Full Proposal for a Scientific Programme

in the Physical Engineering Sciences

PROGRAMME TITLE:
Optimization with PDE Constraints

Programme acronym: OPTPDE

Acronym of the Standing Committee in whose domain the proposal falls: PESC

Principal Proposers: *Ronald R.W. Hoppe* (**Contact Person**), Professor of Mathematics, Department of Mathematics, University of Augsburg, Germany & University of Houston, USA; *Karl Kunisch*, Professor of Mathematics, Institute of Mathematics, University of Graz, Austria; *Olivier Pironneau*, Professor, Université Paris VI, Laboratoire Jacques-Louis Lions

Summary: This project is concerned with the development, analysis and application of new, innovative mathematical techniques for the solution of constrained optimization problems where a partial differential equation (PDE) or a system of PDEs appears as an essential part of the constraints. Such optimization problems arise in a wide variety of important applications in the form of, e.g., parameter identification problems, optimal design problems, or optimal control problems. The efficient and robust solution of PDE constrained optimization problems has a strong impact on more traditional applications in, e.g., automotive and aerospace industries and chemical processing, as well as on applications in recently emerging technologies in materials and life sciences including environmental protection, bio- and nanotechnology, pharmacology, and medicine. The appropriate mathematical treatment of PDE constrained optimization problems requires the integrated use of advanced methodologies from the theory of optimization and optimal control in a functional analytic setting, the theory of PDEs as well as the development and implementation of powerful algorithmic tools from numerical mathematics and scientific computing. Experience has clearly shown that the design of efficient and reliable numerical solution methods requires a fundamental understanding of the subtle interplay between optimization in function spaces and numerical discretization techniques which can only be achieved by a close cooperation between researchers from the above mentioned fields.

Having this in mind, the proposed project has two equally important goals. The first one is the creation of a network of leading European and US research teams in the area of PDE constrained optimization and its applications to provide an improved theoretical understanding of the basic principles and to develop, analyze and implement efficient and reliable numerical solution techniques. The second one is to make these tools accessible to those industries where there is an increasing need for advanced optimization methods that lead to a significantly better operational behavior of existing devices and systems as well as to the development of new, innovative products. Herewith, the project participants would like to give a valuable contribution to the scientific progress, the improvement of industrial processes, the welfare and development of the nations and to the education of its people. Indeed, this project will reveal a carefully prepared communication among its participants from the academic world and with the various practitioners from outside of the universities, continuous education with a variety of teaching and training programs, workshops and conferences, scientific publications in premium journals and reports to interested parts of the publicity as well as the active

integration and exchange of advanced students.

R&D keywords of the proposal: Optimization and optimal control, partial differential equations, numerical analysis, scientific computing

Status of the Research Context, the Goals and the Envisaged Achievements of the Programme Initiative:

In the last decade, the analysis, implementation and utilization of advanced mathematical methods for real-world problems of process optimization and control has made an impressive progress. Besides those achievements which are mentioned above, robust optimization has been established and applied for technological and financial tasks. Significant parts of robust optimization can be regarded as optimization with constraints which, moreover, includes very relevant disciplines such as linear programming, semi-definite programming and conic quadratic programming; for all of which interior point methods (IPM) are a well developed methodology. There is a further scientific and practical potential given for comparing and combining robustness and robust methods with the theories of stability and structural stability as being deeply studied in semi-infinite optimization, and with robustness from modern information theory.

Our project proposal

1 firstly bases on the achievements made in the regions of classical optimization procedures such as, e.g., simplex, gradient, quasi-Newton methods and IPM, and intends to compare and connect them with developing less conventional approaches such as evolutionary strategies (ES), including genetic or particle-swarm algorithms or hybrid schemes, in contexts where robustness is a very severe constraint.

2 The second pillar of our research is based on the interaction between the theory and the treatment of PDEs and optimization and optimal control theory. In both areas, new methodologies have been developed over the past decade which already have led to a significant progress in PDE constrained optimization.

3 For large-scale problems, the emerging power of modern computers allows to handle problems which were out of reach before. Also, the project will foster the practical experience and further readiness of the participating researchers which is an achievement that should not be underestimated.

