–157, 1995.

[6] T. Jebelean. Design of a systolic coprocessor for rational addition. In P. Capello, C. Mongenet, G-R. Perrin, P. Quinton, and Y. Robert, editors, *ASAP '95, Strasbourg, France, July 1995*, pages 282–289. IEEE Computer Society Press, 1995.

[7] T. Jebelean. Integer and rational arithmetic on MasPar. In *DISCO'96 (Design and Implementaton of Symbolic Computation Systems)*, pages 162–173, Karlsruhe, Germany, September 18-20 1996. Springer Verlag LNCS 1128.

[8] W. Krandick and T. Jebelean. Bidirectional exact integer division. *J of Symbolic Computation*, 21:441–455, 1996.

CURRICULUM VITAE

Name: Ferdinand Kickinger

Date and Place of Birth: 1. December 1973, St. Pölten

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Title: Dipl.- Ing.

Education:

1991:	High School Diploma (Matura)
1991 - 1996:	Studies in Technical Mathematic at University Linz
since 1996:	Ph.D. Studies (Mathematic) University Linz

Employment:

1996 - :	Ph.D. Student, Inst. f. Mathematik , University Linz

Selected Project Experience:

1994 - 1996:	Investigation of Tools for the Numerical Simulation of 3D Magnetic Field Problems (Diploma Theses)
1996 - :	Development of Algebraic Multigrid Solvers
1996 - :	Development Automatic Multiscale Mesh-Generators

Publications:

[1] F. Kickinger. Algebraic multigrid for discrete elliptic second order problems. Technical report, Institut für Mathematik, Abteilung Numerische Mathematik und Optimierung, 1996.

[2] F. Kickinger. Automatical optimal 3d mesh generation. Technical report, Institut für Mathematik, Abteilung Numerische Mathematik und Optimierung, 1996.

[3] F. Kickinger. Algebraic multigrid for discrete elliptic second order problems. *Institusbericht, Institut für Mathematik*, 513, 1997.

CURRICULUM VITAE

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Title: Dipl.-Ing.

Education:

1990:	High School Diploma (Matura)
1990 - 1996:	Studies in "Technical Mathematics" at the University of Linz
1997:	"Diplomingenieur", University of Linz

Employment:

1997: Industrial Mathematics Institute, University of Linz

Publications:

[1] Stefan Kindermann. On the applicability of nonlinear regularization methods to thermal tomography. *Diplomarbeit*, 1996.

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Title: Univ.-Ass.

Education:

1988:	High School Diploma (Matura)
1988 - 1993:	Studies in Computer Science at University Linz
1993:	Diploma (Computer Science), University Linz

Employment:

1991 - 1993:	Student Assistant, Computer Science Institute, University Linz
1994 - 1995:	Research Assistant, Computer Science Institute, University Linz
1996 :	Assistant, Computer Science Institute, University Linz
1997 - :	Assistant, Systems Programming Institute, University Linz

Selected Project Experience:

1994 - 1995:	Development of GDDT [1, 4, 5]

Scientific Cooperations:

Institute for Software Technology and Parallel Systems, University of Vienna.

Publications:

[1] S. Grabner and R. Koppler. GDDT - A Graphical Data Distribution Tool. In Klaus Ecker und Joerg Apsel, editor, *Proc. ICOLE'94 Workshop*, pages 98–113, Lessach, September 1994.

[2] R. Koppler. Werkzeug fuer die Bearbeitung von THINK-Pascal-Programmen. Master's thesis, Computer Science Institute, Software Department, University Linz, 1993.

[3] R. Koppler. A Systematic Approach to Fuzzy Parsing. *Software: Practice and Experience*, 1996. (to appear).

[4] R. Koppler, S. Grabner, and J. Volkert. Graphical Support for Data Distribution in SPMD Parallelization Environments. In *Proc. IEEE 2nd Int'l Conference on Algorithms and Architectures for Parallel Processing*, pages 21–28, Singapore, June 1996. IEEE Press.

[5] R. Koppler, S. Grabner, and J. Volkert. Visualization of Distributed Data Structures for HPF-like languages. *Scientific Programming, special issue High Performance Fortran Comes Of Age*, 6(1):115–126, Spring 1997.

[6] D. Kranzlmueller, R. Koppler, S. Grabner, Ch. Holzner, and J. Volkert. Parallel Program Visualization with MUCH. In L. Boeszoermenyi, editor, *ACPC'96 - Parallel Computation, Proc. of the 3rd Int'l ACPC Conference*, LNCS 1127, pages 148–160, Klagenfurt, Austria, September 1996. Springer Verlag.

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Title: Univ. Assistant

Education:

1987:	High School Diploma (Matura)
1987 - 1992:	Studies in Computer Science at Joh. Kepler University Linz
1992:	Dipl.-Ing. (Computer Science), Joh. Kepler University Linz
1992 - 1997:	Studies in Computer Science at Joh. Kepler University Linz

Employment:

1989 - 1992:	techn. Programmer for E. Eisenbeiss, Enns - Mechanial Engineering
1993:	Head of computing department for E. Eisenbeiss, Enns - Mechanial Engineering
1993 - 1995:	Research Assistant, Inst. f. Computer Science, Joh. Kepler University Linz
1995 - :	Univ. Assistant, Inst. f. Computer Science, Joh. Kepler University Linz

Selected Project Experience:

1993 - :	Research on Computer Aided Parallel Software Engineering
1994 - :	Research on Monitoring and Debugging Parallel Programs

Societies and Activities:

- Secretary of the ACPC Head, 1994.
- Reviewer for ACPC Technical Report Series.
- Reviewer for CONPAR-VAPP VI, 1994.
- Reviewer for IEEE Computer and Parallel and Distributed Computing, 1995.
- Reviewer for Australian Computer Journal, 1995.

- Reviewer for HICSS 29, 1996.
- Reviewer for IEEE VL'96, 1994.
- Reviewer for ETPSC III, 1996.
- Reviewer for HICSS 30, 1997.

Scientific Cooperations: Cooperating Research with Apache Group, IMAG Grenoble, France, 1997.

Publications: Total number of refereed publications: 20, with 16 contributions to international conferences and workshops, 2 contributions to international technical report series, and 2 contributions to books. A list of major publications relevant to this project is given below.

[1] S. Grabner and D. Kranzlmüller. Monitoring for detecting bugs and blocking communication. In *Proc. of CONPAR 94-VAPP VI (Linz, Austria)*, pages 66–75, 1994.

[2] D. Kranzlmüller, S. Grabner, and J. Volkert. Combinging the benefits of error debugging and performance evaluation. In *Proc. of PCAT'94 Conference (Wollongong, Australia)*, pages 78–88, 1994.

[3] D. Kranzlmüller, S. Grabner, and J. Volkert. Message passing visualization with atempt. In *Proc. of PARCO 95 Conference on Parallel Computing (Gent, Belgium)*, pages 653–656, 1995.

[4] D. Kranzlmüller, S. Grabner, and J. Volkert. Event graph visualization for debugging large applications. In *Proc. of ACM SIGMETRICS Symposium on Parallel and Distributed Tools, SPDT'96 (Philadelphia, PA)*, pages 108–117, 1996.

[5] D. Kranzlmüller, S. Grabner, and J. Volkert. Monitoring strategies for hypercube systems. In *Proc. of 4th EUROMICRO Workshop on PDP (Braga, Portugal)*, pages 486–492, 1996.

[6] D. Kranzlmüller, S. Grabner, and J. Volkert. *P. Eades, K.Zhang (Eds.) Software Visualization*, chapter Program Analysis through Visualization. World Scientific Publishing Company, Singapore, 1996.

[7] D. Kranzlmüller, S. Grabner, and J. Volkert. The tools of the monitoring and debugging environment. In *Proc. of 2nd European School of Computer Science, ESPPE'96 (Alpe d'Huez, France)*, pages 169–172, 1996.

[8] D. Kranzlmüller, R. Koppler, Ch. Holzner, S. Grabner, and J. Volkert. Parallel program visualization with much. In *Proc. of ACPC 96 Conference (Klagenfurt, Austria)*, pages 148–160, 1996.

CURRICULUM VITAE

Name: Manfred Kaltenbacher

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Title: Dipl.-Ing. Dr. techn.

Education:

1986:	High School Diploma (Matura)
1986 - 1992:	Studies in Electrical Engineering at the Technical University of Graz (Austria)
1996:	Dr.-techn. (Electrical Engineering), Johannes Kepler University Linz (Austria)

Employment:

1992 -	Research and Teaching Assistant, Institut of Electrical Measurement Technology, Johannes Kepler University Linz (Austria)

Selected Project Experience:

1994 - :	Various research projects with industrial companies in the area of magnetomechanical sensors and actuators (e.g. Joint project with VÖEST Linz "Magnetomechanical based thickness Sensor")

Societies and Activities:

- Member ÖVE, Österreichischer Verband für Elektrotechnik
- Member IEEE, Institute of Electrical and Electronics Engineering
- Member ICS, International Compumag Society

Scientific Cooperations:
Siemens AG Erlangen, VÖST Linz, Pennstate University

Publications:

1 book and 12 publications in journals and conference proceedings.

[1] M. Kaltenbacher and J. Saari. An asymmetric thermal model for totally enclosed fan-cooled induction motors. Technical Report ISBN 951-22-1361-3, Helsinki University of Technology, 1992.

[2] M. Kaltenbacher, F. Lindinger, H. Landes, and R. Lerch. Finite Element Optimization of a Piezoelectric Acceleration and Force Sensor. In *Tempus-Report JEP 4143-93*, Prag, 1994.

[3] R. Lerch, H. Landes, M. Kaltenbacher, and F.Lindinger. Piezoelectric CAD-System. In *Sensor 95*, pages 297–302, Nürnberg, 1995. ACS Organisations GmbH.

[4] M. Kaltenbacher, H. Landes, and R. Lerch. Simulation Tools for Magnetomechanical Systems with Moving Parts. In *Studies in Applied Electromagnetic*, Cardiff, 1995. IOS Press.

[5] M. Kaltenbacher and F. Lindinger. Software Environment for the Computer Modeling of Magnetomechanical Systems. In *Third Conference on Mechatronics and Robotics*, pages 319 – 330, Paderborn, 1995. B.G. Teubner Stuttgart.

