SES Research Area 1
Information and Communication Technologies

November 21, 2006

Source Information	revision 1229, last change November 20, 2006 by birk
`https://subversion.eecs.iu-bremen.de/svn/eecs/eecs/research-report/2006/report.tex`	

1 Information and Communication Technologies

The increasing impact of information and communication technology dominates our everyday life, our society, and the environment. Examples comprise the World-Wide-Web, the ubiquitous use of computers, cellular multimedia and wireless communications, robots in factories as well as in offices and homes, and sophisticated computer models used to predict the evolution of complex systems such as the global climate.

The enormous level of integration in microelectronics has enabled unprecedented progress in many sectors – and even more importantly, it has created many new profitable technologies and services based on them. The 21st century will witness technologies that enable machines to do things that have been so far restricted to humans: machines will be able to sense, act, speak, listen, decide and sometimes understand. Our T-shirts may have their own Internet addresses and wirelessly tell the laundry machine about proper treatment. We will see cars that negotiate with each other in order to maximize traffic flow while reducing pollution using sophisticated energy management systems. Manufacturing technologies will improve using a combination of detectors and software to control processes. Robots are also more and more used in domains where some autonomy and intelligence is necessary. They work under conditions where it is unpleasant or even risky for humans like in abandoned mines or at disaster sites and where they have to deal with situations unforeseen by their designers and programmers. The hallmark of such smart systems is their integration of technologies from analogue devices and sensors, communication systems and networks, internet services, artificial intelligence, machine learning, robotics, and many more.

The School of Engineering and Science actively contributes to this rapidly growing, boldly interdisciplinary endeavor, focusing on the areas described in the following:

1.1 Communication Networks and Systems

The basic desire of modern society to be able to access and distribute "any" information at "anytime" and "anywhere" is the driving force for the rapid development of communication networks and systems. The implications of these goals are manifold and require truly interdisciplinary research efforts. A typical, but clearly not complete, list of involved high level research fields reads as follows:

- Wireless Network Engineering and System Design
- Network Interoperability
- System capacity management and optimization
- Information transmission
- Network protocols
- Information security

All these research areas are strongly inter-related and the strength of a research cluster in "communication networks and systems" resides in the close cooperation of the respected research groups involved. The particular 'flat hierarchy' at IUB (no departments and chairs) fosters such cooperations.

1.1.1 Cellular and Wireless Communications

Research Team Harald Haas (Professor), Rami Abu-Alhiga (PhD Student), Zubin Bharucha (PhD Student), Hany Elgala (PhD Student), Ellina Foutekova (PhD Student), Birendra Ghimire (PhD Student), Dennis Kolyuzhnov (PhD Student), Raed Youself Mesleh (PhD Student), Abdurazak Mudesir (PhD Student), Hrishikesh Venkataraman (PhD Student), Sinan Sinanovic (Research Associate), Peter Omiyi (Postdoctoral Fellow), Mostafa Afgani (Research Engineer)

Research in Cellular and Wireless Communications is geared towards new technologies for wireless systems. Particular focus is placed on the development and the interaction of key air-interface building blocks:

- multicarrier transmission (in particular OFDM (Orthogonal Frequency Division Multiplexing),
- duplexing techniques (in particular time division duplexing (TDD)),
- multiple-input multiple-output (MIMO) techniques,
- wireless ad hoc systems,
- medium access control (MAC) algorithms,
- multiple access and scheduling techniques,
- dynamic channel assignment (DCA) algorithms,
- mobile positioning
- visible light communication

Highlights *1. Spatial Modulation:* Spatial modulation (SM) is new and patented multiple antenna transmission approach for wireless systems that increases the spectral efficiency (number of bits transmitted per Hz bandwidth) by utilizing the transmit antenna number as an implicit source of information. A block of information bits is mapped to an information symbol and a transmit antenna number. As a consequence, at any given time instant only a single antenna of the antenna array is transmitting signal power. The actual block of information bits determines which antenna is active at a particular time instant. As a result, inter-channel interference (ICI) at the receiver input and the need to synchronize the transmit antennas are completely avoided. Simple receiver algorithms such as maximum receive ratio combining (MRRC) can be used to retrieve the information bits. The performance and the receiver complexity of SM and V-BLAST (Vertical-Bell Labs Layered Space-Time) algorithm in flat fading channels are compared. V-BLAST applies zero forcing detection based optimum ordering, nulling and successive interference cancellation. The basic principle of SM is depicted in Fig. 1, and results of the comparison with state-of-the-art V-BLAST are shown in Fig. 2. From the results

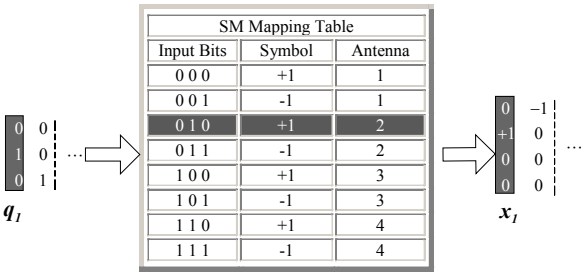

Figure 1: 3bits/symbol spatial modulation mapping table using binary phase shift keying (BPSK) and four transmit antennas

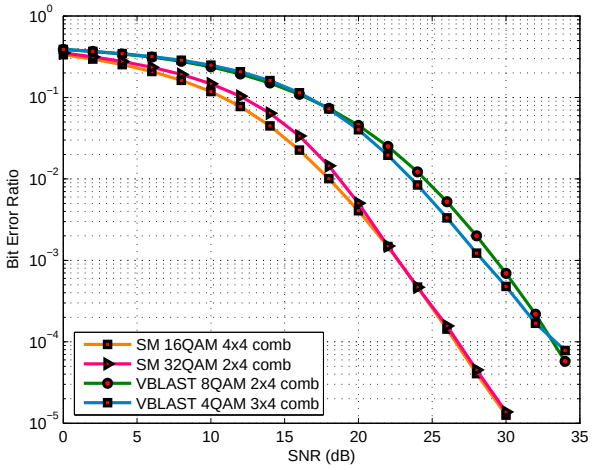

Figure 2: Bit error performance as a function of signal-to-noise ratio (SNR) for state-of-the-art V-BLAST and novel SM.

it can be found that the performance gains are significant. In both schemes the same number of bit per unit bandwidth are transmitted (for fair comparison), but with SM the bit error performance is reduced considerably. For example, at an SNR of 20dB a 10-fold reduction in the BER is observed.
2. Dynamic Resource Allocation: In this work a fully decentralized interference avoidance algorithm to manage interference in an *ad hoc* wireless network, applicable to wireless sensor networks, is developed and analyzed. Fig. 3 depicts a randomly chosen distribution of transmitting (Tx) and receiving (Rx) nodes. The new algorithm, called *busy tone interference tolerance signaling*, is of low complexity and is very easy to implement. It is based on different functions to set the busy tone signal power dependent on the level of tolerable interference, and their performance is compared with a special case of a fixed power system which provides maximum capacity assuming equal transmit powers. Results show that an appropriately chosen function for setting the busy-tone can lead to gains in capacity using very little power. This power efficiency advantage is quite significant, implying that battery life of units can be extended while providing a similar capacity than a fixed power system.

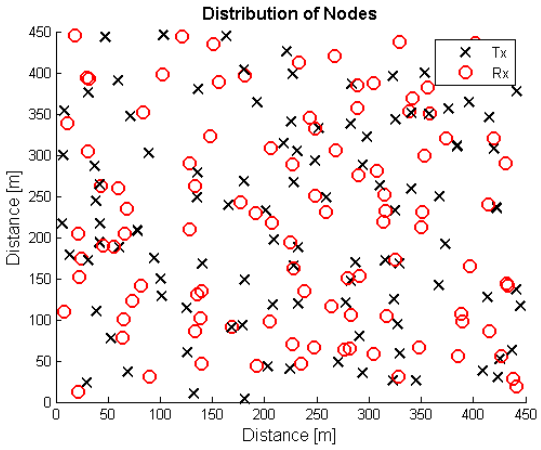

Figure 3: Random distribution of nodes in an *ad hoc* wireless network

Organization

1. Member of Technical Program Committee of and session chair at *IEEE International Conference on Personal, Indoor & Mobile Radio Communications* – PIMRC 2006
2. Member of Technical Program Committee of *International IEEE Conference on Vehicular Technology* – VTC 2006

Collaborations

1. *The University of Edinburgh, UK*
   Prof. Stephen McLaughlin
   Joint project with industrial partner on *Hybrid Cellular and Multihop Wireless Networks*

Grants

1. Collaboration with industry partner, project: *Cellular TDD-OFDM (Time division duplex - orthogonal frequency division multiplexing)*
2. Collaboration with industry partner and University of Edinburgh, project: *Hybrid Cellular and Multihop Wireless Networks*
3. Collaboration with industry partner, project: *Link Adaptation and Scheduling in Cellular Systems*
4. Bremen T.I.M.E program funded by BIS Bremerhaven, project: *Mobile Positioning (MPos)* in collaboration with MobilTec GmbH and supported by T-Mobile.
5. DFG Schwerpunktprogram TakeOFDM (322-1163), project: *DCA Algorithms and MAC Protocols for COFDM Based Cellular and Ad hoc Systems Using Carrier Sensing Time Division Multiple Access (CSTDMA)*

Patents

1. Four new patent applications submitted
2. Three previously submitted patents got granted in 2006

Awards, Prizes

1. Nominated for the Chinese 111 Program – Guest Academic Talents Programme for the Development of University Disciplines in China

2. Invited Talk at the University of Mondragon (Spain)

Conference Proceedings

Books/Collections

1.1.2 Digital Transmission Methods and Coding

Research Team Werner Henkel (Professor), Fangning Hu (PhD Student), Neele von Deetzen (PhD Student), Khaled Shawky Hassan (PhD Student), Apirath Limmanee (PhD Student)

We currently concentrate on iterative decoding and unequal error protection in coding and physical transport. In iterative decoding, we study the convergence behavior and properties of analog Turbo-like codes and the possible design of Turbo and LDPC codes for unequal error protection (UEP). In the design of UEP codes, we especially cooperate with ENSEA, France, and Luleå University, Sweden. UEP is also the goal in our multicarrier research, where we design bit-allocation algorithms that allow for easy realization of different protection classes in an arbitrary way. UEP will be a must for current and especially future triple-play data services to different devices at varying channel qualities.
The analog codes have a strong relation to signal processing. Regarding practical applications of such codes, we especially look into the correction of impulse-noise and clipping effects. There, the most important task is to determine statistical properties that allow for easy erasure marking, which would support further decoding steps, analog and digital.
We further started a project on data transmission using ultrasound signals. We currently design lab experiments to deliver data for later modeling of the channel and disturbances.