The proposed programme is fostered by many of the top-ranking, internationally distinguished experts in the fields of our project. We submitters are glad that several of those participants are working in complementary areas; they are authors of numerous highly influential journal articles and books in optimization and optimal control. The programme is addressed to the following main research areas, with a strong attention to interdisciplinary interactions, including vivid communication and guided by education and continuous learning:

1 *Mathematical foundations of PDE constrained optimization and control.*

2 *Numerical methods in PDE constrained optimization.*

3 *Applications to real-world and real-time process controls problems.*

Mathematical Foundations of PDE Constrained Optimization and Control:

In the real-world contexts of industry, of natural and social sciences, optimization problems involving systems governed by PDEs are becoming more and more complex. Here, the major difficulty often consists in the costly evaluation of a functional by means of a simulation; the numerical method to be employed has to exploit at best the problem characteristics, e.g., regularity, smoothness or local convexity. In many other cases, there are several criteria to be optimized, and some are non-smooth or non-convex. A large parameter set, sometimes including different parameter types, e.g., Boolean, integer, real or functional, has to be incorporated, as well as a large constraint set, revealing various types of constraints, e.g., physical and geometrical ones. What is more, today's most interesting optimizations are founded on or addressed towards a multi-disciplinary work; this causes strong needs for further finding and improving a common language and exchange platform. All of this complicates and retards a direct application of mathematics and requires extra scientific efforts. In particular, the development of robust optimizers has become very essential.

In the area of numerical optimization algorithms, the proposed programme intends to combine classical with less conventional methods. As a consequence of this, discussed by us here for large shape-optimization applications with an emphasis on the PDE approximation, the cost-efficiency has to be examined. In this context, we are especially interested in

1 best approximation and shape parameterization,

2 convergence acceleration (especially, by multi-level methods),

3 model reduction (e.g., by POD),

4 parallel and grid computing.

For enhancing the robustness of algorithms in the optimization or evolution of shape, the modeling of a moving geometry is a great challenge. There is a tradeoff between the pure geometrical viewpoint and the numerical implementation. It consists of the fact that the shape gradients are distributions and measures lying in the dual spaces of the shape and geometrical parameters. Usually, these dual spaces are very large. Any finite dimensional approach refers to the Hilbert space framework, whereas dual spaces are identified implicitly to the shape parameter spaces. These finite-dimensional spaces sometimes mask their origin as discretized Sobolev spaces. Any ignoring of this point can cause instabilities; therefore, appropriate smoothing procedures are needed to stabilize the evolution of the shape. One question has been: How can we "get rid" of a smooth geometry in the direction opposite to a non-smooth field, that is going to destroy the boundary itself, its smoothness or curvature, and generates oscillations? An answer to this question is given by the notion of a shape differential equation; it arises from the functional analysis framework which has to be further developed to quantitatively manage the lack of duality.

Theoretical complications for a numerical realization are simplified when we are back in a Hilbert space setting. This can be achieved, however, at the "price" of a large order of the differential operator implied as the duality operator. The latter one can always be chosen as an ad hoc power of an elliptic system. In this sense, the crucial issue is the optimal regularity of the solution of the considered system, e.g., aerodynamical flow or electromagnetic field, up to the moving boundary whose regularity is itself governed by the evolution process.

Numerical Methods in PDE Constrained Optimization:

Over the 1990s significant progress has been made in the numerical treatment of PDE constrained optimal control problems. Mainly two directions of research have been followed and are still the focus of highly active research activities.

One direction is mathematical programming driven. The PDE is considered as a constraint and appropriate forms of Newton, quasi-Newton, sequential quadratic programming (SQP) and other optimization approaches are investigated. Convergence and rate of convergence in an appropriate function space setting, taking into consideration the two-norm discrepancy and higher order optimality conditions were analyzed and efficient numerical realizations were derived.

The second approach is driven by numerical methods for PDEs. The optimality system of the PDE constrained optimization problems is a coupled system of PDEs with special structure. Efficient techniques for the numerical solution of PDEs are extended to the optimality system. In particular, multigrid and domain decomposition methods have been studied. More recently a-posteriori error estimates are being derived and adaptive grid generation is being used in the context of optimal control of PDEs.