[6] R. Lerch, M. Kaltenbacher, H. Landes, and F. Lindinger. Computerunterstützte Entwicklung elektromechanischer Transducer. *ÖVE Verbandszeitschrift*, Band 113, Heft 7/8:532 – 546, 1996.

[7] H. Landes, R. Lerch, M. Kaltenbacher, and F. Lindinger. Effiziente numerische Berechnung elektromechanischer Komponenten. In *Simulation mit der Finite-Element-Methode in Feinwerk- und Mikrotechnologie*, München, 1996.

[8] A. Kugi, K. Schlacher, and M. Kaltenbacher. Object oriented approach for large circuits with substructures in the computer algebra program Maple V. In *Third International Conference Electrosoft*, pages 491–500, UK, 1996. Computational Mechanics Publication.

[9] M. Kaltenbacher, H. Landes, R. Lerch, and F. Lindinger. A Finite-Element / Boundary-Element Method for the Simulation of coupled Electrostatic-Mechanical Systems. In *2nd European Conference on Numerical Methods in Electromagnetism*, 1996.

[10] H. Landes, C.-P. Eccardt, M. Kaltenbacher, and R. Lerch. FEM/BEM Verfahren zur Berechnung von Schallwellen sowie akustischen Abstrahlungs- und Beugungsproblemen. In *Daga 97*, 1997.

[11] R. Lerch, H. Landes, M. Kaltenbacher, F.Lindinger, R. Angerer, and H. Wöllwitsch. Computer Simulation of Magnetomechanical Sensors and Actuators. In *Sensor 97*, volume Vol. 1, pages 199–204, Nürnberg, 1997. ACS Organisations GmbH.

[12] M. Kaltenbacher, H. Landes, and R.Lerch. A Strong Coupling Model for the Simulation of Magnetomechanical Systems Using a Predictor/Multicorrector Algorithm. *Applied Computational Electromagnetics Society Journal*, 1997.

CURRICULUM VITAE

Name: Michael Kuhn

Date and Place of Birth: September 5, 1969, Chemnitz

Nationality: German

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Title: Vertragsassistent

Education:

1988:	High School Diploma (Abitur)
1988 - 1994:	Studies in Mathematics (second subject: Information Science) at the Technical University of Chemnitz
1991 - 1992:	Master course in Numerical Analysis at Brunel University in London, graduated to M. Sc.
1994:	Graduated to Dipl.-Math., Technical University of Chemnitz, respectively Dipl.-Ing., Johannes Kepler University Linz

Employment:

1988 - 1989:	Military service
Since 1994:	Research assistent at the Institute of Mathematics, Johannes Kepler University Linz, currently funded via FWF Project P11215-TEC

Selected Project Experience:

1993:	Extension of scientific software, implementation of parallel algorithms.
1994 - 1996:	Work on the project *Adaptive Domain Decomposition Methods for Finite and Boundary Elements*, involving 2D domain decomposition preprocessing.
1996 - :	Work on the project *Design, Analysis and Implementation of Parallel Algorithms in the 3D Magnetic Field Computation.*

Publications:

[1] M. Kuhn. Parallele Lösungsstrategien für das Magnetfeldproblem über einem unbeschränkten Gebiet. Diplomarbeit, TU Chemnitz–Zwickau, FB Mathematik, 1994.

[2] G. Haase, B. Heise, M. Jung, M. Kuhn, and O. Steinbach. FEM⊗BEM - a parallel solver for linear

and nonlinear coupled FE/BE-equations. DFG-Schwerpunkt "Randelementmethoden", Report 94–16, University of Stuttgart, 1994.

[3] M. Goppold, G. Haase, B. Heise, and M. Kuhn. Preprocessing in BE/FE domain decomposition methods. Technical Report 96–2, Johannes Kepler University Linz, Institute of Mathematics, 1996.

[4] B. Heise and M. Kuhn. Parallel solvers for linear and nonlinear exterior magnetic field problems based upon coupled FE/BE formulations. *Computing*, 56(3):237–258, 1996.

[5] M. Kuhn and U. Langer. Parallel algorithms for symmetric boundary element equations. *ZAMM*, 76(S2):269–272, 1996.

[6] B. Heise, M. Jung, and M. Kuhn. Multi-level methods and parallelization in magnetic field computations for electrical machines. In *Proceedings of the 7th IGTE Symposium on Numerical Field Calculation in Electrical Engineering*, 1996.

[7] M. Kuhn. DD–BEM: Preprocessing and Parallel Solution. In W. Hackbusch and G. Wittum, editors, *Boundary Elements: Implementation and Analysis of Advanced Algorithms*, volume 54 of *Notes on Numerical Fluid Mechanics*, pages 147–158, Braunschweig, Wiesbaden, 1996. Vieweg. Proc. of the 12th GAMM–Seminar, Kiel, January 19 to 21, 1996.

[8] M. Kuhn and U. Langer. Adaptive domain decomposition methods in fem and bem. In *The Mathematics of Finite Elements and Applications – Highlights 1996, (J. R. Whiteman ed.), Uxbridge*, pages 103–122, Chichester, 1996. John Wiley and Sons Ltd.

[9] G. Haase, B. Heise, M. Kuhn, and U. Langer. Adaptive domain decomposition methods for finite and boundary element equations. In *Reports from the Final Conference of the Priority Research Programme Boundary Element Methods 1989–1995, (W. Wendland ed.), Stuttgart, October 1995*, pages 112–138, Berlin, 1997. Springer Verlag.

[10] C. Carstensen, M. Kuhn, and U. Langer. Fast parallel solvers for symmetric boundary element domain decomposition equations. *Numer. Math.*, 1997. Accepted for publication.

CURRICULUM VITAE

Name: Ulrich Langer

Date and Place of Birth: 17 August 1952, Marienberg (Germany)

Nationality: Germany (Citizenship: Austria, Germany)

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Title: University Professor

Education:

1971:	High School Diploma (Matura)
1971 - 1975:	Studies in Mathematics at the Technical University of Chemnitz (Germany)
1980:	Ph.D. (Numerical Mathematics), University of St.Petersburg (Russia)
1986:	Habilitation for Mathematics, Technical University of Chemnitz (Germany)

Employment:

1975 - 1976:	Research Assistant, Department for Mathematics, Technical University of Chemnitz (Germany)
1976 - 1980:	Research Assistant, Faculty of Mathematics and Mechanics, University of St.Petersburg (Russia)
1980 - 1987:	University Assistant, Department for Mathematics, Technical University of Chemnitz (Germany)
1987 - 1989:	University Docent for Numerical Mathematics, Department for Mathematics, Technical University of Chemnitz (Germany)
1989 - 1993:	University Professor for Numerical Mathematics, Department for Mathematics, Technical University of Chemnitz (Germany)
1993 - :	University Professor for Numerical Mathematics, Institute for Mathematics, Johannes Kepler University of Linz
1986:	Visiting Assistant Professor on the Faculty of Mathematics and Mechanics at the State University of St.Petersburg (Russia), 6 months
1995:	Visiting Professor at Kuwait University (Kuwait)

Selected Project Experience:

1991 - 1993:	Project "Domain Decomposition Methods for Finite Elements and Boundary Elements" (La 767/1-1) within the Priority Research Program *"Boundary Element Methods"* of the German Research Foundation
1993 - 1995:	Project "Adaptive Domain Decomposition Methods for Finite Elements and Boundary Elements" (La 767/1-3) within the Priority Research Program *"Boundary Element Methods"* of the German Research Foundation
1995 - :	FWF-Project "Domain Decomposition Methods in Structural Mechanics" (P10643-TEC)
1996 - :	FWF-Project "Parallel 3D Magnetic Field Computation" (P11215-TEC)

Societies and Activities:

- Member, Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)
- Member, IFIP WG 2.5
- Member, Scientific Council of the HLRZ of the KFA Jülich (Germany)
- Chief of the GAMM scientific committee for *"Discretization Methods in Solid Mechanics"*
- Associate Editor, *GAMM Mitteilungen*
- Advisory Board Member, *Computing*
- Advisory Board Member, *The Electronic Journal of Szécenyi István College*
- Advisory Editorial Board Member, *Numerical Linear Algebra with Applications*

Scientific Cooperations:
AVL, Graz, Austria – University of Innsbruck, Innsbruck, Austria – Technical University of Chemnitz, Chemnitz, Germany – Christian Albrecht University, Kiel, Germany – Szèchenyi Istvàn College, Györ, Hungary – University of Oslo, Oslo, Norway – University of Novosibirsk, Novosibirsk, Russia – University of St. Petersburg, St. Petersburg, Russia – University of Maryland, Baltimore, USA.

Publications:
2 books and more than 60 publications in journals, books, and and conference proceedings.

10 Selected Publications:

[1] G. Haase and U. Langer. The non-overlapping domain decomposition multiplicative Schwarz method. *International Journal of Computer Mathemathics*, 44:223–242, 1992.

[2] G. Haase and U. Langer. The efficient parallel solution of PDEs. *Computers Math. Applic.*, 31(4):151–159, 1996.

[3] G. Haase, U. Langer, and A. Meyer. The approximate Dirichlet decomposition method. Part I,II. *Computing*, 47:137–167, 1991.

[4] G. Haase, U. Langer, A. Meyer, and S.V. Nepomnyaschikh. Hierarchical extension operators and local multigrid methods in domain decomposition preconditioners with. *East-West Journal of Numerical Mathematics*, 2:173–193, 1994.

[5] M. Jung and U. Langer. Applications of multilevel methods to practical problems. *Surveys on Mathematics for Industry*, 1:217–257, 1991.

[6] V. G. Korneev and U. Langer. *Approximate Solution of Plastic Flow Theory Problems*, volume 69 of *Teubner–Texte zur Mathematik.* Teubner–Verlag, Leipzig, 1984.

[7] M. Kuhn and U. Langer. Adaptive domain decompostion methods in FEM and BEM. In *MAFELAP (ed. by J.R. Whiteman)*, xxx, pages yyy–yyy, Brunel University of West London, June 25 - 28, 1996. John Wiley & Sons, Ltd. to appear.

[8] M. Kuhn and U. Langer. Parallel algorithms for symmetric boundary element equations. *ZAMM*, 76(2):269–272, 1996.

[9] U. Langer. Parallel iterative solution of symmetric coupled FE/BE- equations via domain decomposition. *Contemporary Mathematics*, 157:335–344, 1994.

