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Preface

Since 2007, the participants of numerous German Research Foundation's (DFG) Research Training Groups (RTG) and similar programs in the field of computer science meet once a year at Schloss Dagstuhl - Leibniz Center for Informatics, one of the world's premier venues for computer science related seminars. This DFG-funded networking meeting is intended to facilitate an exchange of ideas and experiences between PhD students and to strengthen the contacts within the German computer science community. These meetings have proven to be excellent for PhD students and the associated institutions. The networking meeting is organized by PhD students and welcomes PhD students in all stages of their work in order to give researchers the opportunity to present their ideas, current topics, and results.

This year the networking meeting is organized by RTG 1564: *Imaging New Modalities* and RTG 1362: *Cooperative, Adaptive and Responsive Monitoring in Mixed Mode Environments.* Due to a growing number of computer science orientated RTGs and limited space at Schloss Dagstuhl, the networking meeting was divided into two parts in the year 2011 and 2012. However, in 2012 an extension building was opened, which enables Schloss Dagstuhl to accommodate a larger number of guests. According to this, the networking meetings 2013 are held in parallel.

In the context of this networking meeting, Robotics and Autonomous Systems are comprehended as an interdisciplinary application domain. Every PhD student has a specific question in his PhD work. In this meeting we encourage all PhD students of all computer science areas to think out of the box. With the result that all participants will consider how their work could influence Robotics, Autonomous Systems and related topics in the future. During the meeting, PhD students have the opportunity to choose between two separate tracks, beside a joint track, where all PhD students present their research work in a fast forward session. To support the connection among the students an extended abstract of every PhD student's work was submitted to present their research topic. These abstracts along with short descriptions of the general scope of the RTGs are collected in these proceedings.

The theoretical track revolves around the main topics of the networking meeting. During a first phase groups will work on selected topics forming 'expert groups'. These expert groups will then be split and recombined with members of the other groups, and are asked to solve a problem that requires the combined expertise.

The practical track is shaped as a challenge involving Robotics and Wireless Sensor Networks, which allows interested participants to acquaint themselves with programming concepts from the Robot Operating System (ROS) and the Contiki OS. Here development teams are formed and asked to improve a basic, but fully working, solution for a miniature disaster scenario. This scenario can be simulated beforehand to test modifications. The challenge will then be run on a real setup (with Turtlebots and MSP430-based sensor node) at the end of the Workshop.

In the course of the meeting organization, we were fortunate to be supported by all involved sides. Thus we would like to express sincere thanks to everyone who contributed to the organization of the networking meeting. Special thanks go to the abstracts' authors and the RTG's administration for their cooperation. Furthermore, we would like to thank our invited Speakers Prof. Dr. Bernt Schiele - 'Scene Understanding - It's Time to Address it Again' and Prof. Dr. Frank Kirchner - 'Robotics and Artifical Intelligence'. Finally, we would like to thank the DFG for funding this meeting and the staff of Schloss Dagstuhl who showed their professionalism in taking care of the venue details and organization.

Julian Bader
Christian Feinen
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Contents

1 GRK 1042: Explorative Analysis and Visualization of Large Information Spaces

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The program of the Research Training Group focuses on the development of methods for supporting exploration, analysis, and management of large information spaces, especially in the fields of visualization, computer graphics, and user-interaction. These information spaces may of visual nature as well, e.g., multimedia documents or complex geometric structures. A further emphasis of research is the systematic exploration of large data spaces emerging for example in the analysis of software systems. The relevant fields in the Research Training Group are information visualization, computer graphics, digital signal processing, human computer interaction, intelligent data analysis, information retrieval, databases, and information systems. One of the objectives of data mining and explorative data analysis is to find new, previously unknown, yet useful information. The research aims at perfecting existing procedures to be more effective and more efficient, and at the same time it seeks to develop new procedures with regards to exploration and analysis, which serve more adequately special requirements, such as the vast information stored and transferred in the internet. Applications that are investigated in the Research Training Group are for example analysis of cell image sequences and graphs in bio-informatics, network analysis of textual corpora, feature engineering for search in multimedia databases, and visualization and analysis of performance measurements from sport- and training-sciences. The Research Training Group implements a structured concept for advising and teaching of its doctoral students. In the first phase, for the duration of two semesters, special courses are provided and special lecture series are held during summer schools. The students are introduced to research tasks in their respective research workgroups and seminars, and acquire soft skills qualification in university wide courses.