While there has been gratifying progress towards the development, analysis and application of efficient numerical methods, many of the current approaches are only analyzed and applied in rather simple settings. Extensions of methods and their analysis from fairly standard test problems to real-world problems involving multi-physics, multiple scales, strong nonlinearities, vector valued constraints, etc. present many challenges. The proposed scientific programme provides an ideal environment to significantly advance the design of numerical methods, their analysis and their integration into software frameworks for the solution of challenging problems. The interdisciplinary collaborations between the international research groups made possible by this programme enable advancements that would be out of reach for single research groups or small collaborations. Some of the areas that will be pursued are as follows.

***Numerical methods for problems with control and state constraints*:**
PDE constrained optimization problems with pointwise constraints, especially pointwise constraints on the solution of the governing PDE, so-called state-constraints, are especially difficult. The rigorous application of interior-point methods to such problems in a function space setting has only recently been carried out for rather simple model problems. In addition, new classes of algorithms based on semi-smooth Newton methods have been developed for these classes of problems and have been applied with great success to several test problems. The extensions of these methods and analysis to more complicated setting are actively pursued by many research groups participating in this project.

***Interaction of discretization and optimization*:** The careful integration of discretization and optimization is important for the overall efficiency of the solution process. Mesh independence principles are important for mesh refinement strategies. Discrepancies between the optimality system of the discretized optimization problem and the discretization of the optimality system can influence the approximation properties of the computed solution. Recently, new stabilization techniques have been proposed for problems governed by PDEs relevant for flow control that do not exhibit these discrepancies. Likewise, discontinuous Galerkin discretizations in time have recently been shown to allow commutation of the optimization and the discretization in the above sense.

Fast iterative solution of quadratic programming subproblems: SQP type algorithms for PDE constrained optimization problems require the repeated solution of quadratic subproblems. For large scale PDE constrained problems, the solution of these problems consumes the vast majority of computing time. Development of efficient iterative methods for these problems are therefore very important. Many iterative solvers, such as multigrid and domain decomposition methods have been successfully extended to some PDE constrained quadratic programs. However more research is required for time dependent problems, problems arising from multi physics applications and problems with a special structure induced by interior point or semi-smooth Newton methods.

Model reduction: Model reduction seeks to replace a high dimensional mathematical model (typically a (semi-)discretized PDE) by a small dimensional model with approximately the same input (controls/design parameters) to output (objective function) behavior of the high dimensional model. Popular approaches are balanced truncation and proper orthogonal decomposition (POD). For some settings, e.g., linear time invariant problems, theory and numerical technique are fairly well developed. For many problems model reduction methods with a rigorous mathematical backing and efficient numerical implementation are still missing and subject of active research. The incomplete sensitivity approach is a typical example of reduced order modelling (cf., e.g., B. Mohammadi and O. Pironneau, Applied Shape Optimization for Fluids, 2001, Oxford Science Publications).

Adaptive methods: Adaptive methods attempt to locally refine the PDE discretization such that an approximate solution to the optimization problem can be computed within a prescribed tolerance and with minimal computational effort. Recently, adaptive methods have been proposed for special classes of PDE constrained optimization problems. The development and analysis of such methods for nonlinear problems with state and control constraints is still at the beginning.

Robust optimization: For the application of optimization to real-world problems it is important that the computed solution is robust against perturbations of the problem. The goal of robust optimization is to integrate this demand in a rigorous way into the optimization. For several classes of finite dimensional optimization problems there exists mathematically rigorous and computationally tractable robust optimization approaches. However, these do not carry over to most PDE constrained optimization problems because of their problem sizes.

Handling of inexact problem information: In many application contexts, parts or all of the governing PDEs have to be satisfied at every iteration of the optimization algorithm. If the PDE is solved iteratively, the PDE solution cannot be computed exactly. Consequently, objective and constraint functions and their gradients cannot be evaluated exactly. Optimization algorithms have to deal with this. Similar issues arise when PDE discretizations are refined based on the progress of the iteration. Even if the PDE is included as a constraint, optimization algorithm requires the repeated solution of very large scale linear systems, involving the linearized PDE. This is done iteratively and, hence, inexactly. The control of these sources of inexactness within the optimization in a practical and efficient way while guaranteeing convergence of the overall optimization loop is being actively researched.