Highlights The design of UEP Turbo codes by a pruning approach led us to a structure that we named hybrid concatenation, a combination of outer parallel and inner serial concatenation. The study of the decoding convergence with so-called EXIT charts yielded the result that the area between the curves describing the outer iterations depend on the number of inner iterations. This allows for minimizing the decoding complexity by a scheduling with varying number of iterations in the different decoding steps (see Fig. 5). The pruning concept was also the starting point for our design of UEP LDPC codes with an irregular check-node profile (pat. pending).
In analog coding, we further improved the presentation of our proof that Turbo-like decoding leads to a least-squares solution. We can now exactly forecast the convergence limits for the stepsize and can also modify them for every iteration to allow for very fast convergence. For impulse-noise detection, we currently investigate new statistical properties, e.g., the slope distribution, and correlation approaches. This study will also close a gap in impulse-noise modeling regarding the autocorrelation function of impulse noise.
By designing a new bit-allocation algorithm (pat. pending), following the principles of an existing one by Chow, Cioffi, and Bingham, we can obtain UEP properties in a very elegant way. It allows for an arbitrary number of error-protection classes with arbitrary margins between them and an arbitrary number of bits per class. Figure **??** shows a resulting bit and power allocation according to the channel SNRs, assuming three error protection classes with a 3 dB separation.

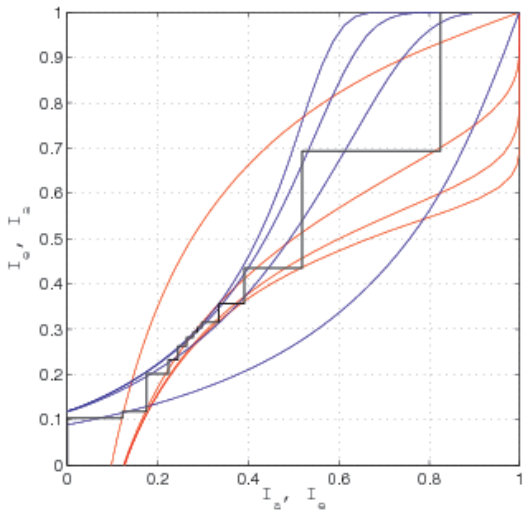

Figure 4: *Convergence scheduling for hybrid concatenation*

Organization

1. Program Committee member of ICC 2006

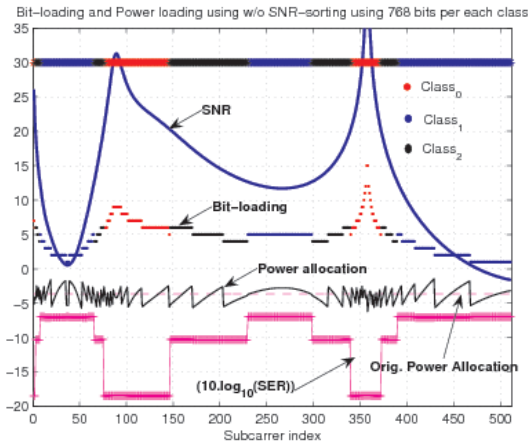

Figure 5: *UEP bit and power allocation for three protection classes*

Grants

1. FP 6 IST strep “M-Pipe”

Conference Proceedings

Patents

1.1.3 Networks and Distributed Systems

Research Team Jürgen Schönwälder (Professor), Ha Manh Tran (PhD Student), Vlad Balan (MSc Student), Matus Harvan (MSc Student), Vladislav Marinov (MSc Student)

Computer networks such as the Internet continue to change many aspects of our daily life. The networks and protocols research group carries out research related to Internet protocols, with strong relationships to work undertaken by the Internet Engineering Task Force (IETF), an organization responsible for Internet protocol standardization, and the Internet Research Task Force (IRTF), an organization responsible for longer-term research related to Internet protocols.

Highlights The operation of increasingly complex communication networks requires supporting systems, so called network management systems. Network management protocols and associated data definitions have been developed and standardized over the last decade to support open, vendor-neutral access to management and control information. While some of these technologies are in wide-spread usage, there is little information how the underlying protocols are utilized and what the specific characteristics of network management interactions are. As a consequence, there are no well accepted models which can be used to analyze the impact of protocol changes.

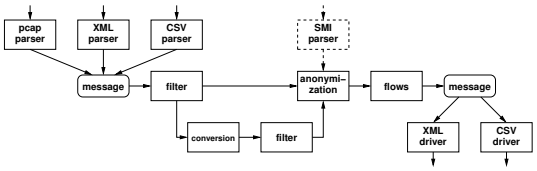

Figure 6: *Data flow within the* `snmpdump` *tool*

A larger empirical study has been started in 2006 where we collect network management packet traces from operational networks. This study is carried out in collaboration with international research groups and supporting operators in order to obtain traces from live networks. Based on an anonymization algorithms developed in 2005 [HS06], our group has designed and implemented a tool chain (Fig. 6) for the analysis of network management traffic traces [PSH+07]. Further research is ongoing to develop analysis algorithms able to infer high-level management operations from observed primitive protocol operations.

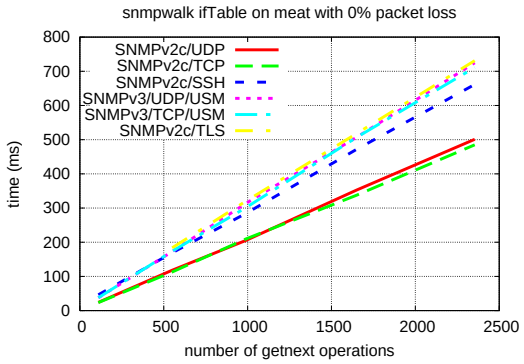

Figure 7: *Latency of SNMP/SSH and SNMP/TLS*

A related activity concerns the security of network management interactions (Fig. 8). We have prototyped and analyzed a security extension proposed for the SNMP which leverages transport layer security protocols such as SSH or TLS [MS06]. This work is related to standardization efforts undertaken by the Integrated Security Model for SNMP (ISMS) working group of the IETF.

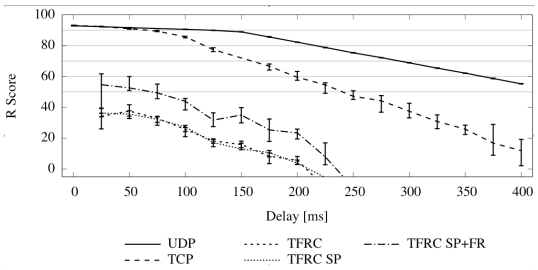

Figure 8: *R scores for G.711 over DCCP*

Finally, we have conducted research on the performance of voice stream transmission over the new Data Congestion Control Protocol (DCCP) being standardized by the IETF [BENB07]. This work was carried out in close collaboration with NEC C&C Research in Heidelberg, Germany.

Organization

1. Editorial board member of the IEEE electronic Transactions on Network and Service Management
2. Guest Co-Editor of a special issue on Peer-to-Peer Technologies in Network and Service Management of the Journal of Network and Systems Management
3. Program Committee member of NOMS 2006, ACC 2006, DSOM 2006, IM 2007, ICCC 2007 NSO, SASO 2007, AIMS 2007
4. Reviewer IEEE Communications Magazine, IEEE Transactions on Software Engineering, Springer Journal of Network and Systems Management
5. Co-Chair of the IETF ISMS working group
6. Member of the Security Directorate of the IETF
7. Chair of the Network Management Research Group (NMRG) of the IRTF
8. Chair of the 19th NMRG workshop on "Promise Theory and New Approaches to Distributed Management", KTH, Stockholm, January 2006
9. Chair of the 21st IRTF NMRG workshop on "Future Direction of Network and Service Management Research", SurfNet, Utrecht, October 2006
10. Dissemination Activity Leader / Member of the Executive Committee of the EMANICS Network of Excellence

Collaborations

1. *University of Twente, The Netherlands*
   Prof. Aiko Pras
   Network Management, Traffic Measurements
2. *INRIA Lorraine, France*
   Prof. Olivier Festor
   Scalability of Management Protocols
3. *NEC C&C Research*
   Dr. Lars Eggert
   Analysis of Voice over the Datagram Congestion Control Protocol
4. *NEC C&C Research*
   Dr. Jürgen Quittek
   Integrated Security Model for the Simple Network Management Protocol (SNMP)
5. *Huawei*
   David Harrington
   Architectural Models for Internet Management Protocols
6. *IEEE Project 802*
   Tony Jeffree
   SNMP over IEEE 802 Networks

Grants

1. EU, "EMANICS (EU Network of Excellence for the Management of Internet Technologies and Complex Services)"

Publications , , , ,

1.1.4 Machine Learning

Research Team Herbert Jaeger (Professor), Mingjie Zhao (Postdoctoral Fellow), Mantas Lukosevicius (PhD student)

Herbert Jaeger and his team develops Machine Learning methods for the automated construction of prediction models from empirical time series data. Target applications (and collaborations) are in the fields of neurobiology, human music understanding, handwriting recognition, control engineering and telecommunication. Two main methods investigated in Herbert Jaeger's group are recurrent neural networks of the "Echo State Network" (ESN) type and observable operator models (OOMs). ESNs are interesting not only because they yield highly efficient learning algorithms but also because they offer a biologically plausible model of learning in natural brains. OOMs generalize hidden Markov models, a standard tool in speech and text recognition, yielding more expressive models in a fraction of the learning time required for hidden Markov models. Both ESNs and OOMs have been originally found by Herbert Jaeger and have been investigated in his group over the last few years.

Highlights An important application of machine learning methods for time series data is speech recognition. Almost all current methods in this field rely on "hidden Markov models" as the basic machine learning technique. Although recurrent neural networks (RNNs) would be more plausible from a bionics perspective – after all, our brains are RNNs –, and although it is known that artificial RNNs can, in principle, yield optimal speech signal decoders, these models have not in practice been used due to the extreme computational cost and the danger of instability of previously known training methods for RNNs. RNNs of the Echo State Network type are computationally cheap to train and intrinsically stable. Thus, one research direction in Jaeger's group is to tailor ESNs to speech processing tasks.

A widely used benchmark task in this field is the "Japanese Vowels" problem[1]. The training data consist of pre-processed vocal recordings from 9 Japanese speakers, with 30 recordings per speaker. The task is to train from these data a classificator that can recognize the speaker in test recordings. Figure 9 shows some recordings from the training set. The task is difficult because of high intra-speaker and low inter-speaker variability. The best known classification methods achieve a test error rate of slightly less than 2 %. Using ESN-based models with an unconventional architecture (combining the classification "votes" of 1,000 tiny ESNs with a particular neuron model which is more biologically plausible than standard artificial neuron models), Jaeger et al. achieved a *zero* test error [JLPSar].