1.1 Event Detection in Time Series Data

Iris Adä (iris.adae@uni-konstanz.de)
Supervisor: Prof. Dr. Michael R. Berthold

A long time ago the collection of data was a very rare process. At a total maximum every minute a new value was measured. But with the exponential speed of technical development, data points can now even be achieved in real time; Online information can be summarized as sensor data. In the area of analyzing and monitoring this information, a subfield of data mining, which is called stream mining, interesting additional requirements have to be taken into account. The data has to be processed online, which means it is never possible to consult all the data, or only all previous data. Secondly the algorithm must be able to predict a new data point at any time.
One very interesting challenge in data stream mining is called event detection. An event is defined as anything irregular in the data. This could simply be an outlier or an incorrectly classified pattern. But with more sophistication, an event can also be caused by a change or drift in the data. My research mainly focuses on these two aspects: Detecting an event in an online data stream and evaluating which type of event occurred.
Our first approach yields in monitoring the data stream using an idea adapted from meta learning for data streams. To monitor the stream different base learners are used to model different parts of the data stream. A new base learner is started with every data point, an old learner is stopped, and the achieved model is saved. By comparing these base learners an event can be detected if there is a big difference or distance between the learners. The approach was successfully applied with Gaussian Mixture Models as base learners to model a multidimensional real-valued data stream. For the model comparison an approximation of the Kullback-Leibler-Divergence was used.
Another recent development is the EVE-Framework[1]. As previously mentioned, various methods for event detection have been proposed for different types of events. However, a lot of them make the same prior assumption, following the core idea behind EVE. EVE is a more general framework for event detection. The framework enables generic types of time slots and streaming progress to be incorporated through time. It allows measures of similarity to included between those slots, either based directly on the data, or on an abstraction, e.g. a model built on the data. A large number of existing algorithms fit nicely into this framework by choosing appropriate window combinations, progress mechanisms, and similarity functions.

[1] Adä, Iris, Berthold, Michael R., Unifying Change - Towards a Framework for Detecting the Unexpected. In: Data Mining Workshops (ICDMW), 2011 IEEE 11th International Conference on Data Mining

1.2 Generation of Natural Metameric Colors and its Applications

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Supervisor: Prof. Dr. Dietmar Saupe, Prof. Dr. Matthias O. Franz

In the thesis a new method for generation of metameric colors will be implemented and compared with the state of the art methods. Metamerism is the phenomenon which causes *different* objects to have the *same* visual stimuli under a fixed illuminant.
The problem of generation of the metamers has got a lot of attention in the literature. There are a lot of methods available which try to generate natural metamers. Most of these methods are capturing the properties of the spectral reflections in mathematical terms. Afterwards a wide range of approaches is applied to find spectral reflectances which a) satisfy these properties and b) deliver the desired colors under a fixed illuminant. These methods have drawbacks. The most important one is that their definition of naturalness is not necessarily *natural*.
Our idea is to capture the properties of the natural spectral reflectances statistically. For this, we are building a system for the acquisition of multispectral images. This system will allow us to gather a huge database of natural spectral reflectances. The next step will be to estimate the probability density function that models this data. After that we will be able to generate spectral reflectances that have exactly the same statistical properties as the ones in the database, hence they will be *natural*. It is still to investigate the computational needs of the described approach and compare it to those of the existing methods.
The other sub-project, that is the part of the thesis is the analysis of the properties of mobile displays. The goals of this sub-project are:

- to determine the exact properties of mobile displays;
- to compare mobile displays to normal LCD/OLED displays;
- to find out to which extent existing state-of-the-art models for display characterization can be applied for mobile displays.

Prior to the analysis a lot of measurements should be performed. A system was designed which allows to performed unattended measurements of mobile displays using a web server, a spectrometer and the control software which was developed by us. The system is agnostic to the programming environment on the mobile device. The only requirement is the availability of the web browser. Currently first batch of measurements is done and we are processing them.

