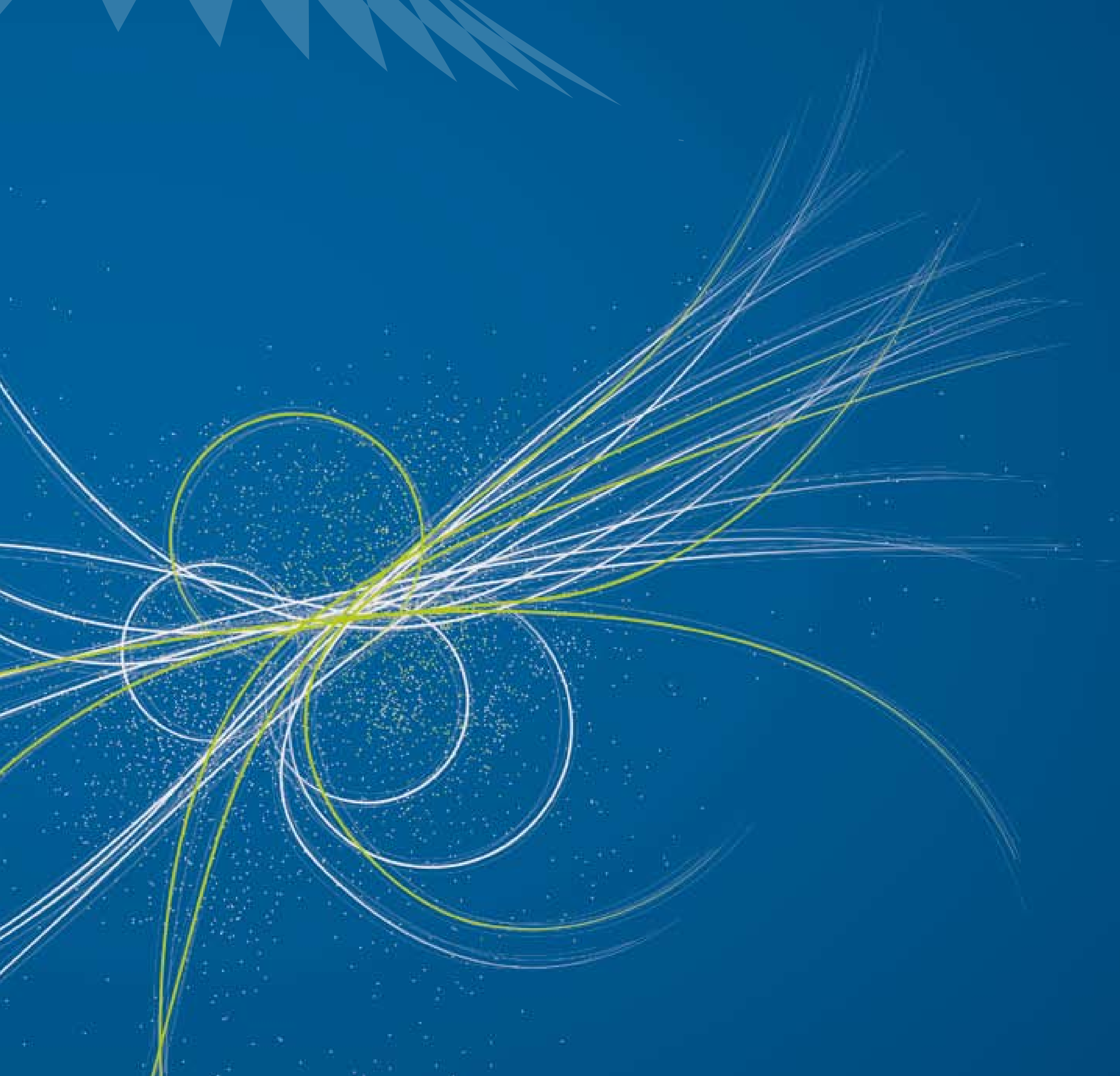
Annual Report

TUM Institute for Advanced Study

2009



IAS TUM Institute for Advanced Study

Annual Report

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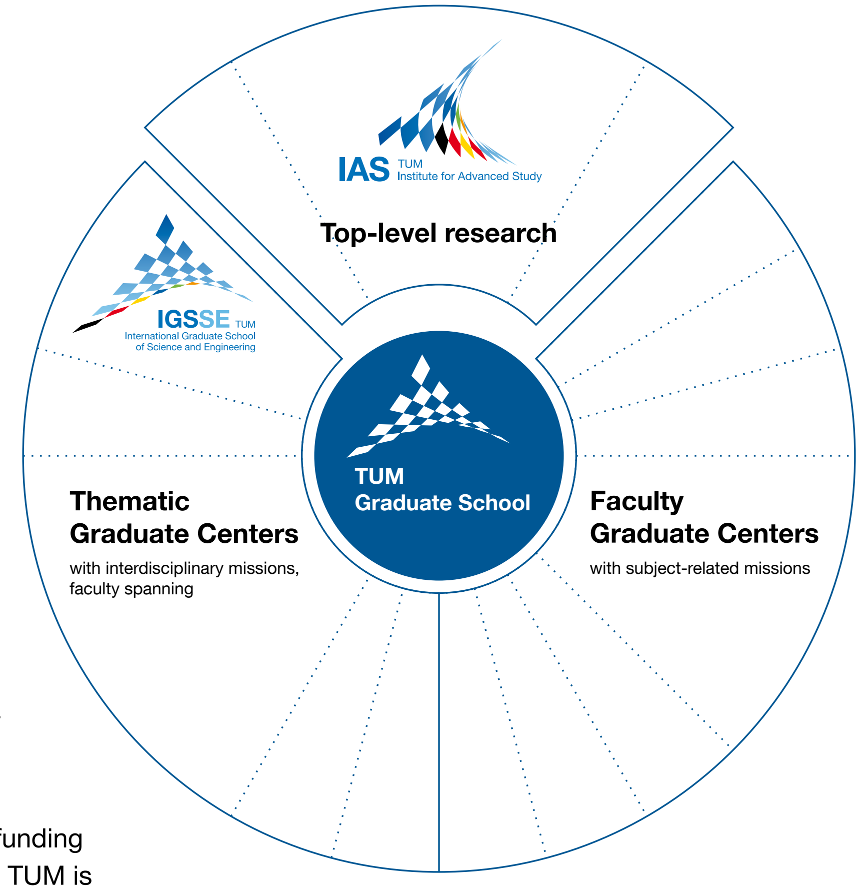
Foreword of TUM President

When I came to office as President of TUM in 1995, I was eager to cultivate an atmosphere in this university that is most conducive to freedom, speculation, and creativity. Thanks to the TUM community's performance-oriented, international mindset, many efforts and initiatives have been realized during the past few years to reach this goal. The idea of a TUM Institute for Advanced Study was central in this context, and three years into the Excellence Initiative I am pleased to see that the idea of the TUM-IAS on paper has become a living institute full of dynamic Fellows pursuing top-level research, working out new ideas, and designing new instrumentation. As a matter of fact, TUM's principles of scientific competition and intellectual dialogue culminate in the new Institute. To show this, we have positioned the new TUM-IAS building right in the center of the Garching campus. As one of our TUM Alliance of Excellence partners, the BMW Group has given concrete reality to the idea of advanced study by donating the new building (EUR 10 million).

Unlike many Institutes for Advanced Study, the TUM-IAS is truly integrated into the university and plays a key role in its strategic development. At the same time, the TUM-IAS is greatly strengthened by being embedded in the university. Thanks to this symbiosis, the Institute is able to offer the variety of laboratory spaces and efficient access to research groups that are available through TUM. It is to be noted that the TUM-IAS includes top-level researchers from industry and from the full range of engineering fields.

2009 has been a year of significant structural changes at TUM. I particularly note the charter of the new TUM Graduate School, which is based on the model of our International Graduate School of Science and Engineering (IGSSE). Over the past three years, IGSSE has developed a comprehensive graduate school program involving multidisciplinary research and training. It takes doctoral candidates beyond the traditionally isolated research experience with a professor or research group, exposing them to multidisciplinarity, international collaboration, and special skills. The Graduate School is building on the IGSSE program to offer an official framework for doctoral candidates at TUM.



The TUM-IAS also plays an important role in the newly created Graduate School at TUM. Young scientists have a unique opportunity to collaborate with the top researchers of the Institute by getting involved with TUM-IAS Focus Groups. Top research cannot move forward without the creative energy of the next generation; the close integration of Fellows and Graduate School support takes care of this issue and gives the doctoral candidates a better chance of making an impact at the start of their scientific careers.

The first round of the Excellence Initiative funding will end in October 2012. In the meantime, TUM is busy crafting the new proposal, which will feature plans for new Clusters and Graduate Schools as well as plans to strengthen and solidify the Institute for Advanced Study. I am very optimistic that the university is well positioned for the ever-increasing level of international competition. In the upcoming Excellence Initiative review process, the TUM-IAS will help to show how TUM has carried out its strategic plans. The new proposal will not only highlight the superb research being conducted by internationally renowned scientists at TUM, or closely associated with us, but also the positive impact the Institute has on the whole university.

I wish the Fellows and the staff of TUM-IAS all the best in creating an excellent Institute that is driven by an open, critical scientific dialogue and embodies, more truly every day, the vision of a free and creative university.

Wolfgang A. Herrmann
President

Risking Creativity

is the formula that maybe best describes what the TUM Institute for Advanced Study stands for. To open up pathways where no one has gone before and there by create new fields of scientific endeavor is the primary goal of our Institute. It is also the single most important criterion we want to be judged on. Risk and creativity, both together, should form the rod that will measure our performance.

Risking creativity is also the recipe for producing scientific excellence. It's not the count of publications or citations that defines excellence, but the choice of the scientific problem and the insight in how to solve it. A new vision and the will to realize it are the key elements. Together with our Advisory Council, we select our Fellows based partly on their track record and partly on their vision, and then try to support their move into the future as well as we can, by giving them time, freedom from bureaucratic worries, and facilities. TUM-IAS has awarded 16 new fellowships in 2009. In the section "Presentation of New Fellows and their Research Plans," the new Institute members introduce themselves and their statement of purpose.

To be sure, the main theme of our Institute is technology, understood as "the science of creating and manufacturing technical things." However, we do not exclude pure natural science, so long as it is firmly established in TUM. Just as "risking creativity" needs a balance between vision and effectiveness, technology and science need each other. We understand more of nature because we have better instruments, and we get better instruments as our knowledge of nature's phenomena deepens. Even in the purest of all scientific endeavors, particle physics, instrumentation and engineering play a determining role. In our Institute we do strive for a careful balance between science and engineering, but we see this as a process that evolves from the work and insights of our Fellows and their Hosts.

Our Fellows, with their ideas and energy, are our greatest asset. However, we are also aware that "freedom to explore" has a tendency to annihilate itself. Once you launch a new idea, the full weight of the hard work and dedication needed comes down on your shoulders. Our Institute therefore has a number of measures to support its Fellows in their often arduous quest to realize their ideas. One is the provision of stipends for doctoral candidates and postdoctoral researchers. Another is our investment program in what we call "Start-up Funding," available for Fellows, their hosting groups, and even TUM research groups engaging in the exploration of new Research Areas. One area in which we have strongly invested has been the devel opment of new types of scientific instruments, allowing us to "see more and see better." All these programs are amply documented further on in this Annual Report. In 2009, we made great strides toward improving visibility in the sub-micron range, developing haptics in the micron range, and visualizing the behavior of atoms and molecules on interfaces.

The connection with applicability and industry is often considered a tricky point for an Institute engaging in top-level research. TUM-IAS deals with this question in a variety of ways, but the most important one is the institution of Rudolf Diesel Industry Fellowships. In 2009, we awarded three such fellowships to top-level

researchers in industry who have established a close collaboration with TUM laboratories. Their commitment to "risking creativity" was at least as strong as that of our Fellows from academia. Some application domains turn out to be inexhaustible sources of challenging scientific problems. Let me mention Smart Energy Systems, Geo Engineering, Medical Instrumentation, Man-Machine Interaction, and Electromobility. Technological research is often characterized by a manyfaceted approach to problem solving. Our very first Rudolf Diesel Industry Fellow, Khaled Karrai, combines many such facets (instrumentation, nanoscience, and application engineering) in one person, thereby influencing and motivating several research groups at TUM and elsewhere. In our section "Industry Cooperation," you can read more about this topic.

True to their goals, our Fellows have been engaging enthusiastically in the exploration of new topics. This they did mostly through the organization of exploratory workshops, as described in a later section of this report. In 2009 we co-organized many of those, the most pro minent being the International Workshop on the Impact of Control, which brought the world's absolute top people in the area together in Berchtesgaden and produced an impressive map of the future in System Science. (See the contribution of our Hans Fischer Senior Fellow Anuradha Annaswamy, who was the main force behind the workshop.) We believe this branch of science has not received the attention it deserves. Just think of how badly systems like worldwide climate change or distributed energy systems are understood, or consider our grasp of the stochastics of economic processes.

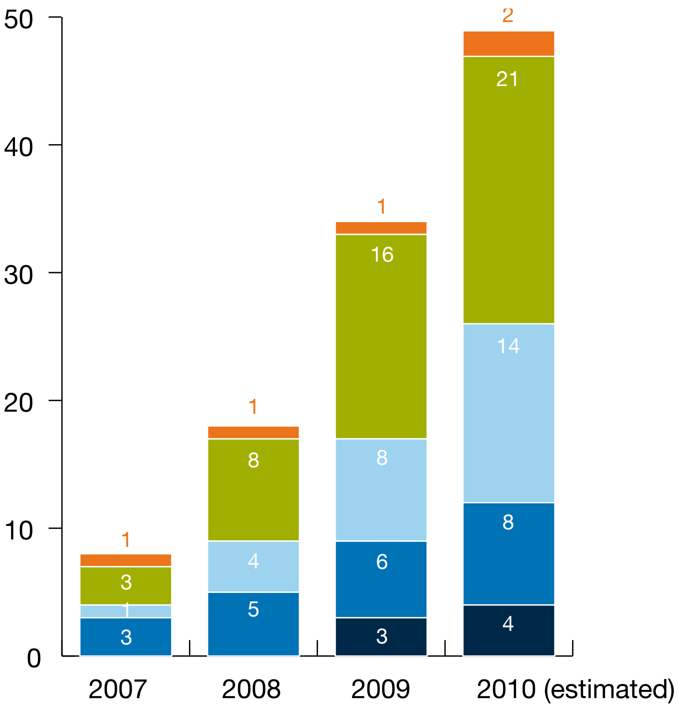
We can safely say that our Institute has been flourishing in 2009. Although it is young on the scene, we can already document impressive highlights and main achievements; a section is devoted to them in this report. However, all this has been possible not only thanks to the manifold talents of our Fellows, but also to the dedication of our staff, who have been bringing it all together. Markus Zanner has been coordinating finances to accommodate the very diverse needs of our Fellows and providing support for their activities. Margaret Jaeger has become our Associate Managing Director and has been running the TUM-IAS office with humor and gusto. Stefanie Hofmann and Margaret Jaeger have taken care of the selection process for new Fellows and the daily assistance of all our Fellows, their Hosts, and their students. In particular they saw to it that our new guest house in Schwabing got well furnished and would provide a happy environment for our guests. Sigrid Wagner has been organizing the large collection of events taking place under the aegis of the Institute, including the monthly Fellows' Lunches, the meetings and workshops, and our very successful General Assembly. All this needed a lot of secretarial support, expertly and joyfully provided by Rebecca Innerhofer. Also the close collaboration with the central staff of the Excellence Initiative should be mentioned, in particular Melanie Hüttinger and the staff of IGSSE, with whom we have a very close and fruitful collaboration. We also appreciate the services of TUM-ForTe and the TUM Corporate Communications Center. A warm word of thanks goes to Patrick Regan of TUM-CCC, who did the final editing of this report. Last but certainly not least, TUM-IAS has profited very much from the enthusiastic support of the TUM community, the EHL, the Deans of the Faculties, many Professors and their staff. Risking creativity, like launching a space probe, requires a special mission team and large bursts of energy!

Patrick Dewilde
Director

TUM-IAS in a Nutshell

The TUM-IAS has awarded 16 new fellowships in 2009, among them 3 Rudolf Diesel Industry Fellows, 1 Carl von Linde Senior Fellow, 4 Carl von Linde Junior Fellows, and 8 Hans Fischer Senior Fellows. The TUM-IAS Fellows come from diverse disciplines and from 12 different countries.

Total Number of TUM-IAS Fellows



Hans Fischer Tenure Track

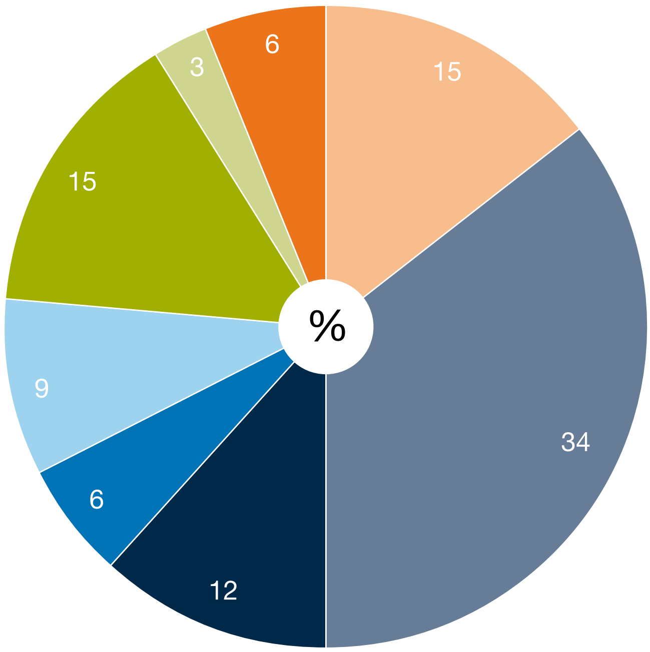
Hans Fischer Senior Fellow

Carl von Linde Junior Fellow

Carl von Linde Senior Fellow

Rudolf Diesel Industry Fellow

Distribution According to Faculties



Informatics

Chemistry

Medicine

Mathematics

Mechanical Engineering

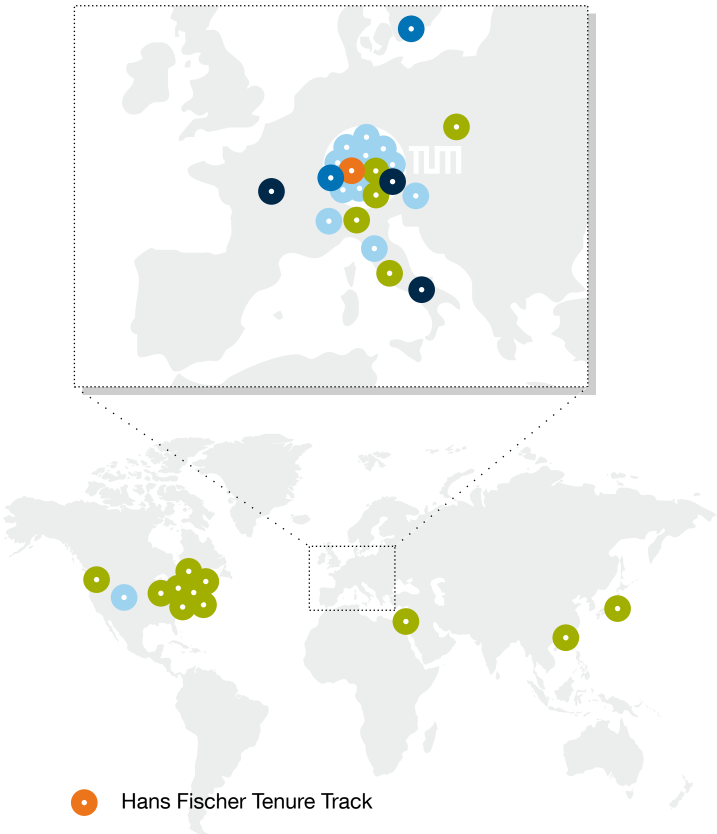
Civil Engineering

Physics

Electrical Engineering

Support for the TUM-IAS Fellows includes funding doctoral candidates and postdocs, who collaborate closely with them.

Where do the TUM-IAS Fellows come from?



- Hans Fischer Tenure Track
- Hans Fischer Senior Fellow
- Carl von Linde Junior Fellow
- Carl von Linde Senior Fellow
- Rudolf Diesel Industry Fellow

TUM-IAS Supported Doctoral Candidates

Focus Group: Risk Analysis and Stochastic Modeling
- Martin Moser
- Oliver Pfaffel
- Eckhard Schlemm
- Christina Steinkohl
- Florian Ueltzhöfer

Focus Group: Nanophotonics
- Matthias Firnkes
- Norman Hauke
- Markus Schuster
- Alexander Schwemer
- Thomas Zabel

Focus Group: Nanoimprint and Nanotransfer
- Edgar-Otto Albert
- Yadav Anandi
- Mario Bareiß
- Qingqing Gong
- Muhammad Imtaar

Focus Group: Nanoscale Control of Quantum Materials
- Wolfgang Krenner

Focus Group: Biophysics
- Heinrich Grabmayr

Focus Group: Molecular Aspects in Interface Science
- Selin Rüdiger

Focus Group: Cognitive Technology
- Arman Kiani
- Andreas Schmid
- Harald Voit
- Bernhard Weber

Focus Group: Fundamental Physics
- Emmanuel Stamos

Start-up Funding: Prof. Florian Holzapfel
- Sebastian Klose
- Jian Wang

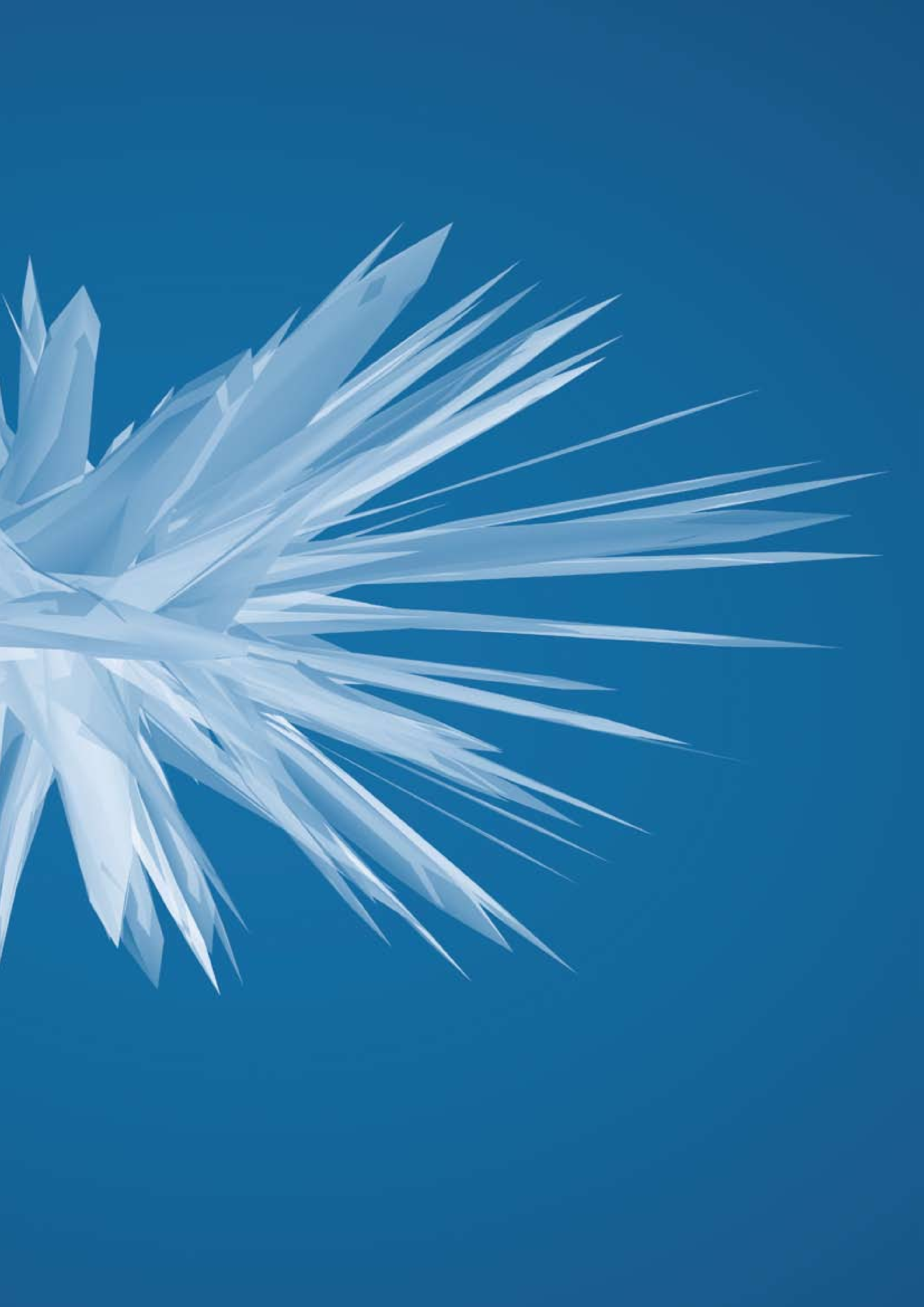
TUM-IAS Supported Postdocs

Focus Group: Clinical Cell Processing and Purification
- Dr. Stefan Dreher

Focus Group: Functional Nanosystems
- Dr. Marin Steenackers

Focus Group: Risk Analysis and Stochastic Modeling
- Dr. Codina Cotar

Focus Group: Fundamental Physics
- Dr. Joachim Brod



Presentation of new Fellows and their Research Plans

Advanced Computation

Computational Biology

Cognitive Technology

Risk Analysis and Stochastic Modeling

Biomedical Engineering

Computational Biomechanics

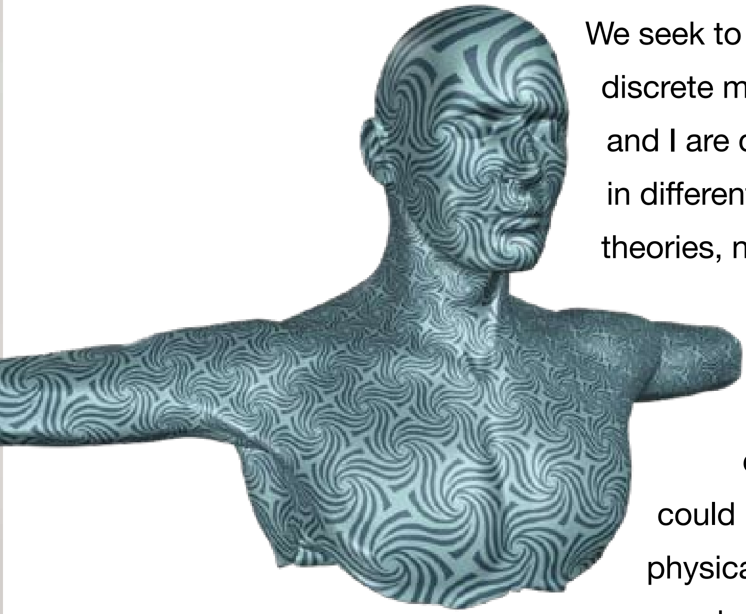
Nanoscience

Fundamental Physics

Focus Group **Advanced Computation**

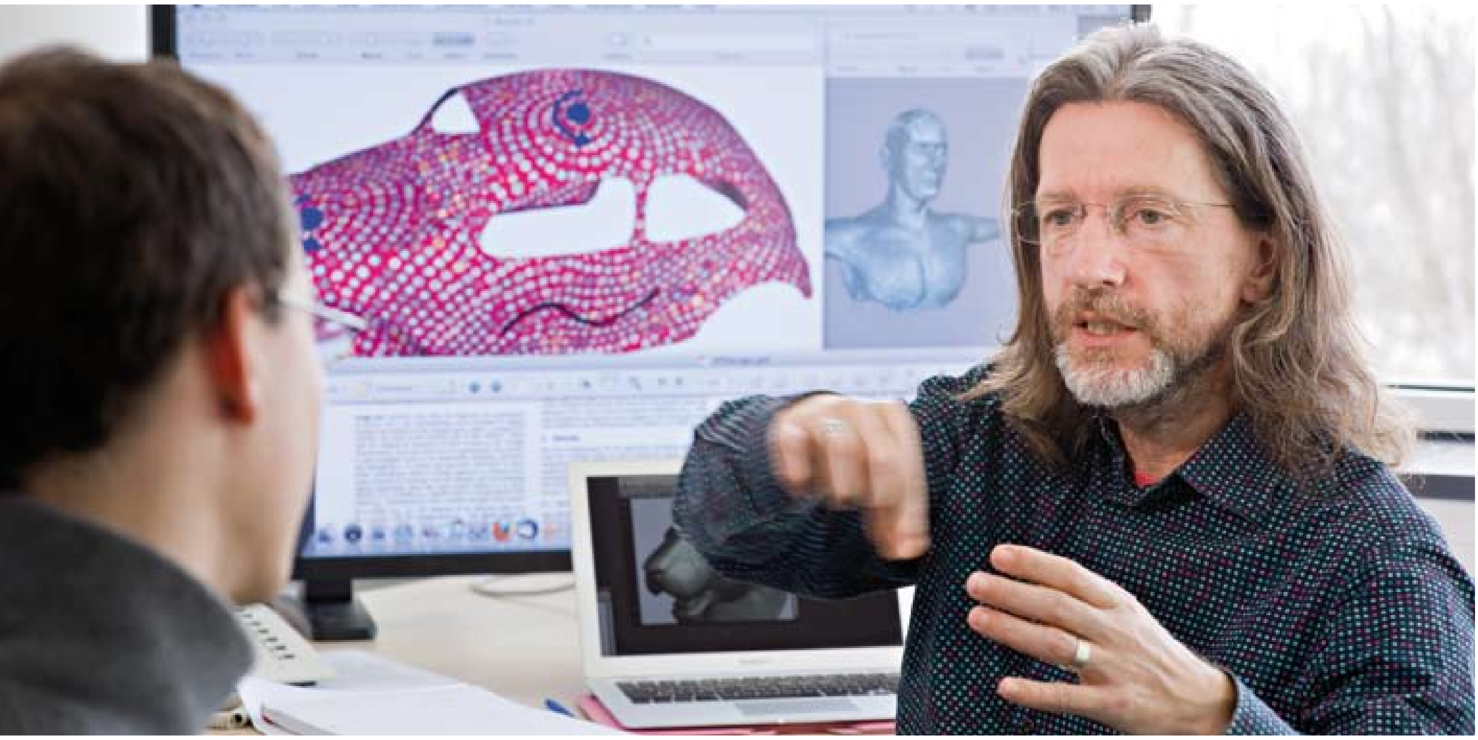
Prof. Peter Schröder | Hans Fischer Senior Fellow
Host: Prof. Rüdiger Westermann, Computer Graphics and Visualization, TUM

Research in Discrete Differential Geometry
Theoretical exploration that could lead to new tools

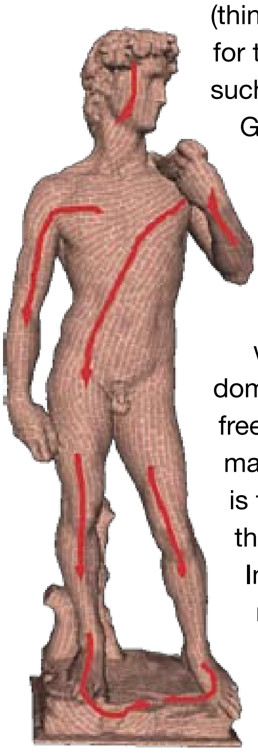


We seek to extend both theoretical and practical aspects of discrete mathematics into new domains. My collaborators and I are developing a discrete theory for classical concepts in differential geometry with the aim of "discretizing" entire theories, not just equations. These theories should mimic the classical notions as far as possible and certainly recover them in the limit, but at the same time yield useful results at a finite level of discretization. Theoretical advances in this direction could make it more practical to compute solutions to physical modeling problems, delivering more robust and accurate simulations with predictive power. This in turn could endow the software tools that product designers, architects, animators, and other professionals rely on with new capabilities.

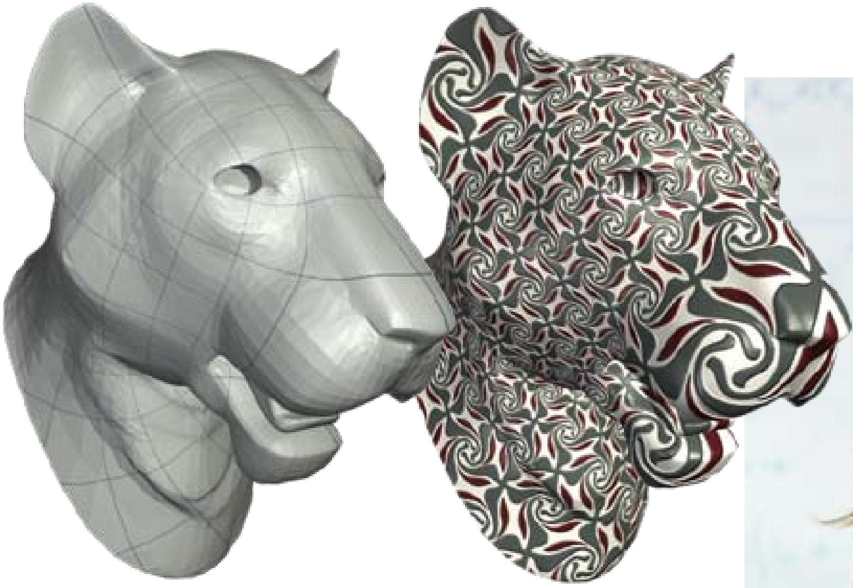
This program is very broad, and the particular subject matter I am pursuing while in Munich is greatly influenced by the opportunities presented in the context of the local research groups. I am already engaged with local researchers in mathematics (Prof. Tim Hoffmann) and computer science (Prof. Daniel Cremers and Prof. Rüdiger Westermann), and I anticipate studying problems in discrete differential geometry with others I have yet to meet.