[10] U. Langer and W. Queck. Preconditioned Uzawa–type iterative methods for solving mixed finite element equations. Wissenschaftliche Schriftenreihe 3, Technische Universität Karl–Marx–Stadt, 1987.

CURRICULUM VITAE

Name: Reinhard Lerch

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Title: University Professor

Education:

1972:	High School Diploma (Matura)
1972 - 1977:	Studies in Electrical Engineering at the Technical University of Darmstadt (Germany)
1980:	Dr.-Ing (Electrical Engineering), Technical University Darmstadt (Germany)

Employment:

1977 - 1981:	Research Assistant, Department for Electroacoustics, Technical University of Darmstadt (Germany)
1981 - 1991:	Senior Scientist at Siemens Research Center, Erlangen (Germany)
1991 - :	University Professor for Electrical Measurement Technology, University of Linz (Austria)

Selected Project Experience:

1991 - :	Various research projects with industrial companies in the area of electromechanical sensors and actuators
1994 - 1996:	FFF - project "Füllstandskontrolle von Metallbehältern"
1996:	BMWF project METEOR "Micromachined acceleration sensor"
1997:	Joint project with Fraunhofer Munich "Silicon Micropump"

Societies and Activities:

- Member VDE, Verein Deutscher Ingenieure
- Member ITG, Informationstechnische Gesellschaft

- Member, Deutsche Akustische Gesellschaft DEGA
- Member, ITG Fachausschuß 7.1
- Member, Acoustical Society of America
- Member IEEE, Institute of Electrical and Electronics Engineering
- Associate Editor, *IEEE Trans. UFFC*
- Technical Program Committee ISATA
- Administrative Committee IEEE UFFC Society
- Technical Program Committee IEEE Ultrasonics Symposium

Scientific Cooperations:
Siemens AG Erlangen, München und USA, VÖST Linz, Keba Linz, BMW Steyr, Technologiezentrum Steyr, Nokia Straubing, Pennstate University, Fraunhofer Gesellschaft München

Publications:
2 books and more than 70 publications in journals, books and conference proceedings.

10 Selected Publications:

[1] R. Lerch and H. Kaarmann. Three-dimensional finite element analysis of piezoelectric media, *IEEE Ultrasonics-Symposium Proc.*, 1987, Denver, ISSN 0090-5607, p. 853 - 858

[2] R. Lerch. Finite element analysis of piezoelectric transducers, *IEEE Ultrasonics-Symposium Proc.*, Chicago, 1988, ISSN 0090-5607, p. 643 - 654

[3] R. Lerch. Analyse hochfrequenter akustischer Felder in Oberflächenwellenfilter-Komponenten *Archiv für Elektronik und Übertagungstechnik AEÜ*, Hirzel Verlag Stuttgart, Band 44, Heft 4, 1990, p. 317 - 327

[4] R. Lerch. Finite element modelling of membrane sensors surrounded by gaseous or fluid media *Acustica 73*, 1991, p. 107 - 113

[5] R. Lerch. CAE–Tools for Piezoelectric Sensors *International Journal of Computer Applications in Technology*, vol. 5, No. 2/3/4, 1992, p. 191 - 197, ISSN 0952 8091

[6] R. Lerch, H. Landes, W. Friedrich, R. M. Hebel, A. Höss, H. Kaarmann. Modelling of Acoustic Antennas with a Combined Finite–Element–Boundary–Element–Method *IEEE Ultrasonics Symposium Proc.*, 1993, p. 581 - 584, ISSN 1051–0117

[7] R. Lerch, H. Landes, H. Kaarmann. Finite Element Modeling of the Pulse-Echo Behavior of Ultrasound Transducers *IEEE Ultrasonics-Symposium*, Cannes, Nov. 1994, ISBN 0-780-32012-3, p. 1021 - 1025

[8] P. Bauerschmidt and R. Lerch. Optical Voltage Sensor based on a Quartz Resonator *IEEE Ultrasonics-Symposium 96*, USA, San Antonio, November 1996

[9] R. Lerch, M. Kaltenbacher, H. Landes, F. Lindinger. Computerunterstützte Entwicklung elektromechanischer Transducer *e&i, Band 113*, 1996, Heft 7/8, p. 532 - 546

[10] M. Kaltenbacher, H. Landes, R. Lerch. An Efficient Calculation Scheme for the Numerical Simulation of Coupled Magnetomechanical Systems *IEEE Trans. on Magnetics*, 1997, Vol. 33, No. 2, p. 1646 - 1650

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Name: Ewald Hans Lindner

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Title: Univ.-Ass.

Education:

1977:	High School Diploma (Matura)
1977 - 1983:	Studies in Technical Mathematics at Johannes Kepler University Linz
1983:	Dipl.-Ing. (Technical Mathematics), Johannes Kepler University Linz
1983 - 1986:	Studies in Technical Mathematics at Johannes Kepler University Linz
1986:	Dr.techn. (Technical Mathematics), Johannes Kepler University Linz

Employment:

1980 - 1981:	Programmer, Institut of Mathematics, JKU Linz
1981 - 1983:	Student assistent, Institute of Mathematics, JKU Linz
1983 - 1987:	Research assistent, Institute of Mathematics, JKU Linz
1988 - :	Assistant, Institue of Mathematics, JKU Linz

Selected Project Experience:

1982 - 1989:	Optimization of hydro power plants (contract with an provincial power supply company)
1991 - 1994:	Optimal design of asynchronous motors (contract with an Austrian company)
1994 - :	Parameter design for transparantly insulated façades of buildings (contract with an local company)

Societies and Activities:

- Member of GAMM, ÖMG
- Member of the Educational Committee of the European Consortium for Mathematics in Industry (ECMI)

Scientific Cooperations:

European Consortium for Mathematics in Industry

Publications:

[1] Wolfgang Bauer, Helmut Gfrerer, Ewald Lindner, Alfred Schwarz, and Hansjörg Wacker. Optimization of the Hydro Energy Power Plant System Gosau - Gosauschmied - Steeg. *Math.Engng.Ind*, 1(3):169–190, 1987.

[2] Wolfgang Bauer, Helmut Gfrerer, Ewald Lindner, Alfred Schwarz, and Hansjörg Wacker. Optimal production scheme for the Gosau hydro power plant system. In P.Deuflhard and B.Engquist, editors, *Large Scale Scientific Computing*, pages 307–328, Boston/Basel/Stuttgart, 1987. Birkhäuser Verlag.

[3] Heinz W. Engl and Ewald Lindner. A combined boundary value and transmission problem arising from the calculation of eddy currents: well-posedness and numerical treatment. *Jour.Appl.Math.Phys.*, 35:289–307, 1984.

[4] Heinz W. Engl and Ewald H. Lindner. Computing eddy current losses in reactor coils. In Heinz W. Engl, Hansjörg Wacker, and Walter Zulehner, editors, *Case Studies in Industrial Mathematics*, volume 2 of *European Consortium for Mathematics in Industry*, pages 1–19, Stuttgart, 1988. B.G.Teubner.

[5] Anton Haumer and Ewald H. Lindner. On the optimal design of three-phase asynchronous motors. Institutsbericht nr.485, Johannes Kepler University Linz, Institute for Mathematics, December 1994.

[6] Anton Haumer and Ewald H. Lindner. An Approach for the Optimal Design of Three-phase Asynchronous Motors. *ZAMM*, 76(3):455–456, 1996.

CURRICULUM VITAE

Name: Manfred Minimair

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Title: Dipl.-Ing.

Education:

1979 - 1983:	Volksschule Thalheim
1983 - 1991:	Bundesgymnasium Dr. Schauerstraße, Wels
1983 - 1997:	Dipl.-Ing. in Technical Mathematics at Johannes Kepler University Linz, Austria

Employment:

1993 - Date	Lecturer for Mathematics tutorial for computer science at Joh. Kepler Univ, Austria

Publications:

[1] Manfred MINIMAIR. Design, Analysis and Implementation of an Adder by Ladner and Fisher. Technical Report 95-15, RISC-Linz, Johannes Kepler University, Linz, Austria, 1995.

[2] Manfred MINIMAIR. Volume of Parametrised Polyhedra. Technical Report 97-03, RISC-Linz, Johannes Kepler University, Linz, Austria, 1997.

CURRICULUM VITAE

Name: Ralf Uwe Pfau

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Education:

1988:	High School Diploma (Abitur)
1990 - 1996:	Studied Technical Mathematic in Karlsruhe, Germany, and Prague, Czech Republic, (1993/1994), graduated to Dipl.-Math.techn.

Employment:

1988 - 1990:	community service
Since 1996:	Assistant at the Institut for Industrial Mathematics, Universität Linz, financed via the Christian Doppler Laboratory for Mathematical Modelling and Numerical Simulation

Publications:

Bernauer, J., Pfau, R. U., Schwab, A.J.: Two Dimensional Current Diffusion of Elliptical Conductors, *Proceedings of the Third International Conference on Electromagnetic Field Problems & Applications*, Oct. 9-11, 1996 Wuhan, China.

Pfau, R.U., Bernauer, J., Schwab, A.J.: Eddy Currents in a Prolate Spherodial with Symmetric Current Injection *Proceedings of the Third International Conference on Electromagnetic Field Problems & Applications*, Oct. 9-11, 1996 Wuhan, China.

Pfau, R.U., Analytische Berechnung des Strömungsfeldes eines punktförmig stromgespeisten, rotationssymmetrischen Hohlellipsoids, Diploma Thesis, Universität Karlsruhe, 1995.

CURRICULUM VITAE

Name: Esther Radmoser

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Title: Dipl.-Ing.

Education:

1989:	High School Diploma (Matura)
1989 - 1995:	Studies in "Technical Mathematics" at the Technical University of Graz
1993 – 94:	Studies in "Applied Mathematics" at the University of Rennes I, France
1995:	"Diplomingenieur", Technical University of Graz

Employment:

1996 - : Employee of the Christian–Doppler—Laboratory
"Mathematische Modellierung und numerische Simulation",
University of Linz

Publications:

[1] E. Radmoser. Parameteridentifikation bei elliptischen differentialgleichungen. *diploma thesis*, 1995. supervisor K. Kunisch.

CURRICULUM VITAE

Name: Dr. Peter Paule

Date and Place of Birth: 14 May 1958, Ried im Innkreis

Nationality: Austria

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Title: Univ.-Doz.