1.3 Simulation and Optimization of Race-Bike Training on Realistic Tracks

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The Powerbike Project contributes to the subdiciplines of acquisition, processing, analysis and optimization of physical and physiological performance data in cycling, computer-aided training control, motion analysis, and information visualization. Its goal is to realistically simulate outdoor riding on existing tracks in the lab, extract the relevant information of a multitude of available measurement data and visualize this information for optimal training control and performance prediction. This thesis focuses on the simulation and optimization of race-biking on realistic tracks. This system shall enable athletes to familiarize themselves with even unknown tracks and optimally prepare them for competition.
We designed a simulator based on a Cyclus2 ergometer (RBM Elektronik), which allows the user to mount his personal bicycle. The resistance control relies on a validated P-v-model that describes the relation between pedaling power P and speed v on a cycling track, whose height profiles was measured by differential GPS augmented by height profile estimations of the model based on calibration rides. Electronic gear levers have been incorporated into the model as well as physical limitations of the eddy current brake have been compensated at best. An algorithm to compensate for the inertia mismatch has been developed, yet needs to be implemented using the RS-232 interface, since the standard TCP/IP interface does not provide the necessary sampling rate. The display of the simulator shows a video playback synchronized with the cyclist's current position on the track together with various course and performance parameters. The accuracy of the system has been validated comparing outdoor measurement, simulator measurements, and model predictions.
The optimal pacing strategy is sought by minimizing the time an athlete needs to complete a course according to the P-v-model subject to calibrated physiological dynamics and constraints that reflect the individual endurance capacity of an athlete. This questions leads to a complex optimal control problem for which robust numerical algorithms must be designed. Direct discretization using pseudo-spectral collocation methods as well as the use of saturation functions and system extensions to transform the constrained optimization problem to an unconstrained one, have proven best performance. In the near future, we plan to design custom ergometer tests to calibrate the physiological models. Furthermore, a model predictive control seems appropriate to turn the current open-loop optimal pacing strategy to a closed-loop feedback control.

1.4 Declarative Access to Filesystem Data

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This PhD project deals with the design and development of XML/XQuery driven information architectures that process formerly heterogeneous data sources in a standardized and uniform manner. Filesystems and their vast amounts of different file types are a prime example for such a heterogeneous dataspace. A new XML dialect, the Filesystem Markup Language (FSML), is introduced to construct a database view of the filesystem and its contents. FSML provides a uniform view on the filesystem's contents and allows developers to leverage the complete XML technology stack on filesystem data. BaseX, a high performance, native XML-DBMS developed at the University of Konstanz, is pushed to new application domains. We interface the database system with the operating system kernel and implement a database/filesystem hybrid (BaseX-FS), which is working on FSML database instances. A joint storage for both the filesystem and the database is established, which allows both developers and users to access data via the conventional and proven filesystem interface and, in addition, through a novel declarative, database-supported interface. As a direct consequence, XML languages such as XQuery can be used by applications and developers to analyze and process filesystem data. Smarter ways for accessing personal information stored in filesystems are achieved by retrieval strategies with no, partial, or full knowledge about the structure, format, and content of the data ("Query the filesystem like a database").
In combination with BaseX-Web, a database extension that facilitates the development of desktop-like web applications, we present a system architecture that makes it easier for application developers to build content-oriented (data-centric) retrieval and search applications dealing with files and their contents. The proposed architecture is ready to drive (expert) information systems that work with distinct data sources, using an XQuery-driven development approach.

1.5 Parallel Algorithms for Improving Accuracy of Data Analysis Including Analysis of Gene Expression Data in Predictive Toxicology.

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Supervisor: Prof. Michael Berthold, Prof. Marcel Leist

Research in Parallel Data Mining traditionally is focused on accelerating the analysis process - understandable in times of limited compute power and increasingly complex analysis algorithms, especially when it has to deal with big data, such as gene expression data.
However, parallel resources could be used in another fashion, namely to increase the accuracy of the data mining algorithms. Many relevant algorithms for the preprocessing and analysis(for example feature selection) of expression array data rely on heuristics or user supplied parameters to somewhat reduce the otherwise entirely infeasible hypothesis space. Modern architectures, which provide access to numerous parallel computing resources, emphasized by the recent advance of multi-core architectures, can be utilized to reduce the effect of these user parameters or other algorithmic heuristics. Instead of trying to provide the same results faster then conventional algorithms we aim at using parallel resources to provide **better** results.