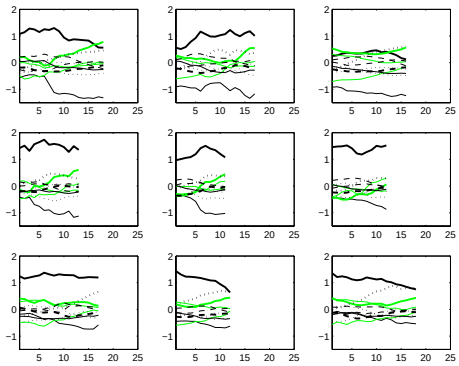

Figure 9: Some samples from the "Japanese Vowels" benchmark dataset. Each row shows three recordings from one speaker.

Another important application of machine learning methods for time series data is the recognition of handwritten texts. This task occurs, for instance, in automated check reading systems or automated mail or parcel sorting facilities. The text that is to be recognized is read from left to right with a video reading head, yielding a video sequence much like the visual input used by humans who read a text. One difficulty in this domain arises from the circumstance that handwritings can be narrow or stretched – and this may even change within a single written text. This is known

[1] Data donated by Mineichi Kudo, Jun Toyama, and Masaru Shimbo; obtainable at http://kdd.ics.uci.edu

as "time warping". An automated reading system must be able to accomodate itself online to changing character widths – it must "read faster" when the characters are narrow and "read slower" when they are stretched. This poses a nasty chicken-and-egg problem: accomodation would be easy if the characters were already recognized, but in order to recognize them, the reading system must first accomodate to the local "writing speed". Today's standard approach is to use dynamic programming methods to optimize the local "reading speed". These methods are computationally expensive and again, not biologically plausible.
In a collaboration with Planet AG (Schwerin), a company specializing in text recognition systems, a new ESN design was developed which achieves an online accomodation to "writing speed" with no additional computational cost, neither in the training phase nor in the exploitation phase. So far, this method was tested on synthetic data only, where it achieved a close-to-optimal recognition performance [LPJS06, JLPSar]. The collaboration with Planet AG will continue through 2007 and beyond.

Organization

1. Interdisciplinary College 2006, Gnne, Germany (member of program committee)
2. Studienstiftung Summer Academy Alpach 2006, Course "Neuronal Plasticity" (with D. Jaeger, Emory University)
3. Special issue of *Neural Networks* on ESNs and "Liquid State Machines", guest co-editor
4. ESN and "Liquid State Machine" workshop at NIPS 2006 (co-organizer)
5. Coordinator of a joint IUB – University Bremen *Exzellenzinitiative* proposal "Bremen Graduate School for Computational Modeling of Complex Systems"

Collaborations

1. *TU Graz*
   Prof. Wolfgang Maass
   Echo State Networks and Liquid State Machines
2. *Planet AG, Schwerin*

   Echo State Networks for handwriting recognition
3. *Emory University, Atlanta*
   Prof. Dieter Jaeger
   Biological and artificial models of neuronal plasticity
4. *Universit de Montral*
   Prof. Douglas Eck
   Echo State Networks for music processing
5. *Fraunhofer Institute IAIS, Sankt Augustin*
   Prof. Paul Plger
   ESNs for robot control
6. *Universitt Kln*
   Dr. Alexander Schnhuth
   Mathematical theory of observable operator models

Grants

1. Funded by DFG "Quadratic observable operator models
2. Funded by Planet AG, Schwerin "Time-warping invariant echo state networks

1.1.5 Harmonic Analysis applied to Communications Engineering

Research Team Götz Pfander (Professor), Niklas Grip (Postdoctoral Fellow)

In Multi-Carrier Modulation (MCM) communication schemes, the channel input signal is synthesized as a linear combination (superposition) of certain basis functions whose coeffcients (weights) are bearing digital information. The performance of an MCM system depends largely on the choice of the basis functions which should allow the receiver to perform a fast and reliable recovery of the transmitted information from the channel output.
For years, Orthogonal Frequency Division Multiplexing (OFDM) has dominated MCM transmission systems, originally in time invariant environments as in DSL applications but more recently also in slowly time varying channels. The reason for this lies in the fact that, in the stationary set-up, the OFDM carrier signals are approximate eigenfunctions of the channel operator.
Mathematically, or more precisely, within harmonic analysis, OFDM has been extensively studied under the disguise of Gabor analysis, where stability issues, synthesis and analysis algorithms, and carrier functions design are discussed at length (see also Section **??**).

Highlights In recent years, we have applied Gabor analysis to provide mathematical contributions to MCM communications. For example, we have shown that Gabor systems (OFDM, DMT) clearly outperform wavelet systems (DWMT) in time invariant channels and we have analyzed estimates of the crest factor of trigonometric polynomials which underly OFDM.
In mobile and therefore wireless and time variant communication environments, the transmitted signal reaches the receiver along a continuum of different signal paths, each featuring a path dependent time delay and a frequency shift caused by the doppler effect. Nevertheless, physical constraints imply that this time–frequency dispersion of the transmission signal is of limited extent. Hence, wireless channels can be modelled by operators, which are weighted superpositions of time and frequency shifts occupying a limited region, the so–called spreading support in the time–frequency plane. The weight functions are the so–called spreading functions which play a fundamental role in our research (Section **??**).

Transmission Basis Design: Since Fall 2004, we are working on a DFG funded project, whose aim is the mathematical analysis and optimisation of coded orthogonal frequency division multiplexing (COFDM) in view of transmission stability in wireless and other time variant environments. One of the cornerstones of this project is the analysis of the perturbation stability of different bases when used in wireless channels.

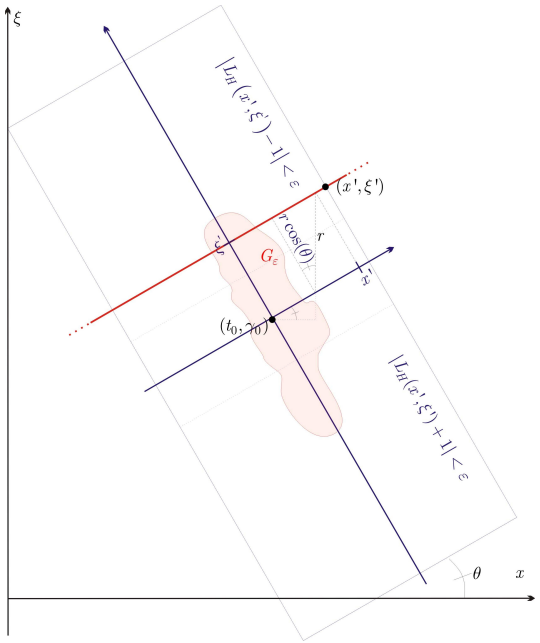

Figure 10: *Construction of a channel spreading function whose operator causes a large distortion to a function with time–frequency ϵ-support G_ϵ.*

Within this realm, we derived estimates which relate the worst case distortion of a function to the functions time–frequency concentration and the channel operators spreading support (see Figure. 10). These results should, similarly to our previous work on time invariant channels, allow us to show that OFDM outperforms wavelet

methods in mobile communication channels.
Further, we continued our work on the modelling of narrowband finite lifelength systems such as wireless radio communications by smooth and compactly supported spreading functions. Our results were used to derive a fast algorithm for computing the matrix representation of a channel operator with respect to pulseshaped OFDM bases [GP06].

Operator/Channel Identification: One of the key problems in the design of elementary building blocks for mobile communications is the incomplete knowledge of the ever–changing transmission channels. The goal of operator/channel identification is to obtain complete knowledge of a (channel-) operator by observing the output caused by a single input signal.
Within the last years, we showed that classes of operators characterized by a bounded spreading support region allow identification of its members if and only if the area of the spreading support region is less than or equal to one, a phenomenon which is closely related to Heisenberg's uncertainty principle [PW06b, PW06a]. The theory, motivated by communications engineering, has lead to the development of a sampling theory of operators which is described in Section **??**.

Coding: Discrete, overcomplete Gabor systems can be used to encode finite dimensional vectors in order to gain robustness to errors introduced in communications channels. In [KPR06], we construct a large class of Gabor like equal norm tight frames that are maximally robust to erasures. Further, we discuss consequences of our findings to the theory of recovering and storing signals which have sparse time–frequency representations.

Götz Pfander is also involved in "Applied Mathematics" (Section **??**).

Collaborations

1. *International University Bremen*
   Prof. Harald Haas, Prof. Werner Henkel, Dr. Niklas Grip
   Design of OFDM systems for time–varying channels
2. *George Mason University, USA*
   Prof. David Walnut
   Operator sampling and channel measurements
3. *Numerical Harmonic Analysis Group and European Center for Time–Frequency Analysis, Vienna University, Austria*
   Prof. Hans Feichtinger, Prof. Karlheinz Gröchenig
   Gabor analysis and applications to mobile communications

Grants

1. DFG, "Analysis and design of COFDM multicarrier modulation techniques in view of transmission stability in time variant channels," Pf450/1-1 within the DFG priority program 1163.

1.1.6 Research Area: Channel Characterization, Electromagnetics, Prototype System Development

Research Team Wallace, Jon (Professor)

Dr. Wallace's research combines the diverse areas of electromagnetics and propagation, signal processing, and communications, to allow more accurate modeling of realistic communications systems, revealing how to optimize the performance of complex systems as a whole rather than just the constituent parts. This research involves a strong experimental component, allowing results to be based on real-world experiments and measurements and not just theoretical analysis. This effort has led to the development of a number of prototype multiple-input multiple-output (MIMO) wireless channel sounders and the fabrication of RF/microwave antennas and components, facilitating the development of accurate channel models and revealing the impact of factors such as antenna mutual coupling, directivity, and polarity. Dr. Wallace's work also encompasses the development of real-time systems based on DSP and FPGA architectures for implementing proposed communications algorithms as well as advanced measurements techniques.

Highlights Dr. Wallace was a Research Associate at Brigham Young University, USA until September of 2006, when he became Assistant Professor of Electrical Engineering at International University Bremen.
His work during 2006 has focused primarily on understanding the complex behavior of time-varying MIMO wireless channels. The rate of time variation determines whether the MIMO communications channel can be adequately tracked, allowing high throughput to be achieved with the multiple antennas. Measurement and analysis of time-varying channels in indoor and outdoor environments at different frequencies revealed that for moving users, the channel must be sampled at the receiver approximately every 0.1 wavelength or shorter for high-capacity communications, as depicted in Fig. 11. It was also found that channel information at the transmitter is less critical and can be updated at the slower rate of every 1 wavelength for high capacity.

Figure 11: *Capacity loss from time-varying channel with receiver movement due to channel errors at (a) transmitter and (b) receiver*

This study on channel time-variation also led to metrics that quantify the impact of the temporal variability as well as accurate methods of capturing this behavior in computer simulations. For very rapidly fading channels (where learning the channel is not possible) it was discovered that mutual coupling of the transmit array is a critical factor affecting the system performance, and that not including mutual coupling in the system model leads to erroneous conclusions about the optimal configuration of the transmit antenna array.
Additional channel modeling work done in collaboration with the University of Pretoria, South Africa, has demonstrated interesting properties of indoor propagation channels. It has been discovered that the multipath structure, antenna correlation, and channel capacity are very similar, even when the center frequency is scaled.