Education:

1976:	High School Diploma (Matura; mit Auszeichnung)
1976 - 1983:	Studies in Mathematics at the University of Vienna
1983:	Ph.D. (Mathematics), University of Vienna

Employment:

1983 - 1984:	Research Fellowship (Austrian Ministry of Science)
1984 - 1986:	A. v. Humboldt Fellow at the University of Bayreuth (Germany)
1989:	Civil Service (Austrian “Red Cross”)
1986 - 1994:	Vertragsassistent at the University Linz
1994 - :	Universitätsassistent at the University Linz
1996:	Docent (Habilitation) in Mathematics

Selected Project Experience:

1986 - 1988:	Computer-assisted chemical synthesis design (Austrian FFF)
1989 - 1992:	Computer algebra algorithms for q-series (Austrian FWF)
1993 - 1995:	Symbolic summation and combinatorial sums (European HCM)

Societies and Activities:

- Member of the mathematical societies *ÖMG*, *AMS* und *SIAM*.
- Member of the editorial board of the Journal of Symbolic Computation.
- Referee for various journals (JSC, Discrete Mathematics, J. Comb. Th., El. J. Comb., Europ. J. Comb., ACM Trans. for Math. Software, etc.) and for conferences (e.g., since several years for FPSAC and ISSAC).

- Reviewer for Mathematical Reviews and Computing Reviews.
- Organizer (jointly with V. Strehl) of the MSI Workshop “Symbolic Computation in Combinatorics” (1993) at the Cornell University (U.S.A).
- Program committee member of FPSAC’96 (“8th International Conference for Formal Power Series and Algebraic Combinatorics”, Minneapolis, 1996).
- Program committee member of ISSAC’97 (“International Symposium on Symbolic and Algebraic Computation”, Hawaii, 1997).
- Program committe chair (jointly with V. Strehl) of FPSAC’97 (Vienna, 1997).
- Editor (together with D. Zeilberger) of JSC special issue “Symbolic Computation in Combinatorics” [3].
- Editor (together with V. Strehl) of JSC special issue “Symbolic Computation in Combinatorics Δ_1” [4].
- Beta-tester for version 2.0 of computer algebra package Mathematica.

Scientific Cooperations:

- TMR Network “Symbolic Summation”: University of Erlangen-Nürnberg, INRIA-Paris, University of Amsterdam, RIACA, University of Vienna, University of Ljubljana (submitted).
- Amadeus: Austrian researchers are Krattenthaler (U. Vienna), Prodinger (TU Vienna) and Paule (RISC); French researchers are Chyzak, Flajolet and Salvy (all INRIA-Paris).
- Joint research with G.E. Andrews (PennState) who for this reason will spend his sabbatical at RISC in spring 1998.

Publications:

- Ph.D. thesis: [5].
- JSC special issues: [3] and [4].
- Selected technical reports, etc.: [8], [12], [13], [14], and [15].
- Papers in refereed journals or proceedings: all other entries listed under “References”.

[1] G.E. Andrews and P. Paule. Some questions concerning computer-generated proofs of a double sum identity. *J. Symbolic Computation*, 16:147–153, 1993.

[2] P. Lisonek, P. Paule and V. Strehl. Improvement of the degree setting in Gosper’s algorithm. *J. Symbolic Computation*, 16:243–258, 1993.

[3] P. Paule and D. Zeilberger, editor. *Symbolic Computation in Combinatorics*, London, 1992. Academic Press. (Special Issue of JSC - Vol. 14).

[4] P. Paule and V. Strehl, editor. *Symbolic Computation in Combinatorics* Δ_1, London, 1995. Academic Press. (Special Issue of JSC - Vol. 20).

[5] P. Paule. *Zwei neue Transformationen als elementare Anwendungen der q-Vandermonde Formel.* PhD thesis, University of Vienna, 1982.

[6] P. Paule. Ein neuer Weg zur q-Lagrangeinversion. *Bayreuther Mathem. Schriften*, 18:1–37, 1985.

[7] P. Paule. On identities of the Rogers-Ramanujan type. *J. Math. Anal. Appl.*, 107:255–284, 1985.

[8] P. Paule. Über die Inversionsstatistiken von MacMahon und Goulden-Jackson. In *Actes du Seminaire Lotharingien - Vol. 13*, pages 77–82. IRMA Strasbourg, 1985.

[9] P. Paule. Über das Involutionsprinzip von Garsia und Milne. *Bayreuther Mathem. Schriften*, 21:295–319, 1986.

[10] P. Paule. A note on Bailey's lemma. *J. Comb. Th. (A)*, 44:164–167, 1987.

[11] P. Paule. A remark on a lemma of Ingleton and Piff and the construction of bijections. *Bayreuther Mathem. Schriften*, 25:123–127, 1987.

[12] P. Paule. The concept of Bailey-chains. In *Actes du Seminaire Lotharingien - Vol. 18*, pages 53–76. IRMA Strasbourg, 1988.

[13] P. Paule. A Lagrange inversion proof of a conjecture of J. D. Louck. *RISC-Linz Report Series*, 89(3), 1989. (5 pages).

[14] P. Paule. Mellin's series from one variable Lagrange-inversion. *RISC-Linz Report Series*, 89(4), 1989. (3 pages).

[15] P. Paule. Solution of a Seminaire Homework Example (28th SLC). *RISC-Linz Report Series*, 92(59), 1992. (8 pages).

[16] P. Paule. Short and easy computer proofs of the Rogers-Ramanujan identities and of identities of similar type. *Electronic Journal of Combinatorics*, 1(10):1–9, 1994.

[17] P. Paule. Greatest factorial factorization and symbolic summation. *J. Symbolic Computation*, 20:235–268, 1995.

[18] P. Paule. A classical hypergeometric proof of an important transformation formula found by J.-B. Baillon and R.E. Bruck. In A.G. Kartsatos, editor, *Theory and Applications of Nonlinear Operators of Accretive and Monotype Type*, pages 241–242, Toronto, 1996. Marcel Dekker. (Lecture Notes in Pure and Applied Math., Vol. 178).

[19] P. Paule. A proof of a conjecture of Knuth. *Experimental Mathematics*, 5(2):83–89, 1996.

[20] P. Paule and I. Nemes. A canonical form guide to symbolic summation. In A. Miola and M. Temperini, editor, *New Methodologies in Symbolic Computation Systems.* Text and Monographs in Symbolic Computation, Springer Wien New York, 1997. (to appear).

[21] P. Paule and A. Riese. A Mathematica q-analogue of Zeilberger's algorithm based on an algebraically motivated approach to q-hypergeometric telescoping. In M. Ismail and M. Rahman, editor, *Special Functions, q-Series and Related Topics.* Fields Institute Toronto, AMS, 1997. (to appear).

[22] P. Paule and M. Schorn. A mathematica version of Zeilberger's algorithm for proving binomial coefficient identities. *J. Symbolic Computation*, 20:673–698, 1995.

[23] P. Paule and V. Strehl. Symbolic summation - some recent developments. In J. Fleischer, J. Grabmeier, F. Hehl, and W. Kuechlin, editor, *Computer Algebra in Science and Engineering - Algorithms, Systems, and Applications*, pages 138–162. World Scientific Singapore, 1995.

[24] R. Folk, A. Kartoshov, P. Lisonek and P. Paule. Symmetries in neural networks: A linear group approach. *J. Phys. A: Math. Gen.*, 26:3159–3164, 1993.

[25] S.A. Abramov, P. Paule and M. Petkovšek. q-hypergeometric solutions of q-difference equations. *Discrete Math.*, 1997. (to appear).

CURRICULUM VITAE

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Title: —

Education:

1977 – 1981	Primary School, VS 30, Linz
1981 – 1989	High School, BG Ramsauerstraße, Linz
1989 – 1995	Studies in "Technische Mathematik, Studienzweig Informations- und Datenverarbeitung" at J. Kepler University, Linz
1995	Dipl.-Ing. (Mathematics), J. Kepler University Linz
1995 –	Ph.D. study at Research Institute for Symbolic Computation, J. Kepler University, Linz

Employment:

—

Selected Project Experience:

—

Societies and Activities:

- Member of the RISC combinatorics group

Scientific Cooperations: —

Publications:

- Diploma thesis: [2]
- Ph.D. thesis: [4]
- Papers in refereed journals or proceedings: [1], [3]

[1] P. Paule and A. Riese. A Mathematica q-analogue of Zeilberger's algorithm based on an algebraically motivated approach to q-hypergeometric telescoping. In M. Ismail and M. Rahman, editors, *Special Functions, q-Series and Related Topics*. Fields Institute Toronto, AMS, 1997. (to appear).

[2] A. Riese. A Mathematica q-analogue of Zeilberger's algorithm for proving q-hypergeometric identities. Diploma thesis, J. Kepler University, Linz, 1995.

[3] A. Riese. A generalization of Gosper's algorithm to bibasic hypergeometric summation. *Electronic Journal of Combinatorics*, 3(R19), 1996.

[4] A. Riese. Contributions to symbolic summation: q-hypergeometric identities. Ph.D. thesis, J. Kepler University, Linz, 1997. In preparation.

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Title: Research Assistant

Education:

1991 -	PhD program in applied mathematics at the University of New Mexico, Albuquerque, NM, USA (expected completion: July 1997).
1985 - 1988	PhD program in pure mathematics at the University of Wisconsin-Madison, Madison, WI, USA.
1984 - 1985	Certificate of Advance Studies in Mathematics program at Cambridge University, Cambridge, England.
1981 - 1984:	B.Sc. spécialisé bidisciplinaire en mathématiques et physique at the Université de Montréal, Montreal, Canada.

Employment:

1994 -	Applied Mathematics Research Assistant at the Albuquerque Resource Center of the High Performance Computing, Education and Research Center, Albuquerque, NM, USA.
1992 - 1994	Applied Mathematics Graduate Research Assistant at the Center for Nonlinear Studies and Division T7, Los Alamos National Laboratory, Los Alamos, NM, USA.
1991 - 1992	Mathematics Teaching Assistant at the University of New Mexico, Albuquerque, NM, USA.
1990 - 1990	Statistics consultant.
1990 - 1990	Physics Consultant at the University of New Mexico, Albuquerque, NM, USA.
1988 - 1993	Private tutor in mathematics, science, engineering and econnomics.
1988 - 1991	Professional musician.
1985 - 1987	Mathematics Teaching Assistant at the University of Wisconsin-Madison, Madison, WI, USA.
1984 - 1984	Mathematics Research Assistant at Simon Fraser University, Burnaby, British Columbia, Canada.
1982 - 1984	Physics Research Assistant at the Centre de recherche nucléaire, Université de Montréal, Montreal, Quebec, Canada.