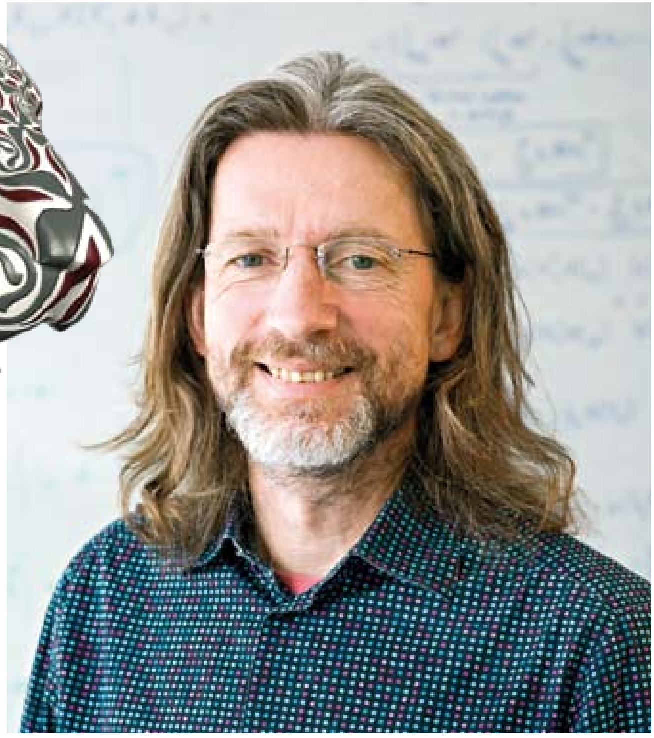


One project concerns theory and practical algorithms for the construction of piecewise planar structures (think: glass and steel in architectural form) for the approximation of free-form surfaces, such as the Munich Olympia Stadium roof. Given some desired smooth surface, how can it be approximated with planar quadrilaterals? The requirement that the corners of every facet must lie in a plane constrains the motion of individual vertices in very complex ways. What are the right degrees of freedom to present to users, to give them the freedom to design the desired shape while maintaining the planarity constraint? What is the appropriate representation "under the hood" to maintain these constraints? In this project, work from classical geometry of lines and planes meets human interface and computational machinery from computer science to produce practical solutions.



In another aspect of my research I am considering discrete models of elasticity based on classical differential geometry concepts that yield geometrically nonlinear low-order models, which can be implemented very efficiently. Re-interpreting classical notions from mechanics in the context of differential geometry yields insights that facilitate faster algorithms, and more robust computations. During my stay in Munich we've already been able to describe a discrete variational integrator that maintains important invariants while being only slightly more complex than standard linear models. The challenge now is to extend these models to thin shell equations without losing the computational advantages we have so far.





Another project just starting up concerns the use of L1 approximation as a relaxation for L0 approximation, in the context of sparsification of physical models as they appear in incompressible flow (vorticity driven simulation) as well as in geometry processing tasks (optimal placement of cone singularities).
A main challenge in this work is to find optimization algorithms that can deal with large systems (tens of thousands of variables are a minimum). Much of the recent work in optimization that attacks these kinds of problems cannot, by a wide margin, scale up to such problem sizes at this time. Fresh computational approaches and, so I hope, deeper geometric insights, are needed.

Peter Schröder
is a Professor of Computer Science and Applied and Computational Mathematics at the California Institute of Technology, where he began his academic career in 1995. Prior to Caltech and a short stint as a Postdoctoral Research Fellow at Interval Corporation (summer 1995), he was a Postdoctoral Research Fellow at the University of South Carolina Department of Mathematics and a Lecturer in the Computer Science Department. He received his Ph.D. in computer science from Princeton University in 1994. Prior to Princeton he was a member of the technical staff at Thinking Machines, where he worked on graphics algorithms for massively parallel computers.

Focus Group **Computational Biology**

Prof. Burkhard Rost | Alexander von Humboldt Professor

Probing evolutionary information for biomedical insights

Prof. Burkhard Rost

Our research is driven by a conviction that protein and DNA sequences encode a significant core of information about the ultimate structure and function of genetic material and its gene products.

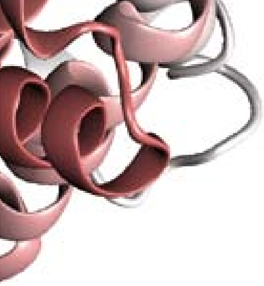
Research goals of the lab involve using protein and DNA sequences along with evolutionary information to predict aspects of protein structure and function. Another significant research focus is to improve the effectiveness and efficiency of experimental solutions in molecular and medical biology. For instance, we have actively been involved in the target selection for several large-scale structural genomics projects in the United States. Those few, focused centers have contributed the first representatives for about one-third of all structure-sequence families of experimentally known structure.

One unique aspect of our research is the combination of evolutionary information and machine learning – more generally, the particular way in which we turn data accumulated in the life sciences into methods that help medical and molecular biologists. We dedicate unusual amounts of resources to the maintenance of Internet servers that make the fruits of our research available to the biomedical community at large. These include PredictProtein (www.predictprotein.org), the first Internet server for protein structure prediction and protein sequence analysis, and one of the first four Internet servers in molecular biology (which will soon be running at the TUM).

Over the last year we have shifted our focus largely onto three main subjects. The first is the prediction of the effect of single-residue mutations (non-synonymous SNPs). Ultimately, this project aims at a better understanding – in an operational sense – of protein structure and function. An important short-term goal is to develop methods that will be essential for the development of individualized medicine.

A second focus is the prediction of “disorder” (natively unstructured regions). Traditionally, the assumption in molecular biology has been that a particular protein sequence folds into a particular protein structure and that the details of this structure are important for particular functions. Over the last decade, structural biology has been confronted by more and more examples of proteins that do not adopt regular structures at all in isolation but only when bound to substrates, or that never adopt regular structures. Those observations pose challenges for prediction methods. Our group contributed significantly to the realization that these types of regions (usually dubbed disorder) are seemingly an important development on the way from simple prokaryotic organisms to complex, multicellular eukaryotes. One of our recent results demonstrates that disorder is extremely difficult to conserve, while random sequences astonishingly have preferences for the formation of regular secondary structure (a feature of protein structure typically perceived as the opposite of disorder).

Third, we continue the development of methods that can predict protein-protein interactions from sequence alone. Ultimately, we thereby try to bridge from the micro-molecular world of atoms to the macro-molecular world of networks of interactions.



Dr. Marco Punta | Carl von Linde Junior Fellow

Prof. Burkhard Rost, Bioinformatics, TUM

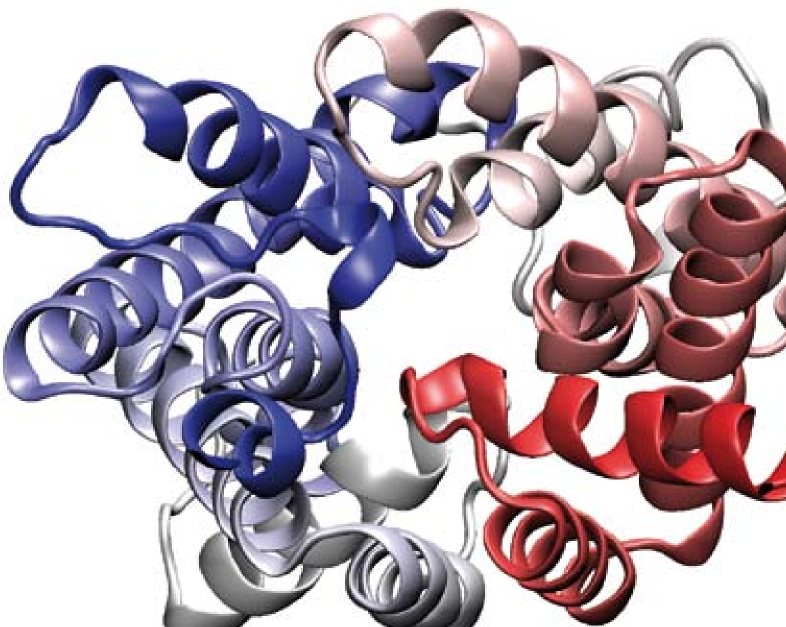
Our research plans for the near future revolve around the use of computational techniques to study integral membrane proteins (IMPs).

IMPs are estimated to constitute about one-fourth of all proteins in an average genome. Due to their localization in the membrane of cells and of cell organelles, they play a crucial role in the exchange of material and information between the different cell compartments and between the cell and the external environment. Viral membrane proteins, for example, play a pivotal role in host infection. Unfortunately, membrane localization makes IMPs extremely difficult targets for experimental studies.

With the New York Consortium on Membrane Protein Structure, we have been working to identify proteins that are more amenable to experimental analysis in the context of a high-throughput protein production pipeline. (NYCOMPS is a structural genomics consortium that has as its goal high-resolution structure determination of IMPs.) Over the last year, we developed a machine-learning-based predictor of IMP expression and purification that is currently in the test phase; if successful, it will routinely be used for target selection at NYCOMPS.

For the next year, we plan to extend data analysis to other aspects of the experimental pipeline, such as detergent optimization and crystallization, as well as to different experimental conditions. On a longer term, we would like to go beyond yes-or-no questions to why: not, for example, “Is the guanine-cytosine content of genetic material important for expression success?” but rather, “Why is GC content important for expression success?” In order to achieve this goal, it will be necessary to design feature-specific experiments that may help to shed light on strengths and limits of current experimental techniques. Finally, we will keep working in close collaboration with NYCOMPS experimental teams to elucidate sequence-structure-function relationships in proteins.

Marco Punta
received his Bachelor of Science and his Master of Science in physics (of biosystems) in1998 from the University of Rome “La Sapienza”. In 2002 he was awarded his Ph.D. degree in biophysics at the International School for Advanced Studies, Trieste, Italy. Punta joined the group of Prof. Burkhard Rost at the Department of Biochemistry and Molecular Biophysics at Columbia University, New York, USA, as Postdoctoral Researcher in that same year. Today he is an Associate Research Scientist at the Herbert Irving Cancer Center of Columbia University.

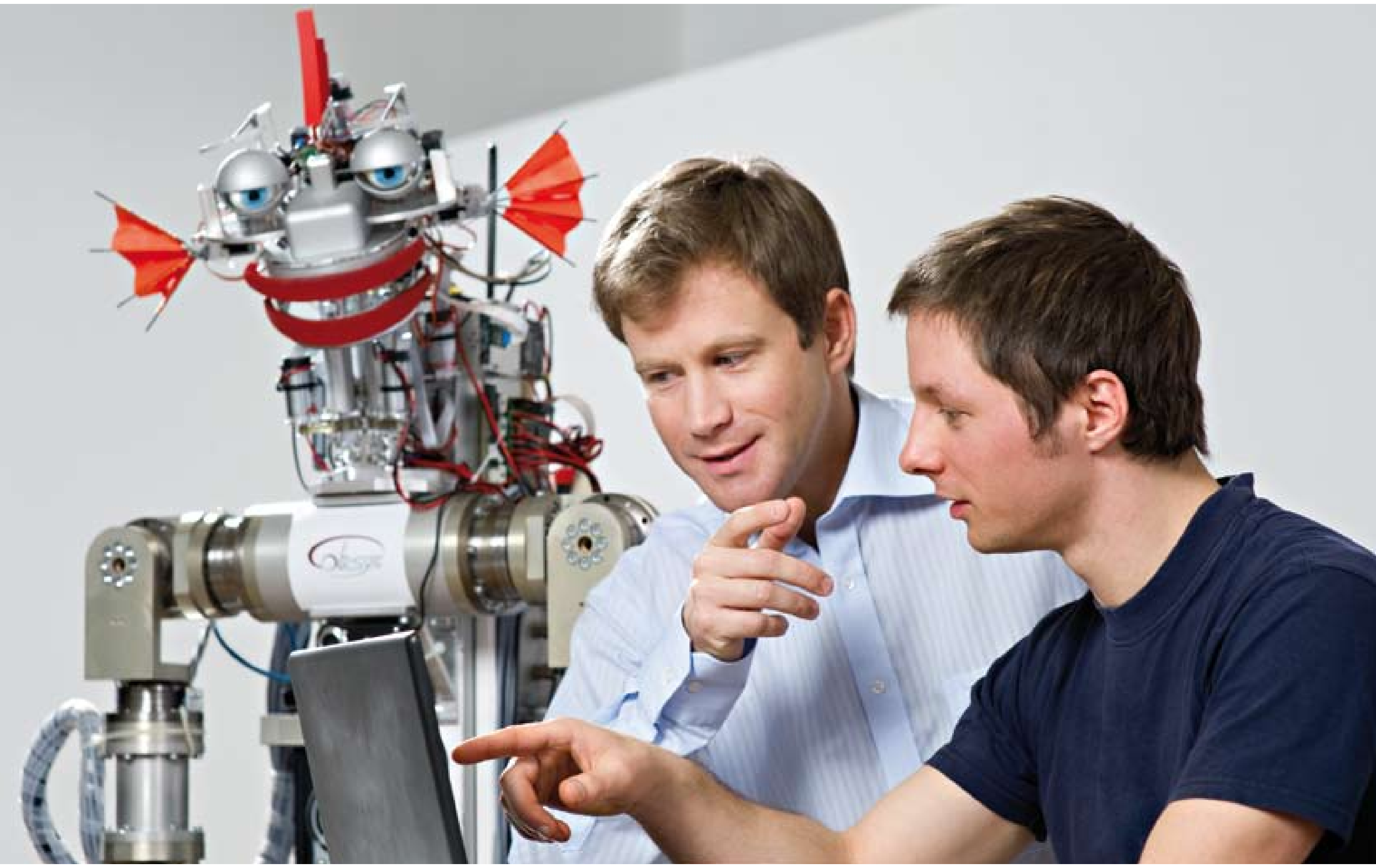


Presentation of new Fellows and their Research Plans

Focus Group **Cognitive Technology**

Dr. Kolja Kühnlenz | Carl von Linde Junior Fellow

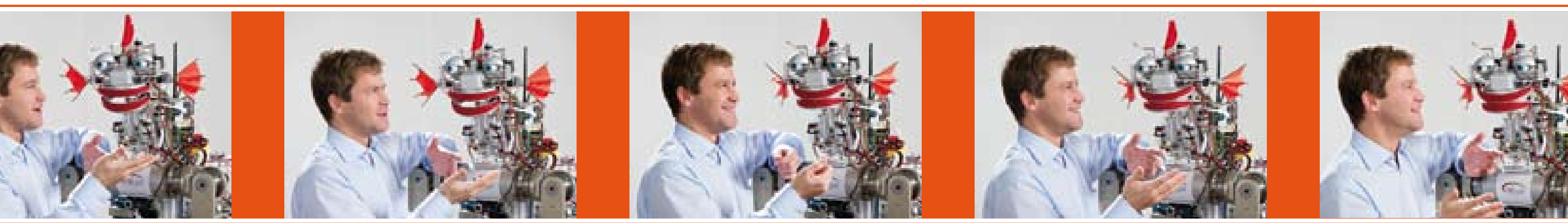
Prof. Martin Buss, Automatic Control Engineering, TUM



Equipping machines to work with people, and without supervision

We are interested in interactive robots for real-world applications with enhanced perceptual capabilities and control structures, which facilitate autonomous action and close (co-)operation in human-centered environments. For this purpose we target a broad spectrum of research on various levels, from fundamental interdisciplinary research on visual perception and human factors, to robot action planning and control strategies, as well as complex integrated systems and application scenarios.

One drawback of today's personal robots is the still strong limitation of perceptual resources. Even though the current trend goes toward multi-modality and multi-sensory coverage including vision, hearing, and haptics, workspaces shared by humans and robots are not covered sufficiently due to the small number of sensors commonly used. Consider manipulation and interaction tasks close to humans, where robot motions have to be coordinated with high accuracy and responsiveness to avoid collisions with humans and to achieve smooth interaction. In order to overcome such problems, we focus on high-speed vision-based robot control and extended compound-eye strategies inspired by our past work in the field of insect vision.
A novel concept we are currently working on is perception with skins of densely distributed vision sensors, which in future may cover complete robot manipulator



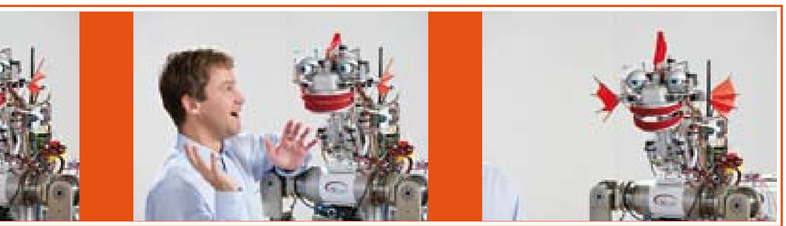
surfaces. Common haptic sensor skins for contact perception could be enhanced with visual capabilities to enable distance measurements for geometrical structures and motions, including humans, target objects, and environmental structures.

Obviously, human emotions strongly influence human action and interaction, so we believe it is crucial for tomorrow's social robots to be aware of emotional aspects in reactive and proactive behavior control. Robots will need to recognize and predict the progression of human emotional states, particularly in response to robot actions or interaction dynamics. In this context, we are pursuing emotion recognition based on observation of human motion.

A particular focus is human gait, which could provide a means for emotion recognition from distance, where common techniques like physiological data, facial expression, and speech evaluation are not applicable. Results will include objective functions for emotional motion optimization, which could also be used to equip robots for emotionally expressive motion to influence human responses during interaction.

Moreover, we target stochastic dynamic systems approaches to modeling the dynamics of human emotion, in order to provide a means for emotion estimation and prediction as well as to enable emotionally enriched action planning by robots. Potential application scenarios are manifold, including social robotics, manufacturing, cognitive automobiles, and surveillance. Our testbed for emotional interaction principles is EDDIE, the interactive robot head EDDIE we developed, which is now a central part within the CoTeSys Central Robotics Lab.

We consider it also important to carry laboratory research to real-world applications, in particular, in order to learn about the implications of robot interaction with novice users in everyday life. In the Autonomous City Explorer (ACE) project – see www.ace-robot.de – we worked with Dr. Dirk Wollherr's group to develop a



robot that managed to travel all the way from the TUM main campus to the city center of Munich while interacting with pedestrians and asking them for directions. This was a pilot approach to study the feasibility of having personal robots extend their knowledge through interaction with humans. This project now continues on the European level in the FP7 project IURO, see www.iuro-project.eu.

Kolja Kühnlenz
is currently a Senior Research Scientist and Lecturer at the Institute of Automatic Control Engineering, Faculty of Electrical Engineering and Information Technology, TUM, and Director of the Dynamic Vision Research Laboratory. He is also the leader of an Independent Junior Research Group within the Munich Cluster of Excellence "Cognition for Technical Systems - CoTeSys" and Principal Investigator within the Bernstein Center of Computational Neuroscience Munich. He received a Doctor of Engineering degree in electrical engineering in 2007 from TUM.

Dr. Dragan Obradovic | Rudolf Diesel Industry Fellow
Prof. Sandra Hirche, Automatic Control Engineering, TUM

Applying networked control systems in automation systems and in power grids

Networked Control Systems (NCS) are decision-making and control systems whose elements do not share the same information and, hence, have to communicate with each other, typically over shared communication networks. Our research addresses open issues in the analysis and design of NCS:

- How to reduce the impact of communication on the dynamics of the control system. Here we focus on wired Ethernet communication, where the stochastic nature of Ethernet leads to random delays of control messages. In order to circumvent this problem, we look at the Industrial Ethernet, where a deterministic scheduling of the control messages is achieved through synchronization of all communication network elements. We will show that the clock synchronization according to the IEEE 1588 standard is itself a tracking control problem, and we will study appropriate estimation and optimal control algorithms.

- How to address power grid decision-making and control problems within the NCS framework. The grid is a network itself, with a variety of control agents and strong physical coupling due to the Kirchhoff laws. We will focus on power grids with a high percentage of renewable sources, which are intrinsically stochastic due to the uncertainty in availability of solar and wind energy. At the same time, these grids have to satisfy relatively stringent constraints – on voltage levels, for example, and on the power balance between produced and consumed power. This work will address the optimal control of such grids at different levels of detail:

  - **Optimal decision making in the steady state.** Here we will define and solve the typical problem of optimal power dispatch under constraints. We will investigate what amount of information is necessary at each node to produce a distributed (local) solution that is close to a global solution where the optimization is done centrally. In addition, different constraints on the information transmission – such as the connectivity (graph topology) and the pricing of different information sources – will be considered. The steady-state solution implies that obtained system states can be achieved rapidly enough by the underlying control mechanisms.

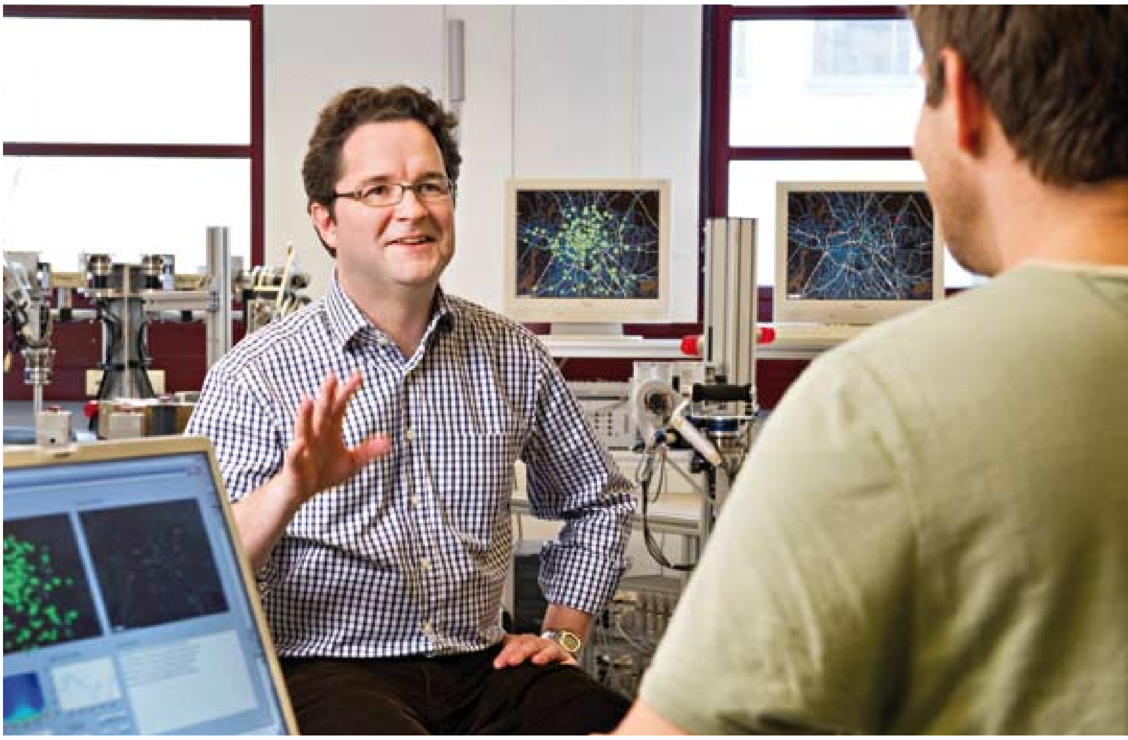
  - **Optimal distributed control with dynamics.** We will implement the optimal set points from the above optimization in a dynamic model of the grid and investigate what influence different transmission delays have on network stability and performance. We will consider the use of the Industrial Ethernet type of communication in power grids.

Solving these two steps is a prerequisite for a further advance – moving on to the case of a power grid seen and treated as a hierarchical system. This would shed light on networked control of a power grid when the sources might actually be other grids the current grid is connected to, or a wind farm that has its own dispatch and control problems.

Dragan Obradovic
received his Ph.D. degree in mechanical engineering from the Massachusetts Institute of Technology in 1990. After finishing his Ph.D., he stayed at MIT until the end of 1991 in the position of Postdoctoral Fellow at the Laboratory for Information and Decision Systems (LIDS). Since 1992, Obradovic has been with Siemens Corporate Technology, Information and Communications, in Munich, where he currently holds the position of Principal Research Scientist. In addition, since 2001 Obradovic has been teaching as an Industrial Lecturer in the international "Masters of Science in Communication Engineering (MSCE)" program within the EE Department at TUM.

Dr. Georg von Wichert | Rudolf Diesel Industry Fellow
Prof. Martin Buss, Automatic Control Engineering, TUM

Toward cognitive systems for the autonomous management of complex technical plants and processes



In virtually every technical system one can find humans assuming responsibility for supervision and control tasks. Examples can be found across all sectors of industry ranging from classical factory automation and process industries to power generation and distribution, and all the way to traffic control and city management.

The large technical plants and processes behind these applications typically consist of some thousand subsystems, each having its own individual process dynamics and local control system. Their operation, however, will be complexly correlated via the overall plant control system. It is obvious that the joint state space of the combined plant dynamics is huge and can hardly be handled in detail. Current automation systems therefore typically have a restricted, local scope focusing only on partitions of the plant or process. The global state of such a system, however, cannot be assessed by looking at the individual subsystems alone.

The main contribution of the human operator in the plant control room is that he or she has a true understanding of the overall process, the plant structure, and the major cause-and-effect chains across the numerous subsystems. This enables the operator to assess the plant's state at a somewhat abstracted level, without the need to know in detail the precise value of each of the thousands and thousands of signals in which the plant renders its state to the external world. This type of knowledge is not available to today's automation systems, so technical systems continue to need human supervision.

On the other hand, it is obvious from many human failures resulting in disasters, such as the Transrapid incident in 2006, that operators are sometimes highly overextended by the complexity of the systems they control. This especially holds true in extremely dynamic situations and has led to disasters such as the nuclear incident in Chernobyl.

Therefore the objective is to lay the foundations for cognitive systems at least supporting, but ultimately replacing, the human operators of complex technical plants. Such systems need to understand the state and dynamics of complex technical processes. They need higher-level situational understanding and assessment capabilities, as well as models and strategies for actively controlling plant operations on all levels.

To handle complex real-world problems, it is necessary to formulate the required models on different levels of abstraction. Obviously the abstraction as well as all kinds of real-world effects will introduce significant uncertainty into the reasoning procedures of our systems. To explicitly deal with these uncertainties, we adopt a probabilistic approach and focus on methods allowing us to declaratively formulate the structure of complex hybrid, dynamic domains.

Humans analyzing the state of complex systems would typically start with an approximate global overview of the situation and then, based on their understanding of the system, direct the diagnostic activity toward selected phenomena observed in the available data. This approach is closely related to the procedures underlying active perception. Working along a coarse-to-fine-grained strategy will – in addition to planning its perception-related activity – require the system to purposefully switch and translate between the model structures used to represent, integrate, and fuse the available information. In our research we implement such “active thought processes,” which traverse the various levels of abstraction.

Georg von Wichert
received his Diploma (M.Sc.) in electrical and control engineering from Darmstadt University of Technology in 1992. From 1992 to 1998 he was a Research and Teaching Assistant at the Institute of Control Engineering at Darmstadt University of Technology. In Darmstadt he also received a Ph.D. degree in electrical engineering in 1998. Since 1998, he has been with Siemens Corporate Research and Technologies, where he currently holds the position of Program Manager in the Intelligent Autonomous Systems Department. He was involved in several national and European research activities in research and managing functions.

Focus Group **Risk Analysis and Stochastic Modeling**

Prof. Richard Davis | Hans Fischer Senior Fellow
Prof. Claudia Klüppelberg, Mathematical Statistics, TUM

Richard Davis
received his Ph.D. degree in mathematics in 1979 from the University of California at San Diego, where he studied under the direction of Professor Murray Rosenblatt. He spent two years, 1979-1981, as an Instructor in Applied Mathematics at the Massachusetts Institute of Technology (MIT) before joining Colorado State University (CSU) as an Assistant Professor in Statistics. From 1990 he was Professor at the Department of Statistics at CSU. After spending 26 years at CSU, Davis joined the Statistics Department at Columbia University in 2007. He also acts as the Co-director of Program for Interdisciplinary Mathematics, Ecology and Statistics (PRIMES), an NSF IGERT funded project at CSU.

To harness the power of the wind, capture it in theoretical models

I visited the Risk Analysis group in the summer of 2009, when one of my doctoral candidates from Columbia University, Chun Yip Yau, spent a month working with the Chair of Mathematical Statistics. I interacted with a number of students, from diploma to Ph.D., on various research projects. We will highlight two of these interactions.

Enzo Ferranzzano, a doctoral candidate in the statistics program at TUM, has been working on the analysis of high-frequency wind speed data. According to theory, the sample paths of these data should follow those produced by either a semi-martingale or a semi-martingale with jumps. Prof. Ole Barndorff-Nielsen and Prof. Jean Jacod (two frequent collaborators with the Risk Analysis group) suggested looking a statistic called the p-lagged bipower, which should provide insight for discriminating between the two types of models. Unfortunately, this statistic was not behaving as the theory predicted. Part of the deviation from the predicted theory could be explained by the presence of measurement noise. The concept of measurement noise can often be viewed as an umbrella to cover a range of issues with the data. For example, if the data have been coarsely discretized or the level of precision is insufficient to accommodate such high-frequency measurements, then this is often manifested as measurement error. As Enzo explores these ideas more deeply, we are developing models that can help explain some interesting and subtle features found in the data. Some of this activity involved Chun Yip and ultimately provided an excellent learning and collaborative research experience for both students and their advisors.

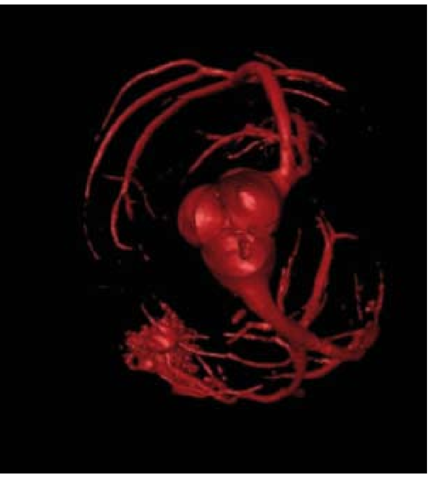
Christina Steinkohl completed her diploma thesis, “Analysis of Multivariate High Frequency Wind Speed Data using Time Series Methods and Techniques from Extreme Value Theory”, in November of 2009 and is now pursuing a Ph.D. under the direction of Professors Klüppelberg and Davis, with support from TUM-IAS. Christina’s diploma thesis arose out of a wind modeling project supported by General Electric. The ultimate goal is to study wind characteristics, specifically maximum wind speeds, in order to design and control wind turbines to withstand extreme wind events. Since GE designs and builds turbines for placement in wind farms, it is important to consider the impact of extreme winds over an entire field. In Christina’s diploma thesis, she integrated ideas from finance, volatility modeling, and co-integration to formulate new wind speed models. While the data were restricted primarily to a single site, we hope to extend these notions into a space-time framework during her Ph.D. studies.

We also hope to build on research initiated with Yau dealing with modeling spatial extremes. The basic idea is to use a suitable rescaling of space for a Gaussian random field that allows one to get interesting classes of max-stable random fields in a limiting sense. The goal is then to develop a full modeling toolbox for these models, including methods for model identification, parameter estimation, and interpolation.

Presentation of new Fellows and their Research Plans

Focus Group **Biomedical Engineering**

Prof. Axel Haase | Carl von Linde Senior Fellow
Prof. Markus Schwaiger, Nuclear Medicine, TUM



1 | 3D MR image of the coronary arteries of a mouse *in vivo* measured in a MRI magnet of a magnetic field strength of 7 T.

Challenging the temporal and spatial limits of magnetic resonance imaging

I have been working for more than three decades for the progress of magnetic resonance imaging in many biomedical applications from cells to plants, laboratory animals, and patients. Success in this research field depends on an excellent and permanent cooperation of scientists in chemistry, physics, engineering, and medicine. The TUM-IAS is a perfect place where these disciplines come together, and I am fascinated to contribute to this institution.

Magnetic resonance imaging (MRI) is one of the most important diagnostic modalities in clinical practice. It is non-invasive, and no harmful side effects have been described. The reason for this fact is that MRI uses energies up to nine orders of magnitude lower than other imaging techniques, such as X-rays or radioisotopes. Unfortunately the MRI signal is weaker by the same factor, and increasing the signal is a quite challenging technological task. It is important to note that each step forward in signal enhancement gives new possibilities for applications in basic biological sciences and clinical diagnosis. We have seen this in many areas during the last years.

The first invention where I contributed was a much more efficient use of the signal by a method called FLASH (Fast Low Angle Shot) MRI, which reduced the measuring time of a single image from several minutes to a few seconds. For the first time, the beating heart and other moving organs within the body could be observed in detail, showing even 3D images of the coronary arteries (see figure 1). Today FLASH and other fast MRI methods allow researchers and physicians to evaluate the function of organs like the brain. About a decade ago, a few research teams demonstrated that multiple MR array coils – which acquire the signal in parallel – can further reduce the measuring time and improve the spatial resolution. We have built several versions of these “phased-array MR coils” (see figures 2).

Our project at the TUM-IAS will be to develop this idea further and to construct an array of more than a hun dred coils. It is evident that this experiment has risks (we are not sure at the moment if it works!). Here we really need the interaction of physicists, engineers, and scientists from informatics, modeling, and medicine.

2 | 8-channel phased-array MRI coil for human brain studies at a magnetic field strength of 7 T.

MR tomogram of a head of a volunteer measured at 7 T using an 8-channel phased-array coil.

Another possibility is to enhance the MRI signal by increasing the magnetization of the nuclei under inves tigation, so called magnetic hyperpolarization. Under certain experimental conditions it is possible to do this for 13C-labeled substances by a factor of 10,000. The substances can be injected into the blood stream of laboratory animals, and even clinical applications are not far away. The substances are metabolized in the organs and can be observed, in a short time interval, for several minutes. These experiments are currently under way in a cooperative project with the Clinic for Nuclear Medicine (Prof. Markus Schwaiger), the Chemistry Department (Prof. Steffen Glaser), an industrial partner, General Electric Research Institute at the Garching Campus, and my own group at TUM-IAS.

My fellowship at the TUM-IAS gives me an excellent opportunity working together with the other Fellows, Profs. Kessler, Kucharczyk, Nüsslin and my Host Prof. Schwaiger. The mission of TUM-IAS is that the Fellows should be integrated into the TUM environment. I am a visible example that this works: Coming from the university of Würzburg a few weeks ago, I was appointed Director of the TUM Institute of Medical Technology (IMETUM), a center where sciences, engineering, and medicine come together to develop the next generation of technologies in clinical diagnosis and treatment for the benefit of the patients.