During this time, Dr. Wallace also performed defense-related contract work for San Diego Research Corporation, USA, whose primary goal was to quantify how the blockage (or shadowing) of electromagnetic signals in urban environments limits communications reliability, and whether this could be improved by robotic relays. As depicted in Fig. 12, a transmitter operating at 300 MHz, 900 MHz, and 2 GHz, was mounted on a remote control car and the signal strength was measured on a fixed receiver. The car was driven in many different scenarios: indoor hallway, indoor room, outdoor-to-indoor channels, behind automobile, under automobile, etc. Analysis of the resulting shadowing versus position revealed that shadowing can cause a drop of 10-30 dB when going around a corner or behind an automobile. A simple daisy-chain relay model, however, indicated that self-configuring robotic relays may be effective in allowing reliable communications in these environments.

Figure 12: *System for rapid shadowing/pathloss measurements and possible improvement using relays for a hallway environment*

Having newly arrived at IUB in Germany, Dr. Wallace is now building up new experimental capability for ultrawideband multiple antenna channel sounding and cognitive radio, as well as forming collaborative relationships with other key researchers in Germany and Europe.

Collaborations

1. *University of Pretoria, South Africa*
   B. T. Maharaj and L. P. Linde
   Indoor Channel Measurement and Modeling

Publications [WJ06b, WJ06a, WSJ06]

1.2 Robotics and Embedded Systems

Robotics is the driving force behind the increasing omnipresence of automation, not only in industry but also in many areas of our daily lives. In addition to their well-established role as programmable machine-tools, robots are more and more used in domains where some autonomy and intelligence is necessary, where the system is not constantly supervised by a human operator and where it has to be adaptive as the developer of the system can not fully predict which situations the system will encounter in its application environment. The related computer hardware and software are the key ingredients of robots.

1.2.1 Robotics

Research Team Andreas Birk (Professor), Kaustubh Pathak (Postdoctoral Fellow), Winai Chonnaparamutt (PhD Student), Mohammed Nour AbdelGwad Ahmed (PhD Student), Max Pfingsthorn (PhD Student), Jann Poppinga (PhD Student), Sören Schwertfeger (PhD Student)

The research of the Birk group focuses on Autonomous Systems. The related work ranges from the development of embedded hardware over mechatronics and sensors to high-level software. On the basic research side of autonomous systems, machine learning and cooperation are core themes of his activities. The robotics systems developed are used in various domains including underwater and especially rescue robots.
Rescue Robotics is a new field dealing with systems that support first response units in disaster missions. Especially mobile robots can be highly valuable tools in urban rescue missions after catastrophes like earthquakes, bomb- or gas-explosions or daily incidents like fires and road accidents involving hazardous materials. The robots are used to inspect collapsed structures, to assess the situation and to search and locate victims. There are many engineering and scientific challenges. Rescue robots not only have to be designed for the harsh environmental conditions of disasters, but they also need advanced capabilities like intelligent behaviors to free them from constant supervision by operators. IUB robotics is among the world-wide leading groups in this domain.

Highlights In 2006 several achievements were made in the area of autonomous systems in general and in the field of rescue robotics in particular. First of all, the IUB rescue robots demonstrated their capabilities on several occasions including technology demonstrations, especially the Rescue Robot Field Test Demo (figure 13) and the European Land Robotics Trials (ELROB). The robots also demonstrated their capabilities at several competitions, namely three RoboCup events. At the RoboCup US Open in Atlanta, the IUB team won the first place in the rescue robot league, beating the favored US American groups. The team also won the first place at the European RoboCup competition, the Dutch Open in Eindhoven. The team also got the Innovation Award at the RoboCup World Championship in Bremen for demonstrating for the first time the successful combined usage of a tele-operated with a fully autonomous robot at rescue missions. IUB was the only European team that made it to the final round at the RoboCup World Championship, and it was beaten in the end by Asian teams that purely relied on tele-operated devices without any on-board intelligence.
On the research side, several contributions have been made ranging from the robot mechatronics over on-board intelligence up to cooperative systems level. Regarding the mechatronics of the robots, a new locomotion system [**?**] and a special mobile communication system were developed [BCssb]. The latest type of robot from IUB robotics, the so-called rugbot, short for rugged robot, is meanwhile one of the most advanced systems in this field [**?**]. But this holds not only for its mechatronic side but especially also with respect to its on-board intelligence going up to full autonomy [BCC$^+$ss]. Contributions to several core topics for intelligent mobile robot have been made in this context, especially for map generation [BCssa], for the vectorization of maps [**?**], for the integration of autonomous behaviors with user interactions [BPss], and for the underlying architecture for autonomy [**?**]. The group also contributed to a high fidelity simulator for mobile robots [CBLJss] that plays a significant role in the prototype development of intelligent robot software. Last but not least, work regarding cooperative robot teams was done. The contributions include a novel algorithm for multi robot exploration [**?**] that can be used for search and rescue missions by robot packs [RBss]. A second important result is a novel algorithm for multi robot mapping [**?**].
IUB robotics made in 2006 also first successful practical steps in the domain of underwater robotics by developing an Autonomous Underwater Vehicle (AUV). The work was jointly done

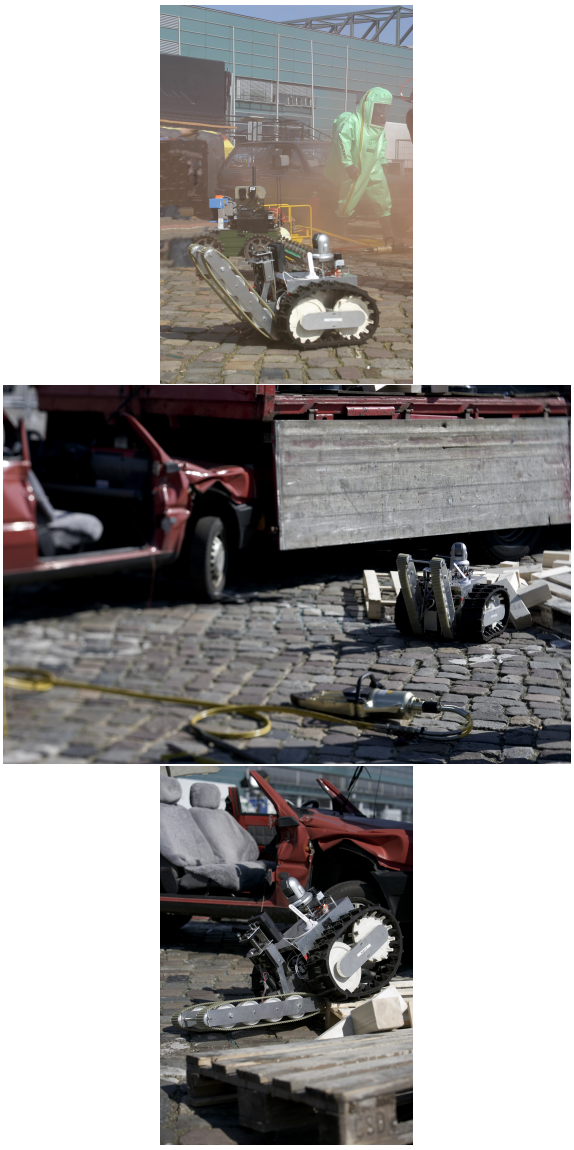

Figure 13: An IUB robot at a drill dealing with a hazardous material road accident.

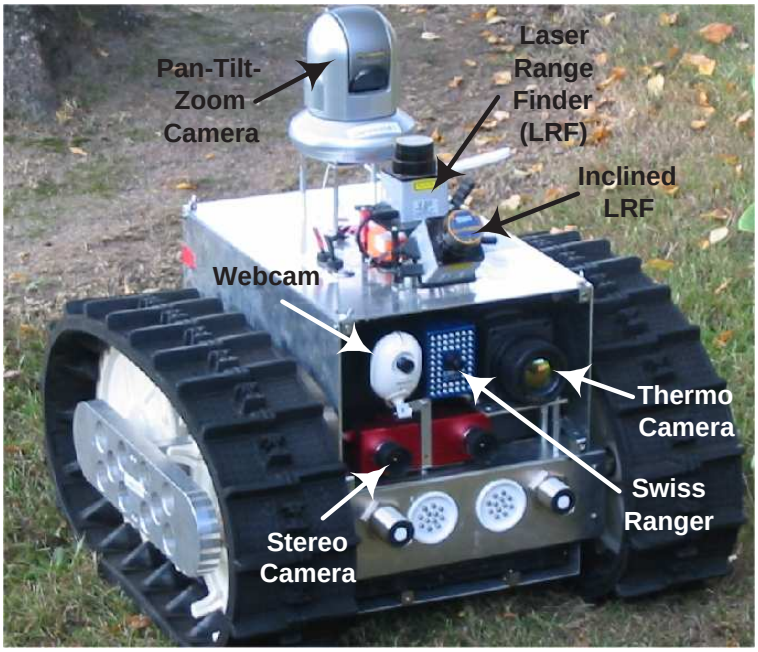

Figure 14: A rugbot with a selection of on-board sensors. Several sensors are dedicated to 3D range sensing to generate 3D environment models with a novel approach.

Figure 15: The RoboCup rescue competition features a very complex test environment (left), which includes several standardized test elements. The IUB team demonstrated at the world championship 2006 a combined usage of a teleoperated with a fully autonomous robot (right).

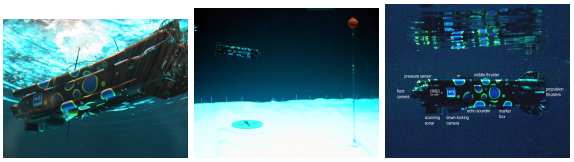

Figure 16: The IUB-ATLAS Autonomous Underwater Vehicle (AUV) diving in a test pool (left). The AUV on an autonomous mission, searching for a midwater target in form of a submerged orange buoy (center). An overview of the main sensors of the AUV (right).

with ATLAS Elektronik in a cooperative project including also the IUB robotics club. The most basic vehicle parts, namely the hull, the batteries, the motors with propellers, and some sensors were provided to IUB by ATLAS. The on-board control electronics and software were completely developed by IUB. This work is based on the CubeSystem, a collection of hard- and software-components for fast robot prototyping, which is also used for the IUB land robots. The AUV features fully autonomous motion control and mission planning. It has an on-board vision system that allows to recognize targets and to trigger appropriate behaviors. The system already successfully demonstrated its capabilities at the Student Autonomous Underwater Challenge - Europe (SAUC-E), which took place in August at the Pinewood movie studios near London. The IUB-ATLAS-AUV came in on second place in the performance evaluations, beating several of the established underwater robotics research institutions.