Selected Project Experience:

None as Principal Investigator.

Societies and Activities:

- Referee for computer algebra, numerical analysis and mathematical physics journals.
- Member of the local arrangements committees of the 1997 IMACS Conference on Applications of Computer Algebra (co-chair with S. Steinberg), ISSAC'97 (International Symposium on Symbolic and Algebraic Computation) and PASCO'97 (Second International Symposium on Parallel Symbolic Computation).
- Co-organizer with T. Robey of an international workshop on automatic differentiation which took place on February 16th, 1996 at the Albuquerque Resource Center of the High Performance Computing, Education and Research Center in Albuquerque, NM, USA.

Talks at International Conferences:

- *User Friendly Reviews of Computer Algebra Systems*, presented at the Second IMACS Conference on Applications of Computer Algebra, July 17-20, 1996, at the Research Institute for Symbolic Computation, Hagenberg, Austria.
- *High Order Adjoint Discretizations of the Gradient and the Divergence*, presented at Finite Volumes for Complex Applications: Problems and Perspectives, First International Symposium, July 15-18, 1996, Rouen, France.

- With Hong, H., Jahn M., Liska, R. and Steinberg, S., *Parallel Quantifier Elimination on the SP2*, presented by Hoon Hong at the 1995 IMACS Conference on Applications of Computer Algebra, May 16-19, 1995 at the University of New Mexico, Albuquerque, NM, USA.

- *Custom Design of Interpolants Using a Computer Algebra System*, presented at A Workshop on Knowledge Engineering and Computer Algebra, June 30-July 1, 1994 at the Center for Nonlinear Studies, Los Alamos National Laboratory, Los Alamos, NM, USA.

- *Investigating Interpolation and Numerical Differentiation with a Computer Algebra System: Examples Using Axiom*, presented at A Workshop on New Technology for Symbolic Computational Mathematics and Applications in Research and Education, June 6-10, 1994 at the CAIP Center, Rutgers University, Piscataway, NJ, USA.

Scientific Cooperations:

- University of New Mexico, Albuquerque, USA (Stanly Steinberg).

  Development of a differential forms version of the Finite Volume Method. Application to the modeling of flow through porous media.

- Czech Technical University, Prague, Czech Republic (Richard Liska), RISC-Linz, Hagenberg, Austria (Hoon Hong and Ovidiu Podisor), University of New Mexico, Albuquerque, USA (Chaouki Abdallah, Peter Dorato, Stanly Steinberg and Wei Yang).

  Symbolic-numeric algorithms for quantifier elimination, parallel implementation and tuning of the QEPCAD software package("Quantifier Elimination by Partial Cylindrical Algebraic Decomposition"), preprocessors and shortcuts for special classes of problems, and applications to the stability analysis of systems in control theory and discretizations of partial differential equations.

- Ecodynamics Associates, Inc., Albuquerque, USA (Pat Knupp).

  Developement of a new framework for the variational generation and smoothing of numerical grids.

- Los Alamos National Laboratory, Los Alamos, USA (James Hyman, Michael Gehmeyr).

  Efficient discretizations of the biharmonic equation for a vorticity formulation model of pipe flow.

- Spectra Research Institute, Albuquerque, USA (Tom Robey).

  Smoothing of grids minimizing material inhomogeneities within cells in a model of flow through porous geological structures.

- Los Alamos National Laboratory, Los Alamos, USA (James Hyman, Mickhail Shashkov).

  Application of interpolation theory to the development of Support Operator Methods with application to the modeling of flow through porous media. Homogeneization theory.

- Los Alamos National Laboratory, Los Alamos, USA (Mark Mineev), Mesa College, Grand Junction, USA (Warren Macevoy).

  Density of the logarithmic basis in the solution space of the Laplacian Growth Equations model of two-fluid fingering.

Publications:

[1] C. T. Abdallah, P. Dorato, R. Liska, O. Podisor, N. Robidoux, S. Steinberg, and W. Yang. Multi-objective controller design using quantifier elimination. Technical report, Albuquerque Resource Center of the High Performance Computing, Education and Research Center, 1601 Central NE (Galles Bldg), University of New Mexico, Albuquerque, NM, 87131 USA, 1996. http://www.arc.unm.edu/~pqe/controller.html.

[2] Nicolas Robidoux. Does AXIOM solve systems of ODE's like Mathematica? Technical Report LA-UR-93-2235, Los Alamos National Laboratory, Los Alamos, NM, USA, 1993. Also available from infodesk@nag.com.

[3] Nicolas Robidoux. Orientation: the parallepiped way. Technical report, SciComp, Inc., 5806 Mesa Drive, Suite 250, Austin, TX, 78731 USA, 1995. Available from stanly@math.unm.edu (Stanly Steinberg).

[4] Nicolas Robidoux. A new method of construction of adjoint gradients and divergences on logically rectangular smooth grids. In F. Benkaldoun and R. Vilsmeier, editors, *Finite Volumes for Complex Applications: Problems and Perspectives, First International Symposium, July 15-18, 1996, Rouen, France*, pages 261–272, Paris, France, 1996. Editions Hermès.

[5] Nicolas Robidoux. Computer algebra and interpolation: a lesson plan. *J. Symbolic Computation*, (23), 1997. To appear.

CURRICULUM VITAE

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Title: Universitätsassistent

Education:

1987:	High School Diploma (Matura)
1987 - 1994:	Studies in Computer Science at Technical University of Vienna
1993 :	Four month stage for diploma thesis at the European Space Agency ESA ESTEC, The Netherlands (training and simulations facilities section)
1994:	Dipl.-Ing. (Computer Science), Technical University of Vienna
1994 - :	Studies in Computer Science at J.K. University of Linz

Employment:

1990 - 1993:	Studentassistent at the Technical University of Vienna, Department of Information Systems, Databases and Expertsystems Section
1994 - 1995:	Contractor at the Johannes Keppler University Linz, Department of Computer Graphics and Parallel Computing
1995 - :	Assistant at the Johannes Keppler University Linz, Department of Computer Graphics and Parallel Computing

Selected Project Experience:

1995 - :	Investigation of Real-Time 3D Graphics
1995 - :	Research in Virtual Reality
1995 - :	Research on Image Based Rendering Methods
1994 - :	Investigation of Multiresolutional Modelling

Societies and Activities:

- Reviewer for SIGGRAPH, 1997.

- Reviewer for EUROGRAPHICS, 1997.

Publications: Total number of refereed publications: 11. A list of major publications relevant to this project is given below.

[1] T. Mazuryk G. Schaufler and D. Schmalstieg. High fidelity for immersive displays. In *CHI '96, Vancouver, Canada, April 1996*, 1996.

[2] G. Schaufler. Dynamically generated impostors. In *GI Workshop 'Modeling - Virtual Worlds - Distributed Graphics', D.W.Fellner (Ed.), infix Verlag, November 1995*, pages 129–135, 1995.

[3] G. Schaufler. Exploiting frame to frame coherence in a virtual reality system. In *VRAIS '96, Santa Cruz, California, April 1996*, pages 95–102, 1996.

[4] G. Schaufler and W. Stürzlinger. Generating multiple levels of detail for polygonal geometry models. In *Virtual Environments '95*, pages 33–41. Springer Verlag, 1995.

[5] G. Schaufler and W. Stürzlinger. Three dimensional image cache for virtual reality. *Computer Graphics Forum*, 15(3):227–235, 1996.

[6] D. Schmalstieg and G. Schaufler. Incremental encoding of polygonal models. In *Proceedings of the 30th Hawaii International Conference on System Sciences, Software Technology Track, (HICSS-30, Maui/Hawaii) Jan. 1997*, pages 638–645, 1997.

[7] D. Schmalstieg and G. Schaufler. Smooth levels of detail. In *VRAIS '97, Albuquerque, New Mexico, March 1-5, 1997*, 1997.

[8] W. Stürzlinger and G. Schaufler. Parallel rendering with the three dimensional image cache. submitted, 1997.

[9] W. Stürzlinger, G. Schaufler, and J. Volkert. Load balancing for a parallel radiosity algorithm. In *Parallel Rendering Symposium 95 (Atlanta, USA)*, pages 39–45, 1995.

[10] W. Stürzlinger, G. Schaufler, and J. Volkert. Load balancing strategies for a radiosity algorithm. In *High Performance Computing Symposium 95 (Montreal, CA)*, pages 217–228, 1995.

CURRICULUM VITAE

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Title: Univ.-Ass.

Education:

1982:	High School Diploma (Matura)
1982 - 1987:	Studies in “Technical Mathematics” at the University of Linz
1987:	“Diplomingenieur”, University of Linz
1990:	Ph.D., University of Linz

Employment:

1988 - 1992:	Assistant, Mathematics Institute, University of Linz
1992 - 1994:	Employee of the Christian–Doppler—Laboratory “Mathematische Modellierung und numerische Simulation”
1994 - :	Assistant, Mathematics Institute, University of Linz
1995:	Docent (Habilitation) in Mathematics
1995–96:	Research Scholarship of the “Austrian Science Foundation” (FWF) for visiting Texas A&M University, College Station, Texas, USA and University of Delaware

Selected Project Experience:

1995 - 1996:	Research Fellowship of the Austrian Science Foundation (FWF)

Societies and Activities:

- Member of ÖMG (Österreichische Mathematische Gesellschaft)
- Referee for various scientific journals
- Member of the ECMI research comittee

Publications:

[1] A. Binder, H. W. Engl, C. W. Groetsch, A. Neubauer, and O. Scherzer. Weakly closed nonlinear operators and parameter identification in parabolic equations by Tikhonov regularization. *Applicable Analysis*, 55, 1994.

[2] B. Blaschke, A. Neubauer, and O. Scherzer. On convergence rates for the iteratively regularized Gauss–Newton method. *IMA Journal on Numerical Analysis*, 1997. to appear.