Axel Haase
holds the Chair of Biophysics and was President at the University of Würzburg between 2003 and 2009. Since October 2009 he was delegated to TUM and became Carl von Linde Senior Fellow at TUM-IAS. Since 1980, he has worked in the field of magnetic resonance imaging technology and its biomedical applications, first at the Department of Biochemistry of the University of Oxford, later at the Biomedical NMR Group of the Max-Planck-Institute for Biophysical Chemistry in Göttingen, and, since 1989, at the University of Würzburg.

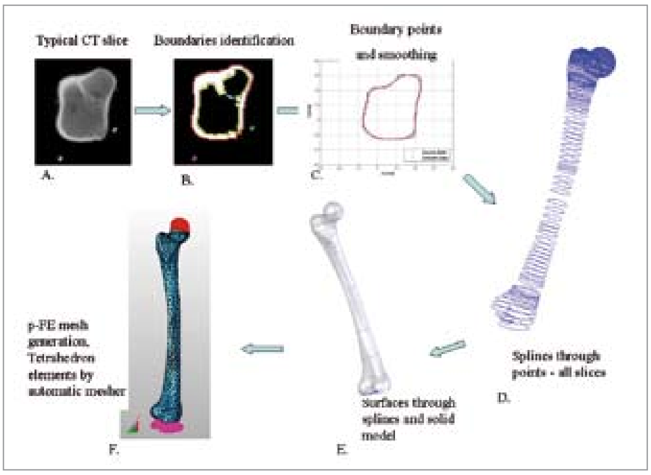
Focus Group **Computational Biomechanics**

Prof. Zohar Yosibash | Hans Fischer Senior Fellow
Prof. Ernst Rank, Computation in Engineering, TUM)

Virtual bones to help real patients, and their doctors

Bone simulations by finite element methods have been performed for more than 25 years; however, these have had very little impact on clinical practice.

At the same time, new technological methods and advanced computational mechanics algorithms have emerged which, in conjunction with experimental procedures, allow a change of paradigm: We strive to generate a Computer Aided Patient Specific Orthopedic (CAPSO) simulation tool to be used on a daily basis by clinicians. Bone's precise geometry and internal cortical/trabecular surface (see figure 1), as well as the anisotropic and inhomogeneous material properties, can be estimated nowadays by quantitative computerized tomography (qCT) scans. The patientspecific data is manipulated by new and promising high-order finite element/cell methods developed in the group of TUM Prof. Ernst Rank, which provide means to estimate and control the numerical errors and process the simulations in fractions of a second. This is a necessary requirement for "what if" experiments in optimization of surgical procedures.



1 | The steps for generating the high-order-FE model: From CT scans through boundary recognition; approximated smooth sur face; solid body and finally meshed model with two different mesh regions.

These simulations should be validated by a well designed set of experiments on fresh-frozen human femurs to demonstrate their accuracy and assure their applicability (see figure 2).

In this context we intend to investigate several topics:

- Femur's mechanical response under a complex physiological loading state

2 | Experiment and high-order-FE analysis of a human femur with displacements prediction.

- Fracture prediction capabilities for healthy and osteoporosis-affected bone by high-order multi-scale finite-element/finite-cell interaction
- Optimization procedures for total hip replacement (THR) surgery
- Quantification of bone material and geometrical uncertainties by generalized polynomial chaos methods.

Due to their multiscale and/or stochastic nature, the simulations are computationally intensive and therefore require scientific expertise and hardware availability for high-performance computing, and thus would need to be closely embedded in the research activities of MAC, the newly created Munich Center for Advanced Computing.

We hope the new capabilities will provide orthopedic doctors with a comprehensive understanding of the patient-specific pathological situation and enable an optimal treatment, which is unavailable at the moment.

Our aim is to give doctors a new tool that can be used on a daily basis for predicting risk of fractures due to osteoporosis, metastasic or benign lesions, and fatigue and for optimizing fixture procedures for THR and trauma.

Zohar Yosibash
is a Professor of Mechanical Engineering at the Ben-Gurion University of the Negev, Beer-Sheva, Israel (since 1995) and the Head of the Computational Mechanics Laboratory. He received his D.Sc. in mechanical engineering in 1994 from Washington University in St. Louis Missouri, USA. Zohar spent a year as a visiting Assistant Professor at the Department of Mechanical Engineering at Washington University during 1994-1995, and a year as a visiting Associate Professor at the Division of Applied Mathematics at Brown University in Providence, Rhode Island, USA, during 2002-2003. During 2003-2007 he held a visiting associate professorship at Brown University. Since March 2006 he serves as a member of the Advisory Board of the Bavarian Graduate School of Computational Engineerin

Presentation of new Fellows and their Research Plans

Research Area **Nanoscience**

Focus Group **Molecular Aspects in Interface Science**

Dr. Julia Kunze | Carl von Linde Junior Fellow
Prof. Ulrich Stimming, Interfaces and Energy Conversion, TUM

Electrochemistry research in energy conversion and storage - from fundamentals to nanotechnology application

Our research focuses on interface science, where we investigate the properties of two adjacent condensed phases.

Such properties are important in materials science, energy conversion and storage, catalysis and electrocatalysis, and for medical applications. In all these areas, nanostructures play a crucial role. We fabricate nanostructured surfaces and characterize them in terms of their catalytic activity and their use in the respective applications. Prof. Ulrich Stimming's group has found that the variation of the physical parameters for a given catalyst system had more influence on the catalytic activity than the variation of the chemical composition. This new bottom-up approach, relying on a separation of the physical parameters, is used to study innovative and promising catalyst systems. We employ scanning probe microscopy, electrochemical techniques, and surface analysis tools such as X-ray induced photoelectron and infrared spectroscopy for detailed investigations of the systems. Especially scanning electrochemical potential microscopy (SECPM), which is a powerful scanning probe technique, is applied. This technique images the potential distribution of large organic molecules with nanometer-scale resolution and can provide information on the local pH.

Currently my group is investigating three specific topics:

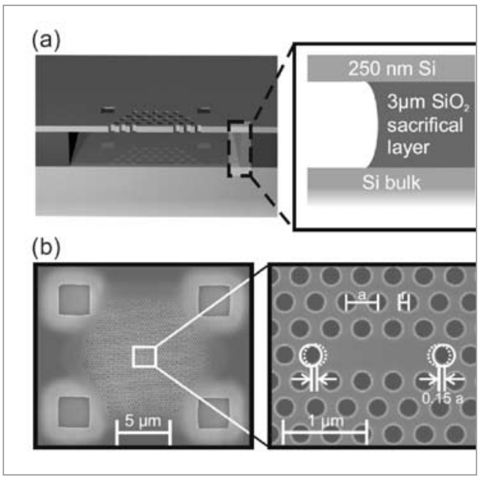
- **Novel material systems for electrocatalysis**
  In previous studies, we used a high-temperature treatment in acetylene that converts the semiconducting anatase or rutile phases of TiO_2 into carbon-rich Magnéli-type phases (TiO_xC_y) that show semi-metallic conductivity. This makes the material suitable for use in high-throughput electrodes. Currently, we use conductive TiO_xC_y as support material for catalyst nanoparticles. This novel system is particularly interesting because it was found that catalytically inactive material, such as gold supported on titania, shows high activities for carbon monoxide (CO) oxidation.

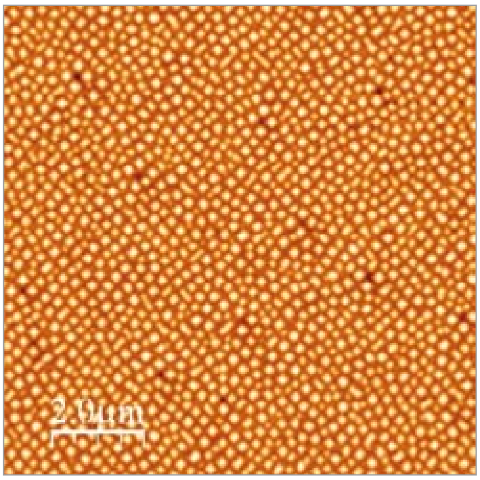
- **Study of biological molecules for electrocatalysis**
  This project deals with the investigation of the local reactivity of redox enzymes, immobilized on nanostructured model surfaces. Redox enzymes are proteins that catalyze charge-transfer reactions and play a crucial role in cellular metabolism. Major driving forces for electrochemical studies of redox enzymes include the development of biosensors, bioelectronics, and bioelectrochemical fuel cells, since redox enzymes often function faster, more efficiently, and more selectively than noble metal catalysts. In a multistep approach, we will investigate for the first time the electron transfer between enzyme and electrode, as well as the electrocatalytic activity of different redox enzymes immobilized on model electrode surfaces. In this project, we are collaborating with Prof. Jacek Lipkowski from the University of Guelph in Canada and with Prof. Nathaniel Cady from the College of Nanoscale Science & Engineering in the USA.

- **Self-assembled anodic titania nanotubes – Fundamentals and Application**
  Self-organized formation of TiO_2 nanotubes on titanium can be induced by a simple electrochemical anodization technique. Using in-situ scanning electrochemical potential microscopy (SECPM), the influence of the oxide film structure on self-organized nanotube growth will be elucidated. The nanotubes can be made conductive to be used as support material for catalyst nanoparticles. Another highly interesting application of the conductive nanotubes is the use as binder-free anode material in lithium batteries. The group will start doing research in the field of rechargeable lithium batteries in close collaboration with the Fraunhofer Institute for Chemical Technology and Applied Electrochemistry in Pfinztal, Germany, which can provide promising new electrolyte materials, such as gels filled with ionic liquids.

Julia Kunze
was awarded her Ph.D. degree at Heinrich Heine Universität Düsseldorf (HHU) in 2002 and was for a short time a Post-Doctorate associate at the Institute for Physical Chemistry and Electrochemistry at HHU. From 2003 to 2005 she continued as a Post-Doctorate associate at the Department of Chemistry and Biochemistry at the University of Guelph, Canada. Julia was a Habilitand (to qualify as a professor) in the Department of Materials Science at Friedrich-Alexander Universität Erlangen-Nürnberg from 2005 to 2009. She became a Senior Scientist at the Technical University of Munich (TUM) in May 2009 in the group of Prof. Ulrich Stimming, Physics Department (E19), Interfaces and Energy Conversion, for the continuation of her habilitation and further steps towards a professorship.

Prof. Yasuhiko Arakawa | Hans Fischer Senior Fellow
Prof. Gerhard Abstreiter, Experimental Semiconductor Physics, TUM





Light emitting devices based on silicon and germanium

Group members
Prof. Yasuhiko Arakawa, Univ. of Tokyo (Hans Fischer Senior Fellow)
Prof. Gerhard Abstreiter, WSI, TUM (Host and Carl von Linde Senior Fellow)
Prof. Jonathan J. Finley, Physics Department, TUM
Dr. Dominique Bougeard, WSI, TUM (group leader, SiGe MBE)
Norman Hauke (TUM-IAS doctoral candidate)
Thomas Zabel (TUM-IAS doctoral candidate)

The overall aim of the project is to develop efficient monolithic light sources on a silicon chip. Efficient light sources and other optoelectronic devices are needed on Si for future development of CMOS technology. The internal quantum efficiency of the devices will be enhanced by combining quantum size effects with cavity-QED phenomena in tailored photonic materials. This nanophotonic approach has already been shown to be highly effective for III-V semiconductors, where ultralow-threshold lasers have been realized, but has been hitherto relatively unexplored in silicon.

The project started in spring 2009, and the first interesting results have been achieved already, based on enhanced photoluminescence emission from novel two-dimensional silicon photonic crystal nanocavities. We have observed light emission up to room temperature from the cavity mode of the photonic crystal structure fabricated with e-beam lithography and selective etching on so-called SOI (silicon on insulator) wafers (see figure 1). One publication has been submitted on this subject so far. In addition the MBE (molecular beam epitaxy) growth of Ge islands on Si and SOI has been optimized (see figure 2), and such quantum dots have been embedded as active emitters in two-dimensional SOI photonic crystal nanocavities.

Yasuhiko Arakawa received his Ph.D. degree in electrical engineering from the University of Tokyo in 1980. He began his academic career by joining the University of Tokyo as an Assistant Professor. From 1993 he worked as a Full Professor at the University of Tokyo. Today, Arakawa is Professor of the Research Center for Advanced Science and Technology and Director of the Institute for Nano Quantum Information Electronics at the University of Tokyo.

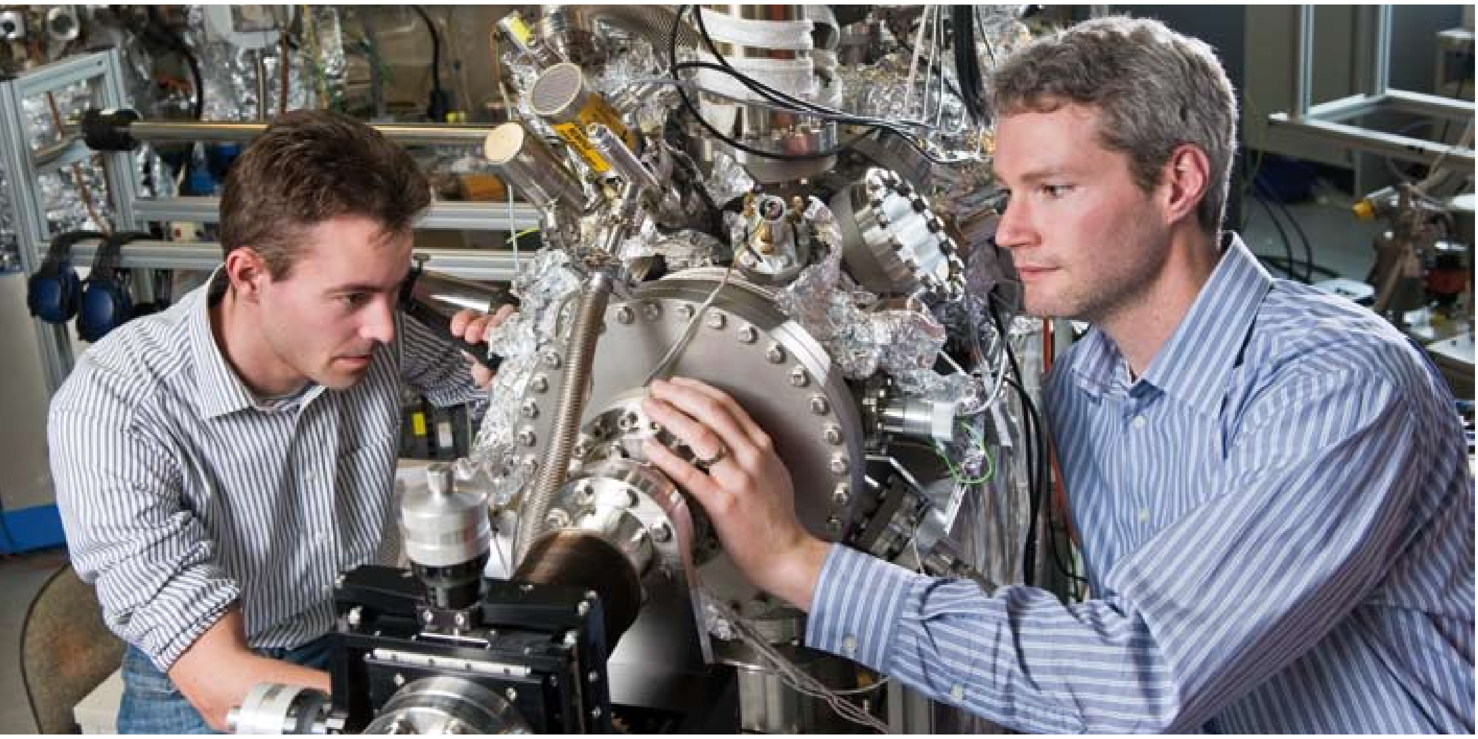
1 | Schematic cross section (a) and scanning electron microscope image (b) of a 2-dimensional silicon photonic crystal nanocavity.

2 | Atomic Force microscopy image of MBE grown SiGe quantum dots on Si.

Focus Group **Functional Nanosystems**

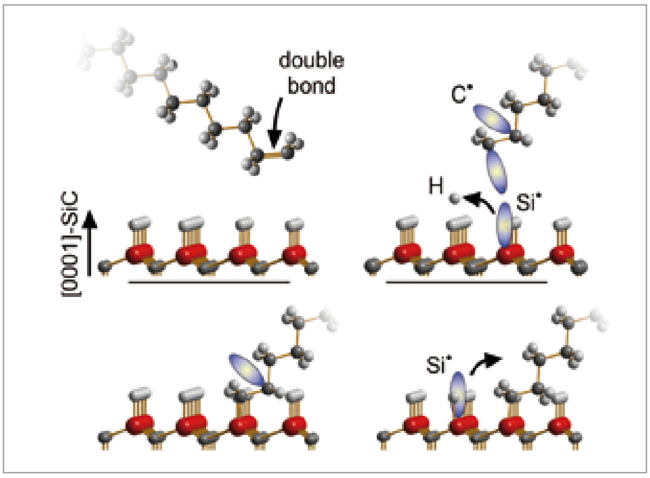
Dr. Ian Sharp | Carl von Linde Junior Fellow

Prof. Martin Stutzmann, Experimental Semiconductor Physics, TUM



At the interface between semiconductor physics and biology

The aim of our work is to functionalize semiconductor surfaces and develop a more comprehensive understanding of charge-transfer processes that occur at the interface between inorganic semiconductors and bio-organic systems.



Mechanism of alkene-based functionalization of hydrogen-terminated semiconductor surfaces.

Such findings have the potential to accelerate the integration of semiconductors as active elements in applications ranging from renewable energy generation to medical device implantation.

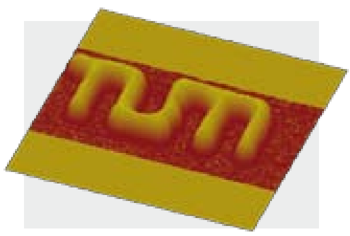
Semiconductors, as the basic components of the "digital age," have allowed striking advancements in communications, data management, and computation. However, these devices are largely isolated from the surrounding world. Chemical modification of surfaces provides a means of integrating semiconductors with organic and biological systems.

Our research includes various elements of surface functionalization that together define the electrical and chemical interactions between semiconductors and organic systems. Such work naturally begins where the semiconductor crystal ends: at the bare surface. We have utilized existing methods and developed new processes for altering the terminal surface atoms in order to create well-defined chemical reactivities and reduce the impact of defects. Onto these surfaces, a wide range of organic molecules are bound; simple carbon chains enable us to study bonding-induced defects, specific chemical endgroups allow us to graft oriented proteins onto surfaces and enhance cell viabilities, and deposition or direct growth of polymers provides access to new semiconductor heterojunctions.

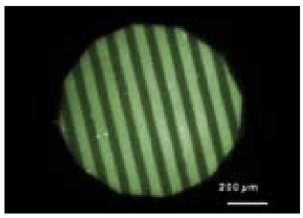
A specific emphasis of our work is toward understanding and tuning the energetics of photosynthetic protein complexes immobilized on wide-bandgap semiconductor surfaces. Through natural design alone, such proteins are characterized by nearly ideal internal quantum efficiencies and thus show great promise for use in bio-electronic and bio-photonic devices. By binding them onto semiconductor surfaces, we have demonstrated charge-transfer processes that we are currently seeking to control through informed alteration of energetic levels within semiconductors.

We have recently extended these methods to study graphene, a perfectly two-dimensional material that consists of a single layer of graphite, the form of carbon found in pencil lead. Although graphite itself is a common conductor, isolated sheets of graphene exhibit unique and extraordinary electrical properties that suggest great promise for a wide range of future applications. Our work is devoted to developing a balanced approach to chemical functionalization of graphene while simultaneously maintaining its impressive electronic properties. This is not an easy task since covalent functionalization necessarily introduces defects into the perfect two-dimensional graphene lattice. In the first phase of exploratory research, we have successfully grown graphene on the wide-bandgap semiconductor silicon carbide and have demonstrated chemical functionality via photoreactions to form covalently bonded polymer brushes. Ultimately, we will explore the viability of utilizing graphene for biosensor and bioelectronic devices with well-defined chemical selectivity via chemical functionalization.

Ian Sharp
received his B.S. in chemical engineering and materials science and engineering from the University of California, Berkeley, in 2002. He was awarded his M.S. and his Ph.D. in materials science and engineering, also at the University of California, in 2004 and 2006. Today he is part of the Walter Schottky Institute at TUM within the group of Prof. Martin Stutzmann.



Atomic force micrograph of surface-bound, structured polymer brushes grown following plasma-modification of graphene.



Fluorescence microscopy image of patterned fluorescently labeled proteins covalently bound to a silicon carbide substrate.

Focus Group **Nanoimprint and Nanotransfer**

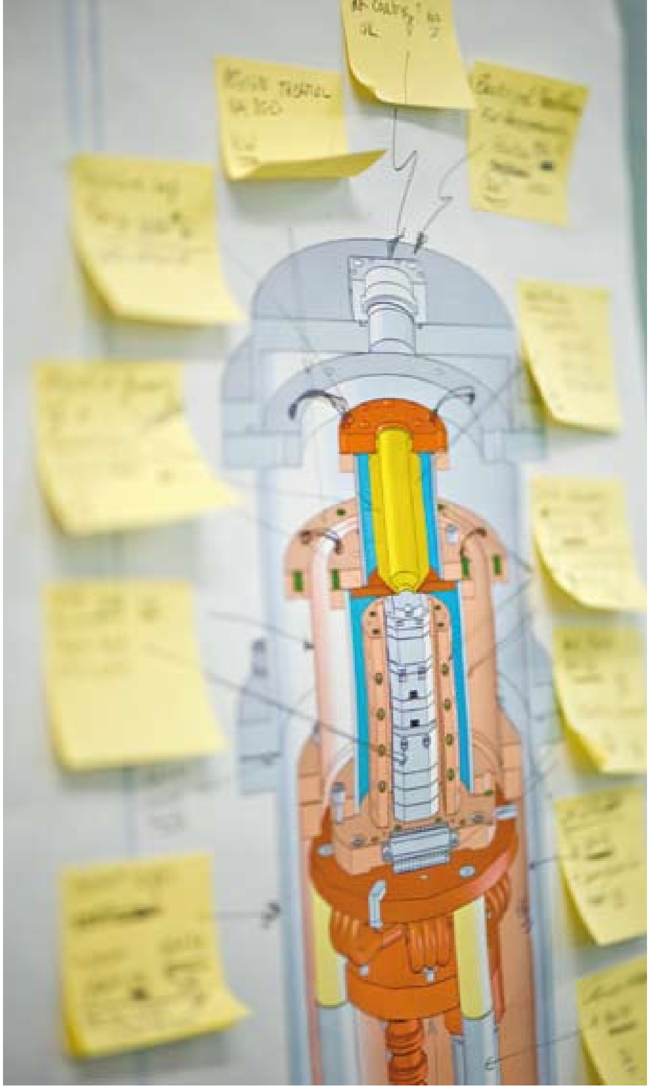
Prof. Khaled Karrai | Rudolf Diesel Industry Fellow
Prof. Paolo Lugli, Nanoelectronics, TUM

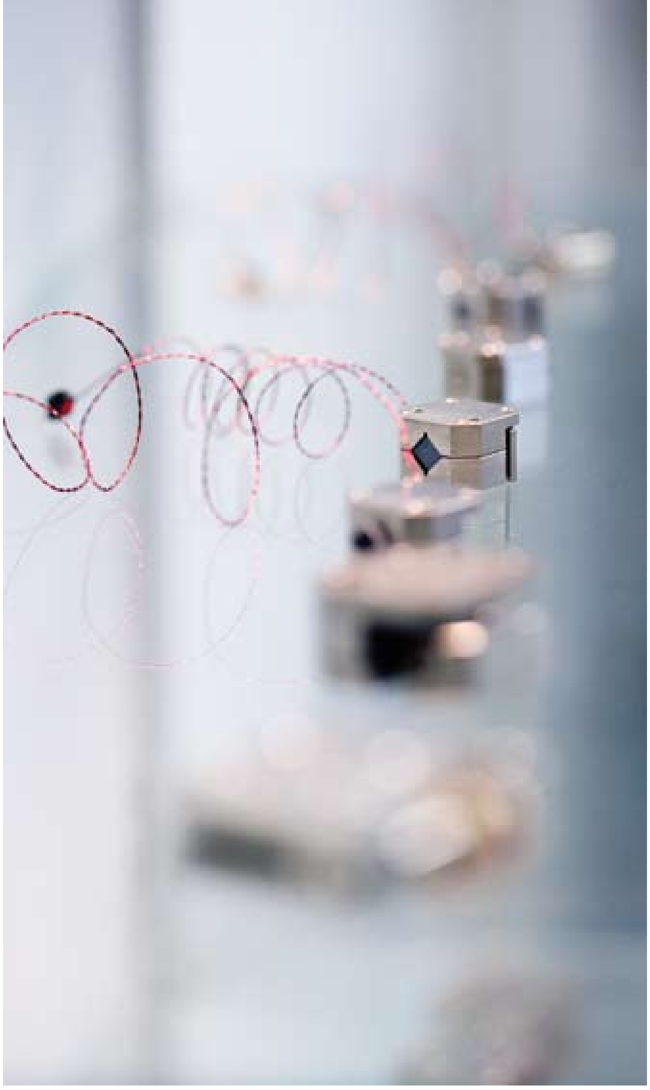
Precision metrological positioning for nanoimprint technology

Printing and stamping are centuries-old technologies commonly used for reproducing patterns on a vast range of materials with an equally large variety of substances, and this with high repeatability. Nanoimprint and nanotransfer technology has the same function with the added requirement that structure sizes and pattern positioning precision should be both in the nanometer range.

Precision positioning and alignment of printed patterns are crucial, for instance, in fabricating components that require multiple individual nanoimprinting steps to achieve a given functionality. A large body of published work and commercial solutions exists on ways of structuring films by means of a stamp with nm-size patterns. However, positioning such patterns with the required nm precision is still a very serious challenge.

From a top-down engineering point of view, three important requirements need to be fulfilled with regard to nanoprinting alignment. First, the device positioning the target substrate in relation to the stamp should be precise enough to move over a cm-wide range with nm sensitivity. Second, the technique for monitoring the target's location with position sensors should be sensitive, precise, and repeatable in the nm range.



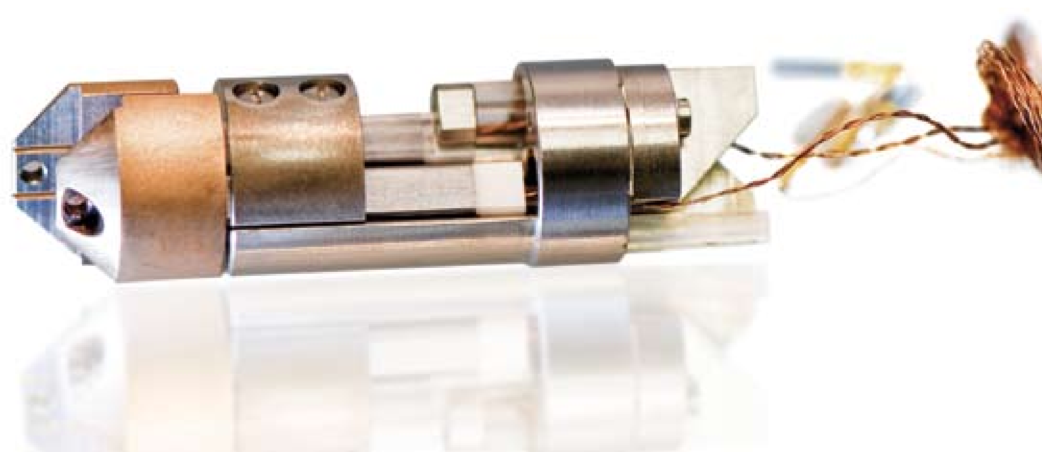


Finally, the location of the patterned structure on the stamp with respect to the origin of the positioning sensors should also be measurable with nm precision. The same applies for the target location.

In this phase of the project we are addressing the first two requirements. The step of implementing high-sensitivity positioning systems based on piezo-driven steppers is largely addressed in attocube systems AG, with all its core know-how in the matter of precision positioning. We will implement a novel miniature ultrahigh-resolution laser interferometer recently invented in attocube systems AG as part of the position sensing scheme. This interferometry, based on attocube wavelength-modulated quadrature detection technology, allows the most compact long-range precision position sensing heads available on the market.

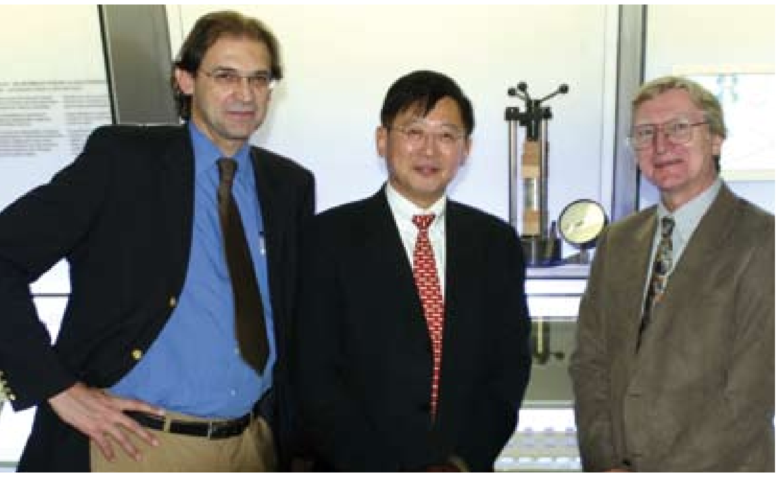
In the near future, a TUM doctoral candidate associated with the Institute for Nanoelectronics will be recruited to work on combining these two particular requirements to achieve precision nanoimprinting.

In particular, reaching nm position sensing with absolute precision is far more challenging than just having nm position sensitivity. The doctoral candidate will further develop the novel interferometry measurement method by analyzing in detail the Doppler effects of the moving target, as well as by analyzing and correcting for the effects of pressure and temperature fluctuation on the optical index of air, to compensate precisely for changes in the effective laser wavelength. Finally, laser wavelength locking and stabilization schemes as well as laser noise reduction will be carefully investigated and implemented.



Focus Group **Nanoimprint and Nanotransfer**

Prof. Wolfgang Porod | Hans Fischer Senior Fellow
Prof. Paolo Lugli, Nanoelectronics, TUM



The planned collaborative research will focus on utilizing Prof. Paolo Lugli's nanoimprint and nanotransfer technology on two topics of Prof. Wolfgang Porod's recent activities.

Making an impression on the public, and an impact on the field

During 2009, I started my research program in collaboration with Prof. Paolo Lugli as part of the TUM-IAS Focus Group Nanoimprint and Nanotransfer.

We discussed the specifics of the research project during several short-term visits, and three TUM-IAS funded students joined the team. These students are Muhammad Atyab Imtaar, Anandi Yadav, and Mario Bareiss. Prof. Paolo Lugli's Institute for Nanoelectronics hosted a kick-off meeting on November 18, which also included TUM-IAS Rudolf Diesel Industry Fellow Khaled Karrai.

It just so happened that the day following the kick-off meeting, the exhibit "Neue Technologien" opened at the Deutsches Museum, and Prof. Paolo Lugli and I were present. Prof. Lugli and his group had helped to create a display on nanoimprinting, featuring a novel imprinter developed at TUM. Also present at the opening was Prof. Stephen Chou from Princeton University, who is credited with the invention of nanoimprint lithography, and who will be collaborating with our TUM-IAS Focus Group. Prof. Stephen Chou had donated to the museum his original imprinting tool, which is shown in the photo above in the background behind Profs. Lugli, Chou, and Porod.

Nanomagnetic Logic
The quantum-dot cellular automata (QCA) concept, which I co-invented, provides a new approach to computing based on direct physical interactions between nanodevices. In recent years, I have applied this concept to magnetic interactions between closely spaced nanomagnets. One of the main challenges for magnetic QCA is the reliable fabrication of arrays of magnetic islands, and we believe that the nanoimprint fabrication process offers advantages over the processes used so far. Such an improved fabrication process would open the doors for the fabrication of larger-scale magnetic logic circuits and would offer the possibility of large-scale production, with obvious benefits for industrial applications. If successful, this project would point the way to all-magnetic information processing systems that would utilize magnetics for both data storage and logic.

Infrared (IR) and Terahertz (THz) Imaging
In recent work, I have investigated the feasibility of using nano- and micrometer-scale antenna structures for the detection of infrared radiation. This would provide an exciting new way to design uncooled and CMOS-compatible IR detectors, with significant potential for applications. We plan to extend this nanoantenna work to the THz regime, which will take advantage of Prof. Paolo Lugli's expertise with quantum-cascade laser sources. In addition, we will investigate the feasibility of fabricating such nanoantenna-based IR and THz detectors using imprint technologies developed by Prof. Paolo Lugli's group. This new fabrication technology would open the door for the realization of large-scale antenna arrays, with significant potential for numerous applications, including energy harvesting. Such nanoantenna radiation collectors could harvest the energy contained in the long-wavelength portion of the solar-radiation energy spectrum, which is inaccessible to conventional silicon-based solar cells.