Organization

1. Chair "RoboCup World Championship 2006, Rescue Robot League", Bremen, Germany
2. Organizer "Rescue Robot Field Test Demo", opening event of RoboCup World Championship 2006, Bremen, Germany
3. Program Committee Member/Reviewer: Journal of Robotics and Autonomous Systems; Journal of Control Engineering Practice; International RoboCup Symposium; IEEE International Workshop on Safety, Security, and Rescue Robotics

Collaborations

1. *International Rescue Systems Institute, Kobe, Japan*
   Prof. Satoshi Tadokoro
   Rescue Systems and Applications
2. *University of Rome "La Sapienza", Italy*
   Prof. Daniele Nardi
   Autonomous Intelligent Functionalities within Rescue Robotics
3. *Imperial College, London, UK*
   Dr. Yiannis Demiris, Senior Lecturer
   World Modeling by Autonomous Intelligent Systems

Grants

1. DFG, Learning of 3-Dimensional Maps of Unstructured Environments on a Mobile Robot
2. ATLAS Elektronik, IUB-ATLAS Autonomous Underwater Vehicle,
3. EU, EUropean RObotics research Network (EURON), EU-IST NoE
4. RoboCup Federation, IUB Rescue Robots Team Support

Journals

Conference Proceedings

Books/Collections

1.2.2 Applied Algorithms

Research Team Stefano Carpin (Professor), Hamed Bastani (PhD Student), Gorkem Erinc (MSc Student), Andreas Kolling (MSc Student)

The main research focus is on the computational aspects of robotics, with a special emphasis on motion planning and cooperative tasks. By their very own nature, robots are machines that execute their tasks in the physical world. Their control algorithms have then to consider physical laws and constraints, and process noisy information acquired during their execution. This unique combination of challenges calls for the design of algorithmic techniques that bring together computer science, control theory, probability and computational geometry. Another area of active research is on the development of tools for the realistic simulation of robot systems, with special attention to multi-robot systems. The goal in this case is to produce the tools for a fast development of robot algorithms.

Highlights During the year 2006 a major effort has been spent to perfect and promote the USARSim simulator. This project, jointly developed with the National Institute of Standards and Technology (USA) and the University of Pittsburgh is experiencing significant popularity and is rapidly becoming one of the most widely used robot simulators (packages composing the software have been downloaded more than 6000 times). The software provides an ideal experimental environment to perform early validation of robot algorithms for tasks like planning, navigation, exploration, mapping and the alike. The simulator has been adopted as software infrastructure for a new Robocup competition held for the first time during the 2006 event held in Bremen. During the competition, the IUB team led by Prof. Carpin won the second place.
Continuing a well established vein of research in cooperative multi-robot systems, a new solution for the Cooperative Multi-robot Observation of Multiple Moving Targets (CMOMMT) has been proposed. The designed algorithm overcomes some of the deficiencies found in formerly suggested approaches by introducing explicit communication between the pursuer robots, as well as motion prediction mechanisms that are not programmed a priori, but rather learned by the system. This investigation led to the discovery of more additional fundamental research topics that are currently being pursued. Applications in the long term can be envisioned in the field of assisted surveillance.
Finally, a novel algorithm for determining the translation collision distance between convex polyhedra has been developed. The problem of distance computation is fundamental in tasks like motion planning, virtual prototyping and computer aided design. The proposed algorithm exhibit interesting properties. It performs well both on computations where no prior information is available, but it can also favorably exploit prior knowledge obtained from formerly resolved problem instances (so called *incremental computation*. Comparisons with state of the art alternatives outline better asymptotic trends (figure **??** shows and example of comparative results with other algorithms).

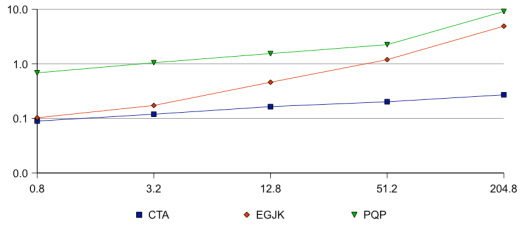

Figure 17: *Time spend to solve a collision query as a function of the complexity of the involved polyhedra. The blue line outlines the performance of the proposed algorithm.*

Organization

1. 6th IEEE International Workshop on Robot Motion and Control: program committee member
2. IEEE 2006 International Conference on Information Reuse and Integration: program committee member
3. PerMIS 2006: program committee member

4. 6th international joint conference on autonomous agents and multiagent systems: program committee member
5. Robocup Federation: elected Executive Member for the 2007-2009 term
6. Organizer of a tutorial on "USARSim/MOAST: Highly Realistic Simulation and Control for Multi Robot" held at the IEEE International Conference on Robotics and Automation (Orlando-FL, May 2006)
7. Organizer of a tutorial on "USARSim and MOAST: Advanced Tools for High-Fidelity Simulation of Distributed Robot Systems " held at the annual conference of the American Association for Artificial Intelligence (Boston-MA, July 2006)

Collaborations

1. *National Institute of Standards and Technology, USA*
   Dr. Steve Balakirski
   Organization of the Virtual League Competion and development of USARSim
2. *University of Pittsburgh, USA*
   Prof. Mike Lewis
   Organization of the Virtual League Competion
3. *University of Udine, Italy*
   Prof. Claudio Mirolo
   Development of Algorithms for Collision Detection
4. *University of Padova, Italy*
   Prof. Enrico Pagello
   Development of Algorithms for Multi-Robot Motion Planning

1.3 Knowledge and Information Management Systems

Today's information services are rapidly changing from statically served data to information that is dynamically tailored to each individual user's current needs. This information is fetched instantaneously from networked, distributed sources which themselves change and evolve continually. At the same time, new representation formats allow to discover and specify the internal and functional structure of information and drive services that previously required (human) understanding. Technically, we observe the convergence of databases, Internet, and distributed systems into semantically enriched knowledge systems which allow the casual as well as the professional user to deal with the ever-growing amount of information available. Another issue is the presentation of information to the user. Data visualization is concerned with the management of large data, the filtering and extraction of salient features, and their visual representation in an expressive, intuitive, and interactive manner.

1.3.1 Reasoning, Semantics, and Knowledge Management

Research Team Michael Kohlhase (Professor), Heinrich Stamerjohanns (Head of EECS Labs, see 1.4.6), Christoph Lange (PhD Student), Christine Müller (PhD Student), Normen Müller (PhD Student), Immanuel Normann (PhD Student), Florian Rabe (PhD Student), Andrea Kohlhase (Research Programmer)

The ability to represent knowledge about the world and to draw logical inferences is one of the central components of intelligent behavior, as a consequence, reasoning components of some form are at the heart of many artificial intelligence systems.

The work of the KWARC (Knowledge Adaptation and Reasoning for Content) group centers around building knowledge management systems for e-science applications, in particular for the natural and mathematical sciences. The main assumption in this work is that if the structure of the factual content of scientific documents, their contributions and dependencies regarding a larger knowledge context is made sufficiently explicit, then this structure becomes amenable to machine manipulation. Thus high-level added-value (web)-services can be offered, e.g. semantic search and navigation (independent of the surface presentation), user-adaptive presentation and content tailoring, and extended semantic quality control up to proof verification.

Highlights The highlight in 2006 was the publication of a 500 page book on OMDoc in the Springer Lecture Notes in Artificial Intelligence series [Koh06d]. OMDoc (Open Mathematical Documents) is an XML-based representation format for mathematical knowledge developed in the KWARC group. This format is used in various ($\geq$ 10) international projects as the knowledge representation base.

We have extended the knowledge representation infrastructure in OMDoc to other topics in the natural sciences to make it into a general semantic representation language that supports seamless computer support in a "*Scientific Semantic Web*" [HKS06]. Our starting point is the view of the *scientific method* as a spiral (Fig. 18). In this view, scientific research moves in a spiral trajectory from original ideas to results and applications. At the moment, most of the steps in Fig. 18 are separately supported by software systems, e.g. literature searches in Google Scholar or Wikipedia, theory exploration in computer algebra systems and experiments in simulation systems. But the systems are, largely, not able to inter-operate since they use differing data formats, make differing model assumptions, and are bound to an implicitly given context that is only documented in publications about the systems. A joint and universally applicable representation language will be an enabling technology that alleviates these problems.

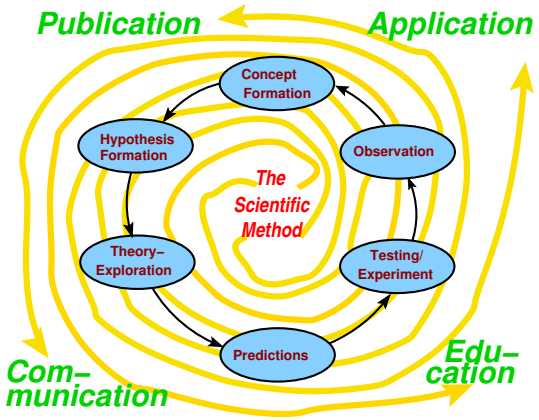

Figure 18: *The Spiral View of Scientific Method*

To make this vision come true, we have developed

1. a highly efficient, content-based document retrieval engine for mathematics [KS06],
2. an OMDoc-based semantic WIKI [LK06b, LK06a, Lan06],
3. a theoretical foundation for invasive editors and implementations in the MS Office suite [Koh06b, Koh06a, Koh06c],
4. methods for the discovery of theory morphisms in mathematical libraries [Nor06]
5. a methodology for an ontology-based management of change [Mül06b, Mül06a], and
6. a representation format for logical systems with logic morphisms and proofs [Rab06a,

Rab06b]
We have started a research group of undergraduate CS students that undertake the translation of the Cornell EPrint Archive from LaTeX to XHTML+MathML (we can currently translate 45% of 400.000 articles in Physics, Mathematics, Computational Biology, and Computer Science). This corpus will subjected of a semantic analysis with computational linguistics methods and will be the basis of scalability studies for the methods and representation formats presented above.

Organization In 2006, Prof. Michael Kohlhase was

1. Program and Conference Co-Chair of the 29.th Annual German Conference on Artificial Intelligence KI'06[FKS06]
2. Trustee of the Conference on Automated Deduction
3. Trustee of the Mathematical Knowledge Management Interest Group
4. Trustee of the CALCULEMUS Interest Group
5. Member of the Executive Committee of the OpenMath Society
6. Member of the MathML Working Group of the World Wide Web Consortium (W3C)
7. Member of 11 Program Committees of International Conferences.