[3] D. Dobson and O. Scherzer. Analysis of regularized total variation penalty methods for denoising. *Inverse Problems*, 12:601 – 617, 1996.

[4] H.W. Engl, W. Rundell, and O. Scherzer. A regularization scheme for an inverse problem in age–structured populations. *Journal of Mathematical Analysis and Applications*, 182:658–679, 1994.

[5] C.W. Groetsch and O. Scherzer. The optimal order of convergence for stable evaluation of differential operators. *Electronic Journal of Differential Equations*, 1993.

[6] M. Hanke, F. Hettlich, and O. Scherzer. The Landweber iteration for an inverse scattering problem. In K.-W. Wang e.a., editor, *Proceedings of the 1995 Design Engineering Technical Conferences, Vol. 3, Part C, Vibration Control, Analysis, and Identification*, pages 909–915. The American Society of Mechanical Engineers, 1995.

[7] M. Hanke, A. Neubauer, and O. Scherzer. A convergence analysis of Landweber iteration for nonlinear ill-posed problems. *Numer. Math.*, 72, 1995.

[8] F. Hettlich, J. Morgan, and O. Scherzer. On the estimation of interfaces from boundary measurements. In H. W. Engl, A. K. Louis, and W. Rundell, editors, *Inverse Problems in Geophysical Applications*, pages 163–178, Philadelphia, 1997. SIAM.

[9] B. Hofmann and O. Scherzer. Factors influencing the ill–posedness of nonlinear problems. *Inverse Problems*, 10:1277–1297, 1994.

[10] M.Z. Nashed. Stable approximations of a minimal surface problem with variational inequalities. submitted.

[11] A. Neubauer and O. Scherzer. Finite dimensional approximation of Tikhonov regularized solutions of nonlinear ill–posed problems. *Num. Funct. Anal. Opt.*, 11:85–99, 1990.

[12] A. Neubauer and O. Scherzer. A convergence rate result for a steepest descent method and a minimal error method for the solution of nonlinear ill–posed problems. *ZAA*, pages 369–377, 1995.

[13] O. Scherzer. Denoising with higher order derivatives of bounded variation. submitted.

[14] O. Scherzer. A modified landweber iteration for solving parameter estimation problems. *Applied Mathematics and Optimization*. to appear.

[15] O. Scherzer. A multi–scale algorithm for solving non–linear ill–posed problems. submitted.

[16] O. Scherzer. The use of Tikhonov regularization in the identification of electrical conductivities from overdetermined boundary data. *Results in Mathematics*, 22:598–618, 1992.

[17] O. Scherzer. Convergence rates of iterated Tikhonov regularized solutions of nonlinear ill–posed problems. *Numer. Math.*, 66:259–279, 1993.

[18] O. Scherzer. The use of Morozov's discrepancy principle for Tikhonov regularization for solving nonlinear ill–posed problems. *Computing*, 51:45–60, 1993.

[19] O. Scherzer. Convergence criteria of iterative methods based on Landweber iteration for nonlinear problems. *Journal of Mathematical Analysis and Applications*, 194:911–933, 1995.

[20] O. Scherzer. A convergence analysis of a method of steepest descent and a two–step algorithm for nonlinear ill–posed problems. *Num. Funct. Anal. Opt.*, 17:197–214, 1996.

[21] O. Scherzer, H. W. Engl, and R. S. Anderssen. Parameter identification from boundary measurements in a parabolic equation arising from geophysics. *Nonlinear Analysis*, 20:127–156, 1993.

[22] O. Scherzer, H. W. Engl, and K. Kunisch. Optimal a-posteriori parameter choice for Tikhonov regularization for solving nonlinear ill-posed problems. *SIAM J. Numer. Anal.*, 30:1796–1838, 1993.

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Title: Dipl.-Ing.

Education:

1991:	High School Diploma (Matura)
1991 - 1996:	Studies in Mathematics at University Linz
1996:	Dipl.Ing., University Linz

Employment:

1996 - :	FWF-Employe, Inst. for Mathematics, Univ. Linz

Selected Project Experience:

1995 - :	Automatic 3D mesh generation
1996 - :	Multigrid methods in computational mechanics

Societies and Activities:
Scientific Cooperations:

Publications:

[1] J. Schöberl. Netgen - an advancing front 2d/3d-mesh generator based on abstract rules. *Computing and Visualization in Science*, 1997. (Acc. for pub.).

[2] J. Schoeberl. Solving the signorini problem on the basis of domain decomposition techniques. *Computing*, 1997. (Sub. for pub.).

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Title: Diplomingenieur

Education:

1987:	High School Diploma at Kettle Moraine, Wisconsin, USA
1988:	High School Diploma at Linz, Austria
1988 - 1990:	Studies in Mathematics at the University of Graz
1990 - 1996:	Studies in Mathematics at RISC with Diploma

Employment:

1993 - 1996:	Software Engineering for Gödel School GmbH
1996 - 1997:	Civil Service (Hospital of Linz)

Selected Project Experience:

1993 - 1996:	Symbolic Summation as Diploma Thesis
1993 - 1996:	Leitstand for a window production line, a large software system

Societies and Activities: none
Scientific Cooperations: none

Publications:

- Diploma thesis: [2].
- JSC special issues: [1].
- Problem solution: [3].

[1] P. Paule and M. Schorn. A mathematica version of Zeilberger's algorithm for proving binomial coefficient identities. *J. Symbolic Computation*, 20:673–698, 1995.

[2] M. Schorn. Contributions to symbolic summation. Master's thesis, RISC, 1995.

[3] M. Schorn. Solution to problem 95-1. *SIAM Review*, 38(1):150–151, 1996.

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E-Mail: Peter.Stadelmeyer@risc.uni-linz.ac.at

Title: Dipl.-Ing.

Education:

1989:	High School Diploma (Matura)
1989 - 1996:	undergraduate studies in Mathematics
	Johannes Kepler University Linz
Feb 1996:	Dipl.-Ing. with honors
1996 -	graduate studies
	Research Institute for Symbolic Computation
	Johannes Kepler University Linz

Employment:

Selected Project Experience:

1995:	Research Project "Puiseuxexpansion – a fast technique in CAGD"
	sponsored by Johannes Kepler University Linz

Societies and Activities:
Scientific Cooperations:

Publications:

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Title: Wissenschaftlicher Mitarbeiter

Education:

1984:	High School Diploma (Matura)
1985 - 1989:	Studies in Computer Science at Technical University of Vienna
1989:	Dipl.-Ing. (Computer Science), Technical University of Vienna
1991 - 1993:	Studies in Computer Science at Technical University of Vienna
1993:	Ph.D. (Computer Science), Technical University of Vienna

Employment:

1984 - 1989:	Programmer for RZL Gesmbh - Software for Tax Consultants
1990 - 1991:	Leading Programmer for RZL Gesmbh - Software for Tax Consultants
1991 - 1992:	Assistant, Inst. f. Computer Graphics, Technical University of Vienna
1991 - :	Consultant for RZL Gesmbh - Software for Tax Consultants
1992 - 1995:	Assistant, Inst. f. Computer Science, University Linz
1995 - 1996:	Researcher, Inst. f. Computer Science, University Linz
1997 :	Visiting scholar, Dept of Computer Science, Univ. of North Carolina, Chapel Hill, NC.

Selected Project Experience:

1991 - :	Research on Rendering Methods
1992 - :	Investigation of Parallel Rendering Methods
1995 - :	Research on Image Based Rendering Methods
1997 - :	Investigation of Novel User Interfaces for CAD Systems

Societies and Activities:

- Member, Association of Computing Machinery (ACM)
- Member, Eurographics (EG)
- Member, Gesellschaft für Informatik (GI)
- Member, Österreichische Gesellschaft für Informatik (ÖGI)
- Member, Österreichische Computer Gesellschaft (OCG)
- Reviewer for Graphics Interface 1997.
- Program committee member and reviewer for International Conference in Central Europe on Computer Graphics and Visualization, 1996-1997.
- Program committee member and reviewer for Compugraphics, 1995-1996.
- Program committee member and reviewer for Eurographics Workshops on Parallel Graphics and Visualization, 1996.
- Reviewer for Eurographics, 1996.
- Reviewer for Addison Wesley, 1995.

Scientific Cooperations: Visiting scholar in 1997, Dept. of Computer Science, Univ. of North Carolina, Chapel Hill, NC.

Publications: Total number of refereed publications: 21, with 3 contributions in international journal and 4 contributions to books. A list of major publications relevant to this project is given below.

[1] G. Schaufler and W. Stürzlinger. Generating multiple levels of detail for polygonal geometry models. In *Virtual Environments '95*, pages 33–41. Springer Verlag, 1995.

[2] G. Schaufler and W. Stürzlinger. Three dimensional image cache for virtual reality. *Computer Graphics Forum*, 15(3):227–235, 1996.

[3] W. Stürzlinger and G. Schaufler. Parallel rendering with the three dimensional image cache. submitted, 1997.

[4] W. Stürzlinger, G. Schaufler, and J. Volkert. Load balancing for a parallel radiosity algorithm. In *Parallel Rendering Symposium 95 (Atlanta, USA)*, pages 39–45, 1995.

[5] W. Stürzlinger, G. Schaufler, and J. Volkert. Load balancing strategies for a radiosity algorithm. In *High Performance Computing Symposium 95 (Montreal, CA)*, pages 217–228, 1995.

[6] W. Stürzlinger and C. Wild. Parallel visibility calulations for radiosity. In *Proceedings of Third Joint International Conference on Vector and Parallel Processing (CONPAR94-VAPP VI)*, pages 405–413. Springer Verlag, 1994.

CURRICULUM VITAE

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Title: Dr.

Education:

Ph.D. (Prize)	Computer Science, 1996. Research Institute for Symbolic Computation (RISC–Linz), University of Linz, Austria. Especially, I got "The best Ph.D. dissertation of the year" prize, an award of US$2000 from the Austrian bank "Erste Allgemeine Sparkasse" for the year 1996.
M.Sc.	Computer Science, 1992. Division of Computer Science, the Asian Institute of Technology, Bangkok, Thailand.
Dipl-Ing.	Mathematics and Computer Science, 1984. Department of Mathematics & Computer Science, University of HCM city, Vietnam.