Khaled Karrai

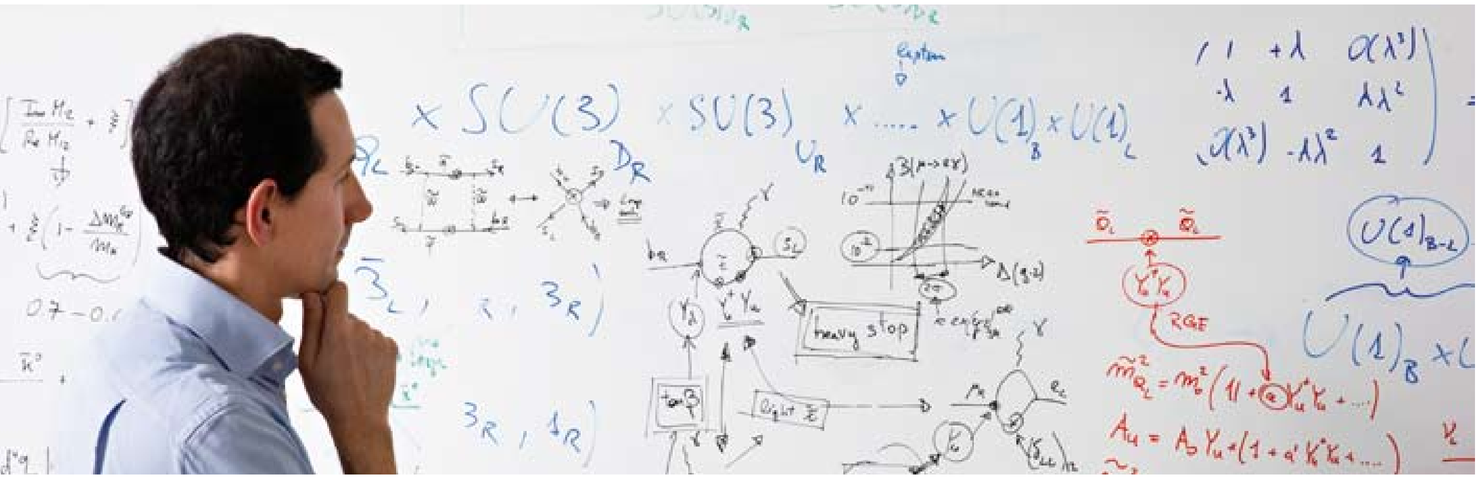
was awarded his Ph.D. in physics at Université Joseph-Fourier in 1987. The next five years he worked as a Research Associate and an Assistant Research Scientist at the Department of Physics and Astronomy of the University of Maryland. He came to TUM in 1993 as a Humboldt Research Fellow. From 1995 to 2006 Karrai was part of the Physics Department at Ludwig-Maximilians-Universität in Munich as a Professor in Experimental Semiconductor Physics. In addition, in December 2001 he co-founded attocube systems AG, manufacturing precision positioners and scanning probe microscopes for extreme environments. Since 2007 Karrai is Chief Technical Officer and R&D Head of attocube systems AG.

Wolfgang Porod

has been a member of the University of Notre Dame faculty since 1986, and holds the Frank M. Freimann Chair in Electrical and Computer Engineering. He received his Diplom (M.S.) in 1979 and his Doctorate in 1981, both from the University of Graz, Austria. After appointments as a Postdoctoral Research Fellow at Colorado State University and as a Senior Research Analyst at Arizona State University, he joined Notre Dame as an Associate Professor, until becoming a Professor in the Department of Electrical Engineering in the summer of 1992, where he now serves as the Director of its Center for Nano Science and Technology.

Focus Group **Fundamental Physics**

Prof. Gino Isidori | Hans Fischer Senior Fellow
◎ Prof. Andrzej Buras, Theoretical Elementary Particle Physics, TUM



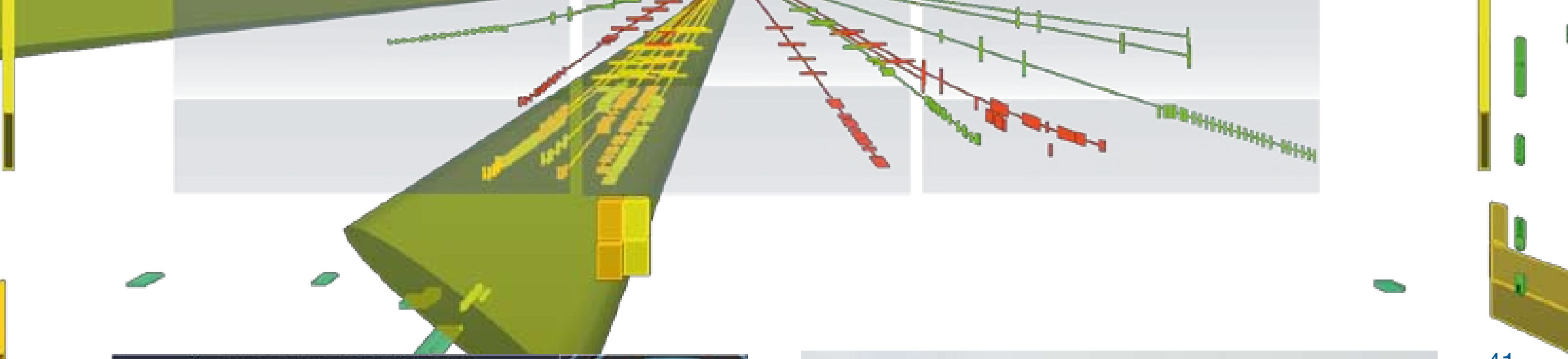
Pushing beyond the Standard Model

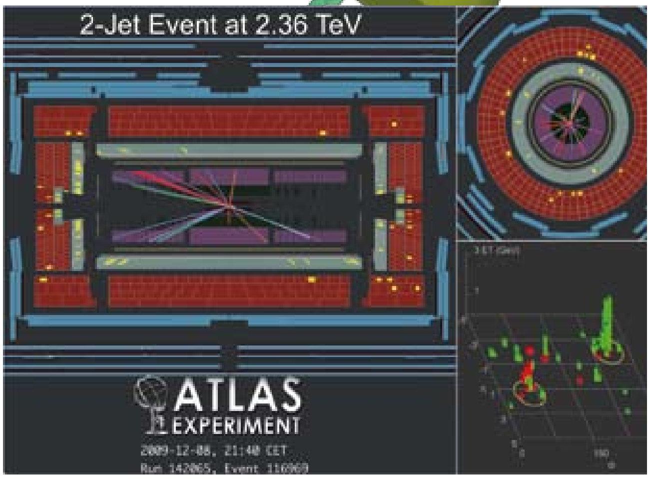
My colleagues and I aim both to advance new theoretical ideas and to show how they can be tested experimentally. Our larger goal is to open up a new frontier of physics research "beyond the Standard Model."

In the last three decades, high-precision experiments performed at high-energy laboratories all over the world have established the so-called Standard Model of elementary particles as the reference theoretical framework to describe fundamental interactions. According to this model, the basic constituents of matter are three sets of elementary particles called quarks and leptons. The strong, weak, and electromagnetic interactions of these particles are ruled by appropriate symmetries and are described as the exchange of further particles, the gauge bosons (or force carriers). This relatively simple model describes with success very different physical systems, from the structure of the atomic nuclei to the structure of the stars.

Despite many successes, the Standard Model suffers a consistency problem if we try to extend its validity at high energies (energies of the order of 1000 times the proton mass). It also leaves unanswered questions, such as why the masses of the various quarks and leptons are so different. The search for a new theory of elementary interactions, able to reproduce the successes of the Standard Model at low energies and able to cure its problems at high energies, is the ultimate goal of our Focus Group.

The theoretically less convincing ingredient of the Standard Model is the so-called Higgs sector: a new interaction, not ruled by symmetry principles, which has been postulated in order to explain the non-vanishing masses of the weak gauge bosons, as well as quark and lepton masses. Elementary particle masses are described as the interaction with a background field, the Higgs field, which constitutes an effective non-trivial medium for the propagation of all the elementary constituents. A direct verification of this mechanism is the main purpose of the Large Hadron Collider (LHC) at CERN: If this mechanism is correct, the LHC experiments should be able to produce and detect the Higgs particle, namely the excitation of this background field.





Display of a 2-jet candidate, taken at the first 2.36 TeV Collision at the LHC on December 8th, with transverse energies of approximately 16 GeV and 6 GeV, respectively, at large rapidity in two different views (CERN ATLAS experiment).

Since the Higgs sector is the origin of all the open problems of the Standard Model, we are convinced that this is only an effective description of a new, hidden sector of elementary constituents, which will be revealed at the energies probed by the LHC experiments (the Tera electron-Volt scale). Our research activity, in close collaboration with Andrzej Buras and his group, is focused on identifying the flavor structure of this hidden sector, namely the characteristic of the model (technically the symmetry and symmetry-breaking pattern) that determines how the different sets of quarks and leptons get their different masses. On the one hand, we are proposing new theoretical ideas (new symmetries) to describe the observed pattern of masses. On the other hand, we are analyzing how this structure can be identified from future experimental data. As we have demonstrated in a series of recent works, a few selected high-precision low-energy experiments are very important in discriminating different models, and the combination of both low- and high-energy data (which are both expected soon) is a key element in unveiling the nature of physics beyond the Standard Model.

Gino Isidori
received his Ph.D. in physics from the University of Rome in 1996. He came to the S.L.A.C. Theory Group in Stanford, California, USA, in 1997 as a visiting scientist and joined TUM Theory Group in 2000 as a visiting scientist. From 2000 to 2002 he was a CERN Fellow at the C.E.R.N. Theory Division in Geneva, Switzerland. In 2004 Isidori became a Guest Professor at the Physics Department at Bern University. He worked as Professore a Contratto at the Scuola Normale Superiore in Pisa (Italy) from 2007 to 2008. Today, he is Research Director at I.N.F.N. Frascati National Laboratories in Italy.

Focus Group **Fundamental Physics**

Prof. Stefan Pokorski | Hans Fischer Senior Fellow
Prof. Andrzej Buras, Theoretical Elementary Particle Physics, TUM

My research plan for the next few years is closely linked to the quest for a deeper theory of elementary interactions, beyond the Standard Model, that will resolve open issues such as the origin of mass, the nature of the so-called dark matter, and the as yet inexplicable bias of our universe toward matter over antimatter.

After 100 years of research and profound revolutions in physics, the observations of Henri Becquerel, Marie and Pierre Curie, and Ernest Rutherford have been finally (almost) understood in the framework of quantum field theory. The Standard Model of strong, electromagnetic, and weak interactions is a very successful theory, describing all data in particle physics available at present and clarifying important events in the history of the universe such as Big Bang nucleosynthesis and, much later, atom recombination.

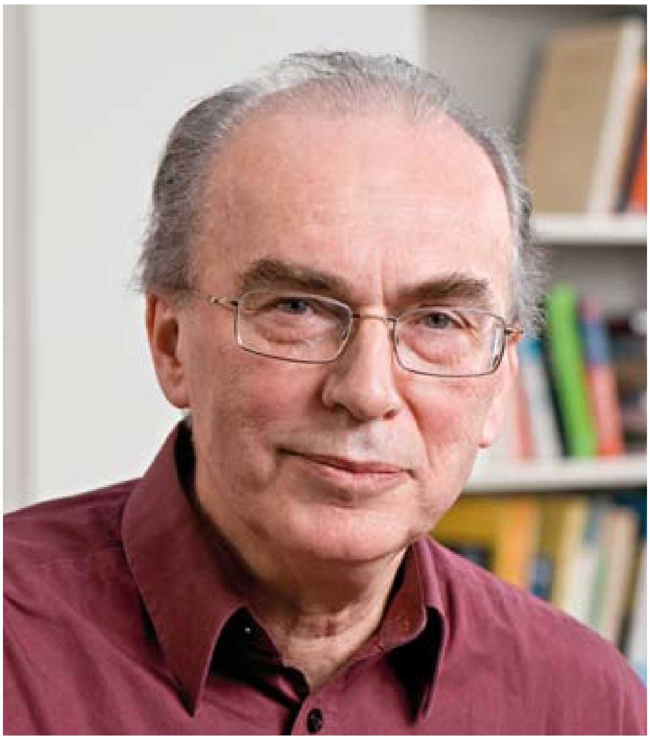
Despite the grand successes of the Standard Model, for some time now particle physicists, cosmologists, and astroparticle physicists have been grappling with several of the most challenging and fundamental questions in science: What is the origin of mass of elementary particles and of its quantum stability? What explains the hierarchy of masses and couplings? What is the dark matter of the universe? What explains the predominance of matter over anti-matter in our universe?

These questions are not answered by the Standard Model, and this lack of answers nicely summarizes the evidence for physics beyond the Standard Model. There are good indications that these questions are closely connected and have answers in the framework of a deeper coherent theory of nature. At present, the main theoretical ideas are supersymmetry, extra dimensions, or new strong interactions responsible for the electroweak symmetry breaking.

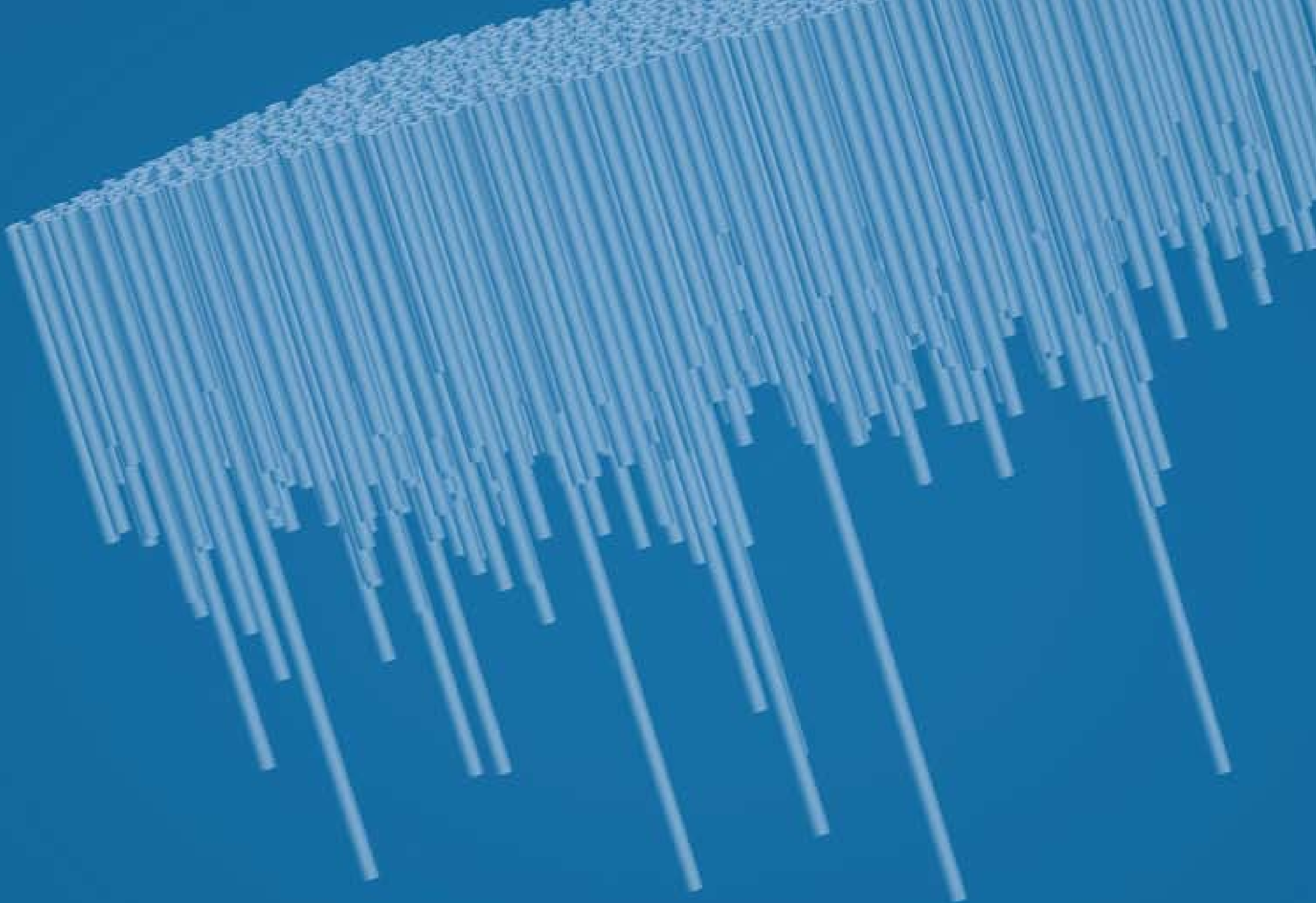
We have good reasons to anticipate experimental discoveries beyond the Standard Model at the TeV mass scale, which would indicate the correct direction for the theory. The Large Hadron Collider experiments at CERN will lead us directly into the territory of the electroweak symmetry breaking, and understanding its mechanism and the origin of mass is the main focus of of my research program. This may also enable us to discover dark matter. Perhaps one of the most interesting developments in particle physics theory is the discovery that some of the most promising ideas that solve the quantum stability problem of electroweak symmetry breaking can also provide an excellent dark matter candidate.

Generation of the matter-antimatter asymmetry in the universe (called baryogenesis) requires the existence of sources of CP violation in the physics beyond the Standard Model, possibly correlated with other interesting effects in the physics of flavor. We will study such effects, particularly in the three basic physical pictures, which can show up in electric dipole moments, triple gauge boson couplings, etc.

The most plausible theoretical framework should emerge from the synergy of the new experiments and the theoretical research. Interaction among the members of the TUM-IAS Focus Group “Fundamental Physics,” who are partly complementary to each other in expertise, will be very helpful in this research program.



Stefan Pokorski
received his Ph.D. degree and his Habilitation (Doctor of Science) in physics from the University of Warsaw in 1967 and 1971. Since 1978, he works as a Professor of Theoretical Physics at the University of Warsaw. From 1984 to 1993 Pokorski was Director of the Institute for Theoretical Physics at the University of Warsaw and since 1989 he is Head of the Chair for Theory of Particles and Elementary Interactions. He had long-term research appointments with CERN in Geneva, the University of Geneva, Fermi National Laboratory in Batavia Illinois, and the Max Planck Institute in Munich.



Highlights and Main Achievements

Introduction

In this section, Fellows who were active in the Institute in 2009 give short descriptions and documentation of their results. The most prominent happening in 2009 was definitely the launch of the GOCE satellite, which allowed our Focus Group on Satellite Geodesy to start exercising their sophisticated software on the real data produced by their new source. A little less than a year later it appears that the results are astounding. Never before has such accuracy on the distribution of masses on Earth been achieved. Going from the planetary scale down to the level of what we could call Protein Engineering, Carl von Linde Senior Fellow Horst Kessler reports major new findings with applications in some very different directions, cancer research and structural properties of silk fiber assembly. Hans Fischer Senior Fellow Walter Kucharczyk reports on considerable improvements in Image-guided Surgery based on the fusion of information obtained from NMR and CT scans. He also mentions the efforts the Institute has made in consolidating this branch of research here through the nomination of Axel Haase as Carl von Linde Senior Fellow. Axel Haase is a great specialist in NMR and will bring needed additional expertise in this area.

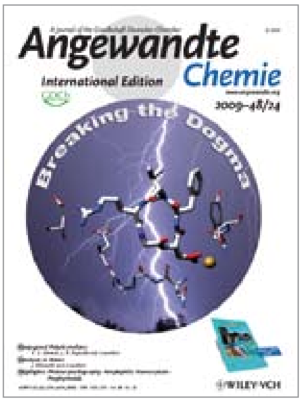
Even further down the scale, our Focus Group on Fundamental Physics has made great strides in refining the Standard Model, calculating through new possibilities and preparing for interpretation of the new data the Large Hadron Collider at CERN in Geneva will produce. This is called a General Theory of Flavor, and the group has produced an original code characterizing particle observables under a theoretical hypothesis (which they call a particle “DNA code” in analogy to the genetic sequencing). Carl von Linde Junior Fellow Ulrich Rant reports new results obtained by the Focus Group on Nanoscience, where the investigations have concentrated on the study of Nanopore Devices – artificial orifices of nanometer dimension through which a molecule (DNA or a protein) migrates or can be pulled, revealing its structure through measurement of the ionic current, or as fluorescent bursts. This technique has already been shown to hold great promise for speedy (and cheap) analysis of DNA molecules; understanding its precise mechanisms and extending them to other types of molecules will be of paramount importance.

We live in the age of networking. The prime network, which conditions our lives and generates our intelligence, is the neural network of our neocortex. The TUM-IAS Focus Group in Neuroscience has been diligently applying its original methods for *in vivo* analysis of neural circuits to understand the neurological basis of major diseases, in particular Alzheimer's disease and multiple sclerosis. In both cases the researchers made major discoveries. In the case of Alzheimer's, Carl von Linde Senior Fellow Arthur Konnerth has discovered a mechanism characteristic for the illness that is different from what has been assumed so far. Hans Fischer Tenure Track Fellow Thomas Misgeld has been studying how axon damage originates in the case of MS, finding new mechanisms in the process that may also be occurring in the case of Alzheimer's disease. Meanwhile, Hans Fischer Senor Fellow Bert Sakmann has been studying the connection between neural cells and the behavior they spawn. He created an experimental setup in which he could concentrate on one type of neural cell activity generating one type of actuation, enabling him to study forward and feedback propagation of signals and allowing him to understand how the network functions from end to end.

TUM-IAS Focus Groups have obtained major results in 2009 also at the system level. Some of those are documented elsewhere in this report, in particular the work on new instruments. (See the description of the work of our Hans Fischer Senior Fellows Mandayam Srinivasan, David Weitz, and Douglas Bonn in the section on Instrumentation.) We also had major work and results in the area of Risk Analysis and Stochastic Modeling. The results have gone in two directions, one being the development of new methods in transport theory (by Carl von Linde Senior Fellow Claudia Klüppelberg and associates), the other continuing development of adequate, non-Gaussian stochastic models in economic or industrial situations where they play a determining role. Noteworthy in particular is the work of doctoral candidate Christina Steinkohl, who has been modeling wind turbine characteristics. (See in this respect the interests of our new Rudolf Diesel Industry Fellow Dragan Obradovic.) Carl von Linde Junior Fellow Robert Stelzer concentrated on extending non-Gaussian models to a more general class of systems, represented by rational transfer functions, driven by a Lévy-Pareto process.

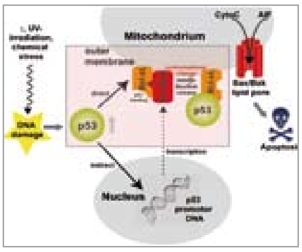
Prof. Horst Kessler | Carl von Linde Senior Fellow

In 2009 we published 20 papers with a total impact factor of 159,92. Three highlights are given below.



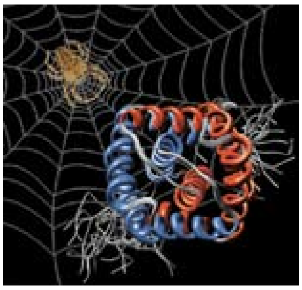
In the last 20 years, thousands of integrin ligands have been described which all contain a carboxyl group to bind to the metal atom in the so-called MIDAS region of the integrin receptor. Any attempt to replace this carboxylic group with any other group – which would be better suited for using the ligands as drugs – has failed so far. We found that hydroxamic acids can not only be substituted for this group, which is a key step forward to bioavailable drug-like ligands, but also can improve receptor subtype selectivity.

Publication D. Heckmann, B. Laufer, L. Marinelli , V. Limongelli, E. Novellino, G. Zahn, R. Stragies, H. Kessler; **Breaking the dogma of the Metal-Coordinating Carboxylate Group in Integrin ligands: Introducing Hydroxamic Acids to the MIDAS To Tune Potency and Selectivity**. In: Angew. Chem. Int. Ed. 2009, 48, 4436-4440.



In our NMR group, we investigated the interaction of the tumor suppressor protein p53 with the mitochondrial protein BclxL. This only recently discovered direct apoptotic function of p53 at the mitochondrion had not been characterized structurally. We found that the DNA binding region of p53 interacts with a negatively charged surface region of BclxL, which introduces an allosteric conformational switch in the region where the pro-apoptotic proteins Bax/Bak bind. The release of the latter causes mitochondrial leakage and induction of apoptosis.

Publication F. Hagn, C. Klein, O. Demmer, N. Marchenko, A. Vaseva, U. M. Moll, H. Kessler, **Bcl-xL Changes Conformation upon Binding to Wild-type but Not Mutant p53 DNA Binding Domain.** In: J. Biol. Chem/. *2010*, /285(5)/, 3439-3450.



We have determined the structure of the C-terminal domain of the major ampullate protein of the spider silk "spidroin," which regulates controlled silk fiber assembly. It turned out that it forms an intertwisted homodimeric domain that unfolds upon defined stimuli (salt conditions and shear stress). This controls the formation of spider silk by providing correct alignment of the repetitive sequence elements of the silk spidroin, a prerequisite for stable inter-chain hydrogen bonds and the formation of crystalline β-sheets within the fiber.

Publication F. Hagn, L. Eisoldt, J. G. Hardy, C. Vendrely, M. Coles, T. Scheibel, H. Kessler, **A conserved spider silk domain acts as a molecular switch that controls fibre assembly**. In: Nature 2010 in press.

Biomedical Engineering

Prof. Walter Kucharczyk | Hans Fischer Senior Fellow

My 2009 TUM-IAS-related activities were widespread and varied. They consisted of sustaining the collaborations I had developed with Prof. Tim Lueth and his group at TUM, establishing my own image-guidance laboratory at my home institution in the Toronto Medical Discovery Tower (TMDT), developing a relationship with "new" Carl von Linde Senior Fellow Prof. Axel Haase, and fostering continued efforts to supervise TUM graduate students.

Prof. Tim Lueth and I were jointly responsible for organizing a track on "Image-Guided Surgery" at the World Congress on Medical Physics and Biomedical Engineering, Munich, Germany, September 7–12, 2009. This was a major international symposium, widely attended by scientists from around the world. In 2009, one of Prof. Tim Lueth's graduate students with whom I had worked while at TUM, Mario Strauss, was hired by the Karl Storz company as project leader for their endoscopic navigation program, a system developed in Prof. Tim Lueth's department. With Mario Strauss's collaboration, my laboratory in Toronto will test and develop applications of a prototype of the Karl Storz endoscopic navigation system for skull base and pituitary surgery, initially in cadaveric models in our hospital's Surgical Skills Laboratory, and eventually will transfer these methods to patient surgery.

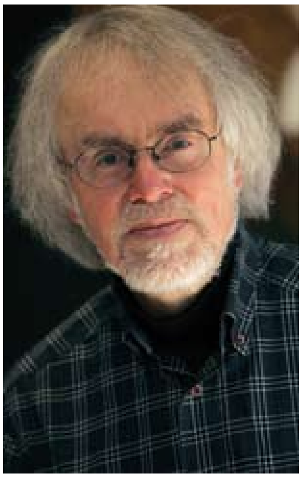
My lab is continuing to develop multi-modality image navigation methods for use in real-time, or near real-time, image-guided diagnostic and therapeutic procedures in radiology. Examples include CT-navigated needle biopsies, fusion of three-dimensional MRI and CT imaging data sets, and combined CT-ultrasound, and MRI-CT-ultrasound guided procedures. We believe our methods will address two of the common practical medical problems faced by doctors that specialize in this type of work. The first problem stems from the fact that some abnormalities caused by diseases are only visible with certain imaging modalities, but from a procedural point of view, the image-guided treatment, such as with radio-frequency ablation, may be best guided by a different imaging modality. For example, certain liver tumors can only be seen with CT, and not with ultrasound. By dynamically co-registering the CT and ultrasound images in space, we can use the CT image to guide the ultrasound transducer, which in turn is used to guide the RF treatment probe. A second common problem is the radiation exposure of the doctor, especially for CT-based image guidance.

By using our methods, the doctor will be provided with more clear delineation of the abnormality, in turn reducing uncertainty, and thereby minimizing the need to re-position and re-image. This will speed up the procedure and reduce the need for additional CT images. Also, using CT fluoroscopy interleaved with image guidance from a real-time navigation system, instead of CT fluoroscopy alone, will further reduce total fluoroscopy time. Radiation dose to the doctor could be reduced by as much as 80-90%.

We are also developing a prototype hybrid optical-electromagnetic (EM) navigation device to overcome one of the major deficiencies of optical navigation. Optical navigation using stereoscopic principles – employing two cameras that track instruments with three or more reflectors – is the most accurate and commonly used method in use in surgery today. The major drawback of optical navigation is that if something gets between the camera and any of the reflectors, such as the doctor's hand, a nurse's body, or a drop of blood on a reflector, the system cannot determine the position of the instrument. Obstruction of the camera's view of the reflectors is commonly referred to as loss of "line of sight." Electromagnetic navigation is less accurate than optical, and it is also degraded in unpredictable ways by the presence of metal, but it does not depend on line of sight. Our hybrid system shows promise in overcoming the line-of-sight problems inherent in optical systems while retaining the improved accuracy of optical over EM-based methods.

I was delighted to learn that Prof. Axel Haase has become a TUM-IAS Fellow. His research and development of MRI coils is of great potential collaborative interest to me because of my own interests in high-resolution MRI. Coils are a critical part of the MRI process. Prof. Axel Haase and I met late in 2009 and discussed plans to establish an ongoing scientific-medical TUM-Toronto collaboration in the field of MRI.

Lastly, I have arranged for TUM graduate student Thomas Wolff to join me for a four- to six-month "internship" in Toronto. Thomas will work with me on designing an "MRI - X ray - surgery-compatible table and transfer system" that will enable the accurate performance of many of the image-guided procedures we will be undertaking.



Prof. Andrzej Buras | Carl von Linde Senior Fellow

Flavor Physics beyond the Standard Model

Six quarks and six leptons of different kinds, referred to as flavors, form the modern periodic table of the fundamental building blocks of matter. The Standard Model (SM) of particle physics successfully describes these elementary particles and the forces between them.

A deeper understanding of the flavor structure of quarks and leptons, of their masses and couplings, is however still missing. Indeed the origin of different flavors of quarks and of the huge hierarchies in their masses and their flavor-violating interactions described by the so-called CKM mixing matrix is not understood at present. The Nobel Prize awarded to Prof. Toshihide Kobayashi and Prof. Makoto Maskawa in 2008 recognizes the global success of their parametrization (CKM matrix) of flavor-violating and CP-symmetry-violating interactions. The fundamental theory behind the structure of the CKM matrix and the observed quark masses remains to be formulated.

Decisive new experiments are about to start in particle physics at the Large Hadron Collider (LHC) at CERN and high-intensity flavor facilities around the world. They will test existing theoretical concepts and inspire new ideas. This should allow researchers to make substantial steps towards the construction of the fundamental Theory of Flavor, which is the main goal of my Focus Group Fundamental Physics.

As an important step toward the construction of the Theory of Flavor, my group – including several postdocs and numerous doctoral candidates – analyzed in 2009 a number of models beyond the SM: supersymmetric models, a model with a new global symmetry (Little Higgs model), a model with an additional space dimension, and a model involving new heavy quarks and leptons. The group has calculated predictions for many observables that can be measured in rare decays of the K and B mesons, the bound states of quarks and antiquarks. The new heavy particles in these models affect the observables, such as the probabilities for observing a given decay or the violation of CP symmetry through quantum effects, so that the predictions for these observables in a given model differ from the SM predictions. These deviations from the SM can be sometimes very large, sometimes moderate, and sometimes tiny depending on the model and the observable considered. Consequently, as proposed by our group, each model can be characterized by a “DNA code” (in analogy to the usual DNA), which describes the size of deviations from the SM for a large set of observables in a given model with the following color coding: very large deviations (three red stars), moderate deviations (two blue stars), or tiny deviations (one black star).

By comparing the DNA of each model with the data, one can identify the correct models and study them in more detail. A symbolic illustration of a DNA Table for five observables (O_i) and five models (M_i) is illustrated here.

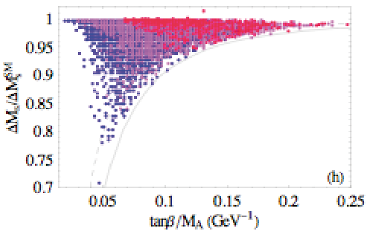
Our results for DNAs of a number of new models have been presented at various conferences. The success of our research can be measured by excellent postdoc offers extended to three young scientists, shown in the photo, who as doctoral candidates were involved in constructing the DNA table: Wolfgang Altmannshofer (second from the right) goes to Fermilab, Stefania Gori goes to Fermi Institute in Chicago, and David Straub (first on the left) goes to Scuola Normale Superiore in Pisa. Fortunately, many doctoral candidates still remain in the group, and three new postdocs related to the Hans Fischer Senior Fellowships of Gino Isidori and Stefan Pokorski will join our Focus Group. The quest for the Theory of Flavor will remain the main focus of our group for the coming years, and we are looking forward to the tests of the models analyzed by us with the help of the forthcoming data.

	M_1	M_2	M_3	M_4	M_5
O_1	★★★	★	★	★	★★
O_2	★	★★	★★★	★★	★
O_3	★★	★★★	★★	★	★
O_4	★★★	★★	★	★★★	★★
O_5	★	★★★	★	★★	★★★

A DNA of New Physics models beyond the SM

Publications

- W. Altmannshofer, A. J. Buras, S. Gori, P. Paradisi, D. M. Straub, **Anatomy and Phenomenology of FCNC and CPV Effects in SUSY Theories.** In: Nucl.Phys.B830:17-94,2010. e-Print: arXiv:0909.1333 [hep-ph].
- M. E. Albrecht, M. Blanke, A. J. Buras, B. Duling, K. Gemmler, **Electroweak and Flavour Structure of a Warped Extra Dimension with Custodial Protection.** In: JHEP 0909:064,2009. e-Print: arXiv:0903.2415 [hep-ph].
- A. J. Buras, D. Guadagnoli, **On the consistency between the observed amount of CP violation in the K- and B-systems within minimal flavor violation.** In: Phys.Rev.D79:053010,2009. e-Print: arXiv:0901.2056 [hep-ph].



The upper experimental bound on the branching ratio of a B meson decaying into a lepton pair sets tight constraints (solid line) on the Bs meson mass difference ΔMs. The Higgs sector parameter tan(β)/MA could be extracted from the measured branching ratio and ΔMs. The colored dots denote allowed regions of the MSSM parameter space.

Dr. Martin Gorbahn | Carl von Linde Junior Fellow

How can the world be described at smallest distances – in a more fundamental way than the Standard Model provides? That this question might be answered in the near future – using precision and high-energy experiments – excites today's particle physicists.

To discriminate among various models of more fundamental physics, using data from precision experiments and direct searches at high-energy colliders, is my research goal. In the near future, new heavy particles could be found at the LHC facility. Their interactions can be studied in rare decays of particles called B and K mesons. Combined with the result of direct searches, these precision studies can provide a decisive test of various extensions of the Standard Model (SM). Yet this endeavor needs dedicated effort from both the experimental and the theoretical side to achieve the desired precision.