Algorithmic differentiation: Algorithmic, or automatic, differentiation is a chain-rule based technique for evaluating derivatives of functions defined by evaluation procedures in a high level computer language like C or Fortran. While early applications concentrated on straight-line programs of small to moderate size, tool-developers are now targeting large-scale codes. The so-called forward mode has been successfully applied to codes with hundred thousands of lines, like for example the commercial CFD code FLUENT, but the resulting sensitivity information may not always be useful when the original evaluation code contains iterative solvers or other adaptive elements. These difficulties mount in the alternative reverse mode, a discrete analog of adjoints in function space. It yields gradients at essentially the same cost as the underlying scalar valued functions and is therefore very attractive for large-scale optimization. Here, nondifferentiabilities which frequently arise in advanced PDE solvers may cause problems, and techniques need to be developed for avoiding storage of full evaluation trajectories, especially on discretizations of instationary PDEs.

Applications to Real-World and Real-Time Process Controls Problems:

A significant part of the work on PDE constrained optimization was driven by the optimal control of fluids. While big advances for open loop control were made with the techniques described in the previous section, many challenges, including control of fluids with high Reynolds numbers, control of specific dynamical behavior, like enhancement of vortices or of mixing, remain to be addressed. The control of fluids interacting with their environment will remain a serious challenge for some time. Other applications areas are:

1. *engineering optimal design for car and aerospace industry and others,*
2. *option pricing in finance.*

Engineering optimal design for car and aerospace industry: Numerical flow simulation is an integral part of the construction process of commercial aircrafts. Due to the advance of computing power and improvements in the efficiency of simulation algorithms, it is nowadays conceivable to design parts of aircrafts or even whole aircrafts on the computer only. Therefore, numerical shape optimization will play a strategic role for future aircraft design and for the respective industry.

Current limitations of numerical optimization methods in this field are mainly due to the high complexity of numerical flow models, resulting in long computation times in the order of weeks and months if a standard optimization algorithm is coupled with a flow solver. To exploit the domain specific experience and expertise invested in these simulation tools one can think of extending them in a semi-automated fashion by the use of algorithmic differentiation. First they should be augmented with an adjoint solver to obtain (reduced) derivatives and then this sensitivity information could be immediately used to determine optimization corrections. This motivates the development of mathematical methods, algorithmic techniques and software tools for the transition from simulation to optimization applied to complex aircraft design.

Additionally, the computation time, typically, even depends on the shape parameterization. That leads again to questions of highly efficient optimization algorithms. Moreover, the optimal representation of shapes on the computer is principally open, resulting in questions of parameterizations and local design refinements. Both questions are of fundamental concern for aerodynamic shape design and, of course, are interacting.

After all, one is interested in real multi-disciplinary optimizations (MDO). Imaginable problems are, e.g., the drag reduction of an airplane while taking into account static wing deformations, and the additional goals of low noise and low radar signature. Here, the use of single disciplinary optimizations applied in sequence is not only inefficient but has also been shown to lead to wrong, non-optimal designs in some cases. Therefore, multi-disciplinary design optimization strategies are necessary in order to reach physically meaningful optimum designs.

Option pricing in finance: Applications of optimization and partial differential equations to mathematical finance, banking and risk management are well known. But nowadays the reign of analytical solutions and simplified models is over and banks, back-offices and insurance companies need all the power of modern numerical methods to solve their multidimensional PDEs derived from the stochastic models by the Ito calculus. Option pricing of baskets for instance requires sophisticated research tools such as sparse grids, wavelets and preconditioned iterative linear system solvers.

Calibration of models is another important application of optimization to finance, because no model is perfect and even the latest one such as Heston's requires in practice an adjustment of the volatility surface or other parameters by least squares and regularization techniques.

Finally, portfolio management requires the computation of Pareto optima, something that is not yet well understood in the context of PDEs. Therefore, financial mathematics is a great application field for new tolols in both optimization theory and partial differential equations.

This component of the OPTPDE proposal complements ongoing research in the AMaMeF project.

Expected Benefit from European Collaboration in this Area:

The proposed project has two main overall goals:

1. The creation and reinforcement of relationships among European research teams in the fields of PDE constrained optimization and its applications with the purpose of undertaking and carrying out highly innovative interdisciplinary and interactive research in applied and computational mathematics and its applications to various areas of scientific, economic and daily life.
2. The cultivation and maintenance of strong and mutually reinforcing links with industrial and public processes and projects in a broad sense, including a further enhancement of the impact and influence of mathematical research on important science-supported enterprises.