Employment:

1995–now	Project's coordinator, project HySaX, Austrian Science Foundation and Research Institute for Symbolic Computation.
1993–1995	Research Associate, project POSSO and SACLIB. Austrian Science Foundation and Research Institute for Symbolic Computation.
1992–1993	Research Associate, Asian Institute of Technology.
1992–1992	Teaching Assistant, Asian Institute of Technology.
1985–1990	Consultant at the Computer Center of the Ministry of Industries, Vietnam.

Selected Project Experience:

1995–now	Project's coordinator, project HySaX, Austrian Science Foundation and Research Institute for Symbolic Computation.
1993–1995	Research Associate, project POSSO and SACLIB. Austrian Science Foundation and Research Institute for Symbolic Computation.

Societies and Activities:

- Member, Association for Computing Machinery (ACM)
- Referee for several international conferences.

Scientific Cooperations:

Publications:

[1] Quoc-Nam Tran. An algebraic approach to mechanical theorem proving in geometry. Master's thesis, The Asian Institute of Technology, Bangkok, Thailand, 1992.

[2] Quoc-Nam Tran. Extended Newton's method for finding the roots of an arbitrary system of equations and its applications. In M. H. Hamza, editor, *Proceedings of the Twelfth IASTED International Conference: Applied Informatics*. IASTED, 1994.

[3] Quoc-Nam Tran. Extended Newton's method for finding the roots of an arbitrary system of equations and its applications. Technical Report 94–49, RISC-Linz, J. Kepler Universität, Linz, Austria, 1994.

[4] Quoc-Nam Tran. A hybrid symbolic-numerical method for tracing plane and space algebraic curves. In *11th European Workshop on Computational Geometry CG'95*, Linz, Austria, 1995. RISC-Linz.

[5] Quoc-Nam Tran. A hybrid symbolic-numerical method for tracing surface-to-surface intersections. In A. H. M. Levelt, editor, *Proceedings of ISSAC-95*, Montreal, Canada, 1995. ACM.

[6] Quoc-Nam Tran. On the symbolic-numerical methods for finding the roots of an arbitrary system of non-linear algebraic equations. In *Proceedings of the First Asian Technology Conference in Mathematics, ATCM-95*, Singapore, 1995.

[7] Quoc-Nam Tran. Extending newton's method for finding the roots of an arbitrary system of equations and its applications. *International Journal of Modeling and Simulation*, 1996. to appear.

[8] Quoc-Nam Tran. *A Hybrid Symbolic-Numerical Approach in Computer Aided Geometric Design (CAGD) and Visualization*. PhD thesis, Research Institute for Symbolic Computation (RISC–Linz), University of Linz, Austria, 1996.

[9] Quoc-Nam Tran. A hybrid symbolic-numerical method for tracing algebraic curves in higher dimensions. In *ICCAM–96 conference, Leuven, Belgium*, 1996. preprint.

[10] Quoc-Nam Tran. Intersection of surfaces. In *The Seventh Mathematics of Surfaces, Dundee, U. K.*, 1996.

[11] Quoc-Nam Tran. A note on irreducible decomposition of algebraic sets and automatic theorem proving. preprint, 1996.

[12] Quoc-Nam Tran. Extending dixon's resultant using pseudoinverse matrices. Preprint, 1997.

[13] Quoc-Nam Tran. On the dimension of the irreducible components of an algebraic set. Preprint, 1997.

[14] Quoc-Nam Tran and K. Kanchanasut. An efficient algorithm for computing a triangular form. Technical report, Asian Institute of Technology, Bangkok, Thailand, 1993.

CURRICULUM VITAE

Name: Jens Volkert

Date and Place of Birth: 23 August 1942, Nürnberg

Nationality: Germany (Citizenship: Austria, Germany)

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Title: University Professor

Education:

1961:	High School Diploma (Matura)
1962 - 1969:	Studies in Mathematics at the University of Erlangen
1983:	Ph.D. Computer Science, University of Erlangen

Employment:

1970 - 1978:	Frauenhofergruppe for Man Machine Communication, Erlangen
1979 - :1989	Research Assistant, University of Erlangen
1989 - :	Univ.-Prof.

Selected Project Experience:

1970 - 1978:	Project "EPIK Erlangen Project Interactive Carthographie", German Ministry of Defence
1979 - 1983:	Project "EGPA Erlangen Processor Array" supported by the German Ministry of Research
1984 - 1989:	Project "SUPRENUM Super computer Numeric" supported by the German Ministry of Research
1991 - 1993:	Project "Paragraph: Parallel Algorithm in Computer Graphics", Austrian Ministry of Research
1991 - 1993:	Project "PEAK": An Intelligent Programming Environment for the Solution of Data Parallel Scientific Applications, Austrian Ministry of Research
1991 - 1993:	Project "CAPSE": Computer Aided Parallel Software Engineering, Austrian Ministry of Research
1996 - :	FWF project: "Visualization of data partitioning", Austrian Ministry of Research

Societies and Activities:

- Member of GI, Gesellschaft für Informatik
- Member of the steering commitee of Fachgruppe APS, Informationstechnischen Gesellschaft (ITG) and GI
- Member of OCG, Österreichische Computergesellschaft
- Member of ACM, Association for Computing Machinery

Scientific Cooperations:
Lehrstuhl für Betriebssysteme, Universität Hannover
Lehrstuhl für Rechnerstrukturen, Universität München
IMAG Fance, Grenoble

Publications: More than 60 publications in journals, books, and and conference proceedings.

10 Selected Publications:

[1] P. Bastian, J.H. Ferziger, G. Horton, and J. Volkert. Adaptive Multigrid Solution of the Convection-Diffusion Equation on the DIRMU Multiprocessor. In *Notes on Numerical Fluid Dynamics*, volume 23, 1989.

[2] J. Volkert D. Kranzlmüller, S. Grabner. Debugging with the MAD environment. *Parallel Computing*, 23:199–217, 1997.

[3] H. Finnemann and J. Volkert. Parallel Multigrid Algorithms Implemented on Memory-Coupled Multiprocessors. In *Int. Topical Meeting on Advances in Reactor Physics, Mathematics and Computers*, pages 1–17, 1987.

[4] S. Grabner, D. Kranzlmüller, and J. Volkert. Debugging of Concurrent Processes. In *Euromicro PDP '95 Workshop*, 1995.

[5] R. Koppler, S. Grabner, and J. Volkert. Graphical Support for Data Distribution in SPMD Environments. In *1996 IEEE Second Intl. Conference on Algorithms & Architectures for Parallel Processing ICA3PP '96 (Singapore)*, pages 21–28, 1996.

[6] R. Koppler, S. Grabner, and J. Volkert. Visualization of Distributed Data Structures for HPF-like Languages. *Scientific Programming spec. issue High Performance Fortran Comes of Age*, 6(1):115–126, 1997.

[7] D. Kranzlmüller, S. Grabner, and J. Volkert. Monitoring Strategies for Hypercube Systems. In *4th EUROMICRO Workshop on PDP, Braga, Portugal*, pages 486–492, 1996.

[8] G. Schaufler, W. Stürzlinger, and J. Volkert. Parallel Radiosity. In *Workshop: Algorithms for Future Technologies (Prag, CZ)*, 1995.

[9] W. Stürzlinger, G. Schaufler, and J. Volkert. Load Balancing for a Parallel Radiosity Algorithm. In *High Performance Computing Symposium '95 (Montreal, CA)*, pages 217–228, 1995.

[10] H. Wabnig, G. Haring, D. Kranzlmüller, and J. Volkert. Communication Pattern based Performance Predicition on the nCUBE 2 Multiprocessor System. In *CONPAR 94-VAPP VI Conference, Linz, Austria*, pages 41–52, 1994.

CURRICULUM VITAE

Name: Kurt Wegschaider

Date and Place of Birth: 21 August 1970, Linz a. d. Donau

Nationality: Austria

Home Address: Bauernfeindstr. 4, A-4040 Linz, Austria

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Education:

1980 - 1988:	High School (Bundesgymnasium Linz Khevenhüllerstraße)
1988:	High School Diploma (Matura; mit gutem Erfolg)
1988 - 1997:	Studies in Mathematics (Technische Mathematik) at the Johannes Kepler University in Linz and the Research Institute for Symbolic Computation

Selected Project Experience:

1994 - 1997:	Developement of the Mathematica package MultiSum, providing efficient functions to compute proofs of binomial multisum identities.

Publications:

- Diploma thesis : [1].

[1] K. Wegschaider. Computer generated proofs of binomial multi-sum identities. Diplomarbeit, Research Institute for Symbolic Computation, J. Kepler University, Linz, 1997.

CURRICULUM VITAE

Name: Franz Winkler

Date and Place of Birth: 24 October 1955, Salzburg

Nationality: Austria

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E-Mail: winkler@risc.uni-linz.ac.at
www-Page: http://www.risc.uni-linz.ac.at/people/winkler

Title: Assistenzprof. Univ.-Doz.