In the past year, my junior research group was active on two frontiers of the theoretical side: a) calculating SM backgrounds with high precision and b) facilitating the extraction of fundamental parameters of the minimal supersymmetric standard model (MSSM).

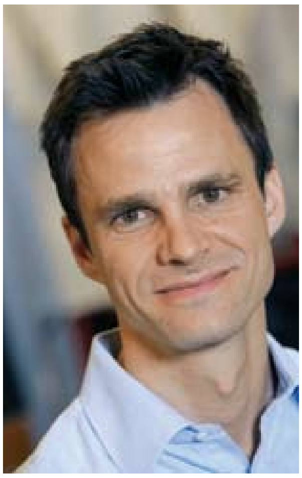
- With our SM precision calculation we could remove the dominant theory uncertainty for various K meson decay properties. The technical difficulty of these calculations increases exponentially order by order, and therefore we had to calculate around 100,000 Feynman integrals. We developed computer algebra methods to reduce these integrals to a small number of master integrals, which could be calculated analytically.

- The MSSM comprises an additional Higgs boson doublet. Some B meson decays are potentially very sensitive to the fundamental parameters of this extended Higgs sector (see figure). Yet the dependence of the B meson decays on the Higgs sector parameters used in collider physics was hitherto unknown: Results of direct searches could not be safely combined with data from precision experiments. Our idea was to relate the MSSM to an effective theory with two Higgs doublets, where the parametric dependence of B meson decays is well defined. Here we performed the first complete matching calculation of the MSSM onto a two Higgs doublet model. This relates the parameters used in collider physics and B physics and removes the aforementioned obstacle. Along this line we found a definition of the tan(β) parameter that is well behaved in perturbation theory and does not depend on unphysical parameters. No such definition was known before in the literature.

Publications

- Martin Gorbahn, Sebastian Jäger, Ulrich Nierste, Stephanie Trine. **The supersymmetric Higgs sector and B-Bbar mixing for large tan beta.** In: [arXiv:0901.2065] TUM-HEP-707-09 (2009) 61 pages.
- Martin Gorbahn. **NNLO contributions to epsilon(K) and rare kaon decays.** In: PoS(KAON09)005, [arXiv:0909.2221] (2009) 9 pages.

Dr. Ulrich Rant | Carl von Linde Junior Fellow



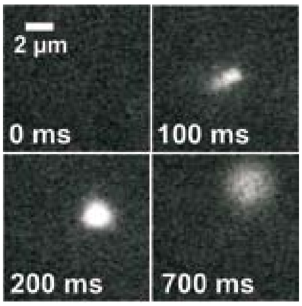
Nanopore devices to study single molecules

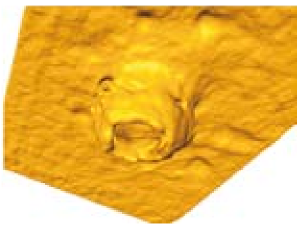
During the last year, we have actively pursued our research on molecules in synthetic nanopores. Nanopores are basic, yet powerful tools to examine single molecules.

A nanometer-sized orifice in a membrane acts as a sensor that reports the passage of individual biomolecules, such as DNA or proteins, as spikes in the measured ionic current across the pore, or as fluorescence "bursts" that can be observed optically.

Much of our research was focused on studying the translocation behavior of proteins through solid-state nanopores, although our experimental observations left us puzzled for quite a while: In contrast to "well-behaved" DNA molecules, the electrical forces that are believed to pull DNA molecules through the pore seemed to have ceased working for proteins. Recently we found an answer to the question: What drives proteins into, through, and out of nanopores? It is a subtle balance of different electro-kinetic effects, mixed with components of molecular diffusion. The conclusions for the "nanopore engineer" are obvious: If proteins are to be probed, the charge of the inner pore walls must be carefully controlled.

To this end, we developed novel means to fabricate a metallic nanopore structure. Metal nanopores offer the advantages that the electrical potential of the pore walls can be adjusted externally and that their inner pore surfaces can be chemically modified in a straightforward way, which we are currently studying. We also devised and realized a new device concept based on two nanopores forming the entrance and exit to a 10 femtoliter (10^{-14} liter) cavity in a silicon chip. The pore-cavity-pore device allows us to investigate nano-objects (particles, biomolecules) in confined geometries one-by-one. The nano-objects can be loaded, trapped, and ejected from the cavity at will by electrical means. Future work will be directed toward using the devices as femtoliter reaction chambers and for time-of-flight measurements on single molecules.





1 | Fluorescence images of individual λ-DNA molecules exiting from a nanopore in a silicon nitride (SiN) membrane.

2 | Transmission electron tomography images of (~50 nm) nanopores in SiN

3 | A SiN pore metallized with gold (SiN substrate invisible).

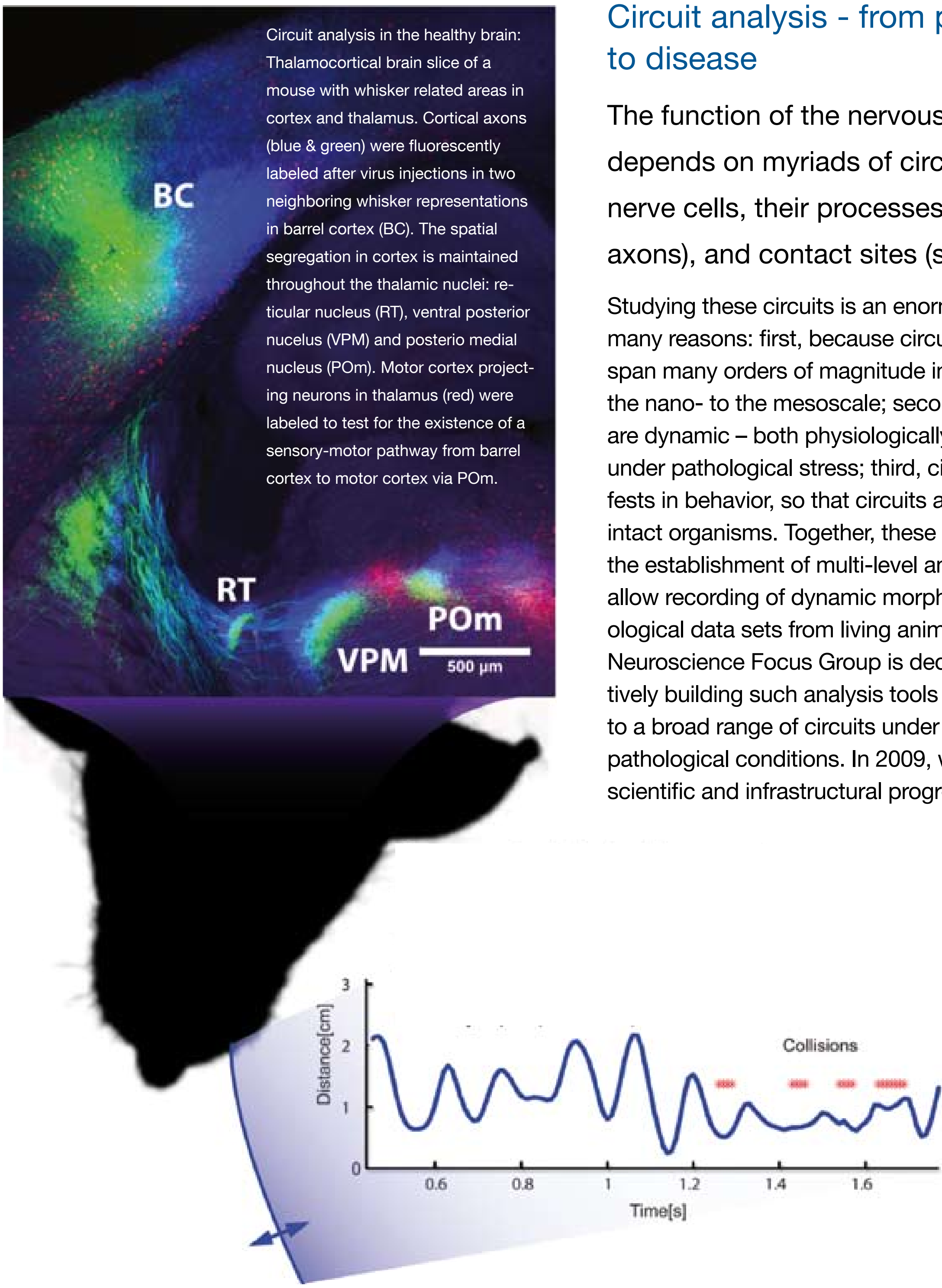
Publications

- Philipp S. Spuhler, Jelena Knezevic, Ayca Yalcin, Qiuye Bao, Erika Pringsheim, Peter Dröge, Ulrich Rant, M. Selim Ünlü **Platform for *in situ* real-time measurement of protein-induced conformational changes of DNA.** In: Proc. Nat. Acad. Sci. Am. published online Jan 2010 doi:10.1073/pnas.0912182107 (2010).
- Daniel Pedone, Matthias Firnkes, Ulrich Rant **Data Analysis of Translocation Events in Nanopore Experiments.** In: Analytical Chemistry 81 (23), 9689-9694 (2009).
- Ulrich Rant, Erika Pringsheim, Wolfgang Kaiser, Kenji Arinaga, Jelena Knezevic, Marc Tornow, Shozo Fujita, Naoki Yokoyama, Marc Tornow, and Gerhard Abstreiter **Detection and size analysis of proteins with switchable DNA layers.** In: Nano Letters 4, 1290-1295 (2009).

Circuit analysis - from physiology to disease

The function of the nervous system critically depends on myriads of circuits made up of nerve cells, their processes (dendrites and axons), and contact sites (synapses).

Studying these circuits is an enormous challenge for many reasons: first, because circuits and their elements span many orders of magnitude in size ranging from the nano- to the mesoscale; second, because circuits are dynamic – both physiologically and especially also under pathological stress; third, circuit function manifests in behavior, so that circuits are best studied in intact organisms. Together, these challenges require the establishment of multi-level analysis tools that allow recording of dynamic morphological and physiological data sets from living animals. The TUM-IAS Neuroscience Focus Group is dedicated to collaboratively building such analysis tools and applying them to a broad range of circuits under physiological and pathological conditions. In 2009, we have made major scientific and infrastructural progress towards this aim.



Circuit analysis in the healthy brain: Thalamocortical brain slice of a mouse with whisker related areas in cortex and thalamus. Cortical axons (blue & green) were fluorescently labeled after virus injections in two neighboring whisker representations in barrel cortex (BC). The spatial segregation in cortex is maintained throughout the thalamic nuclei: reticular nucleus (RT), ventral posterior nucelus (VPM) and posterio medial nucleus (POm). Motor cortex projecting neurons in thalamus (red) were labeled to test for the existence of a sensory-motor pathway from barrel cortex to motor cortex via POm.

1 | Sensory-motor behavior of a mouse: Single frame of a high speed video captured during explorative behavior of a mouse (left). All whiskers but one were trimmed to facilitate automatic 2D whisker tracking. Automatic tracking of a whisker (blue) allows unbiased and fast measurements of motor behavior, as well as sensory input (collisions).

Prof. Arthur Konnerth | Carl von Linde Senior Fellow

A major focus of our recent work is the functional analysis of neuronal circuits in the diseased brain, in particular in Alzheimer's disease.

Alzheimer's disease is a widespread form of dementia that affects millions of people worldwide and has a continuously increasing impact in our aging society. This incurable neurodegenerative disease leads to severe loss of memory and other mental functions. This loss was until now explained by a progressive decrease in neuronal activity caused by the breakdown of the connections between certain neurons in the brain. Recent work from our institute (Busche et al. Science 2008) challenges this view and decisively extends our knowledge on the cellular mechanisms underlying the pathophysiological changes occurring in the brain at advanced stages of Alzheimer's disease. Using novel methods of high-resolution *in vivo* imaging that were developed in our laboratory, we were able for the first time to monitor directly the behavior of neurons located near amyloid plaques in a mouse model of Alzheimer's disease.

An important and unexpected result of our studies was that a large proportion of neurons showed an abnormal increase in electrical activity. We termed these neurons "hyperactive." Hyperactive neurons were found mostly in clusters that surrounded amyloid plaques. A peculiar property of hyperactive neurons was that they were often active in synchrony. Such patterns of synchronous hyperexcitation are a characteristic feature of another brain disease, namely epilepsy. Therefore, our results reveal an interesting clue for the cause of the increased incidence of epileptic seizures in Alzheimer's patients. Together, our results provide a strong basis for a new view of the neuronal mechanisms responsible for the malfunction of the brain in Alzheimer's disease. Instead of the previously proposed general breakdown of neuronal activity, we propose that a reorganization of neuronal circuits, in which some neurons become entirely silent but others excessively active, is the critical reason for the disturbed cognitive functions.

Publication

Busche MA, Eichhoff G, Adelsberger H, Abramowski D, Wiederhold KH, Haass C, Staufenbiel M, Konnerth A, and Garaschuk O (2008) **Clusters of Hyperactive Neurons Near Amyloid Plaques in a Mouse Model of Alzheimer's Disease.** In: Science 321, 1686-1689.

Prof. Bert Sakmann | Hans Fischer Senior Fellow

In order to establish a complete picture of the role of different cell types in brain functions and dysfunctions, various approaches have to be employed.

Accordingly, in the Sakmann lab we not only continued to investigate cell-type specific properties of cortical output neurons on the anatomical level, but also expanded our studies to describe the network functions in sensory processing and the role of defined classes of neurons on the behavioral level (see figure 1).

A focus of our studies is the bidirectional interaction between cortex and thalamus in the sensory-motor system and its constituent cell types. We recently found that the somatotopic relation of sensors (mouse whiskers) is largely maintained, not only until it reaches the cortex, but also after these highly processed signals are fed back by two types of output neurons to the thalamus. Furthermore we were able to demonstrate that these cortical signals are integrated with “naïve” sensory brainstem signals, both converging in the thalamus and indicating coincidence of “inner” and “outer” signals. The coincidence detection of top-down and bottom-up signals expands the classical view of the thalamus in which only “naïve” sensory signals resemble the thalamic drive, which is modulated by weak cortical feedback. In order to understand the consequences of corticothalamic sensory processing, we are currently establishing a behavioral paradigm in which neuronal cell types and the networks they are embedded in can be controlled in a cell-type specific manner. Eventually, this will allow us to provide a complete picture of different neuron classes ranging from single cell-anatomy and physiology to their function in the intact brain and finally their role in behavior.

Publications

- Groh A, Meyer HS, Schmidt EF, Heintz N, Sakmann B, Krieger P. **Cell-Type Specific Properties of Pyramidal Neurons in Neocortex Underlying a Layout that Is Modifiable Depending on the Cortical Area.** (2009) In: Cereb Cortex. doi:10.1093.
- Groh A, de Kock CP, Wimmer VC, Sakmann B, Kuner T. **Driver or coincidence detector: modal switch of a corticothalamic giant synapse controlled by spontaneous activity and short-term depression.** (2008) In: J Neurosci. 28(39), 9652-63.

Prof. Thomas Misgeld | Hans Fischer Tenure Track Fellow

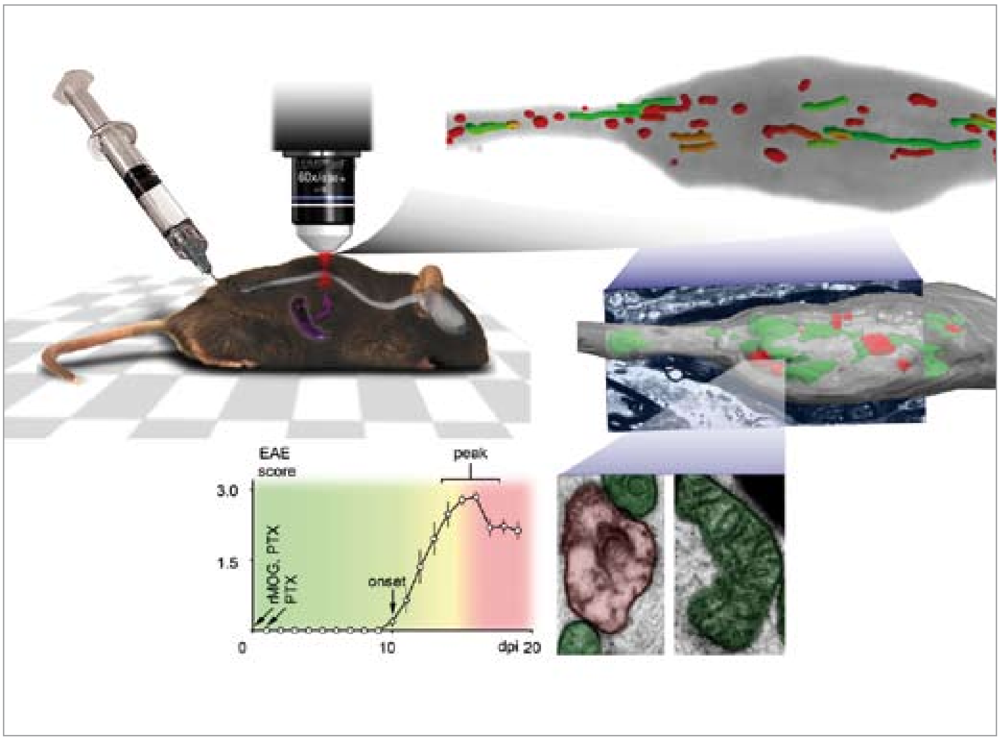
Publications

- Adalbert R, Nogradi A, Babetto E, Janeckova L, Walker SA, Kerschensteiner M, Misgeld T, Coleman MP. **Severely dystrophic axons at amyloid plaques remain continuous and connected to viable cell bodies.** (2009) In: Brain 132(2), 402-16.
- Kerschensteiner M, Reuter MS, Lichtman JW, Misgeld T. **Ex vivo imaging of motor axon dynamics in murine triangularis sterni explants.** (2008) In: Nature Protoc*.* 3(10):1645-53.

Diseases of the nervous system affect and eventually destroy specific neuronal circuits. Axons and synapses seem to be particularly vulnerable to disease-related pathology, but this vulnerability is poorly understood at the level of cellular mechanisms and molecular mediators.

Multiple sclerosis is a particularly complex example of this scenario, as it is primarily an autoimmune disorder that affects the insulating sheaths of axons, myelin. Still, axons get disrupted early during the disease, and this axonal damage eventually determines the level of disability of patients suffering from this condition. In a close collaboration with colleagues at LMU Munich (Kerschensteiner lab) and at Indiana University (Bishop lab), we set out to understand how axon damage emerges in an animal model of multiple sclerosis. This study is based on methods that our group has developed over the past years to assay subcellular axon dysfunction *in vivo* (Kerschensteiner et al., *Nature Protoc.* 2008). In addition to multiple sclerosis, such dysfunction is also found in many neurodegenerative conditions, such as Alzheimer's disease (Adalbert et al., *Brain* 2009). In the past, a number of hypotheses have been formulated regarding the mechanisms of axon damage in multiple sclerosis. These hypotheses focused on the idea that axons needed to lose their myelin sheath before being susceptible to direct and irreversible attack by invading immune cells. In order to test this and related assumptions, we established imaging technology that enables visualization of axon damage during inflammatory attack directly in the spinal cord of living mice. Furthermore, we developed new methods to identify previously imaged axons in the electron microscope and to measure molecular mediators of axon damage *in situ*.

Our investigation has resulted in the first complete *in vivo* description of axon damage in an inflammatory attack and revealed a number of unexpected features (see figure 2): i/ Axonal loss is preceded by a stereotypical sequence of morphological changes, which includes a semi-stable and reversible early stage with swollen axons; ii/ the earliest signs of axon damage are present in fully myelinated axons and manifest as damage to essential energy-producing organelles, mitochondria; iii/ this early damage is mediated by highly reactive derivatives of oxygen (reactive oxygen species), which are released by immune cells. Based on this characterization, we succeeded in treating animals with blockers of reactive oxygen species. In collaboration with neuropathologists (Dr. Doron Merkler, Göttingen), we managed to corroborate involvement of a similar damage mechanism in the human disease, multiple sclerosis. This work is currently being revised for publication in a leading biomedical journal. Currently, we are expanding the technological armamentarium for studying neuroinflammation and axon damage *in vivo* at the subcellular and molecular level. We have succeeded in measuring reactive oxygen species levels in axons, as well as changes in intracellular calcium levels and organelle transport – all factors that likely contribute to early axon damage and represent potential therapeutic targets.



2 | Circuit analysis in the diseased brain: Experimental autoimmune encephalomyelitis (EAE) is the standard animal model of multiple sclerosis. EAE is induced in transgenic mice that express fluorescent proteins in axons and in immune cells. After 8-9 days, animals show an ascending paralysis (EAE score 1.5 corresponds to hindlimb paresis). At the peak of the disease, axons are visualized by *in vivo* microscopy.

Analysis of early axon damage mechanisms in EAE using *in vivo* imaging (left), confocal microscopy (top), and correlated serial-sectioning electron microsocopy (middle and bottom). Even during early stages of axon damage, when the axons are only lightly swollen, disrupted mitochondria (red) are numerous.

Strategic appointment

The TUM-IAS Neuroscience Focus Group has seen a major structural step forward with appointment in September 2009 of Hans Fischer Tenure Track Fellow Thomas Misgeld to the Chair of Biomolecular Sensors. This step provides a clear tenure prospect within TUM's medical faculty as intended in the Hans Fischer Tenure Track Fellowship scheme. The TUM-IAS has critically supported this appointment from its inception phase and has made major contributions to the start-up funding for this research chair. (This enabled us to out-compete an external recruitment offer – "W3-Ruf" – from the CEF excellence cluster at Frankfurt University in 2008). With the final appointment, these start-up funds could be used in 2009 to start expanding the group to its permanent size (to be reached in spring 2010), provide interim laboratory space until renovation of final laboratories for this new chair (to be completed in summer 2010), and financially support necessary expansion of mouse breeding facilities available to the Neuroscience Focus Group (to be completed in spring 2010).

Risk Analysis and Stochastic Modeling

Prof. Claudia Klüppelberg | Carl von Linde Senior Fellow

Since we set up our Focus Group, beginning in late 2008, it has proven to be extremely productive scientifically. Besides continuing fundamental research for Levy-driven continuous time series models and applied work in financial risk management, I started work in some exciting new areas.

Jointly with the TUM-IAS postdoc Dr. Codina Cotar and Prof. Gero Friesecke, I am developing a novel approach to the design of exchange-correlation functionals in density functional theory, based on the viewpoint of optimal transport. These functionals are used in the modeling of electron correlations and are a main ingredient in electronic structure computations in molecules and solids.

With my doctoral candidate Vincenzo Ferrazzano and Prof. (and Humboldt Prize winner) Ole E. Barndorff-Nielsen, I started to investigate high-frequency wind speed data (sampled at 5 kHz). New stochastic models are called for and will enhance the understanding of turbulence data on high Reynold numbers. Moreover, our results will also have practical consequences concerning green energy concepts for wind farms. Certain aspects of this project also involve Hans Fischer Senior Fellow Richard Davis.

Richard Davis was much involved with the diploma project of Christina Steinkohl (since December 2009 doctoral candidate in the TUM-IAS jointly supervised by Davis and Klüppelberg), where she studied wind characteristics, specifically maximum wind speeds, in order to design and control wind turbines to withstand extreme wind events.

Major highlights were the workshops the group organized, and visits to the group by many leading scientists.

Publications

- Eder, I and Klüppelberg, C. **The first passage event for sums of dependent Lévy processes with applications to insurance risk.** (2009) In: Ann. Appl. Probab.*19* (6), 2047-2079.
- Klüppelberg, C. and Kuhn, G. **Copula Structure Analysis.** (2009) In: J. Royal Stat. Soc., Series B,/ *71* (3), 737 - 753.
- Klüppelberg, C. and Pergamenchtchikov, S. **Optimal consumption and investment with bounded downside risk for power utility functions.** (2009) In: Delbaen, F., Rásonyi, M., and Stricker, C. (Eds.) / *Optimality and Risk - Modern Trends in Mathematical Finance*,/ pp. 133-169. Springer, Berlin.

Dr. Robert Stelzer | Carl von Linde Junior Fellow

Over the last year, several interesting questions have been answered and very challenging new research projects started.

Together with Prof. Ole Eiler Barndorff-Nielsen, we developed a multidimensional stochastic process allowing for long-range dependence and analyzed its use in a stochastic volatility model. In joint work with Dr. Eberhard Mayerhofer and Oliver Pfaffel, we managed to give very general existence conditions for certain matrix-valued diffusions currently heavily employed in applications. With Dr. Johannes Muhle-Karbe and Oliver Pfaffel, we studied option pricing in a certain multivariate stochastic volatility model. The latter work constitutes the first paper developing a comprehensive option pricing theory and calibrating the complete model for a truly multivariate stochastic volatility model. Together with my doctoral candidate Eckhard Schlemm, we are investigating quasi-maximum likelihood estimation of multivariate CARMA processes – a fundamental class of continuous time stochastic processes – and together with my doctoral candidate Martin Moser, the extreme value theory of multivariate Lévy-driven stochastic models, which is key to risk analysis. Recently a new project on high-dimensional statistics and the use of random matrix theory has been started with Hans Fischer Senior Fellow Richard Davis and our new doctoral candidate Oliver Pfaffel.

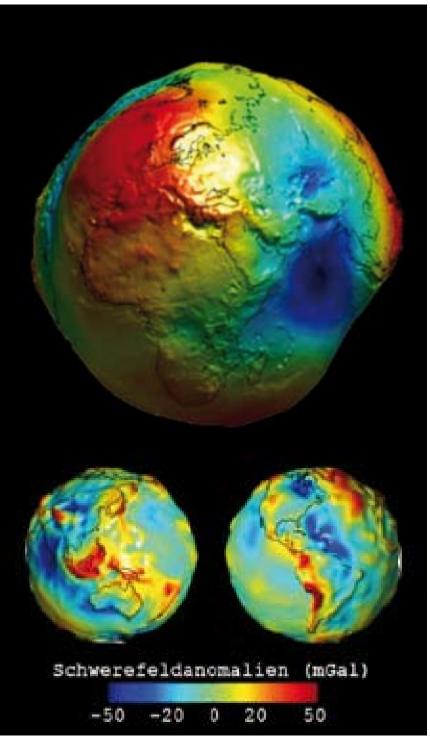
Major highlights were also the two workshops I co-organized, my inspiring research stays at renowned universities, and our visitors' seminar presentations.

Publications

- Pigorsch, C. and Stelzer, R. **On the Definition, Stationary Distribution and Second Order Structure of Positive Semi-definite Ornstein-Uhlenbeck type Processes.** (2009) In: Bernoulli, 15 (3), 754-773.
- Stelzer, R. **First Jump Approximation of a Multivariate Lévy Driven SDE and an Application to ECOGARCH Processes.** (2009) In: Stochastic Processes and Their Applications, 119 (6), 1932-1951.
- Stelzer, R. **On Markov-Switching ARMA Processes - Stationarity, Existence of Moments and Geometric Ergodicity.** (2009) In: Econometric Theory, 25 (1), 43-62.

Satellite Geodesy

Prof. Gerhard Beutler | Hans Fischer Senior Fellow
Dr. Adrian Jäggi | Carl von Linde Junior Fellow



The geoid
gravity anomalies

“Satellite Geodesy” was the first project set up by the TUM-IAS in the framework of the Excellence Initiative.

It is carried by members of the Institute for Astronomical and Physical Geodesy (IAPG) of TUM and the Astronomical Institute of the University of Bern (AIUB) in Switzerland. Prof. Leos Mervart of the Institute of Advanced Geodesy, Czech Technical University, provides the guidance concerning software design. Activities started in fall 2007 with Carl von Linde Junior Fellow Adrian Jäggi and Hans Fischer Senior Fellow Gerhard Beutler spending about half a year at the Institute for Astronomical and Physical Geodesy (IAPG) of the Technische Universität München. Shorter visits followed in 2008, 2009 and early in 2010. In fall 2008 Ulrich Meyer, expert analyst of GRACE data in the GRACE mission team, joined the team from GFZ (GeoForschungsZentrum Potsdam). The project is also supported by the Schweizerischer Nationalfonds (SNF), which sponsored the Ph.D. thesis of Lars Prange with the focus on CHAMP gravity field determination.

Orbit and gravity field determination using the data of the CHAMP (CHAllenging Mini-satellite Payload) mission, of the GRACE (Gravity Recovery And Climate Experiment) mission, and, since its launch on March 17, 2009, of the GOCE (Gravity field and steady-state Ocean Circulation Explorer) mission are central to the project. The analysis methods are, to the extent possible, mission-independent and uniquely based on the foundations of Celestial Mechanics. The data of all missions are analyzed with one and the same method, the so-called Celestial Mechanics Approach (CMA). It was also a declared goal of the project to further develop the CMA and to explore and exploit its full potential for the analysis of the three missions. Politically, it was planned to combine the expertise of the AIUB in Celestial Mechanics with the expertise of the IAPG in terrestrial and spaceborne gravity field determination and validation, to build up a long-lasting collaboration between AIUB and IAPG in satellite geodesy.

Dr. Adrian Jäggi

As judged from today’s perspective, the project was successful well beyond the 2007 expectations:

- A joint proposal to SNF and DFG (Deutsche Forschungsgemeinschaft) of AIUB, IAPG, IGP of ETH (Institut für Geodäsie und Photogrammetrie of the Eidgenössische Technische Hochschule in Zürich), and of swisstopo (Bundesamt für Landestopographie) has the potential to develop the TUM-IAS project “Satellite Geodesy” into a long-lasting activity of a strong consortium.
- The CMA could be established as a central tool for orbit and gravity field determination (Beutler et al., 2010a, 2010b).
- The use of spaceborne GNSS (Global Navigation Satellite Systems) for orbit and gravity field determination was analysed in depth by Jäggi et al., (2009a, 2009b).
- The best CHAMP only gravity field AIUB-CHAMP02S could be established by Prange et al., 2010; an even much better CHAMP-only model is in preparation (to be released in 2010).
- The analysis of GRACE data for static gravity field determination has reached a level of maturity comparable to that of the best analysis groups worldwide (Jäggi et al., 2010a, 2010b). Solutions based on the full available data set will be released in 2010.

The CMA was used as analysis tool by Meyer et al. (2010) to investigate the impact of attitude control on accelerometry and by Zenner et al. (2010a, 2010b) to study the impact of GRACE de-aliasing products on gravity field determination.

Publications

- Beutler, G., A. Jäggi, L. Mervart, U. Meyer (2010a): **The Celestial Mechanics Approach – Theoretical foundations.** In: Journal of Geodesy, in review.
- Beutler, G., A. Jäggi, L. Mervart, U. Meyer (2010b): **The Celestial Mechanics Approach – Application to data of the GRACE mission.** In: Journal of Geodesy, in review.
- Jäggi, A., G. Beutler, L. Prange, R. Dach, L. Mervart (2009a): **Assessment of GPS-only observables for Gravity Field Recovery from GRACE,** In: Observing our Changing Earth, edited by M. Sideris, pp. 113-123, Springer.
- Jäggi, A., R. Dach, O. Montenbruck, U. Hugentobler, H. Bock, G. Beutler (2009b): **Phase center modeling for LEO GPS receiver antennas and its impact on precise orbit determination.** In: Journal of Geodesy, 83(12), 1145–1162.
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- Meyer, U., A. Jäggi, G. Beutler (2010): **The Impact of Attitude Control on GRACE Accelerometry and Orbits,** International Association of Geodesy Symposia, Springer, in review.
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- Zenner, L., T. Gruber, G. Beutler, A. Jäggi, F. Flechtner, T. Schmidt, J. Wickert, E. Fagiolini, G. Schwarz, T. Trautmann (2010a): **Using Atmospheric Uncertainties for GRACE De-Aliasing – First Results,** International Association of Geodesy Symposia, Springer, in review.
- Zenner, L., T. Gruber, A. Jäggi, G. Beutler (2010b): **Propagation of atmospheric model errors to gravity potential harmonics – Impact on GRACE De-Aliasing.** In: Geophysical Journal International, in review.

The most important event in 2009 was the launch of ESA Satellite GOCE on March 17. After ten years of proposals, simulations, and preparations – and after another ten years of work to realize this mission – the satellite was perfectly put into the projected orbit with all instruments healthy and working well. In close cooperation with ten institutes in seven European countries, our group is generating the primary science products of the GOCE mission, i.e. precise orbits and a detailed model of Earth's gravitational field, together with a comprehensive quality analysis. These products will then serve as the point of departure for science applications in the fields of oceanography, geophysics, glaciology, and geodesy.

Last autumn, after a three-month commissioning phase, we carried out our first data tests. Orbits were tested, for example, by comparison with laser tracking from several observatories, and the first attempts were made to analyze the various sensor components and the measured gravitational gradients.

The TUM-IAS project Satellite Geodesy aims at an improved analysis of satellite gravimetric data based on the Celestial Mechanics Approach, originally developed by the AIUB, and extended to gravity field analysis under the TUM-IAS umbrella.

Publications

- Göttl, F., R. Rummel: **A Geodetic View on Isostatic Models,** In: Pure appl. Geophys., 166, 1247-1260, DOI 10.1007/s00024-004-0489-x, 2009.
- Albertella, A., R. Rummel: **On the Spectral Consistency of the Altimetric Ocean and Geoid Surface, A One-dimensional Example,** In: J of Geodesy 83: 805-815, DOI 10.1007/s00190-008-02999-5, 2009.
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Interview of Carl von Linde Senior Fellow Reiner Rummel and Hans Fischer Senior Fellow Gerhard Beutler

by the TUM-IAS team on February 4, 2010.

Introduction

Launched on March 17, 2009, ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) was developed to bring about a whole new level of understanding of the gravity field. Dubbed the "Formula 1" of satellites, this sleek high-tech gravity satellite embodies many firsts in its design and use of new technology in space, to map Earth's gravity field in unprecedented detail. Over its nominal life of 20 months, GOCE will map global variations in the gravity field with extreme detail and accuracy. This will result in a unique model of the "geoid," which is the surface of equal gravitational potential defined by the gravity field.