In Europe, there are well respected research groups, acknowledged centers of excellence with a variety of wealth of expertise in a multitude of different domains, which have come together to this proposal scheme of collaboration. Every group's contribution to the preparation has been unique and precious. The presence of 17 countries, of research groups that include and are inspired by many of the leading international experts in their fields, displays and offers the opportunity within the scope of our proposal for (a) a very significant accentuation in the overall level and visibility of European research, and (b) an effective and scientific response and way forward towards addressing various innovative process optimization and control challenges in Europe and elsewhere in the world.

European Context:

In Europe the number of young researchers entering the field of optimal control with PDE constraints is quite impressive. The number of topics which are addressed has broadened significantly over the last decade. Solution competence which was traditionally strong in analysis is now enriched considerably by numerical methodologies and by joining forces with strong groups in scientific computing. Some of these activities are supported on a national scale. We are not aware of funding on the international level. Two recent Oberwolfach Conferences focused on optimization with PDE constraints: "Numerical Techniques for Optimization

Problems with PDE Constraints; February 06" and "Optimal Control of Coupled Systems of PDEs, April 05". At large international conferences minisymposia on selected topics regarding optimization in the context of PDEs have become standard, e.g., at the European Conferences on Numerical Mathematics (ENUMATH) and at conferences organized by the US-based Society for Industrial and Applied Mathematics (SIAM). Furthermore, there was "The European Conference on Computational Optimization 2004" ("EUCCO 2004") in Dresden The "EUCCO 2007" will take place in Montpellier and will have a similar focus. In industry, in particular in the automotive and aerospace industry as well as in the chemical industry, there is an increasing demand for efficient and reliable algorithmic tools for large-scale PDE constrained optimization problems. Although many researchers within this proposal already interact with industry, this project will set an appropriate frame for a more intensive cooperation on a broader European perspective. In big companies, in the airline and the automobile industry, and also steel production companies, the demand in these fields is certainly increasing.

Programme Work Plan:

- **Workshops** will be organized on the specific topics;
- *Places:* Germany, Spain and Turkey,
- **General Conferences** will be organized, taking place in the first, third and fifth years of the Programme. Cofounding from public and private institutions are expected.
- The programme will organize **3 Summer Schools** on PDE constrained optimization.
- About 40 weeks/year of **short visits** and 30 months/year of exchange grants to establish closer collaboration across the involved partners by emphasizing the multi-disciplinary interactions.
- A **Web Site** with an open access preprint server, conference and job announcements, all relevant information and useful links will be activitated with the start of the programme.
- A **periodic Newsletter** of the Programme will be published and put on the Web Site.
- The **Steering Committee** will meet once per year, generally in connection with a conference or workshop.

Envisaged Programme Duration and Budget:

The duration of the programme will be of **5 years** for a total budget of **486 KEuro.** The requested budget will cover the following operational features (in KEuro):

a) Workshops, Conferences, Schools (including Steering Committee meetings): **210**;
b) Grants: **230**;
c) Web site and Newsletter administration (30% of average salary): **32**;
d) General Programme Brochure: **2**;
e) External administrative costs: **12**

Budget Estimate (in 1000 €) by Type of Activities and per Year of the Programme:

	2008	2009	2010	2011	2012	Total
Workshops, Conferences, Summer schools	30	60	40	40	40	210
Grants	30	50	50	50	50	230
Web site and Newsletter administration	8	6	6	6	6	32
Program Brochure	2	-	-	-	-	2
External Administrative costs	3	3	3	3	3	12
Total	113	109	109	109	109	486

Full Coordinates and Curriculum Vitae of the Applicants:

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Short vitae: Ronald H.W. Hoppe has a dual affiliation as a full professor of Mathematics at the University of Augsburg (since 1995) and at the University of

Houston (since 2002). Previously he was affiliated with the Munich University of Technology, the University of Linköping in Sweden, the Konrad Zuse Institute in Berlin, and the Berlin University of Technology. He is currently leading several research projects on PDE constrained optimization in Germany and in the US. He is editor-in-chief of the Journal of Numerical Mathematics and serves on the editorial board of other journals. He has (co-) authored more than 110 papers and (co-) edited 4 books.