Collaborations Prof. Michael Kohlhase is a Vice Director of the "Safe and Secure Cognitive Systems" of the newly founded Department of the German Research Institute Lab Bremen. This leads to an intensive collaboration of the KWARC group with this research group, which includes joint projects and supervision of students. Further collaborations of the KWARC group include

1. *Rice University, USA*
   Prof. Richard Baraniuk
   Extending the Connexions Representation Format CNXML
2. *National Institute of Standards, USA*
   Dr. Bruce Miller
   Transforming LaTeX documents to OMDoc/CNXML
3. *International University Bremen*
   Prof. Peter Baumann
   Extending OMDoc to GIS-Data/Living Documents
4. *Institute for Science Networking*
   Prof. Eberhard R. Hilf
   Extending OMDoc to PhysML
5. *Carnegie Mellon University, USA*
   Prof. Frank Pfenning, Prof. Peter Andrews
   Higher-Order Theorem Proving and Meta-Logical Frameworks
6. *Universität des Saarlandes*
   Prof. Jörg Siekmann, Dr. Christoph Benzmüller
   Higher-Order Theorem Proving
7. *Deusches Forschungszentrum für Künstliche Intelligenz, Saarbrücken*
   Dr. Dieter Hutter
   Ontology-based Management of Change
8. *Design Science Inc.*
   Dr. Robert Miner
   Mathematical Document Retrieval

Grants

1. EU: ONCE-CS Network Grant, EU Framework 6 IST
2. EU: JEM Network Grant, EU Framework 6 IST
3. Industry: Design Science Inc. Grant for transforming Cornell Eprint archive.

Publications

1.4 Simulation and Control of Complex Dynamical Systems (A.C. Antoulas)

Model reduction seeks to replace a large-scale system of differential or difference equations (the outcome of discretizing a PDE, perhaps) by a system of substantially lower dimension, that ideally, has the same response characteristics as the original system, yet requires far less computational resources for realization than the potentially unmanageable levels that may be required by the larger original system.

Two main currents can be identified among methodologies for model reduction. Balanced approximation methods are built upon a family of ideas with very close connection to the singular value decomposition. These methods preserve stability and allow for global error bounds but often do not scale well in terms of computational efficiency and stability when applied to large scale problems. Moment matching methods are based principally on Padé-like approximations and for large-scale problems have lead naturally to the use of Krylov and rational Krylov subspace methods. These methods generally enjoy greater efficiency and numerical stability. A strong current trend aims at combining these two approaches by deriving iterative methods which achieve approximate balanced reduction.

1.4.1 Highlights

Our research activities are concerned with the circle of ideas surrounding model reduction. It provides efficient and robust methods for producing reduced order models of large state space systems. These activities have an impact both in system theory of complex systems as well as in applied mathematics and in particular numerical methods for large-scale problems. Once the theory and computational methods are developed, we expect that high quality software will result and have applications in many areas of engineering. This will enable at a later stage, the design of real time controllers for complex systems.

Broader impact resulting from the proposed activities. In today's technological world, physical processes are described mainly by mathematical models, which are used to simulate the behavior of the physical processes in question. Sometimes, they are also used to modify or control their behavior. In this framework, there is an ever increasing need for improved accuracy which leads to models of high complexity.

The basic motivation for system approximation is the need in many instances for a simplified model of a dynamical system, which however captures the main features of the original complex model. This need arises from limited computational, accuracy, and storage capabilities. The simplified model is then used in place of the original complex model, either for *simulation*, or *control*.

Important areas of application of model reduction are: VLSI (Very Large Scale Integration) design, weather prediction, air quality management, molecular dynamics simulations, simulation and control of chemical (e.g. CVD - Chemical Vapor Deposition) reactors, car windscreen quality management, simulation and control of MEMS (Micro Electro Mechanical Systems) devices, e.g. micromirrors, to name but a few. Thus the proposed activities have potential benefits for society at large.

1.4.2 Grants and Research Collaborations

1. **Model Reduction for Structured Dynamical Systems**
   Principal Investigators: D.C. Sorensen and A.C. Antoulas, Rice University.
   Funding Agency: US National Science Foundation
   R38570-776000
   NSF CCR-0306503
   Grant duration: 8/15/2003-7/31/2006
   Ammount: $\$436,607.00$
2. **Collaborative Research on Model Reduction of Dynamical Systems for Real-time Control**
   ITR (Information Technology Research) Grant, collaborative with Purdue and Florida State
   Principal Investigators: A. Sameh, A. Gramma, C. Hoffmann (Purdue University),

D.C. Sorensen, A.C. Antoulas (Rice University), K. Gallivan, P.M. van Dooren (Florida State University).
Funding Agency: US National Science Foundation
R38670-776000
NSF ACI-0325081
Grant duration: 9/01/2003-8/31/2007
Amount: $\$1,826,959.00$

3. **Advanced Projection Techniques for Dimension Reduction of Large Scale Dynamical Systems**
Principal Investigators: D.C. Sorensen and A.C. Antoulas, Rice University
Funding Agency: US National Science Foundation
OSR No.: 06052204
NSF CCF-0634902
Project Period: 10/01/2006-9/30/2009
Total Award: $\$250,000.00$

1.4.3 Publications

1.4.4 Raster Data Services

Research Team Peter Baumann (Professor), Angelica Garcia Gutierrez (PhD Student)

Raster data occur in various dimensions, be they observed phenomena or generated data sets. Examples comprise satellite imagery and mapping, geo physics and exploration, medical imagery, engineering data, and statistics data. A key property they have in common is their extreme volumes, often Giga- to Petabyte per object.

With the advent of sufficiently large disk capacities data providers more and more tend to publish such large Multidimensional Discrete Data (MDD) - GoogleEarth is a prominent example. Generally such services are implemented in an ad-hoc manner, and consequently offer limited functionality (such as GoogleEarth: zoom and pan on satellite maps). However, flexible, value-added data navigation and analysis requires more, both for experts (such as exploration engineers) and the general public (where internally complex functionality like local weather prediction obviously should be wrapped for easy access).

MDD database and Web service support raises new questions on all levels: conceptually, formal models are needed to describe data and services; query languages resp. request interfaces need to be designed based on these foundations. Efficient implementation, including optimizing query evaluation and storage structures, is needed. The high volume suggests to include tape robots as near-line storage facilities. Last but not least services for as many application domains as possible need to be realized to gain domain understanding and to evaluate service implementations.

In our research we investigate on the principles of MDD management based on the rasdaman ("raster data manager") system acting as a research platform. Application domains inspected are mainly stemming from earth system research, such as 2-D to 4-D remote sensing, exploration, marine, and climate data. As a byproduct we are actively engaged in the Open GeoSpatial Consortium where we contribute to the standardization of geo raster services.

Collaborations In 2006 several new international research cooperations have been established:

1. *Universidade de Campinas (Unicamp), Campinas, Brazil*
   Prof. Claudia Bauzer Medeiros is Head of the Laboratory of Information Systems (LIS) at the Institute of Computing, UniCamp, and President of the Brazilian Computer Society. With her group she works on advanced Web-based geo services with emphasis on agro-cultural and environmental applications; to this end there is a long-standing relation with the Brazilian Ministry of Agriculture.
   In the collaboration, for which a joint research proposal has been submitted to DAAD/Germany and INPe/Brazil, both partners plan to extend Unicamp's geo services with IUB's raster services, based on the open OGC standards. The resulting system will be exercised in real life operation. Evaluation results will be brought into OGC to give feedback to the standards developers.
2. *Universidad de Sinaloa, Sinaloa, Mexico*
   Dr. Ines Fernando Lopez Vega, who in 2004 has received his PhD from University of Arizona at Tucson, is building up his research on image time series evaluation. Collaboration is foreseen combining his interests with our raster service research and Michael Kohlhase's work on Semantic Web services. Collaboration was initiated in Fall 2006 with a visit of Dr Lopez Vega in the course of his co-supervision of Angelica Garcia Gutierrez's PhD work.
3. *Chinese Academy of Sciences and Jilin University, Changchun, China*
   Prof. Liu Chuang plays an important role in China when it comes to provision and exploration of remote sensing data. Among others, she is Vice Director of the Institute of Geography and Natural Resources (IGNR) and director of the Spatial Data Commission, the Chinese Association of Geographic Information System (CAGIS), and Secretary General of a Working Group of Remote Sensing and Data Information Systems

(RS/DIS).
IUB, IGNR und Jilin University plan joint activities in the field of open standards-based geo services on high-volume in situ and remote sensing data, based on rasdaman. As a real life application IGNR's 100+ TB data archive of Chinese satellite imagery collected over several years will serve, today stored in hundreds of DVDs, unavailable to the researcher community. The Chinese National Disaster Reduction Center will be one of the first users, with application scenarions being river floods and earthquakes.

Highlights An important work package is contribution to geo raster service standardization in the Open GeoSpatial Consortium (OGC, www.opengis.org). We are actively contributing in the Web Coverage Service (WCS) Revision Working Group where the substantially revised WCS version 1.1 has been finished by the end of 2006. Based on the experience gained there and the WCS shortcomings spotted we have propose the concept of a Web Coverage Processing Service (WCPS); Figure.19 exemplifies usage of WCPS by dynamically deriving the NDVI of a Landsat satellite scene; the NDVI I of an image is defined as I=(nir-red)/(nir+red), in the right image it is thresholded as I¿0.6. In June 2006, WCPS has been lifted to a Best Practice Paper (which implies OGC endorsement), it is estimated that WCPS can become a Draft Standard end of 2006 / beginning of 2007, and a full standard by summer 2007. Several institutions, among them German mapping (AdV) and geophysical institutions (such as BGR) have expressed their interest.
In parallel to the conceptual work on WCS and WCPS, our group implements both services. Prototypes have been demonstrated at various occasions in 2006, among them OGC Technical Commitee meetings. For 2007 it is planned to set up large-scale services fo thorough evaluation prior to freezing the final standard document.
The GALEON (Geo-interface to Atmosphere, Land, Earth, Ocean, NetCDF) project launched in 2005 meantime has become an OGCnetwork (www.ogcnetwork.net/galeon); besides contributing to WCS requirements it is starting now to hands-on evaluate the new WCS 1.1. IUB will contribute our WCS implementation, which is under work,
As part of the IRCCM project (www.irccm.org) and in collaboration with IUB's geo group and AWI Bremerhaven, a standards-based open service for marine research data has been set up which combines bathymetry data and video mosaics acquired by a French underwater robot. Data describe an underwater volcano in the Norwegian Atlantic area known as Hakon-Mosby. This service is the first step towards a more comprehensive multi-sensor fusion service between IUB and AWI.
For the ICSU CODATA (Committee on Data in Science and Technology) a German section has been established as an "e.V." and has been accredited with CODATA International. As a side effect of this work, several fruitful research contacts have emerged, such as with the Chinese Academy of Science (see above).