The GOCE launch on March 17, 2009, was a great occasion, but it only happened after considerable delay. How did you experience the launch? Except for the delay, has everything turned out as expected: height, performance of the equipment, strength of signals?

Rummel The two launch delays (September 2008; March 16, 2009) were very nerve-racking.

Beutler Especially the delay on March 16th was a pity, because I had to leave Munich the next day.

Rummel Nevertheless, it was a perfect launch, and all went well since then. The satellite was set into orbit by the Rockot launcher from the Plesetsk spaceport, located approximately 800 kilometers north of Moscow. Soon it turned out that the injection orbit was close to perfect, with an altitude of 283.5 km, only 1.5 km lower than planned. GOCE would then descend gradually to its operational altitude of around 260 km. After one orbit, about 90 minutes after launch, the first signals were captured by the ground stations. And the main instrument, the gravitational gradiometer, a very delicate instrument, successfully survived the harsh vibrations during launch.

Information: At the heart of the spacecraft is a device known as a gradiometer. This gradiometer contains three pairs of test masses, or accelerometers, positioned at the outer ends of three 50-cm-long orthogonal arms.

You are measuring two main quantities in unison: differential gravitation and position. How do you get the desired data?

Rummel With the successful launch of GOCE, the first gravity gradiometer instrument is in orbit, on the lowest orbital altitude ever for a science satellite. The electric ion engine generates up to 20 mN (milli-Newtons) of ion thrust, which is roughly equal to the weight (on Earth) of a few drops of water. But this is sufficient to enable GOCE to maintain its low altitude. The second gravity sensor device is a newly developed European Global Positioning System (GPS) receiver. From its measurements, the orbit trajectory is computed to within a few centimeters.

Information: GOCE is one of the most challenging space missions to date. Its payload includes a gradiometer and a GPS receiver. To ensure such precise measurements, GOCE's own position must be precisely known at all times. The positions provided via GPS will also supply gravity information through analysis of the perturbations in GOCE's orbit.

1 Accelerometer pair
2 Ultra-stable carbon-carbon structure
3 Isostatic X-frame
4 Panel regulated by heaters
5 Intermediate tray
6 Electronic panel

Beutler The GOCE mission strives for a high-accuracy, high-resolution model of the Earth's static gravity field. GOCE is based on a sensor fusion concept: satellite-to-satellite-tracking in the high-low mode (hl-SST) using GPS, plus on-board satellite gravity gradiometry (SGG). The mission, when successfully completed, will provide a huge data set consisting of hundreds of millions of orbit data (derived from hl-SST) plus hundreds of millions of very precise in-orbit gravity gradiometry data.

Information: GOCE is a low Earth orbiting (LEO) satellite dedicated to sensing the Earth's gravity field with a very high spatial resolution (aiming at an accuracy of 1–2 cm for the geoid). The precise orbit information of low Earth orbiting gravity field missions currently in orbit is mainly provided by GPS-SST (satellite to satellite tracking). All these spacecraft have in common that they carry, in addition to GPS, laser retro-reflectors on board. This points out the importance of Satellite Laser Ranging (SLR) as an independent tracking instrument. SLR is a method to measure distances between SLR ground stations and the GOCE satellite by means of very short laser pulses. The SLR technique can very efficiently be used for the calibration and validation of the Earth gravity mission products, in particular to assess the quality of the GPS-derived orbits.

Beutler We know from these validations that the orbit accuracy is as good as the laser technique itself.

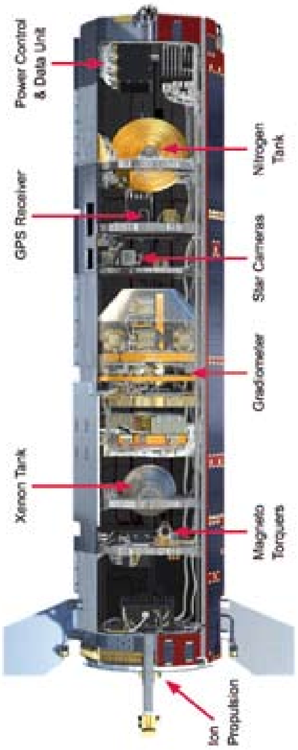
Rummel At the Zimmerwald observatory on Längenberg (Astronomical Institute, University of Bern), Prof. Beutler and his colleagues are able to do such laser distance measurements.

Beutler The Zimmerwald observatory is one of about 30 SLR observatories; undisputedly the one with the most spectacular view – to the Eiger (with the spectacular north wall), Mönch, and Jungfrau mountains. GPS measurements are used regularly to generate kinematic geocentric positions of the GOCE satellite with a spacing of 1 second and with cm-accuracy.

How accurate are your measurements?

Rummel GOCE is equipped with three pairs of ultra-sensitive accelerometers arranged in three dimensions that respond to tiny variations in the gravitational tug of Earth as it travels along its orbital path. The precision of each accelerometer is 10–12 m/s^2. Because of their different positions in the gravitational field, they all experience gravitational acceleration slightly differently. The three axes of the gradiometer allow the simultaneous measurement of six independent but complementary components of the gravity field. There must be continuous compensation for the effect of non-gravitational forces such as air-drag and radiation pressure from the sun. In general, the measurements pretty much meet our expectations. So far, we have slightly less accurate data in the vertical direction. I'm still wondering what the cause could be.

Information: The measurements made by the gradiometer onboard the GOCE satellite are gravity gradients in three directions of space. The vertical gravity gradients computed from the vertical component of the gravity acceleration are classically used in gravity interpretation.



1 | GOCE satellite and instruments
2 | GOCE in orbit

What's the history of measuring the gravity field?

Rummel Measuring the gravity field with satellites began with Sputnik in 1957. It followed a period during which gravity models were derived from a patchwork of orbit segments of many earth satellites. The orbits were obtained from tracking from the ground. In 2000 there was the first dedicated gravity mission: CHAMP generated for the first time simultaneously highly precise gravity and magnetic field measurements.

Are the measurements influenced by non-Earth gravity fields like the gravitation of the Moon, the Sun, and the planets?

Rummel The direct attraction of sun, moon and planets is taken into account. Also the Earth tides and ocean tides are being taken care of.

Beutler Atmospheric drag at this low orbital altitude is, in principle, difficult to model. As the GOCE accelerometers are also used to measure drag in real time and to compensate the main effect by ion thrusters, modeling is easier than in other gravity field missions.

A didactical question: Is documentation on your methods available?

Beutler In 2005 I wrote a two-volume text book on celestial mechanics using about 1000 pages of lecture notes. In this book I focus on aspects like orbit and gravity field determination using GPS, SLR, etc. (Methods of Celestial Mechanics. Vol. I: Physical, Mathematical and Numerical Principles. Vol. II: Application to Planetary System, Geodynamics and Satellite Geodesy. Springer Verlag, Berlin Heidelberg 2005.)

Rummel For gradiometry there is some standard literature, but it is rarely the primary subject in books. Gradiometry is also discussed in some classical physics books.

You get to handle a large amount of data. Have you developed new techniques to deal with them? What has been the experience with such massive data processing?
Rummel The sensors onboard the GOCE satellite collect hundreds of millions observations during the mission period. The observations are used to determine the Earth's gravity field, which will be described by tens of thousands of parameters. Therefore the sheer number of observations and parameters makes the processing of the data a challenge for scientists and software engineers. In order to overcome the computational efforts, we use supercomputers (e.g. at the Leibniz Computing Center, LRZ), and parallel computing techniques come into play.
Information: The satellite gravity gradiometer (SGG) is the core sensor on-board GOCE. It is extremely sensitive to small scale features of the gravity field. What makes processing the SGG observations so difficult is the fact that the SGG observations are highly correlated. For this reason tailored algorithms were derived for the processing of the SGG observations. Digital filters are used to decorrelate the SGG observations. However, in the presence of data gaps, the application of the algorithms is delicate. The need arises to extend the algorithms to be able to safely handle data gaps. These can be roughly divided into short and long data gaps, which require different treatment.

Your aim is to get a good picture of the distribution of masses on Earth. Will you generate maps and data sets that describe that information? What will the results be, and how will you disseminate them?
Rummel A precise knowledge of the geoid is crucial for accurate measurement of ocean circulation and sea-level change, both of which are influenced by climate. Essential new results would show how mass transports in the ocean are functioning, and wheater there are changes over time. With GOCE we are able to contribute to answering such questions. The data from GOCE are also much needed to understand the processes occurring inside Earth. In addition, by providing a global reference to compare heights anywhere in the world, the GOCE-derived geoid will be used for practical applications in areas such as surveying and civil constructions. The last IPCC (Intergovernmental Panel on Climate Change) Report in 2007 was discussing a lack of data. The problems with climate predictions are not due to mathematical modeling, rather to a lack of real data. So the GOCE measurements will be a good way to contribute.
Information: Concerning the use of GOCE data products, five different themes have been distinguished: Oceanography, Solid-Earth, Geodesy, Glaciology, and Sea Level Change studies. For certain applications within these themes, level 1 data products can be used directly, e.g., calibrated SGG observations in certain solid-Earth studies. In certain other applications a spherical harmonic expansion or a linear function of this can be used directly, e.g., in ocean current derivation from satellite radar altimetry, and in precise orbit computations. For some GOCE impact studies, especially level 2 products, other representation forms are needed, such as spherical wavelets.

You are part of the very large GOCE project, responsible for the data processing. How is the collaboration going? How do parties understand each other? How is the leadership arranged?
Rummel GOCE is a very ambitious mission, and many conditions for its success lie at the level of the processing of its data, which for a large part is going to be new to everyone. This implies that special and dedicated care of the data processing be taken, to ensure that the best Earth gravity field model can be delivered to the scientific users. Level 2 is our responsibility. The consortium is composed of 10 European institutes. There's a strict task distribution, and very tightly defined work packages.

Information: These are the bodies that constitute the GOCE project:
*The **ESA project team** is responsible for the management of the GOCE development and the organization and develops the on-board data processing (from level 0 to level 1). The **industry team** is concerned with the realization of the GOCE satellite system as a joint effort of an industry consortium (around 50 companies). The Mission **Advisory Group** advises ESA in all matters concerning the realization and scientific use of the GOCE mission and forms the link between ESA and the science community. (Chairman: Prof. Rummel)*

***The European GOCE Gravity Consortium** is responsible for the determination of the geodetic GOCE gravity products, i.e. the processing from level 1 to level 2. **Science data users** (level 3) are the users of GOCE products in solid earth physics, oceanography, ice research, geodesy, and sea level research.*
Beutler The collaborative work in the consortium is excellent. There are ten European institutions, and all of them have their special skills essential for the success of the mission. They've agreed to join forces and to distribute tasks in an appropriate way. For sure, there are discussions, but in general there's harmony. One reason for this success is the number of young people, including around 50 Ph.D. students. They compete, but as a rule they interact closely and even publish together.
Rummel The young generation found a nice way to cooperate in research beyond institutions and beyond boundaries. They teach each other; they have a certain way to cooperate. That's the secret of their success. We call these young people the follow-up community. We hope that after the mission the young generation of Earth scientists is able to use our measurements to learn more about our planet.

Might this bottom-up approach lack direction?
Rummel In fact, ESA has loosened its rules, but they keep track of our work and check that we do what they want us to do. There are strict quality control rules; e.g. by now Dr. Thomas Gruber from our institute has written about 200 documents to ESA describing the status and changes in software as well as the results of various tests.

Prof. Beutler, you have been part of the GOCE consortium and you are a Fellow of the TUM-IAS just like Prof. Rummel. How have you organized your Focus Group?
Beutler I was invited by Prof. Rummel to join the TUM-IAS in the Focus Group Satellite Geodesy. For our work it is essential that young people are involved; we wanted to create a know-how transfer from our own to the next generation of scientists in this field. Young researchers are developing their careers within the framework of this Focus Group. I hope the collaboration with the TUM-IAS continues and further strengthens the relationship between the Institute in Bern and Technische Universität München. To some extend, I had to change my lifestyle for three years.

I believe that the results achieved will have a long-lasting impact on future developments. We try to work in the Cartesian spirit: The “discours de la méthode”, the development of new and the critical analysis of existing methods, is essential for progress in our field of science.

How does your collaboration work as far as work division is concerned?
Beutler For me it is very important and inspiring to be in Munich together with Dr. Adrian Jäggi. This close collaboration triggered essential developments.
Rummel Prof. Beutler's group is world-leading in the scientific use of GPS. Through the TUM-IAS fellowships we had the opportunity of building a bridge.
Beutler We could easily shift to gravity field determination, because this is nothing other than generalized orbit determination. The result is a truly joint project with focus on gravity field determination using all kinds of satellite techniques.
Rummel I was elected as an TUM-IAS Fellow three years ago. Since January 1, 2010, I feel like a real Fellow, because I don't have the responsibilities of leading an institute any more. The last few years I had a lot of management tasks. It has not been easy to get back into doing real research.

Do you sit together daily or weekly?
Rummel Prof. Beutler and I have daily contact. Either we have a cup of coffee in the morning, or we meet for a beer or dinner. This is our communication style. Of course we have also many formal ESA meetings.

And what is the secret of your efficient collaboration?
Rummel Prof. Beutler is a typical Swiss clock maker; he is never satisfied with his work, so long it is not perfect. By contrast my brain works by imagining new things. But we made the experience that we have a good collaboration between very different types of people. To make a long story short: He's a scientist, I'm an engineer.

Prof. Rummel, from a scientific point of view the present period must be a dream come true. Is your scientific work thereby reaching its goals, or are´there new issues emerging at the horizon?
Rummel I do not consider myself the inventor of the method, but I am indeed the author of several of the first papers on this subject, and I am more than happy that this launch happened. But there are still future challenges. We have to think about future missions. There are several goals to reach: a better spatial resolution, a better temporal resolution, and cross-fertilization with fundamental physics. It has predicted the existence of gravity waves, and to measure them fundamental physics uses the same type of technology. In the future I will not be the initiator, but at best the senior advisor of the young ones for new missions. I want to push the idea of establishing a global geodetic observing system. This is currently being implemented.
Beutler All the experiences gained in the analysis of the GOCE mission may be used for planning future gravity missions.

What is your view on the status quo of the TUM-IAS and the future role the TUM-IAS has to play at TUM?
Beutler We've been the first TUM-IAS Fellows. It was inspiring to be given the opportunity to work in such a special environment without daily obligations.
Rummel Being an TUM-IAS Fellow is a tremendous privilege. The biggest attraction is to be freed from daily duties. My idea for the future would be to proceed in giving space to talented people to do free thinking, even if they are people with crazy ideas. There should not be too much control, and failures should be allowed. For example, satellite projects take a long time, and the risk is high that they do not work.
Beutler My time as an TUM-IAS Fellow has also had an impact on our institute in Bern. The bridge between engineering and natural sciences is of particular interest.

Keynote Contribution

New Directions

Research Areas and New Focus Groups

Instrumentation

Start-up Funding

Industry Cooperation

Collaborations

Prof. Anuradha Annaswamy | Hans Fischer Senior Fellow

Report of the Workshop "Impact of Control: Past, Present and Future"

An international workshop on the "Impact of Control: Past, Present, and Future" was held during October 18-20, 2009, at the InterContinental Berchtesgaden Resort, Berchtesgaden, Germany, and was partially funded by TUM-IAS. Other major sponsors included Cognition for Technical Systems (CoTeSyS), IEEE Control Systems Society, the Deutsche Forschungsgemeinschaft, and the National Science Foundation of the United States. Seventy leading experts invited from all over the world – from academia, government, and industry – attended the workshop and broadly addressed the topic of the impact of control. Participants discussed a range of topics including the successes of advanced control in practice, new and emerging control technologies, grand challenges for the future, research opportunities, and barriers to technology transition.

Held over two and a half days, the workshop addressed the impact of control using two distinct viewpoints. The first was application-based. Participants were grouped into seven sessions: Aerospace, Automotive, Biological Systems, Manufacturing Automation and Robotics, Networked Systems, Process Industries, and Renewable Energy and the Smart Grid. After a day of deliberations, the groups made their presentations summarizing the control achievements, grand challenges, and research opportunities in their particular domains of application. The second approach addressed the workshop topic with a thematic flavor. Related breakout sessions were organized on topics such as Application and Market Requirements, Cognitive Control, Controls Education, Implications for Research Communities, Outreach and Visibility, and Tools and Platforms. Following extended deliberations, session chairs presented key issues related to their topics and their recommendations. Plenary lectures were given by Dr. Peter Terwiesch, Chief Technology Officer of ABB, IEEE Field Medal Winner Prof. Karl Åström from the Lund Institute of Technology, and Dr. Alkis Konstantellos, the European Commission's Deputy Head of Embedded Systems and Control, on the industrial, academic, and government perspectives, respectively. A panel discussion, addressing final thoughts and comments of the participants, closed the workshop.

Significant pre-workshop preparation took place to help carry out the ambitious agenda. Given the broad scope in topics and in content, care was taken to ensure several aspects including the selection of participants who have played leadership roles in their domains, communication of guidelines to these participants in terms of questions that needed to be addressed for session deliberations, and identification of session chairs who would assemble and engage their groups in an extensive dialogue on these questions. These preparations helped the workshop participants to hit the ground running and arrive at a consensus on the impact of control, key achievements, opportunities, and recommendations.

Currently a comprehensive report is being prepared that summarizes the findings of the workshop. We expect the report to be disseminated this spring, both internally within the controls community and externally to various institutions and organizations.

A few highlights of the report related to Grand Challenges in application domains are indicated below.

Aerospace
- Improving autonomy in aeronautics and space exploration
- Enabling new areas and missions via cooperative and distributed control

Biological Systems
- Design of a fully autonomous artificial organ that includes networks of molecular components, biomaterials, and algorithmic designs
- Understanding and treating diseases (e.g. predictive cancer therapy, development of autologous bone and cartilage implants)

Manufacturing Automation and Robotics
- Direct human control of robotic systems (e.g. prosthetic limbs, physical and cognitive assistive robots)
- Smart Factories: Automation systems that are flexible, reconfigurable, robust, self-adjusting

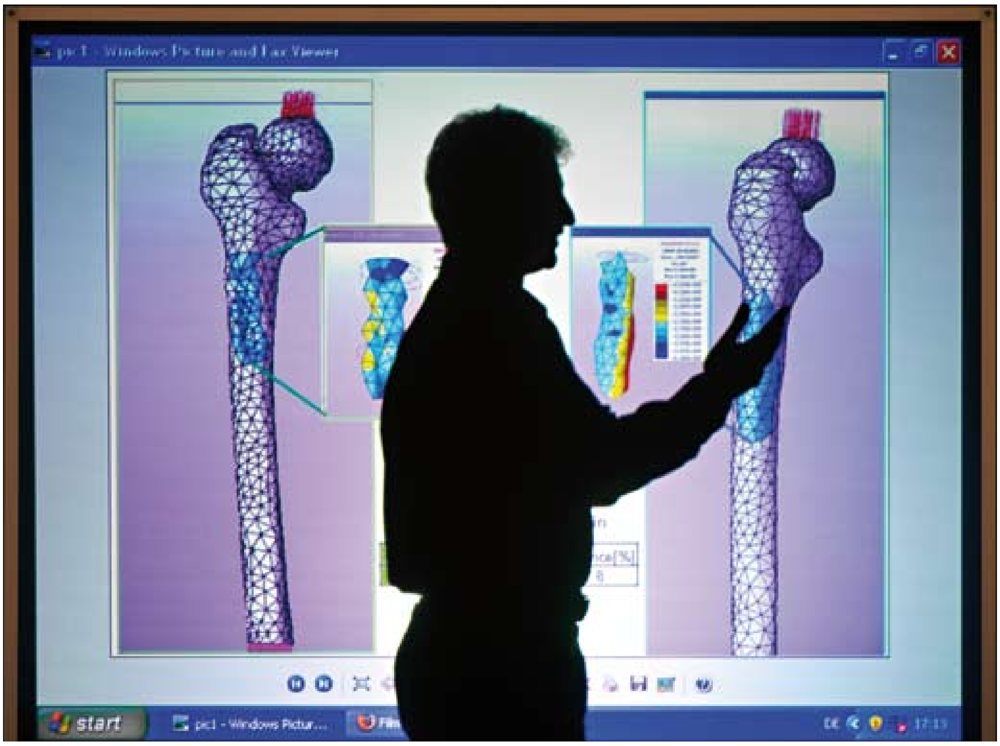
Process Industries
- Saving energy and reducing carbon emissions: Mitigating climate change is perhaps the grand challenge of the 21st century, and the process industries are major users of energy and major emitters of greenhouse gases.
- Very large-scale integrated process control (VLSIPC): The use of economic performance optimizing model predictive controllers is considered a big trend for the future and also ties into energy savings and greenhouse gas emission reduction.

Renewable Energy and the Smart Grid
- Control technologies for demand response control with price signals, communication network design, and rapid fault detection and accommodation
- Improved efficiency and cost of renewable energy sources and storage via control.

The workshop also identified two cross-cutting areas for future research in the community:
- Networked Systems: A key challenge in networks of cooperating agents is the characterization of their fundamental limitations and capabilities, which may depend on the underlying topologies of the networks, the capacities of the communication links, the dynamics of each node, and the computational and storage resources available to each node.
- Cognitive Control: A typical problem concerns adaptive management of cognitive resources under time constraints, and how generalization from a particular application can be carried out to a generic theory to realize flexible attention-inducing decision-making strategies.

Research Areas and New Focus Groups

Research Areas



Although the TUM-IAS constitutes itself through the nomination and selection of outstanding Fellows, natural clusters of Fellows and Focus Groups around some major “Research Areas” are emerging. This process is the result of some mutually strengthening forces. Fellow nominations are often the result of exploratory workshops in which new scientific and technological avenues are discussed – the Institute has strongly supported these workshops. Although it does not want to “manage science,” it wants to create opportunities for great new ideas. The nominated Fellows in turn have a strong drive toward further consolidation of their own insights and those that have been obtained through contacts with each other, such as through group discussions and interactions with their host Focus Groups. We form an evolving community, driven by the personality of our Fellows, who let themselves be influenced by the manifold of contacts and experiences they establish and the scientific possibilities that open up. At the moment the Institute has consolidated the following major Research Areas, responsible for just over half of its activities.

Nanoscience

This Research Area is being developed by five Focus Groups, with interests in new nano-scale devices, quantum dots and photonic sensors, new fabrication methods (in particular nanoimprint technology), and the study of quantum surface properties. Our recently appointed Carl von Linde Senior Fellow Gerhard Abstreiter is providing leadership for this Research Area in a very concrete way, by heading the new Center for Nanotechnology and Nanomaterials in Garching in which all these Focus Groups (and many other research units) will find high-class experimental floors where new physical phenomena can be explored, new nano devices fabricated, and new instrumentation built.

Understanding Intelligence

The importance of "understanding intelligence" has been largely underestimated by the research community, resulting in poorly understood system behavior, incorrect statistical methods, and a dramatic lack of insight in how intelligent biological systems like the human brain are constituted at the system level. TUM-IAS wants to remedy that situation. Foremost in the intelligence area is the Focus Group on Cognitive Technology, including five fellowships hosted by Prof. Martin Buss (also leader of the CoTeSys Cluster of Excellence) and Prof. Sandra Hirche.

Our Intelligence work also has a very strong effort going on in the direction of understanding how biological neural networks function, how neural activity relates to observed behavior, and how neural activity can be measured *in situ*. Carl von Linde Senior Fellow Arthur Konnerth and Hans Fischer Tenure Track Fellow Thomas Misgeld are coordinating this topic. Another important ingredient in the handling of Intelligence is statistical modeling. We have a major effort going on in this area under the leadership of Carl von Linde Senior Fellow Claudia Klüppelberg, who has been exploring the handling of the non-Gaussian statistical models that permeate our modern systems and require new methods of estimation and control.

Biomedical Engineering and Instrumentation

This Research Area accounts for at least one-third of the activities of the Institute, with many Focus Groups participating in it. Although just as in the previous Research Area, there is not one single leadership exponent appearing, we have several strong poles. Our recently nominated Carl von Linde Senior Fellow Axel Haase has taken up the directorship of IMETUM and will focus that Institute in a renewed manner towards Biomedical Instrumentation, much in the same way as our Carl von Linde Senior Fellow Gerhard Abstreiter is setting up the new Center for Nanotechnology and Nanomaterials. TUM-IAS is very much appreciative of such consolidation efforts as they may lead, for example, to new and impressive medical diagnostic instruments.

Besides diagnostic instrumentation for medical purposes, and closely related to it, we are also developing new manipulative instrumentation. There is the effort to develop haptic micro- and nano-robots led by our Hans Fischer Senior Fellow

Mandayam Srinivasan of MIT. A recently formed Focus Group on Clinical Cell Processing and Purification aims at the development of clinically usable cell processing equipment and is lead by our Host, Prof. Dirk Busch. Major efforts are under way to control the production process of new proteins (under the direction of our Carl von Linde Senior Fellow Horst Kessler) or to utilize the properties of DNA as a building block for integrated systems (by our Carl von Linde Junior Fellow Ulrich Rant). The work on Neurophysiology of Fellows Arthur Konnerth, Bert Sakmann, and Thomas Misgeld already mentioned earlier is relevant to this Research Area as well, and so are computational methods developed to model biological systems ranging from large mechanical structures such as bones, muscles, and neurons to the genetic mechanisms that drive the generation of new types of proteins and even cells. We mention the work of our Fellows Zohar Yosibash, Burkhard Rost, and Marco Punta in this respect.

Other Research Areas can be considered “in statu nascendi” at the Institute, in that they have not truly consolidated yet in poles with a larger critical mass. We mention:

Large-scale Modeling and Computing

Much science is devoted to modeling, so much so that modeling has become a technology in its own right. We dispose of an arsenal of classical methods such as finite elements to do the modeling effectively, economically, and mathematically correctly. The difficulties start as soon as truly large-scale or heterogeneous situations must be considered. Discretization creates its own issues as well, and so does the combination of dynamic (time-) evolution with behavior in space. One very promising way of handling these questions is to forge a tight integration of physical with mathematical (numerical) properties. The physics may guide the multilevel abstractions dictated by a multi-scale approach.

A very good example is given by the way our new Hans Fischer Senior Fellow Zohar Yosibash and his Host Prof. Ernst Rank handle bone modeling. Our recently awarded Hans Fischer Senior Fellow Peter Schröder looks at physically sound discretization methods that preserve essential properties, while many of our Fellows are handling large-scale modeling problems directly. For example, our Rudolf Diesel Industry Fellow Dragan Obradovic works with TUM research units at understanding the modeling and control of wind parks, wind-driven power plants whose performance is not only dependent on the availability of wind, but also is strongly influenced by interactions between wind mills (wakes). Large-scale computing is also the rule of the day in our Focus Group on Satellite Geodesy, which has to solve an “inverse problem”: computing mass distributions on Earth from gravity and position measurements made by and on a revolving satellite. Similarly, our newly formed Focus Group on Computational Biology headed by Humboldt Professor and TUM-IAS Fellow Burkhard Rost has to handle and interpret large amounts of genetic data, and so has the start-up genetics group of Prof. Chris-Carolin Schön, who derives phenotypical behavior from genetic data.

Although all these are large computational efforts, it may not be obvious what one has to do with the other. Such a question may seem hard to answer at a higher level of abstraction, but anyone who has taken the pains to go through the detailed calculations and data management will discover common math ematical techniques. This makes it worthwhile for the involved researchers to collaborate and exchange experience.

Environmental Engineering

The TUM-IAS has been a strong supporter of the activities of Emeritus of Excellence, TUM-IAS Board Member, and Stockholm Water Prize Winner Prof. Peter Wilderer. In 2008 TUM-IAS organized the international workshop on “Earth System Engineering: the Art of Dealing Wisely with the Planet Earth,” which led to the famous “Zugspitze Declaration” and the creation of the International Working Group on the Preservation of the Earth (IESP), an independent organization that aims at promoting research in Geo-engineering and of which TUM-IAS is a founding member. The IESP has defined four “Crisis Areas” to which it wants to devote its main attention (Energy, Water, Biodiversity, Society). The support of the TUM-IAS to the IESP is mainly geared towards the organization of workshops exploring the science and technology needed to address the defined crisis areas.

The TUM-IAS has at least four Focus Groups devoted to aspects of Environmental Engineering, and will cultivate this area further within its framework. We mention the work of our Carl von Linde Junior Fellow Julia Kunze with her impressive work on Catalysis for Fuel Cells. Recently we awarded a Carl von Linde Senior Fellowship to Ulrich Stimming, who will lead the efforts of our Institute in the area of Sustainable Energy. Our already mentioned Rudolf Diesel Industry Fellow Dragan Obradovic is developing a distributed control system for power generation, a topic of great interest for his company Siemens and of course an important contribution to “Green Energy.” Economy plays an important role in the energy equation. Not only is there the issue of controlling a distributed network with a large number of green generating stations (such as wind farms), there is also the issue of understanding the overall economic equation connected to selling and buying energy in such a system, not to mention the design of the overall system. Our Focus Group in Risk Analysis and Stochastic Modeling is heavily engaged in these questions. Last but certainly not least, we mention the efforts of our Hans Fischer Senior Fellow Anuradha Annaswamy in developing new paradigms for combustion motor control, as well as her leadership in developing new topics in Advanced Control.

These substantial Research Areas have strong intersections with each other and certainly do not form a hierarchical clustering. We should, on the contrary, rather speak of a matrix structure, many Focus Groups participating in and contributing to more than one Research Area.

Advanced Computation

In 2009, TUM-IAS has nominated two Hans Fischer Senior Fellows who are concentrating on advanced computational methods and are forming a new Focus Group. Hans Fischer Senior Fellow Matthew Campbell is developing new techniques for representing and evaluating mechanical designs with Prof. Kristina Shea of the Faculty of Mechanical Engineering, and Hans Fischer Senior Fellow Peter Schröder is concentrating on new physico-geometric representations for large discretized systems with Host Prof. Rüdiger Westermann.

Computational Biomechanics

As a Hans Fischer Senior Fellow, Zohar Yosibash will enhance the long-lasting collaboration with Prof. Ernst Rank, head of the Institute of Computational Engineering at TUM. This collaboration is hoped to lead to the development of patient-specific computer-aided quantitative planning and analysis tool that will assist orthopedists in diagnosis and treatment of bone diseases.

Computational Biology

Recently, TUM had the pleasure to welcome Prof. Burkhardt Rost as its first Alexander von Humboldt Professor. In this capacity, Prof. Burkhard Rost becomes automatically a Fellow of the Institute and his group a Focus Group of the Institute under the name Computational Biology. TUM-IAS welcomes Marco Punta as Carl von Linde Junior Fellow in this Focus Group, which will concentrate on the analysis of genomes in the context of genetic evolution.

Clinical Cell Processing and Purification

Prof. Dirk Busch from the Faculty of Medicine has brought his large Institute on Cell Processing and Purification into the context of the TUM-IAS with the nomination of Hans Fischer Senior Fellow Stanley Riddell of the University of Washington in Seattle and Carl von Linde Junior Fellow Christian Stemberger. TUM-IAS welcomes this impressive activity with great enthusiasm and hopes to contribute in this way to a substantial improvement of individualized, cell-based therapeutic methods.

Nanoimprint and Nanotransfer

Nanoimprinting is a new technology that allows relatively cheap realization of new nano-devices and nanostructures and could become one of the work horses of future nanoscience. Prof. Paolo Lugli has been pioneering this technique at TUM and has substantially contributed to its development through the invention of new imprinting instrumentation. He will be hosting a TUM-IAS Focus Group devoted to this technique and to more general issues of fabrication of nano-devices. The Focus Group enjoys the strong support of Rudolf Diesel Industry Fellow Khaled Karrai, who is contributing with expertise and instrumentation ideas, and recently awarded Hans Fischer Senior Fellow Wolfgang Porod of Notre Dame University, who will concentrate on original devices in magnetic computing and high-frequency electronics.

Molecular Aspects in Interface Science

In Interface Science the properties of usually two adjacent condensed phases are investigated. Such properties are important in materials science (e.g. stability of

alloys with heterogeneous crystallites), energy conversion (e.g. photovoltaic cells, fuel cells, etc.), catalysis and electrocatalysis (promotion of interfacial reactions). In all examples given, nanostructures play a very important role, since nanostructures supported on other materials are expected to revolutionize electronics, energy conversion, and materials science in general. The research centers on the investigation of nanostructured surfaces at the solid-liquid interface. The main focus lies in basic understanding, but the potential for materials, energy conversion, and electrocatalysis in the context of nanoscience is also being pursued.

Functional Nanosystems

Carl von Linde Junior Fellow Ian Sharp's program of research focuses on the formation and study of bioelectronic and biophotonic systems formed by covalent grafting of photosynthetic reaction centers onto silicon carbide (SiC) semiconductor substrates. The aim of this work will be to develop a comprehensive and fundamental understanding of charge transfer processes occurring at the bio-inorganic interface and to exploit such findings for formation of multi-functional structures at the nanoscale.

Nano-scale Control of Quantum Materials

Hans Fischer Senior Fellow Douglas Bonn from the University of British Columbia (UBC) is focusing on the synthesis and physical properties of transition metal oxides, the high-temperature superconducting cuprates in particular. This research is now entering a new era in which it is apparent that the strong correlations and tunabiltiy can lead to large effects at surfaces and interfaces. The UBC-TUM collaboration brings together Bonn's work on the transition metal oxides with Prof. Johannes Barth's work on scanning tunneling microscopy and spectroscopy.

Instrumentation

TUM-IAS has a strong motivation to stimulate the creation and development of new instrumentation. Instruments drive the advance of science and often embody what science can contribute to society, in particular in areas such as medicine and nanotechnology. Since the development of new instrumentation is costly both in terms of funds and efforts, TUM-IAS has decided to invest the bulk of its material outlay in novel efforts of excellent instrument developments proposed by its Focus Groups. In 2009 three major developments of this kind have taken place. They are described in this section.