1.6 Scalable Information Visualization for Geospatial Datasets

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Supervisor: Prof. Dr. Daniel A. Keim

Most of the current available methods for geo-spatial data with time dependency deal only with movement data without taking into account the spatiotemporal context of the movement. The context includes properties of different places and different times and various spatial, temporal, and spatiotemporal objects affecting and/or being affected by the movement. Context information could be weather or environmental data or any other kind of data influencing the object's behavior. The high amount of available context information and the difficult interdependencies between moving patterns and context influences is challenging to tackle.
Analyses of animal movement is for instance very challenging as there are many possible influences on the animals behavior. There could be feeding grounds, other animals or weather conditions influencing the animal's movement. My aims are to develop theoretical foundations and novel scalable methods for analyzing movement in context. Furthermore the idea of an automatic selection of the influencing context data is followed. Special focus lies also on the calculation and visualization of correlations between movement and context data, especially taking the geo-spatial and temporal information into account.
The developed techniques will be applied through creation of prototype software tools to real world applications. Furthermore, all the proposed visual analytics methods are evaluated in cooperation with domain experts. There will be techniques developed for point- and line-based representations. More in detail, scatter plots are extended to enhance the visibility of local correlations. In the area of line-based visual representations we aim to reduce the visual clutter resulting from overplotting of line segments. We therefor analyze the trajectories and visualize only the most important points while the unimportant ones are discarded. Additionally, we analyzed how to visually boost important or interesting parts in the data[1].

[1] D. Oelke, H. Janetzko, S. Simon, K. Neuhaus and D. A. Keim. Visual Boosting in Pixel-based Visualizations. Computer Graphics Forum, 30(3):871-880, 2011.

1.7 Design and Implementation of Post-WIMP Interactive Spaces with ZOIL

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Supervisor: Prof. Dr. Harald Reiterer

The project aims at creating a design paradigm and software framework for creating collaborative multi-user, multi-surface and multi-device interactive spaces[1]. In these spaces, different post-WIMP (post-"**W**indows **I**cons **M**enus **P**ointer"), devices (e.g. tabletop computers, digital pen & paper, large displays) are physically and logically combined for computer-supported collaboration, e.g., in control rooms, studios or libraries. The new paradigm and software framework "ZOIL" (**Z**oomable **O**bject-Oriented **I**nformation **L**andscape) establishes a novel approach that is intended to achieve a more seamless, natural, visual and direct physical interaction with virtual information items in such spaces. ZOIL informs high-level design decisions through a generic interaction model and design principles. ZOIL also supports the implementation of such user interfaces by providing a software framework with the necessary functionality. Different prototypes demonstrate and empirically evaluate the ZOIL concepts, e.g. [2]. Furthermore ZOIL's applicability and the framework's API usability are evaluated based on a longitudinal user study [3]. For more information, a full list of publications and source code please visit: http://hci.uni-konstanz.de/permaedia/
http://research.microsoft.com/en-us/projects/deskpiles/

[1] Jetter, H.-C., Gerken, J., Zöllner, M., Reiterer, H. *Model-based Design and Prototyping of Interactive Spaces for Information Interaction.* Proc. of 3rd Conference on Human-Centred Software Engineering (HCSE 2010), Springer, p. 22-37, Oct 2010.

[2] Jetter, H.-C., Gerken, J., Zöllner, M., Reiterer, H., Milic-Frayling, N. *Materializing the Query with Facet-Streams – A Hybrid Surface for Collaborative Search on Tabletops* to appear in CHI'11: Proceedings of the 29th international conference on Human factors in computing systems, ACM Press, May 2011. *(Honorable Mention Award).*

[3] Gerken, J., Jetter, H.-C., Zöllner, M., Mader, M., Reiterer, H. *The Concept Maps Method as a Tool to Evaluate the Usability of APIs* to appear in CHI'11: Proceedings of the 29th international conference on Human factors in computing systems, ACM Press, May 2011.

1.8 Engineering Multidimensional Scaling Approaches to Graph Drawing

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Effective *graph drawings* are often a result of a specific *energy model optimization*, an objective common to other fields. It has been shown that *Multidimensional Scaling* (MDS) techniques, primarily tailored for data analysis about proximity, can be successfully exploited. The approaches of *Classical Scaling* (CS) and *Distance Scaling* (DS) usually satisfy the basic aesthetic criteria on the layout. Due to more direct *distance fitting* and allowing for control over different distance influence, DS is the preferred choice. While with complexity requirements prohibitive for large graph drawing, the basic methods offer a promising direction for various visualization purposes. The objective of this thesis is to *refine* and *improve* the use of MDS for graph drawing in terms of *scalability* and *flexibility*.