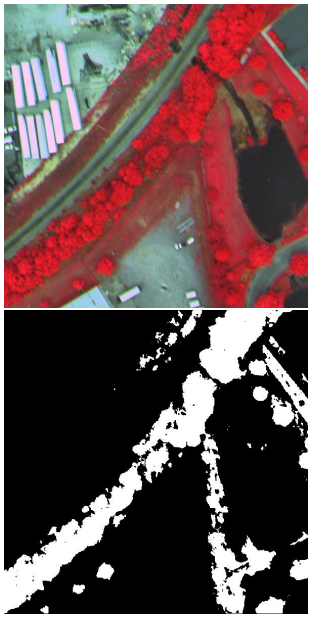

Figure 19: *The Normalized Difference Vegetation Index (NDVI) as a database / Web service query (rasdaman screen shots).*

Several tutorials have been given on the topic of

raster services:

1. CODATA 2006 Conference, Beijing (3 hrs)
2. 1st International Symposium on Cooperation and Promotion of Information Resources in Science and Technology (under the auspices of the Chinese Ministry of Science and Technology), Beijing (2 hrs)
3. 19th IFIP World Computer Congress, Santiago de Chile (3 hrs)

Publications [Bau06a, BSB06, Bau06b]

1.4.5 Visualization and Computer Graphics

Research Team Lars Linsen (Professor), Sherin Al-Shbat (PhD Student), Tetyana Ivanovska (PhD Student), Tran Van Long (PhD Student), Paul Rosenthal (PhD Student)

The Visualization and Computer Graphics Laboratory (VGCL) led by Prof. Lars Linsen is mainly concerned with topics from scientific and information visualization plus some selected topics from computer graphics and geometric modeling. Visualization is an inherently interdisciplinary field with application in many different areas. Scientific visualization deals with the visualization of data with spatial interpretation such as computer-generated data from numerical simulations (physics, chemistry) or measured data using scanning or sensoring techniques (medicine, life sciences, geosciences). The group's efforts are to generate visualization methods that can handle large data sets efficiently, filter distinct features automatically or interactively, and display the relevant information in a comprehensive and intuitive fashion. The research focuses on segmentation and isosurface extraction, hierarchical methods, multi-variate data visualization, flow and tensor field visualization, and user interaction.
Information visualization deals with the visualization of abstract data with no spatial interpretation such as graph- or network-based data (life sciences, social sciences) or multi-dimensional data (databases, ecomomics). The group's efforts focus on interactive exploration and analysis tools for such abstract data.
In the areas of computer graphics and geometric modeling the group's interest lies in point-based methods, multi-resolution surface representation, and curves on surfaces.

Highlights

Direct Isosurface Extraction from Scattered Volume Data. Isosurface extraction is a standard visualization method for scalar volume data and has been subject to research for decades. Nevertheless, no isosurface extraction method existed that directly extracts surfaces from scattered volume data without 3D mesh generation or reconstruction over a structured grid. We have developed a method based on spatial domain partitioning using a kd-tree and an indexing scheme for efficient neighbor search. Our approach consists of a geometry extraction and a rendering step. The geometry extraction step computes points on the isosurface by linearly interpolating between neighboring pairs of samples. The neighbor information is retrieved by partitioning the 3D domain into cells using a kd-tree. The cells are merely described by their index and bitwise index operations allow for a fast determination of potential neighbors. The final rendering step uses point-based rendering techniques.

Figure 20: *Point-based ray tracing of isosurface directly extracted from a scattered volume data. The scattered data set is a uniform random sampling of simulation data of fuel injection into a combustion chamber.*

Using Ray Intersection for Dual Isosurfacing. Isosurface extraction using dual contouring approaches have been developed to generate a surface that is dual in terms of the underlying extraction procedure used when compared to the standard Marching Cubes (MC) method. These ap-

proaches address some shortcomings of the MC methods including feature-detection within a cell and better triangles. We have developed a simple method based on the MC method and the ray intersection technique to compute isosurface points in the cell interior. One of the advantages of our method is that it does not require Hermite data, i.e., the discrete scalar values at vertices suffice. We compute ray intersections to determine isosurface points in the interior of each cell, and then performed a complete analysis of all possible configurations to generate a look-up table for all configurations. We use a look-up table to optimize the ray intersection method to obtain minimum number of points necessarily sufficient for defining topologically correct isosurfaces in all possible configurations.

Structure-accentuating Dense Flow Visualization. Vector field visualization approaches can broadly be categorized into approaches that directly visualize local or integrated flow and approaches that analyze the topological structure and visualize extracted features. Our goal was to come up with a method that falls into the first category, yet reveals structural information. We have developed a dense flow visualization method that shows the overall flow behavior while accentuating structural information without performing a topological analysis. A flow integration step generates a density field by tracing particles under the influence of the underlying vector field. The resulting density is high in attracting regions and low in repelling regions. Density is measured by the number of particles per region accumulated over time. The density fields for forward and backward propagation are explored using texture-based rendering techniques. We obtained dense flow visualizations that display the overall flow behavior, emphasize critical and separating regions, and indicate flow direction in the neighborhood of these regions.

Visual Analysis of Gel-free Proteome Data. We developed a visual exploration system supporting protein analysis when using gel-free data acquisition methods. The data to be analyzed is obtained by coupling liquid chromatography (LC) with mass spectrometry (MS). LC-MS data has the properties of being non-equidistantly distributed in the time dimension (measured by LC) and being scattered in the mass-to-charge ratio dimension (measured by MS). A hierarchical data representation and visualization method is used for large LC-MS data. Based on this visualization we have developed a tool that supports various data analysis steps like deisotoping, landmark-based registration, and differential protein expression analysis. Our visual tool provides a global understanding of the data, intuitive detection and classification of experimental errors, and extensions to LC-MS/MS, LC/LC-MS, and LC/LC-MS/MS data analysis.

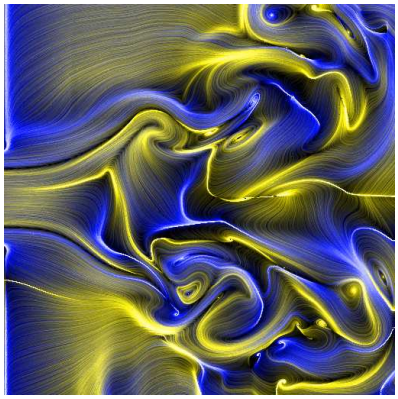

Figure 21: *Structure-accentuating dense flow visualization applied to 2D simulation of a swirling jet.*

Organization

1. International conference on *Visualization in Medicine and Life Sciences (VMLS 06)* held July 19–21, 2006, at Binz, Rügen, Germany (http://www.lars-linsen.de/vmls). Organizers: Lars Linsen, Hans Hagen (University of Kaiserslautern), and Bernd Hamann (University of california, Davis).

Collaborations

1. *Institut für Mathematik und Informatik, Ernst-Moritz-Arndt-Universität Greifswald, Germany.*
   Georg Füllen, Julia Löcherbach, Steffen Rudnick.
   (1) Visualization of protein-protein interaction.
   (2) Visualization of gel-free proteomics data.
   (3) Simulation and animation of urban tree growth.
2. *Institut für Mikrobiologie, Ernst-Moritz-Arndt-Universität Greifswald, Germany.*
   Michael Hecker, Jörg Bernhardt, Dörte Becher.
   Visualization of gel-free proteomics data.
3. *Decodon GmbH, Greifswald, Germany.*
   Matthias Berth, Jörg Bernhardt.
   Visualization of gel-free proteomics data.
4. *Institut für Diagnostische Radiologie und Neuroradiologie, Ernst-Moritz-Arndt-Universität Greifswald, Germany.*
   Norbert Hosten, Sönke Langner, Martin Domin.
   Glyph- and tracking-based visualization of diffusion MRT data.
5. *Poliklinik für zahnärztliche Prothetik und Werkstoffkunde, Ernst-Moritz-Arndt-Universität Greifswald, Germany.*
   Bernd Kordaß.
   Virtual placement and interactive optimization for functional occlusion in prosthodontics.
6. *Institut für Psychologie, Ernst-Moritz-Arndt-Universität Greifswald, Germany.*
   Klaus Landwehr.
   An interactive system for the generation of symmetric images with respct to symmetry groups.
7. *Fraunhofer-Institut für Produktionstechnologie, Aachen, Germany.*
   Christian Brecher, Fritz Klocke, Lothar Glasmacher, Olaf Dambon, Richard Zunke, Timo Wenzel.
   MoldFinish: Intelligent polishing system for automated finishing in tool and mold making.
8. *Institute for Data Analysis and Visualization (IDAV), University of California, Davis, U.S.A.*
   Bernd Hamann, Kenneth I. Joy, Nina Amenta, John D. Owens, Oliver G. Staadt, Oliver Kreylos, David F. Wiley, Sung Park, Jaya Sreevalsan-Nair.
   (1) New approaches in flow visualization.
   (2) Exact dual isosurface extraction.
   (3) Interactive visual exploration of Northern California's water monitoring network.
   (4) Surface-based brain morphing.
9. *Zuse Institut Berlin, Germany.*
   Ingrid Hotz.
   (1) New approaches in flow visualization.
   (2) Interactive visual exploration of Northern California's water monitoring network.
10. *Center for Urban Forest Research, University of California, Davis, U.S.A.*
    E. Gregory McPherson.
    Simulation and animation of urban tree growth.
11. *Center for Functional MRI, Department of Radiology Department, University of California, San Diego, U.S.A.*
    Lawrence R. Frank, German Eichberger.
    Automated segmentation of anatomical scans (MRT) of sharks.

Grants

1. DFG supported the International conference on Visualization in Medicine and Life Sciences (VMLS 06).

1.4.6 Open Access Publishing

Research Team Heinrich Stamerjohanns (Lecturer), also member of KWARC Research Team, see 1.3.1

With the fundamental change of the existing paper publication system towards networked digital publications a variety of new possibilities arise to overcome the existing technical constraints of scientific documents in order to increase the effectiveness of scientific research.

Scientific exchange may be improved in various ways:

- by giving free and and unrestricted access (Open Access) to the results of scientific research
- by enabling access not only to text and pixeled images but to complete sources (data, programs) of the obtained results
- by semantically annotating content in order to improve the searchability hby machines.

Highlights We proposed a content markup language for physics realized by extending the OMDoc format by an infrastructure for the principal concepts of physics: observables, physical systems, and experiments. The formalization of the description of physics observables follows the structural essence of the operational theory of physics measurements. The representational infrastructure for systems and experiments allow to capture the distinctive practice of physics: natural laws are supported by evidence from experiments which are described, disseminated and reproduced by others.

In a collaboration with Prof. Jeltsch we are also developing tools to dynamically publish generated data that will help to understand the genetic and epigenetic basis for DNA-methylation variation in the human genome, to asses sequence specificity of DNA-methylation patterns in normal tissues.