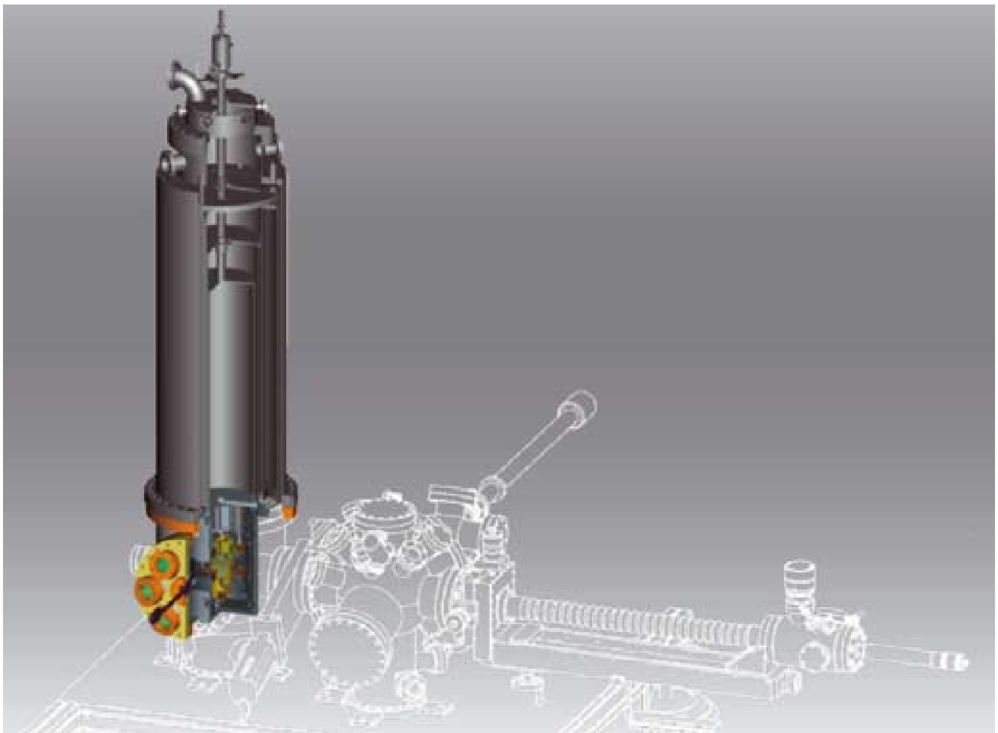
Scanning Tunneling Spectroscopy

Prof. Johannes Barth Host, Molecular Nanoscience and Chemical Physics of Interfaces, TUM
Prof. Douglas Bonn Hans Fischer Senior Fellow, University of British Columbia

Sub-one-Kelvin High-Resolution Scanning Tunneling Spectroscopy for Direct Studies of Quantum Materials

The scanning tunneling microscope (STM) stands out for its very direct ability to probe and manipulate matter on the atomic scale. This versatile instrument allows for the highest spatial resolution and also the ability to measure the electronic spectrum at each point in the surface image, what is now known as Scanning Tunneling Spectroscopy (STS). Since the properties of materials are largely governed by their electronic states, a local picture of the spectrum of electrons, with picometer-level spatial precision, provides a level of information that was unheard of even a few years ago. A cryogenic STM / STS instrument can be enhanced with a wide range of other capabilities that open up fascinating possibilities. We are realizing such a setup, providing unique opportunities for cutting-edge research. Thus over the past year a novel scientific apparatus optimized for spectroscopy in the sub-one Kelvin temperature range was planned and is close to realization.

The prototype instrument, based on a design of Prof. Wulf Wulfhekel of Karlsruhe University and built by the company Specs, will allow measurements at temperatures down to the sub-one-Kelvin range, which are made accessible by a Joule-Thompson cryostat. This is achieved while the size of the experimental setup is kept the same as that of commonly employed standard liquid helium cryostats operated at 4-10 K. Thus one overcomes a major drawback, namely the extensive space demands and investments required for other sub-one Kelvin cooling systems. The reduced operating temperature (< 1 K) of the system offers crucial advantages that are essential for high-resolution spectroscopic work on quantum materials. It is an asset for highest spatial resolution since it practically eliminates all thermally activated atomic Brownian motion on both sample and tip. Furthermore the achievement of sub-one-Kelvin temperatures will allow us to access sample properties truly dominated by quantum phenomena.

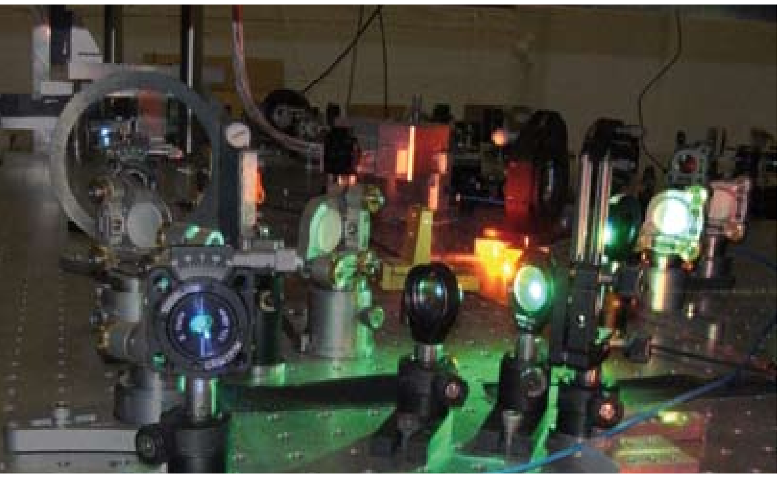


The core piece of the instrumentation – that is, the head and control eletronics of the scanning tunneling microscope, designed for highest signal stability – was purchased with TUM-IAS support. A unique feature of the preparation facilities combined with the STM is the possibility of evaporating material *in situ* onto the sample while the sample is in the cryogenic environment. In addition, the setup is suited for experiments with novel quantum materials in the future, using an *in situ* cleaving mechanism. With this mechanism, clean and well-defined surfaces can be produced at variable temperature, a critical point for the controlled production of superconductor or oxide samples.

We are looking forward to delivery at the end of March 2010 and will subsequently start the assembly and testing phase. First experiments are expected to be carried out by spring or summer of 2010.

STED microscope

Prof. Andreas Bausch Biophysics, TUM
Prof. David Weitz Hans Fischer Senior Fellow, Harvard University



Center for Nanoscopy and Nanomanipulation

The functionality of biological systems is based on the fundamental building blocks of life – the proteins. Being only a few nanometers in size, they are amazing examples of nanomachines. Man-made efforts of nanotechnology still fall short in designing similarly effective and complex machines. The orchestrated local and dynamic interactions of the proteins are the essence of biological functions. To observe processes on this scale, optical microscopy is still the most widely applied method.

The most serious restriction of this method is the Abbey diffraction limit, which restricts the resolution to about the wavelength of the light utilized. SEM (scanning electron microscopy) and TEM (transmission electron microscopy) use much lower wavelengths and can therefore resolve structures in the sub-nanometer range, but they are not compatible with physiological (or biological) conditions. Near field scanning microscopy is not subject to the Abbey diffraction limit, but it is restricted to surface-bound molecules and therefore is not compatible with the most important subjects of study in biophysics, namely cells.

In an exciting new development, the group of Prof. Stefan Hell, MPI Göttingen, invented the field of super-resolution optical microscopy techniques, namely Stimulated Emission Depletion (STED) – with which it had been demonstrated that dynamic processes can be observed at video frequency and with spatial resolution of about 30 nanometers. Super-resolution optical microscopy should therefore revolutionize cell biophysics in a way comparable to what TEM or phase contrast microscopy did.

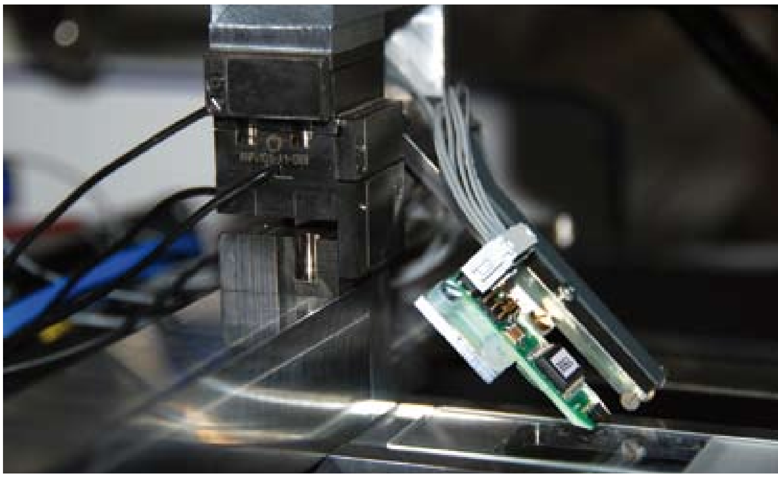
The goal of our start-up project is to self-build and implement a central Nanoscopy facility and complement it with mechanical nanomanipulation techniques – such as optical tweezers. The technique will be applied to understanding the mechanical properties of *in vitro* and *in vivo* biological systems. Reconstitution and adequate labeling of actin bundles will enable us to determine the distribution of crosslinking proteins and the effect of mechanical forces on it. Labeling of crosslinking protein fascin will enable us, to observe in real time the buildup of filipodia and the incorporation of fascin into these cellular structures. Simultaneously, the combination of nanoscopy with optical tweezers will enable us to manipulate and deform the specimen under study – e.g. deforming a growing filipodial tip of a moving cell – and to observe the resulting deformation field with a sub-diffraction resolution.

TUM-IAS start-up funding for the central Nanoscopy facility is thus bringing different sciences together. The facility will be accessible to all interested groups, and special care will be taken in constructing the instrument to make it as user-friendly as possible. To this end the instrument will be based on a white laser source, with reliable turn-key properties – instead of using, for example, a technically more advanced femtosecond laser source.

Telehaptics for Nanoassembly

Prof. Mandayam Srinivasan MIT
Andreas Schmid Institute of Automatic Control Engineering, TUM
Stefan Thalhammer Helmholtz Center;
Ramesh Yechangunja Yantric, Inc. USA

The multidisciplinary research in this project, which we started last year, is driven by the following basic question: Is it possible to develop a system of computer interfaces through which a user can be immersed in nano-scale environments so as to make touching, manipulating, and assembling nanostructures as easy as handling objects in our macroscopic world? The expectation is that just as the light microscope extended our vision into the micro-world, such a system will extend our reach into the nano-world to enable "learning by doing" in nano-scale. The first version of the system capable of operating at nanoscale has been built, but it is being used to explore micro-scale phenomena to start with.



As our first target application, we selected micromanipulation of biological cells. For that purpose a robotic Master – Slave teleoperation system was developed to enable a human operator to touch, grasp, and move cells several microns in size. The Master consists of a single Phantom haptic interface (SensAble Technologies). Through a computer system and appropriate controllers the Master is connected to a small robotic arm capable of moving at resolutions finer than a micrometer. This Slave device consists of piezo-actuator-based nanopositioners (attocube systems AG) that carry a microgripper (Femto Tools) with force sensing capability. By operating the Master at human scale, the human user can control the position of the gripper with four degrees-of-freedom (three spatial directions plus one rotational) at 10-nm resolution and feel the measured gripping force at a resolution of 1 μN as it is scaled by a user-defined factor. To impart visual feedback, the Slave system is placed below a stereomicroscope with a magnification of 150x, which is connected to a video screen that the user can see while operating the Master.

Initial experiments have been carried out utilizing polystyrene beads with diameters of 10, 45, and 75 micrometers in aqueous environment, where they could be successfully gripped, moved, and stacked. However, a major obstacle for precise, reliable, and intuitive handling of microparticles is due to adhesion phenomena. In the micro-world, gravity is not the dominant force as in the macro-scale, and short-range forces such as van-der-Waals and electrostatic forces become significant. Therefore an object grasped by the microgripper tends to stick to the gripper even after release. Several measures have been taken to overcome the adhesive forces, including special coatings to reduce affinity of the particles to the gripper and increase those to the ground. Another approach involves application of small electric fields to release the object from the gripper. Finding suitable methods to accomplish precise release of microparticles is a challenge that is being pursued in this project at present.

We thank TUM-IAS for enabling this research and providing the financial support. We also want to gratefully acknowledge additional support in terms of space and knowledge from Dr. Stefan Thalhammer's group at Helmholtz Zentrum and Prof. Martin Buss's group at TUM.

Publications

- Srinivasan MA and Zimmer R, **Machine Haptics**, In: Squire LR (ed.) /Encyclopedia of Neuroscience/, Vol. 5, pp. 589-595, Oxford: Academic Press, 2009.
- Kyung K-U, Lee J-Y, and Srinivasan MA, **Precise Manipulation of GUI on a Touch Screen with Haptic Cues**, In: Proceedings of the Third World Haptics Conference, Salt Lake City, Utah 2009.

Start-up Funding

The special TUM-IAS budget for Materials is divided into a fund for developing new instrumentation (described in the previous section) and a fund for new initiatives, called start-up funding. Any TUM research unit, TUM-IAS Focus Group, or Fellow may propose a start-up project. The goal can be “exploration of new research topics,” “investment in necessary new equipment,” “organization of a special workshop or conference,” “setting up an attractive collaboration with a research group elsewhere,” “preparation of a major program for EU, DFG, or BMBF,” or any other topic deemed worthwhile and fitting the Institute. The Management Team of the Institute evaluates the proposals on their value and awards budgets depending on the needs and possibilities of the requesting Focus Group. It informs its Advisory Council of these decisions and explains the motivation for acceptance or rejection. Following is a list of projects awarded start-up funds, with a short description of each. This system of start-up funding has proven to be uniquely effective in getting new initiatives hatched.

Imaging System

Prof. Thomas Misgeld, Prof. Arthur Konnerth, Prof. Bert Sakmann
Neuroscience Focus Group

A central feature of the activities of the TUM-IAS Neuroscience Focus Group is work with living animals, including surgery and behavioral characterization. In order to make such experiments possible with minimal stress for the animals, it is important to keep animal recovery and maintenance facilities on-site near the recording setups. Unfortunately, the delicate optical and electrical equipment needed for *in vivo* experiments is easily damaged by dust originating from animal cages. We therefore had to find a “high-tech” solution for this problem. With help of TUM-IAS start-up funds, we acquired ventilated cabinets that allow adequate short-term maintenance of animals near the recording setups during behavioral testing and after surgery. With this support, we have now established a centralized animal behavior laboratory that is conjunctly used by all members of the TUM-IAS Neuroscience Focus Group, and which has especially allowed the Sakmann lab to build up a sophisticated behavioral assay of cortico-thalamic sensory processing.

Molecular Tissue Analysis

Prof. Karl-Friedrich Becker, Prof. Heinz Höfler Institute for Pathology, TUM

In most hospitals worldwide, clinical tissues are typically formalin-fixed and paraffin-embedded (FFPE). New approaches and developments in targeted cancer therapy have raised the need to establish novel tools for precise protein quantification in FFPE tissues. New techniques capable of detecting the entire spectrum of deregulated pathways in tumors before, during, and after treatment are required to assess success or failure of targeted therapies, and also to help determine why only subsets of patients respond to individualized treatments.

In the start-up project "Molecular Tissue Analysis," the Institute of Pathology at the Technische Universität München aims to establish and optimize methods for relative and absolute protein quantification in FFPE tissues, with special emphasis on signaling pathways in breast cancer.

Using a recently developed technology for extraction of full-length proteins from FFPE tissues, we evaluated more than 50 commercial antibodies for specificity in lysates from FFPE breast cancer samples in Western blots and reverse phase protein arrays (RPPA). Purified Human Epidermal Growth Factor Receptor (HER) proteins were used for measuring absolute protein concentrations in FFPE tissue extracts. We confirmed specificity of 35 commercially available phosphospecific and non-phosphospecific antibodies using Western blots with protein extracts from cell lines and tissue extracts from breast cancer patients. Spiking known amounts of purified HER receptor proteins in HER-receptor negative tissue extracts allowed us to precisely measure abundances of HER receptors in FFPE breast cancer tissues using RPPA technology. Adequate controls were designed.

While progress has been made in understanding the role of proteins as important markers for many diseases, robust quantitative analysis of protein biomarkers in human tissues is still difficult in routine clinical settings. Hence, the results of our start-up project will serve as a basis for the development of *in vitro* diagnostic techniques for the quantitative measurement of deregulated HER receptors and downstream signaling proteins in most hospitals.

Technology Push

Prof. Klaus Diepold Institute for Data Processing, TUM
Steven D. Edelson Shadow Laboratories, USA

The Goals
Our start-up project explored a new method to increase the flow of technology from university research labs to industry. A secondary goal was to provide industry input on initial ideas and sponsors for future research.

Background
University Technology Transfer Offices (TTOs) work hard to get innovations to industry. In reality, however, they transfer only a small proportion of university patents. Further, patents cover only a small fraction of all research results and innovations originating within universities. Many innovations have no known applications. This gap is a barrier to the TTO, summed up in the simple question, "What is it good for?" TTOs try to bridge this gap from both ends. Their biggest effort is to present research results to industry representatives and hope that they will recognize a relevant innovation. In a smaller effort, the TTO personnel try to guess applications and contact appropriate companies. Because most applications are hidden in a myriad of industries scattered around the world, neither the TTO staff nor a few industry representatives can adequately cover the required knowledge range.

The Approach
To increase the scope, the project proposed a new Web site targeted to a wide audience of citizens around the world. Visitors are encouraged to suggest applications based on their experience. They do not need to be in positions to purchase or use the innovation – their role is only to identify and discuss possible applications. The site would not offer any explicit compensation. If properly structured, the Web site could harness the voluntary energy abundant on the Internet. The site would follow the techniques of other knowledge-building sites such as Wikipedia.

Without monetary competition, ideas could be posted openly from people all over the world. In such an open forum, the ideas would be visible for enhancements, corrections, and vetting by other visitors. Further, if the site highlights ongoing research areas as well as patented property, visitors can give valuable real-world feedback to inspire researchers for future work and for building up new industry-sponsored research projects.

The Results
The project found that current Internet tech transfer sites do not target third-party "citizen" forums as explored here. They chiefly advertise or aggregate patents for purchasers, automating the industry visitor model.

Interviews with leading-edge TTO offices in the U.S. and Europe confirmed the appropriateness of the proposed methods and the value of the projected results. The TTOs were all willing to participate at varying levels, from simply participating with content to actively participating in design and implementation.

Success of the site depends on implementation and marketing, not technical issues. The site needs a sufficient volume of technology and a large volume of participating readers.

The technology to be transferred needs to be presented in a manner appropriate for a large, volunteer audience – it needs to be easy to read and to be informative to the reader. Volunteers will not labor through dense technical jargon.

Widespread usage requires widespread knowledge of the site by citizens around the world. Participation by multiple universities from diverse regions of the world could facilitate public relations and broaden the audience.

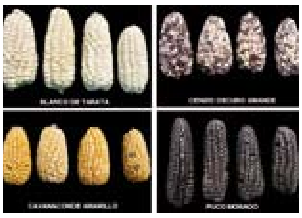
The Next Steps
We plan to implement a pilot system for a select set of pilot universities, focusing on three key aspects:

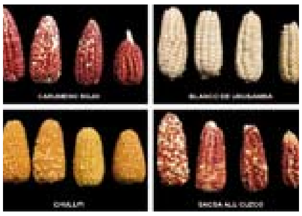
- An on-line system with ease of use for both university authors and citizen visitors
- Content formats designed to maximize readership and suggestion quality from visitors
- Publicity messages and techniques to grow large visitor bases.


EXIT AND PAY!
HAVE A NICE DAY!
CASH & CARRY
RUNNING
TUMSHI
SPECIAL
BASIC
WIZZ
Take away Technology

Understanding Complex Biological Systems

Prof. Chris-Carolin Schön Plant Breeding, TUM Center for Life and Food Sciences, Weihenstephan





The profound understanding of complex biological systems will be key for meeting the challenges of the future with respect to providing sufficient amounts of premium agricultural products: food, feed, fuel, and fiber. The start-up project “Understanding Complex Biological Systems” builds on the collaborative project “Synbreed,” bringing together expertise from five TUM research groups and distinguished colleagues from outside TUM. Synbreed is a unique network of excellent scientists from plant and animal breeding, statistical genetics, molecular biology, bioinformatics, and human medicine that aims toward building an interdisciplinary center for genome-based research in plants and animals. Utilizing advanced technologies such as next-generation sequencing, high-throughput genotyping, and metabolic profiling, research is focused on the functional analysis of native biodiversity and the genetic analysis of complex traits in maize, chicken, and cattle.

An integral part of the project is the analysis and interpretation of massive amounts of data obtained from different biological levels. In close collaboration with colleagues from mathematics and statistics, we are currently developing novel statistical models that account for the fact that the system is more than the sum of individual effects. Methods and tools from population genomics and evolutionary biology will be adopted to be used under the specific conditions of agricultural populations. Wide-ranging synergies will be generated through the joint development of theoretical concepts and tools for simulation and analysis.

The TUM-IAS has enabled us to set up a computational infrastructure that can efficiently handle challenging simulations, optimizations, and statistical analyses required for understanding complex biological systems. It has promoted transdisciplinary contacts with TUM scientists from fields such as electrical engineering and information technology, which are most valuable for the future development of a Focus Group.

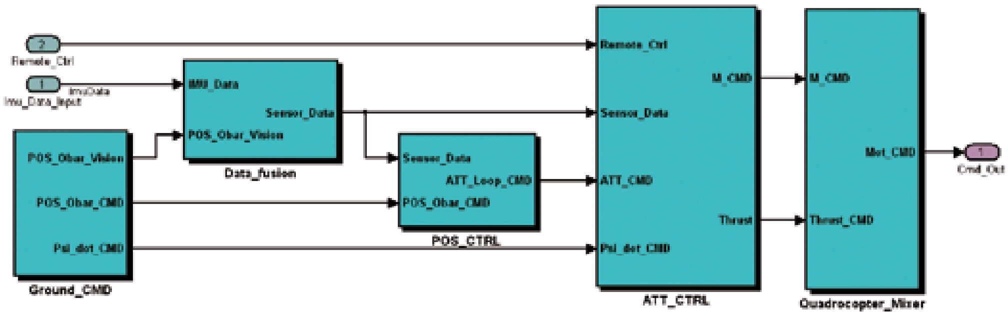
Prof. Florian Holzapfel Institute of Flight System Dynamics, TUM
Prof. Alois Knoll Robotics and Embedded Systems, TUM

Image-Aided Flight Control

Project Team Leader: Prof. Florian Holzapfel
Doctoral candidates: Sebastian Klose, Jian Wang

Recent advances in the field of machine vision, together with the rapidly increasing computing power available on miniaturized platforms, open the perspective of utilizing image-based or derived measurements as auxiliary or primary sources of measurement for flight control applications.

The first phase of the project focused on position control with off-board tracking cameras. The research hardware includes a UAV-quadrocopter, two standard webcams, a ground computer, and wireless data linkage. As the quadrocopter is a highly nonlinear, multivariable, and strongly coupled system, a nonlinear control system based on feedback linearization has been developed. The dynamic inversion is derived on the basis of Newton's second law. There are two cascaded control loops, the position control loop with relative degree 2 and the attitude control loop with relative degree 2. The data fusion algorithm is a modified version Luenberger observer with specific latency compensation to be replaced by Kalman filtering methods in the next step. The Simulink representation of the control system is shown below.



The "Ground_CMD" block carries command from the ground computer, while the "Quadrocopter_Mixer" inverts the motor dynamics; that is, it transfers Moment and Thrust commands into rpm commands of the motors. The current vision system consists of two standard webcams capturing frames at 25 Hz. In each loop, firstly the current measurement prediction of the control system is investigated to provide the visual tracking algorithm with prior knowledge about the current state of the system. Starting from the prediction, a known CAD model is projected into both views of the pre-calibrated cameras. In each single view a local feature search around the predicted state is performed. We are currently using a fusion of two contour-based processing algorithms, one of which uses the edge information of the image. Strong intensity changes are computed using the Canny Algorithm, and the directional information of the edges is obtained from the Sobel operator. The second algorithm builds up color statistics along the contour of the projected model. In order to obtain the visual contour points for the currently investigated state, a visibility checking algorithm is run for each view. This step is done on the GPU for performance reasons. The two algorithms and the two different views are fused together by a joint Gauss-Newton optimization step, which furthermore also investigates the prior covariances from the prediction and calculates current measurement covariances for feedback to the control system. Additionally, the whole computed state information (position + orientation) is fed back to the control system. A rough positional state estimate obtained through color-blob triangulation, together with the heading information from the inertial measurement units of the vehicle, is sufficient to initialize the tracking system. In order to detect possible track losses, the determinant of the covariance matrix is computed and compared to a threshold. When a track loss is detected, it is signaled to the control system, and in the next step an initialization is performed as in the beginning.

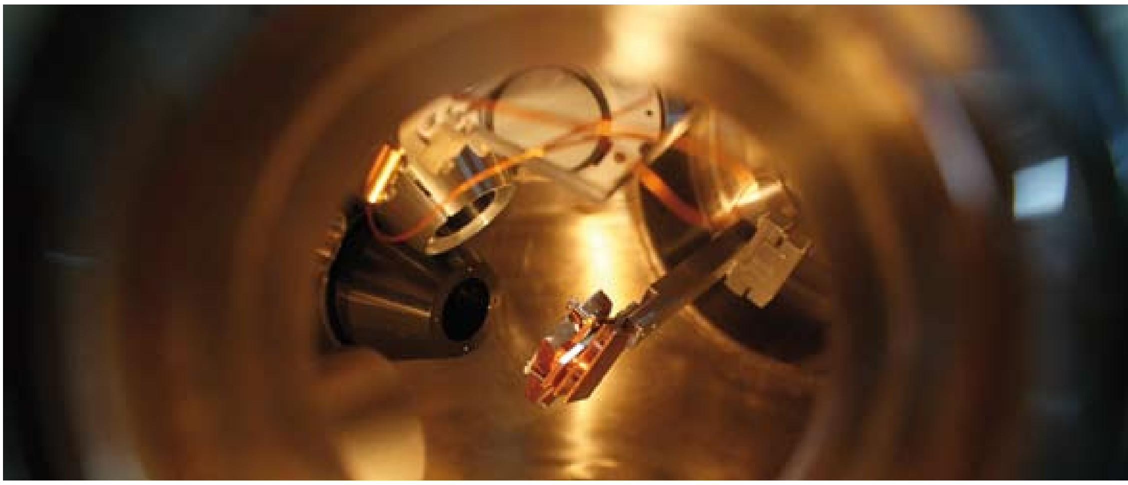
Up to now we have used an artificial marker-object attached to the vehicle, as the quadrocopter was hard to identify in the camera images without it, and the tracking would have been too unstable to use as control input. Lately we are integrating an algorithm to remove background edges to avoid wrong matches, and we are also applying robust estimation techniques (RANSAC) in order to remove the marker.

To increase the bandwidth and robustness of the system, the control system has been recently implemented on-board the UAV-quadrocopter. It is running at 1000 Hz. The image-tracking algorithm is processed on the ground computer, and they communicate with the quadrocopter via Xbee. With sensor data only from the Inertial Measurement Unit (IMU) and two webcams, the quadrocopter is able to perform hovering, position control, and trajectory following.

In the next phase of the project, we are moving the cameras onto the quadrocopter. The plans go toward autonomous indoor flights including obstacle avoidance, self localization, and mapping and tracking another quad from on-board. This should enable multiple UAVs to perform autonomous formation flight, which is the subject of joint research between TUM and Nanyang Technological University (NTU) of Singapore.

Already the current setup attracts a lot of attention. MathWorks is going to present our system as its main attraction in the upcoming “Embedded World Exhibition & Conference” in Nürnberg, Germany. Furthermore, the popular science TV series “Galileo” also expressed interest in presenting the system – the production team has already been here and is now scripting a television segment.

Industry Cooperation



The industrial collaboration TUM-IAS wants to promote has two major components. The first is to establish, where possible and meaningful, a collaboration with industries that engage in strong technological research themselves, especially as it relates to the creation of new products, processes, devices or systems. The second is to engage actively in the societal and industrial furtherance of its inventions, and the creation of start ups involving its own researchers and graduates. We give a short account of each of these three activities as they have taken place in 2009.

Collaboration with Advanced Industrial Research Efforts

To advance collaboration with great industrial research efforts, TUM-IAS has created the Rudolf Diesel Industry Fellowships to be awarded to outstanding industrial researchers who have established a close collaboration with a research group or laboratory at TUM. Some of these have produced a research environment with an impetus to new discoveries that is truly singular. Our first Rudolf Diesel Industry Fellow, nominated in 2009, is Khaled Karrai of attocube systems AG, an original Munich company in the area of Nano Positioning and Microscopy that has become a worldwide leader in this area. Khaled Karrai's very close connections to our Nanoscience Research Area and several of its Focus Groups, as well as his involvement with the NIM cluster (Nanosystems Initiative Munich; a close collaboration with LMU among others), has led to a truly exceptional and productive mutual drive. Our two other Rudolf Diesel Industry Fellows of 2009 have been proposed by the CoTeSys cluster on topics that are of great interest to our Institute, and give form to its collaboration with top researchers from the Siemens Research Laboratories. One is Dragan Obradovic who is active in the area of modeling and control of large distributed systems (with a emphasis on energy distributed systems), and the other is Georg von Wichert, whose interests in Man-Machine interfacing matches very well with the central interest of the Research Area Understanding Intelligence, for which we have recently awarded several Carl von Linde Junior Fellowships.

Industrial, Societal Furtherance of Inventions and Creation of Start-ups

The path from scientific invention to industrial and societal usage is long, costly and arduous. Europe in general and Germany in particular are not very good at it, or to put it differently, the number of great ideas that originate in our laboratories and make it to successful products is largely insufficient. To be sure, TUM has made already a great contribution to this issue by the creation of "Unternehmer-TUM". This is a large and important effort that aims at the creation of new entrepreneurship and to which TUM-IAS researchers have access. Still, we are convinced that a complementary effort is necessary as well, namely one that aims more directly at spanning the distance between scientific discoveries and the availability of a working prototype that could form the basis for the creation of an independent and profitable company. In the United States of America, the strongly subsidized SBIR-STTR program invests in direct development of prototypes and provides strong incentives to scientists to engage in activities that go beyond pure scien tific work toward practical, economic, and societal relevance. We have invested in a start-up program to investigate how a system could be set up that provides for the necessary institutional arrangements, would tie our research groups strongly with the further development efforts in a way that benefits them and rewards them for their efforts, and would contribute to solving this perennial problem of lack of innovation and creation of economic activity. This start-up program was put under the leadership of Prof. Klaus Diepold, who has sought the assistance of Steven Edelson of the United States, an expert with considerable experience and creativity in addressing just this issue. We refer to the description of this start-up project in the present report.

The TUM-IAS benefits from strong collaborations with other institutes supporting top research both within Germany and internationally. Trustees who could offer insight into the management of an Institute for Advanced Study were strategically invited from leading institutes. Out of these connections, strong institutional collaborations have developed that are mutually beneficial.

In May of 2009, a Memorandum of Understanding (MOU) was signed by the Chairman of the Board of the TUM-IAS, Prof. Wolfgang A. Herrmann, and Dr. Georg Schütte, then Secretary General of the Alexander von Humboldt Foundation and TUM-IAS Board member. The MOU was inspired by the fact that Humboldt Research Awards and TUM-IAS Hans Fischer Senior Fellowships are both awarded to top international scientists who will come to Germany, or respectively to TUM, for collaboration with a hosting research group. In the original TUM-IAS proposal, the Humboldt Awardees at TUM were to be considered as TUM-IAS Fellows, while the Humboldt guests were lacking a connection to the university. With the MOU, this relationship has been made official. Humboldt Awardees now receive notification in their letter from the Humboldt Foundation that they will also be welcome in the TUM-IAS, making it an even more attractive award for the recipient. The TUM-IAS also gains by having these top scientists participate in its own interdisciplinary community. Based on the model of this collaboration, we are also planning to set up a similar exchange with the DAAD (German Academic Exchange Service).

In September 2009, the senior management team of the TUM-IAS visited Prof. Dianne Newell, Director of the Peter Wall Institute for Advanced Study (PWIAS), at the University of British Columbia. Prof. Dianne Newell, also a TUM-IAS Board member, invited the staff to visit to exchange ideas on how to best organize fellowship programs. One of the key outcomes from the visit was the opportunity to have a scientific exchange between the two institutes. One method is in the form of reciprocal invitations of TUM-IAS Fellows and PWIAS Faculty Associates Wall Major Thematic Grant project Principal Investigators by the research groups of the other institute. Additionally both institutes have agreed to the organization of workshops bringing scientists from both organizations together. These plans were also committed to paper in the form of a Memorandum of Understanding signed by the directors of TUM-IAS and PWIAS.

Activities of the Institute

Regular

Calendar

Regular

Fellows' Lunches

Every month during the academic year, TUM-IAS organizes a lunch meeting to which all Fellows of the Institute are invited, along with their Hosts, the members of the Advisory Council, and the Humboldt Prize winners. Typically a Fellows' lunch is organized around the discussion of a research theme of general interest to the members of the Institute, with the express goal of fostering a multidisciplinary approach. Themes that have been tackled include nano-devices, device modeling, large-scale system modeling, and control engineering. Some lunches, especially in the beginning of the academic year have been dedicated to presentations of new research topics by Fellows of the Institute. Participants have also dealt with summaries of recent workshops and their import for the various fields the Institute is covering, as well as important themes and research areas for the future of the Institute.

Advisory Council Meetings

The TUM-IAS established its Advisory Council at the end of 2008, consisting of the main leaders of Research Areas in the Institute, leaders of other university-wide scientific initiatives, and some members who were closely involved in setting up the Institute (12 in total). The TUM-IAS Advisory Council functions as a standing advisory board to the TUM-IAS Director and his Management Team. One of its prime functions is advising on the suitability and ranking of nominations of Fellows in the various categories the Institute awards. (This function is in accordance with the decision of the Board of Trustees not to be directly engaged in the nomination process of Fellows and to leave this decision making to a well qualified and appropriate body.) In addition, the Council advises on the scientific and technological course of the Institute, based on an assessment of the potential and needs of the University. The Advisory Council meets regularly, typically once every two months.