The potential of a CS approximation, *PivotMDS*,[1] has been further exploited, for instance, for the purpose of *region emphasis*, but the computational overhead has been addressed, too. Relative to other CS approximations, the resulting method appears to offer more acceptable *time-quality* ratio.

The optimization problem of DS has been successfully subjected to *majorization*, a well-known MDS technique.[2] Besides providing an alternative *majorizing function*, our work addresses the DS initialization issues effectively avoiding poor local minima and yielding faster computation. A more direct DS speedup considers *(i)* evaluating the underlying function only on a linear number of summands, *(ii)* exploiting *almost convergent* node properties, and *(iii)* employing convergence acceleration methods on DS iterands. The proposed methods are therefore tailored for processing large data sets.

The distance fitting nature of DS also allows for extension to different visualization purposes, e.g., region emphasis, visualization sanity check and more uniform node spread. The listed extensions are of particular importance with large data set visualizations.

By considering the MDS *scalability* issue, we allowed for processing much larger data sets, still with the aesthetic properties of the plain methods retained. In addition, the work on *flexibility* has shown that the basic methods might be adapted for different visualization purposes.

[1] U. Brandes and C. Pich. Eigensolver Methods for Progressive Multidimensional Scaling of Large Data. *Proceedings of Graph Drawing-International Symposium*, pages 42–53, 2006.

[2] J. de Leeuw. Applications of Convex Analysis to Multidimensional Scaling. *Recent Developments in Statistics*, pages 133–145, 1977.

1.9 Visual Analytics Methods for News Streams

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Supervisor: Prof. Dr. Daniel Keim, Prof. Dr. Oliver Deussen, Prof. Dr. Harald Reiterer

A vast amount of news is generated every day by an increasing number of sources and the analysis of these data requires automated and interactive visual methods that will facilitate processing of important information for the analysts in different domains. News articles are characterized by textual and temporal attributes and analyzing the relationships between these attributes presents one of the fundamental problems in temporal text data mining. In my research, the goal is to develop a streaming visual analytics framework, which integrates automated and interactive visualization methods that will facilitate the exploration of online information streams. CloudLines[1] presents an incremental time-series visualization technique enhanced by interactive distortion to deal with time-based representations of large and dynamic event data in limited space. The technique allows the user to analyze the event data on atomic level while maintaining the temporal context. The incremental nature of the data implies that visualizations have to necessarily change their content and still provide comprehensible representations. Our method adapts to the incoming data by taking care of the rate at which data items occur and by using a decay function to let the items fade away according to their relevance. Since access to details is also important, we also provide a magnifying lens technique which takes into account the distortions introduced by the logarithmic time scale to enhance readability in selected areas of interest.
We have developed a visual analytics system for exploration of news topics in dynamic information streams[2], which combines interactive visualization and text mining techniques to facilitate the analysis of similar topics that split and merge over time. We employ text clustering techniques to automatically extract stories from online news streams and present a visualization that: 1) shows temporal characteristics of stories in different time frames with different level of detail; 2) allows incremental updates of the display without recalculating the visual features of the past data; 3) sorts the stories by minimizing clutter and overlap from edge crossings. By using interaction, stories can be filtered based on their duration and characteristics in order to be explored in full detail with details on demand.

[1] M. Krstajic, E. Bertini, D. A. Keim: CloudLines: Compact Display of Event Episodes in Multiple Time-Series, IEEE Transactions on Visualization and Computer Graphics, Vol. 17, Issue 12, Dec. 2011

[2] M. Krstajic, M. Najm-Araghi, F. Mansmann, D. A. Keim: Incremental Visual Text Analytics of News Story Development, SPIE 2012 Conference on Visualization and Data Analysis (VDA 2012), 2012

1.10 Semantic Based Methods for Abstract Representations

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Supervisor: Prof. Dr. Oliver Deussen

Non-photorealistic rendering (NPR) is a subdomain of computer graphics that deals with the description and creation of abstract and artistic representations. Such representations are widely used for illustration or schematic drawings (technical documentation, medical visualization, architecture).
Throughout the history of painting it can be observed that human painters vary their styles according to the semantics and materials of painted objects. Sky for example will be painted with a different style than a wooden surface or hair. As seen in figure 1.10 van Gogh used large and uniform brush strokes to represent skies, the wheat field with short messy aligned strokes.
The main goal of this project is to abstractly represent different parts of a 2D input image driven by semantic object recognition. The different parts of the abstractions created by this approach can be varied due to specific semantic characteristics (surface specific, more detailed, intensified color).
As an example, detected parts of a face can be represented with different styles to improve the dissemination of information.
The integration of semantic information in order to parametrize illustrations is a new and interesting extension of the concepts of computer graphics.