As a member of the Deutsche Initiative für Netzwerkinformation (DINI) Working Groups *E-Publications* and *Open Archives*, we are trying to establish common standards for Scientific Institutional Repositories.

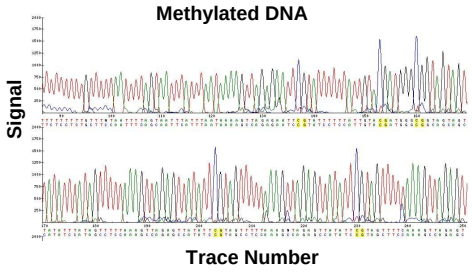

Figure 22: *Dynamically created content of the analysis of methylated DNA. Other researches do not only have access to images, but to full research data.*

Collaborations

1. *IU Bremen*
   Prof. M. Kohlhase
   Extending OMDOC to PhysML, ArXiv conversion
2. *IU Bremen*
   Prof. A. Jeltsch
   Dynamic publishing of SMP Epigenetics Data
3. *ISN Oldenburg*
   Prof. E.R. Hilf
   Extending OMDOC to PhysML
   Citation Linking and Indexing
4. *DINI Working Groups*
   Certificate for Institutional Repositories

Publications [HKS06, Pub06]

1.5 Microelectronic Devices and Technologies

To continue the rate of progress in information and systems and technologies into the next decade fundamental questions in material science and manufacturing technology have to be answered to further reduce the device dimension into the sub 100nm arena and increase the complexity of integrated circuits. Novel Micro and Nano Technologies are needed, either to overcome limitations to further shrinking of devices and/or to implement novel electronic hardware/services (such as large flexible displays). In parallel to the development of novel devices, the integration into large volume manufacturing processes and the specific problems associated to manufacturing and quality/reliability engineering of these have to be addressed, according to the principles of concurrent engineering.

1.5.1 Information and Communication Technologies

Electronic Devices and Nanophotonics group
Dietmar Knipp(Professor), Amare Benor, Kah-Yoong Chan, Christian Haase (external PhD student) (PhD Student)

Research of the Electronic Devices and Nanophotonics group is focused on nano and optical technologies and their applications in information technology and photovoltaics. The major goal of the research is to develop the next generation of electronic and photonic devices bridging from the micro to the nanoscale.

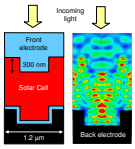

Figure 23: *Cross section of a slice of a nanotextured solar cell (left) and absorption profile in the solar cell)*

Highlights Highlights in the area of Photonics: With the advent of micro and nano fabrication the production of nano-structured materials in the sub 100 nm range became feasible. Such nanostructures are of interest for several optical and photonic applications like solar cells and optical sensors. For example, the conversion efficiencies of thin film solar cells can be increased by nano texturing of the cells. Due to nano texturing a larger fraction of the incoming light is scattered and diffracted, so that the total absorption of light in the solar cell is enhanced. Subsequently the generated photocurrent and the conversion efficiency of the solar cell are enhanced. Despite these improvements the underlying optics in such nano textured solar cells is not fully understood. Classical optics does not facilitate the description of the wave propagation in such a solar cell. Maxwells equations have to be solved in 2D or 3D to gain insights in the optical wave propagation of such devices. The optics were studied by numerical simulations using a Finite Integration Technique (FIT) and Finite Difference Time Domain (FDTD) approach. The device structure is approximated by a solar cell with a periodic groove structure. The figure (left) shows one period of such a solar cell with a groove structure. The numerically simulated absorption is shown in figure, right.
The absorption of light in the cells is increased, due to scattering and diffraction of light. Simulations carried out by Christian Haase show that the grooves cause an increase of the total conversion efficiency of 10-15The optical simulations were not only applied to solar cells. Numerical simulation of metallic nanostructures shows that metallic hole arrays can be applied as optical filters. The filter properties can be tuned by changing the diameter and the spacing of the holes in the metal film. As the fabrication of the metallic structures is comparable with classical micro and nanoelectronics such metallic nanostructures can be integrated in conventional optical sensor or digital cameras. Cameras using such metallic nanostructures would exhibit a reduced pixel cross talk and a higher spectral resolution. In summary, optics on the nanoscale provides a lot of new opportunities for technical applications. Numerical simulations of the optics on the nanoscale are essential to gain a solid understanding and to optimize the device structures. In order to verify the results the numerical simulations have to be compared to experimental results. The research on optics in nanostructured media is carried out in close collaboration with the research group of Dr. H. Stiebig at the Institute of Photovoltaics, Research Center Jlich.

Collaborations

1. *IUB*
   Prof. Veit Wagner
   Organic Electronics Collaboration

2. *IUB*
   Prof. Werner Bergholz
   Photovoltaics and Microelectronics Collaboration
3. *University Bremen*
   Prof. Wolfgang Benecke
   Microsystems Technology Collaboration
4. *Research Center Jlich*
   Dr. Helmut Stiebig
   Nanocrystalline Thin Film Transistors and Optics in nanostructured media Collaboration
5. *Bendit Innovative Interfaces*
   J. Huyer
   Solar Cells for mobile applications Collaboration
6. *Palo Alto Research Center*
   Dr. R.A. Street, A.R. Vlkel. Dr. J. Northrup
   Organic electronics and modelling Collaboration
7. *Stanford University*
   Prof. A. Salleo
   Organic electronics Collaboration

Grants

1. BMBF "Embedded Microsystems Bremen (EMB)"
2. Forschungszentrum Jlich "Funktionale Kontaktschichen"

Awards, Prizes

1. Ernst A.C. Lange Award together with Prof. W. Benecke from the Institute for Microsensors, -actuators, and -systems (University Bremen)
2.

1.5.2 Patents

1. H. Stiebig, D. Knipp, J. Flsch, Three-color sensor with a pin or nip series of layers, Japan, Patent number: Hei-9-535750;
2. D. Knipp, Optical sensor and integrated photonic crystal and method for producing the optical sensor, submitted to German patent office.

1.5.3 Microelectronics

Research Team Werner Bergholz (Professor)

After 30 years of rapid advancements in microelectronics barriers are emerging for a further device shrink and/or improvement of quality/failure rates. Our research focuses on these "brick walls". These barriers are mainly related to defects, which limit yield and reliability and the exploding cost for lithography. The specific research topics are the

- Development of destruction free methods to detect defects in silicon wafers
- Defect - related failure mechanisms and reliability test methods for microelectronic circuits.
- New wafer types with functional layers to mitigate the cost explosion for lithography
- Novel process control methodology to improve quality and productivity. Unless solutions for the listed challenges can be identified, the rapid expansion of information technology will slow down within the next 5 years. In addition, the following additional research topics are being addressed,
- Investigation of defect engineering methods and efficiency detractors in Si solar cell technology (based on an synergy with microelectronics techniques)
- Application of Quality Management methodology and standardisation techniques to nanotechnology and other non-technical areas.

One of the more subtle limitations to further device shrink is a phenomenon known as random telegraph signals (RTS noise) in semiconductor devices. Known and not understood for more than 30 years, it never had particular technological importance. With devices in the 100nm size range or below, it is gradually transforming from a laboratory curiosity to a serious challenge in many application areas.

By a comparative study supported by Infineon Technologies, it has been possible to show that there is a close analogy of the phenomon in CCD chips and in DRAMs (Master Thesis Pravesh Kumar). In CCDs there exist 2 types of defective cells with excessive leakage currents, namely cells for which the currents are high and constant in time and a second type, where the leakage current changes in a random and unpredictable manner, i.e. these cells exhibit the RTS defect behaviour (Fig. 24). This is similar to cells with high leakage currents in DRAMs.

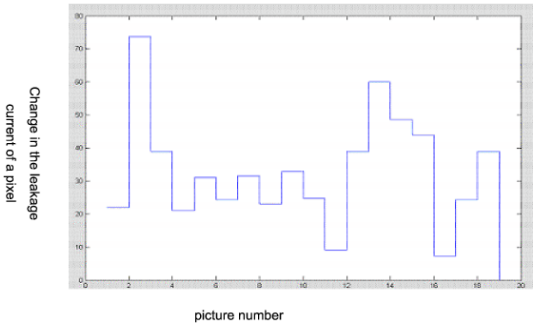

Figure 24: *Leakage dark current of a switching pixel in a CCD camera. The pixel switches between several discrete states*

Highlights To investigate the effect in more detail, with the ultimate aim to identify the atomic mechanism, 2 projects are in progress. In the first, DRAMs are tested with the help of 2 PCs in a search for such cells, which are extremely rare. The feasibility has been shown, so that now it is possible to investigate the behaviour of such cells in detail, which normally would not be possible because of the high operating cost of industrial testers. In the second approach, specially selected capacitance diodes serve as a test device to investigate the RTS phenomenon. Preliminary results on the variation of the leakage current with time indicate that atomic defect pairs of metal impurities and doping atoms may be one of the root causes of RTS noise. The observed change in leakage current is attributed to a pairing reaction of metal imputies and acceptor atoms (Fig. 25) The final objective is to develop a process which reduce the RTS effect.

Organization

1. Workshop: "Silicon Wafers SEMI Standards Workshop", April 14 2005, Munich Trade

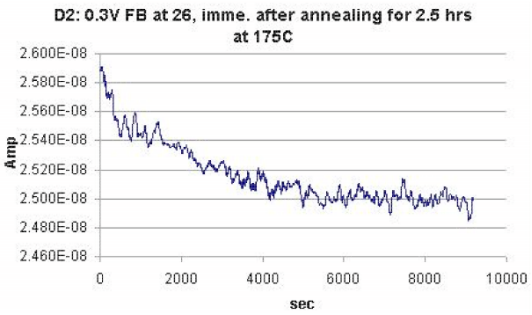

Figure 25: *After heating the diode under reverse bias at* $175°C$ *the leakage current exhibits a transient attributed to defect rearrangements*

Center

2. SEMI Autumn Conference: "Wireless Communication Devices", 26th October 2005 Leuven, Belgium

Collaborations

1. *Infineon Technologies, Dresden*
   RTS noise phenomena
2. *Infineon Technologies, Munich*
   Test Set up for DRAMs
3. *MEMC, St. Peters, Missouri*
   Defect Detection in Silicon Wafers
4. *International University Bremen*
   Dietmar Knipp
   Solar cells, low cost electronics
5. *International University Bremen*
   Peter Ludes (SHSS), C. Schwender (JCLL)
   Visual mass communication
6. *MEMC Microelectronics*
   Dr. Robert Falster
   Defects in Silicon
7. *SEMI (Semiconductor Equipment and Materials) San Jose, Brussels*
   Bettina Weiss, Carlos Lee
   Semiconductor Standards Development

Patents

1. Patent on wafer technology, submitted

Awards, Prizes

1. Karel Urbanek Award for International Leadership in the SEMI Standards Program

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