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Short vitae: Karl Kunisch was full professor of Mathematics at Technical University Berlin between 1993-1996. Since 1996 he is full professor of Mathematics at the University of Graz. He was visiting professor at several universities in the USA and in France. He is the leader of the research group “Optimization and Control” at the Radon Institute, Austrian Academy of Sciences, since 2004. He received the 2006 SIAM outstanding paper prize and is member of the editorial boards of SIAM Journal on Optimization and Control, RAIRO, Mathematical Modelling and Numerical Analysis. He (co-)authored over 200 papers.

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Short vitae: Olivier Pironneau is Professeur classe exceptionnelle at Universite Pierre et Marie Curie (Paris VI), member of the French Academy of Sciences and of the Institut Universitaire de France. He received in 1983 the prize Blaise Pascal of the Academie des Sciences, in 2001 the prize Marcel-Dassault of the Academie des Sciences. He is also recipient of the Ordre National du Merite. He (co-)authored more than 300 articles and 8 books.

The List of the Five Most Recent Relevant Publications of Each Applicant

Ronald H.W. Hoppe

R.H.W. Hoppe, C. Linsenmann, and S.I. Petrova, Primal-dual Newton methods in structural optimization, Comp. Visual. Sci., 9, 71-87, 2006

R.H.W. Hoppe, Y. Iliash, C. Iyyunni, and N. Sweilam, A posteriori error estimates for adaptive finite element discretizations of boundary control problems, J. Numer. Math., 14, 57-82, 2006

R.H.W. Hoppe and S.I. Petrova, Shape optimization of biomorphic ceramics with microstructures by homogenization modeling, In: Multiscale Problems (A. Mielke; ed.), pp. 395-424, Springer, Berlin-Heidelberg-New York, 2006

C. Carstensen and R.H.W. Hoppe, Error reduction and convergence for an adaptive mixed finite element method, Math. Comp., 75, 1033-1042, 2006

R.H.W. Hoppe and S. Petrova, Primal-dual Newton interior point methods in shape and topology optimization, Num. Lin. Alg. Appl., 11, 413-429, 2004

Karl Kunisch

H. Hintermuller, K. Ito, K, Kunisch, The primal-dual active set strategy as a semi-smooth Newton method, SIAM Journal on Optimization, 13 (2002), 865-888.

A. Borzi, K. Kunisch, and D.Y. Kwak, Accuracy and convergence properties of the finite difference multigrid solution of an optimal control optimality system, SIAM J. on Control and Optimization, 41 (2003), 1477-1497.

M. Hintermüller, K. Kunisch, Path-following methods for a class of constrained minimization problems in function space, to appear in SIAM J. on Optimization.

K. Ito, K. Kunisch, Parabolic variational inequalities: The Langrange multiplier approach, Journal de Math. Pures et Appl., 85 (2006), 415-449.

K. Ito, K. Kunisch, Optimal Bilinear Control of an Abstract Schrödinger Equation, to appear in SIAM Journal on Control and Optimization.

Olivier Pironneau
O. Pironneau: Dupire-Like Identities for the Calibration of Complex Options.
Submitted to Compte Rendu de l'Academie des Sciences (2006).

Y. Achdou and O. Pironneau: Computational Methods for Option Pricing. SIAM series in Applied Math, Philadelphia 2005.

R. L. Sani, J. Shen, O. Pironneau, P. M. Gresho: Pressure boundary condition for the time-dependent incompressible Navier-Stokes equations International Journal for Numerical Methods in Fluids Volume 50, Issue 6, Date: 28 February 2006, Pages: 673-682.

B. Mohammadi, O. Pironneau: Optimal shape Design for Fluids. Annual Rev. Fluids Mechanics 2004, 36: 255-279.

S. Delpino and O. Pironneau: Asymptotic Analysis and Layer Decomposition for the Couplex Exercise. Computational Geosciences Alain Bourgeat and Michel Kern, ed.. Vol 8. No 2. pp 149-162. Kluwer Academics Publishers (2004).