Digital Geometry Processing

Speaker: Prof. Peter Schröder | Hans Fischer Senior Fellow
Dept. of Computer Science, Caltech, Pasadena
Date: June 29, 2009

Abstract: Representing the shape of objects through mathematical surface descriptions is one of the fundamental building blocks of many computer applications. These applications can range from classical computer aided design to engineering simulations and all the way to applications in entertainment such as games and special effects. To address this breadth, meshes have emerged as a general and flexible foundation for the digital representation of surfaces. Algorithms are then built from a relatively small set of basic operators manipulating these meshes. The result is a flexible toolbox of digital geometry processing algorithms which continue to be refined by a vibrant research community. In my talk I will motivate these surface representations and use a number of application examples to illustrate how the underlying ideas play out in practice and lead to efficient and robust algorithms for many applications. The talk is conceived as a broad introduction, and no specialist knowledge is assumed.

Computational Bone Mechanics: A patient-specific combined engineering / clinical treatment approach

Speaker: Prof. Zohar Yosibash | Hans Fischer Senior Fellow
Head Computational Mechanics Lab, Dept. of Mechanical Engineering, Ben-Gurion University, Beer-Sheva, Israel
Date: November 10, 2009

Abstract: Advanced simulations, usage of patient-specific CT scans, and detailed sets of experiments provide the opportunity to revolutionize orthopedic clinical treatment and generate a Computer-Aided Patient Specific Orthopedic (CAPSO) tool to be used on a daily basis by clinicians to treat bone-related diseases as osteoporosis, metastasis/benign lesions, and fracture.

This talk concentrates on the femur, for which an overview of the healthy and pathological bone's mechanics will first be presented. Thereafter the applications of CAPSO to total hip replacement procedures and estimation of risk of fracture in bones with metastatic/benign lesions will be discussed.

Nanoelectronics Research at Notre Dame

Speaker: Prof. Wolfgang Porod | Hans Fischer Senior Fellow
Notre Dame University

Cutting-edge technology at attocube systems AG

Speaker: Prof. Khaled Karrai | Rudolf Diesel Industry Fellow
attocube systems AG

Date: November 18, 2009

Abstract: The kick-off of the Focus Group Nanoimprint and Nanotransfer provides a great opportunity for a scientific workshop aimed at presenting the research topics that will be dealt with and introducing the two Fellows associated with the Focus Group. Prof. Khaled Karrai and Prof. Wolfgang Porod will both deliver an inaugural lecture focusing on their present research activities. How the complementary expertise of the two Fellows will benefit and permeate the Focus Group will be illustrated in three short technical contributions from the Institute of Nanoelectronics hosting the group.

Are the high-temperature superconductors semi-metals?

Speaker: Prof. Douglas Bonn | Hans Fischer Senior Fellow
University of British Columbia, Department of Physics and Astronomy
Date: December 10, 2009

Abstract: Over the past two years a new debate has emerged in the study of high-temperature superconductors, following the discovery of quantum oscillations in high magnetic field measurements.

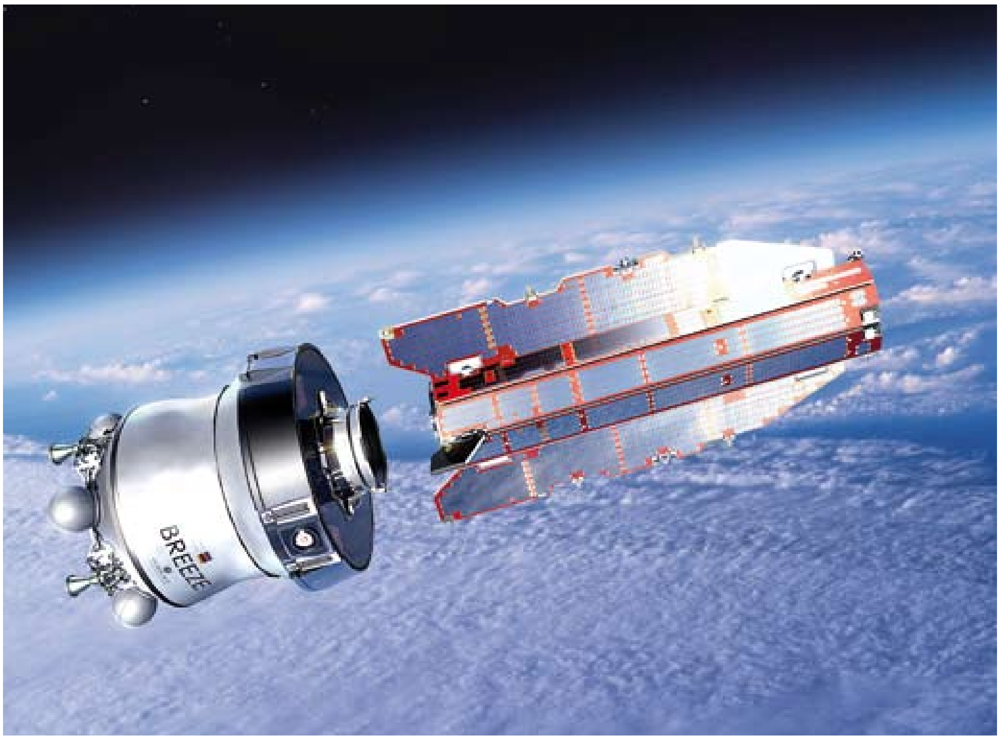
For more than a decade our understanding of the electronic structure of the cuprates has been built up by the refinement of two powerful single-particle spectroscopies: angle-resolved photoemission and scanning tunneling microscopy. These have presented the view that the cuprates have a large Fermi surface that gets progressively disrupted by the opening of a pseudogap. The quantum oscillation measurements are now presenting a very different view, claiming a Fermi surface composed of small electron and hole pockets: a semi-metal.

One aspect of this debate is that both ARPES and STS are surface techniques, and in the important case of YBCO, we now know that the surface and bulk differ drastically. I will review this ongoing debate and place it into the context of a wider movement to study and exploit unusual electronic states on surfaces and interfaces.

March 2009

March 16, 2009 GOCE Satellite launched

Press release from VDI News. March 20, 2009. Nr. 12 “Vermessung der Welt” from Evdoxia Tsakiridou

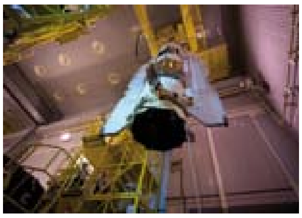


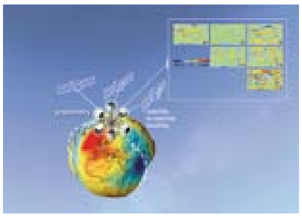
Measuring the World

SPACEFLIGHT: On Tuesday the European Space Agency (ESA) launched its latest earth surveillance satellite into space. Goce’s aim is to measure the earth’s gravitational field and to record – in a more accurate way than was possible before – changes in sea level and ocean currents, as well as the dynamics of ice caps.
He’s had sleepless nights, admits Reiner Rummel in a low voice. The Chair for Astronomy and Physical Geodesy at TU München is the spokesperson and initiator of the Goce (Gravity Field and Steady-State Ocean Circulation Explorer) Project. There’s no doubt that it’s a load off their mind for him and his team, as well as for the scientists of the ten participating EU institutions. Goce’s launch has finally happened. Since Tuesday it has been revolving around the earth at an altitude of 270 km.

Seen from space, the blue planet appears to be a perfect sphere. But when we take gravitational force into account, the picture changes: although this fundamental force is invisible and comparatively weak, it influences many processes, both underneath and on the earth’s surface. Gravitational force is also not homogenously distributed; it depends on the matter in the earth’s interior. In places with an excess of mass, the earth’s gravitational force is greater, which leads to slight elevations. In places with less mass, a depression results. Thus, when we account for gravitational force, the

Earth appears more like a potato with bumps and dents. With the help of radar-based altimetry, geodesists have thus discovered that at the southern tip of India the sea level is around 110 meters lower, while it rises in New Guinea by about 80 meters. In order to prove that the sea level is rising as a result of climate change, for example, scientists need a baseline. They obtain the elevations from an idealized surface, the so-called Geoid. The Geoid is equivalent to the sea's surface at a virtual state of rest.





The "Champ" and "Grace" satellites can already provide data for the Geoid. However, with a geographic area of around 700 km and 500 km, respectively, their resolutions are not yet precise enough; smaller earth structures remain "blurry". Goce's aim is to close these gaps. The satellite will measure the gravitational field with a resolution of 100 km. "In the future, we will be able to illustrate the Geoid with an accuracy of up to 2 cm", Rummel told VDI News.

Rummel has worked on this mission for over 15 years. The man with the silver hair pointed to the approximately 20 cm high Goce model on his desk and rhapsodized: "The Ferrari of satellites". The model is arrow-shaped, with shiny blue solar panels. Goce is a prototype in every aspect: there are no moving parts to its aerodynamic form. The satellite, sensors, and controls form a "gravity measuring unit". A new gauge, the gravity gradiometer, equipped with three pairs of acceleration indicators, can detect variations in the earth's gravitational force to the millionth. "Currently, this is the ultimate in what is technologically possible", said Rummel.

In order to measure the earth's gravitational field in its entirety, the gravity gradiometer alone does not suffice. It can only accurately resolve small-sized structures. Therefore, a second measurement occurs, by which Goce's orbit is calculated using GPS. Consequently, the researchers deduce the large-scale course of the gravitational field and of the Geoid. Geoid and gravitational anomalies are not only of interest to oceanographers and climatologists. Geologists can make conclusions about the tectonics and dynamics of the earth's crust, and geophysicists can detect mineral resources. In the near future, geodesists and land surveyors around the world will have access to a standardized altitude system – and will be able to finally agree on how high Mount Everest really is. In addition, Goce data will facilitate the planning of tunnel, street, and bridge construction projects.

In comparison to other satellites, Goce's lifespan will be short. Normally, satellites' orbits are routed where they can circle the earth without large flight corrections. However, the lower the flight path, the faster the satellite is slowed down by the earth's atmosphere. Since Goce's flight path is enormously important for measuring the gravitational field, deviations will be adjusted by an ionic engine. The fuel on board is expected to last for 20 months; after that, the man-made satellite will burn up in the Earth's atmosphere. Goce's end will not be the end of the surveying of earth from space: "ESA is already working on further missions, which, for example, will measure the magnetic field of the earth", said Mr. Rummel happily.

April 23–24, 2009 General Assembly

On April 23–24, 2009, the first General Assembly of the Institute was held. It consisted of a sequence of presentations by most of the Fellows of the Institute, with




an emphasis on what they viewed as the main research issues in their respective fields. All TUM-IAS Fellows, Board of Trustees members, the Advisory Council, TUM-IAS Host professors, and doctoral candidates directly connected to the activities of the Institute were invited to the meeting, which took place at Hotel Schloss Berg on Lake Starnberg. The Board of Trustees meeting followed the General Assembly in the afternoon.



April 26–May 1, 2009 New Physics, Flavors and Jets

The 2009 Ringberg Workshop on “New Physics, Flavors and Jets” was supported by the TUM-IAS in the context of the Focus Group Fundamental Physics. It took place at Ringberg castle, a conference site of the Max-Planck Society located close to Tegernsee, near Munich. Ringberg castle provides a unique workshop atmosphere through its special remote location and ancient architecture. Similar workshops had been organized in 2003 and 2006.

The workshop brought together 35 well known specialists from Europe, the United States, and Japan, who discussed various aspects of new physics beyond the Standard Model of elementary particle physics in the context of flavor physics and high-energy experiments to be performed soon at the Large Hadron Collider at CERN in Geneva. Fifteen doctoral candidates and young researchers, among others from TUM, had the opportunity to meet leading experts in this field including Prof. Graham Ross (Oxford), TUM-IAS Hans Fischer Senior Fellow Prof. Stefan Pokorski (Warsaw), and Prof. Iain Stewart (MIT). The workshop addressed several important open questions in fundamental particle physics, such as the issue of hierarchies in elementary interactions and hierarchies in particle masses, Higgs physics, solutions to the problems of the Standard Model that invoke new symmetries (like supersymmetry), and additional space dimensions. Also, new field theoretic techniques aimed at studying the outcome of LHC experiments were presented.

The workshop organized by Prof. Gerhard Buchalla (LMU), TUM-IAS Carl von Linde Senior Fellow Andrzej Buras, Dr. Andre Hoang (MPI), and Prof. Thomas Mannel (Siegen) clearly demonstrated that particle physics stands on the threshold of a

From left to right: Martin Gorbahn (TUM-IAS), Thomas Mannel (Siegen), Graham Ross (Oxford), Andrzej Buras (TUM-IAS), Stefan Pokorski (TUM-IAS), Iain Stewart (MIT) and Andre Hoang (MPI).

new exciting era of discovery and that new results from LHC and other smaller experiments around the world could have a profound impact on the way we see our universe. Therefore it is expected that the 2012 Ringberg Workshop will be even more exciting than the 2009 one.

May

May 8, 2009 Advances in Risk Analysis and Stochastic Modeling

TUM-IAS sponsored a workshop on “Advances in Risk Analysis and Stochastic Modeling,” organized by the TUM-IAS Focus Group Risk Analysis and Stochastic Modeling (Prof. Claudia Klüppelberg and Dr. Robert Stelzer). It covered recent developments and applications in finance and other areas, as well as relevant developments in probability theory. Experts from various fields had interesting discussions, which will certainly lead to further collaboration.

May 14, 2009 Challenges and Opportunities of V2X-Communication

This course was provided as activity of the international training network ITS-Edu-Net, which aims to improve training and education in Intelligent Transport Systems and to foster better knowledge transfer for students as well as for professionals. Organized by the TUM chair of traffic Engineering and Control (Prof. Fritz Busch), the course was supported by the TUM-IAS and Audi AG. The course was designed both for transport professionals and decision makers who would like to acquire expert knowledge in “vehicle-to-X communications” (V2X) to set the course for future implementations in their areas of responsibility.

Vehicle-to-X-communications can support a variety of applications that can improve driving safety or traffic efficiency and provide information or entertainment to drivers. Drivers will benefit from the system by receiving warning messages and driving recommendations. Road operators will receive traffic data and can therefore control the traffic in a more efficient way. Currently several projects are under way, where V2Xsystems are being developed and tested. Some applications, such as bus prioritization systems, are already state-of-the-art. The course gave an overview of the actual status, developments under way, and current research aspects.
It also addressed questions of deployment and organizational issues.

June 2009

June 8, 2009 The Gordion knot in environmental water science: predictions of water cycles and water quality in (human) environmental systems of intermediate complexity

Water in environmental systems has many meanings: danger, habitat, transport medium, and essential resource for almost any form of life. Water is the essential glue between the techno-sphere, geo-ecosphere, and human sphere in any environmental system. A sufficient amount of fresh water is essential for the functioning and resilience of all these spheres and thus for sustaining our Earth as a habitable place. Will there be enough water to be shared among the techno-, geo-eco- and human spheres in light of increasing population and possible climate change impacts? How will climate and other global change alter transport and degradation regimes for agricultural chemicals and pharmaceutical substances? How will biota respond to these changes? Will future technology be sufficient to cope with future water problems, or do we over-exploit and over-pollute the water resources of our children, as well as the offspring of animals and plants?

These are simple questions that confront us with our rather limited ability to predict processes of water and energy cycles, as well as the fate of substances in environmental systems even for present climate and demographic conditions. How well can we answer the question “What happens if …?” when struggling with the understanding of the status quo? Nonetheless, whether the sign on our office door shows Hydromechanics, Hydraulics, Bio-Geochemistry, Earth System Science, Hydrology, Urban Water Engineering, or Landscape Ecology, we all face similar cardinal problems:

- Scale incompatibilities
- Lack of useful observations
- Threshold behavior at different levels
- Feedbacks and dynamic processes.

The TUM-IAS workshop provided the opportunity to discuss these key problems and possible ways ahead in a frank and free manner.

July 6, 2009 Laying of the cornerstone: the new TUM-IAS building

From left to right: Prof. Burkhard Göschel, Dr. Wolfgang Heubisch, Dr. Norbert Reithofer, Prof. Wolfgang A. Herrmann

With the ground-breaking the TUM-IAS finally received a home. In their opening speeches, the President of TUM, Prof. Wolfgang A. Herrmann, the Bavarian Minister for Scientific Affairs, Dr. Wolfgang Heubisch, and the Chairman of the Board for BMW Group, Dr. Norbert Reithofer, gave their best wishes for a rapid, accident-free construction of the building and also wished the TUM-IAS a great scientific future.

“Although still without its own premises, since its launch in 2006, the TUM Institute for Advanced Study has already seen excellent development,” stated Professor Herrmann. “TUM has succeeded 16 times in its first two and a half years to attract highly qualified scientists to Munich, among them, for example, researchers from MIT or Harvard.” TUM-IAS already fulfills a multifaceted interface function within TUM: It links pure and applied research, up-coming and experienced scientists, and, through its varied collaborative projects, connects TUM researchers with other top research project teams internationally. With Prof. Patrick Dewilde, TUM gained an experienced leading research scientist and engineer from Delft as TUM-IAS Director, who is strongly engaged in promoting and furthering the development of TUM-IAS.

July 12–18, 2009 German-French Summer University

The 2009 German-French Summer University for junior researchers on “The Future of Mobility” took place on the lake island of Frauenchiemsee. The workshop, co-sponsored by the TUM-IAS, was organized by TUM (Prof. Gebhard Wulfhorst; Spatial Structure and Transportation Planning) and the Laboratoire d’Economie des Transports (LET) / Ecole Nationale des Travaux Publics de l’Etat (ENTPE). The participants discussed trends and challenges for tomorrow’s mobility. Several basic socio-economic and ecological trends lie outside the scope of planning, due to their complexity and timeline for taking effect or because of physical reasons.

Among these megatrends are, for example, globalization, demographic change, and climate change, as well as the shortage of natural resources – and the resulting associated rise in their costs – particularly fossil fuels. With the help of these developmental guidelines, one can draw conclusions regarding basic societal, ecological, and economic conditions for the future of mobility.

July 26–31, 2009 Microscopy in Electrochemistry

The 11th International Fischer-Symposium on “Microscopy in Electrochemistry,” co-sponsored by TUM-IAS, was held in the Monastery of Benediktbeuern. It provided a forum for scientists from all over the world who are working or are interested in the field of electrochemistry. The Fischer Symposium has traditionally been the place where the relations between electrochemistry and other fields of science are discussed and interdisciplinary approaches are developed.

October

October 18–20, 2009 The Impact of Control: Past, Present, and Future

The international workshop on the “Impact of Control: Past, Present, and Future” was co-organized by our Hans Fischer Senior Fellow Anuradha Annaswamy and our Focus Group leader Martin Buss, with the very active involvement of the IEEE Control System Society. Presentations and discussions focused on topics such as the successes of advanced control in practice, new and emerging control technologies, obstacles that limit the practical impact of controls research, global and societal imperatives that the controls community should target, and recommendations for how we can improve our track record of “real-world” success. Leading experts from all over the world – from academia, government, and industry – presented their viewpoints, experiences, and vision for the future.

October 22, 2009 Darwin’s Impact on Technology

On the occasion of Charles Darwin’s 200th birthday, the TUM-IAS and the Carl von Linde Academy organized the collaborative lecture “Darwin’s Impact on Technology,” which took place in the Ehrensaal of Deutsches Museum.
Two major questions pervaded the lecture. One was: “What can be learned from the understanding of evolution to build new technical systems?”

Prof. Christoph von der Malsburg

The other was: “How can evolution be used to achieve technical goals?” Although one might expect the second theme to be dominant because many biological and biomedical processes actively use evolution (only think of the production of vaccines), the first theme actually prevailed. Luckily, there is a strong link between the two viewpoints, because once one really understands, one should be able to build.

Prof. Martin Buss showed how, by using genetic learning, one can let a robot find its way autonomously from the Pinakothek to Marienplatz (work of the group lead by our Carl von Linde Junior Fellow Kolja Kühnlenz). While one may question the practical utility of this specific performance, all adaptive systems such as intelligent cars, planes, or roads may and do profit from such experience. Evolution did an avowedly magnificent job, which the engineers still have yet to match. Careful study, for example, of how the evaluation and control in primitive organisms has evolved may lead the way. An impressive example was the data fusion between vision, infrared sensing, and hearing studied by Prof. Leo van Hemmen on certain types of snakes.

November

November 19, 2009 TUM-IAS Kick off Dinner

On November 19, 2009, the TUM-IAS kicked off the 2009-2010 fellowship program with a festive dinner. New TUM-IAS Fellows were presented with certificates for their fellowships by TUM President Prof. Wolfgang A. Herrmann.

November 26, 2009 Liesel Beckmann Symposium

For the third year in a row, the TUM-IAS hosted the Liesel Beckmann Symposium. The annual symposium highlights the subject areas of gender and diversity, which are of vital interest for the TUM. This year's Liesel Beckmann Symposium dealt with gender in teaching, not only in its formal aspects, but also with the goal of integrating gender into the subject matter.

The symposium was dedicated to the topic "Gender in Teaching" for two reasons in particular: with the call for proposals "Excellent Teaching" and with the second round of the Excellence Initiative, the theme "Teaching" is high on universities' agendas. Furthermore, in 2009 the TUM School of Education was established at the Technische Universität München. The TUM School is committed to the challenge and opportunity of integrating gender aspects and gender qualification from the start, and, of course, using them as quality criteria in the curriculum.

This year's Liesel Beckmann Symposium dealt with the gender topic in different areas of teacher training; it also dealt with the training of student teachers and students, as well as communication in the area of the sciences.

Presentations on current research results highlighted what a gender-sensitive design can look like on different levels. In the workshops that followed, current TUM activities were presented as a basis for the development of implementation strategies in teacher training and schools.

Facilities

New TUM-IAS Building

TUM-IAS Guest House

Resources and Data

Future Perspective

Organization

Board of Trustees

Advisory Council

Management Office

The Future TUM-IAS Headquarters

The TUM Institute for Advanced Study will receive a permanent address on the TUM campus in Garching. The building is being generously donated by the BMW Group. The BMW Group is not only donating the building, with a value of 10 million Euro, but is also expertly managing the entire planning and construction.

On July 6, the ceremony for “Laying of the Foundation Stone” took place, officially marking the start of construction. The Chairman of the Board for BMW Group, Dr. Norbert Reithofer, stated at the event: “This project stands for what in business is called a classic win-win situation for all participants. In this case: science, business, and, naturally, also Bavaria.”

Construction actually began before the ceremony, as the available lot, though ideally situated on the campus, was a very complicated building site. First gas pipes had to be relocated. After that, structural reinforcements in the form of pillars and a wall were installed underground to make sure the building would not be damaged by the potential underground construction to extend the subway line in Garching, which would go directly under the TUM-IAS building. It would truly have been an unbuildable site if not for BMW.

In addition to offices for the Institute Fellows and management team, the new TUM-IAS headquarters will have a café, three conference rooms with top audio-visual equipment, an auditorium, and an event space in the style of a faculty club on the top floor of the building – with a view of the Alps. The building is designed to encourage as much natural interaction as possible among the Fellows from various fields of science and engineering, which we hope will lead to unplanned-for collaboration opportunities. While the building will not have laboratory space, it is centrally located among all the faculty buildings on the TUM campus in Garching, so that TUM-IAS Fellows will have the best of both worlds – office and meeting space among their highly esteemed peers, and a tight interaction with scientists in the TUM faculties. With the construction of the TUM-IAS headquarters, BMW Group further strengthens its decades-long successful collaboration with the Technische Universität München. BMW AG took an active role in developing the Garching campus during the managing directorship of Eberhard von Kuenheim.

By the end of 2009, the TUM-IAS building was on schedule with the outer shell completed. The building will be complete in mid-2010, at which point the Technische Universität München takes ownership of the facility and will fill it not only with furniture and equipment, but also with the top scientists at TUM, namely the TUM-IAS Fellows.

TUM-IAS Guest House

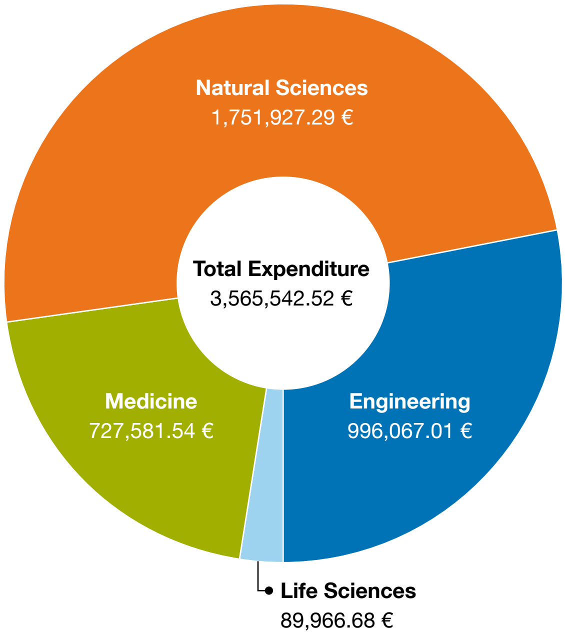
In October 2009, the new TUM-IAS guest house welcomed its first guests. The building offers five fully furnished one-bedroom apartments between 25 and 80 m^2 for TUM-IAS Fellows visiting Munich for longer or shorter stays.

The Jugendstil building was donated to the TUM by the Schmidtler Foundation for the purpose of hosting international guest scientists at TUM, an ideal solution for many of the international Fellows in the TUM-IAS. The building is located in Schwabing between the English Garden and Münchner Freiheit, with a direct subway connection to the TUM campus in Garching.

The TUM-IAS has financed the complete renovation of the building, following the rules for historic preservation. The apartments are now a mix of traditional architecture with sleek modern furnishings. The apartments are almost completely booked through 2010.

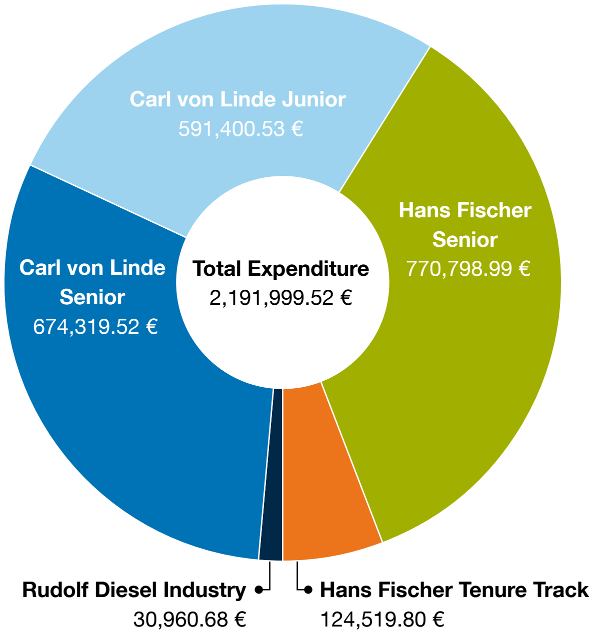
In this section we give a brief survey of financial data. All expenditures of TUM-IAS are covered by the current “third funding line” of the Excellence Initiative. Allowable costs and income are almost precisely in balance in 2009.

Expenditures per TUM Scientific Field in 2009

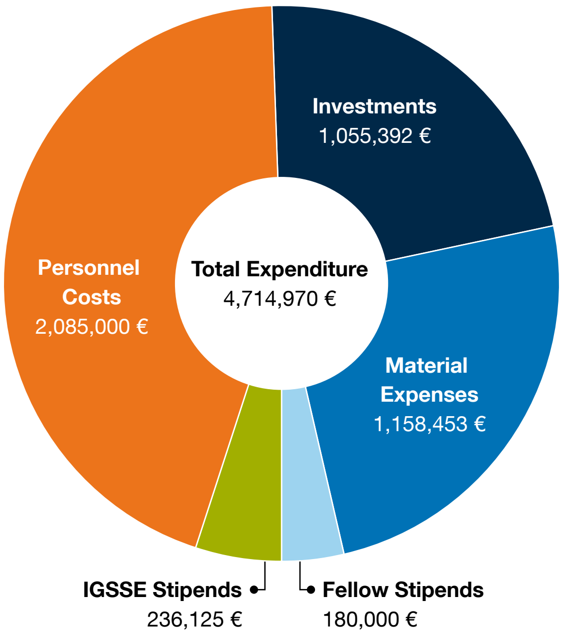


The first chart shows the expenditures per TUM scientific field in 2009. Most of the programs of TUM-IAS are multidisciplinary. As a result, a tally of the benefits of the program for individual faculties is not that meaningful. The chart reflects the global nature of the TUM profile, covering engineering, natural sciences, medicine and life sciences. Not shown in the chart is the cooperation between these fields within the TUM-IAS; information about that issue can be found in the section “Research Areas and New Focus Groups”.

Expenditures per Fellowship Category in 2009



Total Expenditures in 2009



The chart shows that during the last year, the TUM-IAS fellowship program has been more fully estab lished. The TUM-IAS fellowship expenditure that dominates the program in costs is the Carl von Linde Junior Fellowship. It is a successful instrument in the establishment of new fields in science, giving a great opportunity and a good material base to promising young scientists.

The chart also shows that the ratio between the fellowship types has now become very close to that planned in the TUM-IAS proposal for the Excellence Initiative. The TUM-IAS continues to strengthen industry collaboration and to that end is increasing the number of Rudolf Diesel Industry Fellowships.

Hans Fischer Senior Fellowships, for excellent scientists from abroad, are an important and successful part of the TUM strategy and are helping emerging fields establish themselves and gain international visibility. While Hans Fischer Tenure Track Fellowships are complicated to negotiate with the participating faculties, they are very important in making faculties more attractive to promising young researchers. With this instrument, TUM-IAS hopes to make a lasting impact on the evolution of TUM.

Through 2009 the funding for personnel costs and material expenses must be strictly divided according to the funding rules of the German Research Foundation (DFG) and German Council of Science and Humanities (WR). Starting in 2010, funds for these expenditures may be more flexibly allocated, a tangible benefit for the TUM-IAS Fellows.

Panta Rhei, by *Patrick Dewilde*

The primary strategic process of the TUM-IAS is the nomination of outstanding Fellows. They embody the drive for science renewal that a top-level research institution needs. Although we strive for balances between young and experienced, local and international, academic and industrial, our first impulse is to go for quality and ideas, from whatever angle they are presented, as long as they fit our primary topic, technology-oriented, TUM-based research. We are a thoroughly TUM-integrated, people-oriented institution devoted to scientific excellence in technology.

The openness to new ideas and proposals "out of a clear blue sky" does not preclude an effort to consolidate work on some major topics that emerge from the projects of our Fellows and the laboratories in which they participate – after the inspiration comes the perspiration! Our second priority is therefore the creation of Advanced Research Themes, which represent the thrust that drives our research. The balance between our two main priorities is hard to quantify, because some fields of technological endeavor require much larger resources than others, but in terms of nomination of Fellows we strike approximately a 50-50 balance.

The recent flurry of proposals (2010 batch) goes very much along the lines set out in 2009 and shows the following as large emerging topics, accounting for just over half the Institute's efforts:

- Nanoscience: new atom/molecule-based devices, nano-scale technology, atomic properties of surfaces, instrumentation for nano-scale measurement;
- Advanced computation: multi-scale computations, large-scale physics based on geometric modeling, multi-physics systems, numerical aspects of large-scale computations, new statistical approaches;
- Knowledge engineering: robotics, advanced control, smart systems engineering, nano-robotics;
- Biophysics and bio-inspired computations: physical properties of biochemical compounds, integration of DNA on substrates, phenotyping of DNA, combining electronics and bioactive compounds;
- Medical instrumentation: clinical cell treatment, novel MRI concepts, nano-scale haptics.

In its efforts to consolidate topics, TUM-IAS has granted fellowships to top-level scientists whose plan is to create or renew topical research institutes in which our Fellows' activities are concentrated. We mention in particular the new Center for Nanotechnology and Nanomaterials, part of the Walter Schottky Institute, headed by our new Carl von Linde Senior Fellow Prof. Gerhard Abstreiter, the nomination of our new Carl von Linde Senior Fellow Prof. Axel Haase as the new head of IMETUM, our Host, Prof. Martin Buss, heading the CoTeSys consortium and laboratory, and Prof. Ulrich Stimming as a new Carl von Linde Senior Fellow to lead our efforts in Sustainable Energy and Electromobility.

In the future these successful policies will be pursued further. There have been issues with the engineering content of the Institute and the number of women Fellows. On the first point, the engineering content has substantially increased. However, the 2009 batch of Fellows does not show a marked increase in the proportional number of women Fellows. We can already say that 2010 will be better. We have been engaging on a dual policy to improve, on the one hand by promoting fields in which top women scientists are prominent and on the other by offering an extra position to Focus Groups who come up with excellent proposals for new female doctoral candidates. The proportion of female doctoral candidates in our Institute has increased substantially, and we have received a larger number of proposals for female Fellows in the 2010 batch as well.

A third major aspect of the Institutes' policies concerns the development of services and infrastructure. As the new TUM-IAS building will be completed in 2010, making it a vibrant center of scientific life on the Garching campus will be our first concern. Besides our regular activities in organizing workshops and meetings, running a guest house, and providing assistance to our Fellows, we plan to engage in new fund-raising activities and to facilitate the creation of start-ups to develop our inventions further. For most activities seeds have already been sown, as testified in this report.

At the end of 2010 TUM-IAS will have grown into the full-blown center of scientific and technological innovation that was envisioned at its inception in 2005, with close to 50 active Fellows, a central location acting as the focal point of its activities, and major new institutes and research groups intimately connected to it. Let me emphasize the inherent dynamics of the Institute. Only our new building is (we hope) static; our Fellows, topics, investments, and collaborations are constantly evolving. We want to be a major force helping to shape the technological knowledge our world so badly needs for its economic progress and its survival.

Board of Trustees

The Board of Trustees is formed by a group of international advisors from academia, research support organizations, and industry. The International Board of Trustees advises the Director on general scientific, organizational, and technical issues. The Board also defines the general strategy and standards of the Institute.

Members

Advisory Council

The Director is advised by the Advisory Council with regard to recruiting new Fellows and setting the research agenda of the Institute. This body is constituted of members of TUM. The leaders of the TUM-IAS Focus Groups, and the leaders of related bodies in the Excellence Initiative as well as advisors closely connected with the institute, make up this Council.

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Prof. Andrzej Buras Institute for Theoretical Elementary Particle Physics
Prof. Martin Buss Institute of Automatic Control Engineering
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