Education:

1974:	High School Diploma (Matura)
1974 - 1979:	Studies in Mathematics at Univ. Linz
1979:	Dipl.-Ing. (Mathematics), Univ. Linz
1979 - 1980:	Graduate Studies in Mathematics and Computer Science at
	Rensselaer Polytechnic Institute, Troy, New York
1980 - 1984:	Ph.D. studies in Mathematics at Univ. Linz
1984:	Ph.D. (Mathematics), Univ. Linz

Employment:

1979 - 1980:	Teaching and Research Assistant, Dept. Mathematics and Computer Science, Rensselaer Polytechnic Institute, Troy, New York, USA
1980 - 1984:	Assistant, Institut f. Mathematik, Univ. Linz
1984 - 1986:	Visiting Assistant Prof., Dept. of Computer and Information Sciences, Univ. of Delaware, Newark, De, USA
1986 - 1992:	Assistant, Institut f. Mathematik, Univ. Linz
1988:	Guest at Institute of Physical and Chemical Research (RIKEN), Tokyo, for 1 month, Japanese Government Research Award
1990:	Docent (Habilitation) in Mathematics
1991:	Visiting Professor in Algebra, Universidad de Alcalá, Madrid, March 1991
1992 - :	Associate Professor, Institut f. Mathematik, Univ. Linz
1993:	Guest at the Academia Sinica in Beijing and at the Computer Science Dept. of Fudan University in Shanghai, China, Research Cooperation Austrian FWF and NSF China
1994:	Visiting Professor in Algebra, Universidad de Alcalá, Madrid, March 1994
1996:	Visiting Professor in Algebra, Universidad de Alcalá, Madrid, June 1996

Selected Project Experience:

1986 - 1988:	*Ludwig Wittgenstein Research Assistantship* of Österreichische Forschungsgemeinschaft
1988 - 1991:	Principal investigator, *"Algorithmen und Software für die Algebraische Geometrie (ASAG)"*, Austrian FWF, Project P6763
1991 - 1993:	Principal investigator, *"Anwendungen der Computer-Algebra in Algebraischer Geometrie"*, Scientific-Technical Agreement Austria-Spain (Accion Integrada)
1992 - 1994:	Principal investigator, *"Symbolic Geometric Computation — Mathematical Foundations and Algorithms (SGC)"*, Austrian FWF, Project P8573-PHY
1992 - 1995:	Principal investigator, *"Polynomial System Solving (POSSO)"*, Esprit Basic Research Action 6846 and Austrian FWF, Project P9181-TEC
1995 - 1998:	Principal investigator, *"Symbolic and Algebraic Computation (SAC)"*, European HCM-Network, Project CHRX-CT94-0439
1996 - 1998:	Principal investigator, *"A Hybrid Symbolic-Numerical Approach in Computer Aided Geometric Design (HySaX)"*, Austrian FWF, Project P11160-TEC

Societies and Activities:

- Member, Austrian Mathematical Society (ÖMG)
- Member, American Mathematical Society (AMS)
- Member, The Mathematical Association of America (MAA)

- Member, Society for Industrial and Applied Mathematics (SIAM)
- Organizer and main lecturer, "RISC-Linz Summer School in Computer Algebra", July 1990
- Organizer and main lecturer, "RISC-Linz Summer School in Computer Algebra", July 1992
- Organizer (with H.Hong and D.Wang), "Workshop on Algebraic Approaches to Geometric Reasoning", Schloß Weinberg near Linz, August 1992
- Organizer and Chairman of the program committee, "Workshop on Computer Algebra", in the frame of the conference INFORMATIK'96, Univ. Klagenfurt, September 1996
- Chairman, Austrian Working Group for Computer Algebra, since 1996
- Organizer (with B.Buchberger), "RISC-Linz Special Year on Gröbner Bases", March 1997 – February 1998
- Chairman of the program committee, conference "33 Years of Gröbner Bases", February 1998
- Member of the Editorial Board, book series "Texts and Monographs in Symbolic Computation", Springer-Verlag Wien New York
- Editor, "SIGSAM Bulletin", 1986 – 1991
- Editor (with H.Hong and D.Wang), *Algebraic Approaches to Geometric Reasoning*, Special Issue of "Annals of Mathematics and Artificial Intelligence", vol. 13/1-2, editor in chief: M.C. Golumbic, Verlag J.C. Baltzer AG, ISSN 1012 2443, March 1995
- Editor (with C.M. Hoffmann and J.R. Sendra), *Parametric Algebraic Curves and Applications*, Special Issue of "J. of Symbolic Computation", March/April 1997
- Member of the program committee for: ISSAC'88 (Rome), Mathematics and Computers 1989 (M.I.T., Cambridge, Ma, USA), ISSAC'89 (Portland, Or, USA), 2nd Internat. Workshop on Adv. in Robot Kinematics (Linz, Austria), 4th Internat. Conf. Rewriting Techniques and Applic. (Como, Italy)
- Referee/reviewer for the following journals: ACM Trans. Math. Software, Computing Review, SIAM Reviews, Acta Informatica, Algorithmica, AAECC, computers & mathematics with applications, Computing, J. Automated Reasoning, J. Symbolic Computation, National Science Foundation (USA), Software – Practice and Experience, Jahresbericht der Deutschen Mathematiker-Vereinigung
- Referee for the following conferences: EUROCAL'83, EUROSAM'84, EUROCAL'85, RTA'85, AAECC'85, SYMSAC'86, ICALP'87, AAECC'86, ISSAC'88, Comp.& Math.'89, ISSAC'89, ICALP'90, ICALP'92, ISSAC'94, CADE'96, ICALP'97, ISSAC'97

Scientific Cooperations:

- Accion Integrada with Universidad de Alcalá, Madrid, Spain, in 1991–1993, and 1997
- European Research Project "POSSO", with universities at Pisa, Bath, Paris (VI), Nice, Genova, Santander, Hagen, Stockholm
- Research Cooperation between Austrian FWF and NSF China, in 1993/94 and probably in 1997
- European HCM Network, with CAN/RIACA Amsterdam, U.Bath, U.Genova, U.Nice, U.Paderborn, U.Santander, ETH-Zürich

Publications: Besides the following books [4] [3] [11] [2] and scientific papers [1] [7] [9] [5] [6] [8] [10] , the author has published 20 more papers on symbolic computation, computer algebra, and constructive algebraic geometry.

[1] R. Gebauer, M. Kalkbrener, B. Wall, and F. Winkler. Casa: A computer algebra package for constructive algebraic geometry. In S.M. Watt, editor, *Proc. ISSAC '91*, pages 403–410. ACM Press, 1991.

[2] C.M. Hoffmann, J.R. Sendra, and F. Winkler (eds.). *Parametric Algebraic Curves and Applications,* Special Issue of the *J. of Symbolic Computation,* March/April. Acad. Press, 1997.

[3] H. Hong, D. Wang, and F. Winkler (eds.). *Algebraic Approaches to Geometric Reasoning,* Special Issue of *Annals of Mathematics and Artificial Intelligence,* vol.13/1-2. J.C. Baltzer AG, 1995.

[4] B. Kutzler, B. Wall, and F. Winkler. *Mathematische Expertensysteme — Praktisches Arbeiten mit den Computer-Algebra-Systemen MACSYMA, Mathematica und DERIVE.* expert verlag, Ehningen bei Böblingen, 1992.

[5] M. Mňuk, J.R. Sendra, and F. Winkler. On the complexity of parametrizing curves. *Beiträge zur Algebra und Geometrie*, 37/2, 1996.

[6] M. Mňuk and F. Winkler. Casa — a system for computer aided constructive algebraic geometry. In J. Calmet and C. Limongelli, editors, *Proc. DISCO '96*, pages 297–307. Springer-Verlag Berlin Heidelberg New York, LNCS 1128, 1996.

[7] J.R. Sendra and F. Winkler. Symbolic parametrization of curves. *J. Symbolic Computation*, 12:607–631, 1991.

[8] J.R. Sendra and F. Winkler. Parametrization of algebraic curves over optimal field extensions. *J. Symbolic Computation*, March/April, 1997.

[9] F. Winkler. Automated theorem proving in nonlinear geometry. In C.M. Hoffmann, editor, *Issues in Robotics and Nonlinear Geometry,* Vol.6 of *Advances in Computing Research*, pages 183–197. JAI Press, 1992.

[10] F. Winkler. Algebraic computation in geometry. *J. Math. and Comp. in Simulation*, 42(4-6):529–537, 1996.

[11] F. Winkler. *Polynomial Algorithms in Computer Algebra.* Springer-Verlag Wien New York, 1996.

CURRICULUM VITAE

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Title: Univ.-Doz.

Education:

1973:	Graduation from high school (Matura)
1973 - 1979:	Courses in technical mathematics, mathematics and physics for teaching, University of Linz
1979:	Graduation from the University of Linz in Technical Mathematics, diploma degree
1981:	Ph.D. in technical sciences, University of Linz
1989:	Habilitation for mathematics, University of Linz

Employment:

1976 - 1978	Teaching assistent at the Chair for Numerical Analysis, University of Linz
1979 - 1993	Assistant professor at the Institute for Mathematics, University of Linz
1981/1982	Visiting assistent professor at the Georgia Institute of Technology, Atlanta, U.S.A.
Since 1993	Assistenzprofessor (associate professor) at the Institute for Mathematics, University of Linz

Selected Project Experience:

1992 - 1995	Software development in CFD (computational fluid dynamics) for VOEST-ALPINE STAHL Linz
Since 1986	A number of smaller projects on methods in CFD for AVL Graz

Societies and Activities:

- Former Book Review Editor for "Zeitschrift für Operations Research (ZOR), Serie B: Praxis"

- Referee for several scientific journals

Publications:
2 books (co-editor) and 29 publications in journals, books and conference proceedings.

10 selected publications:

[1] J. Hackl, Hj. Wacker, and W. Zulehner. An efficient step size control for continuation methods. *BIT*, 20:475–485, 1980.

[2] W. Zulehner and W. F. Ames. Group analysis of a semilinear vector diffusion equation. *Nonlinear Analysis*, 7:945–969, 1983.

[3] J. Guddat, Hj. Wacker, and W. Zulehner. On imbedding and parametric optimization – a concept of a globally convergent algorithm for nonlinear optimization problems. *Math. Prog. Study*, 21:79–96, 1984.

[4] W. Zulehner. A simple homotopy method for determining all isolated solutions to polynomial systems. *Math. Comp.*, 50:131–154, 1988.

[5] W. Zulehner. On the solutions to polynomial systems obtained by homotopy methods. *Numer. Math.*, 54:303–317, 1988.

[6] A. Preuer, G. Kolb, and W. Zulehner. Computational fluid dynamics in modelling blast furnace erosion. In H. W. Engl and J. McLaughlin, editors, *Proceedings of the Conference "Inverse Problems and Optimal Design in Industry"*, pages 217–228, Stuttgart, 1994. B. G. Teubner.

[7] G. Hendorfer, A. Preuer, G. Zuba, and W. Zulehner. Industrial flow problems in steel production. In W. F. Ames, editor, *Proceedings of the 14th IMACS World Congress on Computational and Applied Mathematics*, Atlanta, 1994. Georgia Tech.

[8] W. Zulehner and H. Rohatschek. Representation and calculation of photophoretic forces and torques. *J. Aerosol Sci.*, 26:201–210, 1995.

[9] T. Kronberger, A. Ortner, W. Zulehner, and H.-J. Bart. Numerical simulation of extraction columns using a drop population model. *Computers chem. Engng*, 19:S 639–S 644, 1995.

[10] A. Ecker and W. Zulehner. On the smoothing property of multi-grid methods in the non-symmetric case. *Numer. Linear Algebra Appl.*, 3:161–172, 1996.