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International Dimension:

PDE constrained optimization is a research area that is actively pursued internationally. Many recent and upcoming international conferences such as the 6th SIAM Conference on Control and its Applications (2005, New Orleans, USA), the 8th SIAM Conference on Optimization (2005, Stockholm Sweden), the 12th Conference on Mathematics of Finite Elements and Applications (MAFELAP) (London, UK, 2006), the 19th International Symposium on Mathematical Programming (2006, Rio de Janeiro, Brazil), the SIAM Conference on Computational Science and Engineering (2007, Costa Mesa, USA) feature(d) plenary talks and/or a large number of minisymposia in the area of PDE constrained optimization. In addition to the PDE constrained optimization activities at large international conferences, there were several recent, focused, international conferences/ workshops in the area of PDE constrained optimization, including conferences at the Mathematics Research Institute Oberwolfach, Germany, workshops organized by Sandia National Laboratories, USA, and a workshop organized by the Centro Internacional de Matematica, Portgual. These activities are evidence of the growing international interest in and international importance of PDE constrained optimization. In addition, as indicated by the titles of the conferences mentioned above, international researchers from a number of diverse mathematical disciplines, such as optimization and control theory, numerical solution of PDEs, scientific computing, as well as researchers from a broad range of application areas contribute towards the development of efficient solution methods for this important class of problems. The existing research activities present an ideal foundation for the proposed scientific programme on Optimization with PDE Constraints. Currently, there are only international collaborations between individual research groups. A broad international scientific programme in this area leverages the existing national research efforts. Additionally, it will enable close collaborations between many international research groups with complementary research expertise and, thus, will allow the participants to tackle problems that are out of reach otherwise.

Below is the list of researcher who will collaborate from the US with those in Europe.

R.E. Bank (Department of Mathematics, Univ. of California at San Diego), L. Biegler (Department of Chemical Engineering, Carnegie-Mellon Univ.), G. Biros (Mechanical Engineering and Applied Mechanics, University of Pennsylvania), B. van Bloemen-Waanders (Sandia National Laboratories), J. Burns (Interdisciplinary Center for Applied Mathematics, Virginia Tech.), J. E. Dennis (Department of Computational and Applied Mathematics, Rice University), O. Ghattas (Center for Computational

Geosciences, Institute for Computational Engineering and Sciences, University of Texas at Austin), M. Gunzburger (School of Computational Science, Florida State Univ.), R. Glowinski (Department of Mathematics, University of Houston), M. Heinkenschloss (Department of Computational and Applied Mathematics, Rice University), K. Ito (Department of Mathematics, Center for Research in Scientific Computation, North Carolina State University), T. Kelley (Department of Mathematics, Center for Research in Scientific Computation, North Carolina State University

Collaboration with USA partners will be coordinated by

Matthias Heinkenschloss: Department of Computational and Applied Mathematics, Mail Stop 134, Rice University, Houston, Texas, 77005-1892, USA, Phone: +1-713-348-5176, Fax +1-713-348-5318, E-mail: heinken@rice.edu

Short vitae: Matthias Heinkenschloss joined Rice University in 1996, where he is now full professor of Computational and Applied Mathematics. Previously he held positions at Virginia Polytechnic Institute and State University, Virginia, USA, and Universität Trier, Germany. He has co-organized a number of conferences and workshops on PDE Constrained Optimization and related areas. He serves on the editorial boards of Sytems & Control Letters and Mathematical Programming; he served on the editorial boards of SIAM J. Control and Optimization and SIAM Reviews. He (co-)authored over 40 papers.

Five Most Recent Relevant Publications

M. Heinkenschloss, H. Nguyen, Neumann-Neumann Domain Decomposition Preconditioners for Linear-Quadratic Elliptic Optimal Control Problems. SIAM J. Sci. Comput., 28 (2006), 1001-1028.

M. Heinkenschloss, Time-Domain Decomposition Iterative Methods for the Solution of Distributed Linear Quadratic Optimal Control Problems, Journal of Computational and Applied Mathematics, 173 (2005), 169-198.

M. Heinkenschloss, F. Abraham, M. Behr, the Effect of Stabilization in Finite Element Methods for the Optimal Boundary Control of the Oseen Equations. Finite Elements in Analysis and Design, 41 (2004), 229-251.

M. Heinkenschloss, S.S. Collis, K. Ghayour, M. Ulbrich, S. Ulbrich, Optimal Control of Unsteady Compressible Viscous Flows. International Journal for Numerical Methods in Fluids, 40 (2002), 1401-1429.

M. Heinkenschloss, L.N. Vicente, Analysis of Inexact Trust-Region SQP Algorithms. SIAM J. Optimization, 12 (2001), 283-302