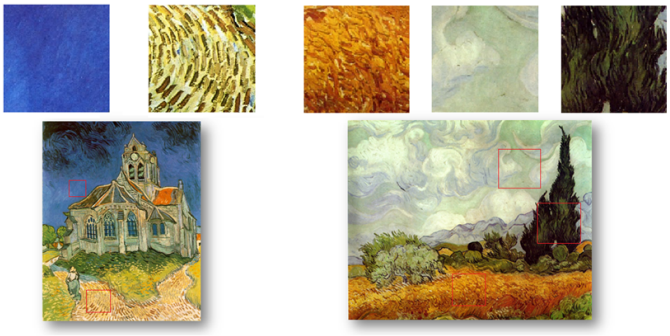

Figure 1.1: Van Gogh's "The Church at Auvers" and "Cypress and Wheat Field". Objects are represented with different strokes according to its semantics.

1.11 Dynamic Network Visualization

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As complex networks receive increasing interest by network analysts, there is a strong need for appropriate network visualizations that allow for visual analysis and exploration. This particularly holds for dynamic networks, comprising a sequence of graphs. The challenge here is to find coherent representations of successive networks that respect qualitative criteria of the drawing, while at the same time preserving the mental map the viewer has built from a previous drawing in the sequence.
Existing layout algorithms for static graphs have to be adapted to integrate constraints on maintaining stability between indiviual drawings. We modify the well-known energy-based graph layout method called stress-minimization to implement different strategies for dynamic graph drawing, e.g., aggregation to obtain one single layout for all individual graphs, or anchoring to constrain movement of vertices w.r.t. a given reference layout.[1]
These fundamental strategies need to be systematically compared with respect to their ability to trade off between displaying structural properties and complying with the mental map. We evaluate them on structured randomly-generated graph sequences and real-world data sets, by means of their realization in the stress-minimization framework.[2]

[1] Ulrik Brandes, Natalie Indlekofer, and Martin Mader: Visualization methods for longitudinal social networks and actor-based modeling, Social Networks, 2011

[2] Ulrik Brandes and Martin Mader: A Quantitative Comparison of Stress-Minimization Approaches for Offline Dynamic Graph Drawing. Proceedings of the 19th International Symposium on Graph Drawing (GD '11), Lecture Notes in Computer Science, volume 7034, Springer Berlin / Heidelberg, pp. 99–110, 2012

1.12 Visual Analytics for Critical Infrastructures

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Monitoring and understanding the function and interdependencies of critical infrastructures, like digital networks, power grids and transportation, are complex analytical issues. Due to the fact that our society, especially our security, economic viability and system stability, is heavily dependent on these critical infrastructures, these issues have to be faced for disaster prevention and crisis response.
My thesis applies visual analytics to the issues of monitoring and understanding critical infrastructures, cascading infrastructure effects and to the management of crisis response. Whereas there already exist detailed models for each individual type of infrastructures such as electric power grids, the interdependencies to other critical infrastructures are missing. The main research question of my thesis is, how to encompass the various interconnections and interdependencies to enable deciders performing operational risk management in this complex and large information space. The goal of my thesis is to combine automatic analysis methods with new visualizations, which join the information for the individual infrastructures to support the planning and decision process by explorative analysis.

1.13 Discovery of Bisociations Between Domains

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In classical data mining two major approaches may be identified. One consists in formulating specific, semantic queries on the given data. The other, called Visual Data Mining, attempts to create an overview of the entire data allowing further drill-down exploration. A disadvantage of both is that they need the user to know in advance what kind of pattern she is looking for. Contrary to this, the discovery of bisociations involves looking for unexpected relations of any kind among seemingly unrelated domains, which could trigger creative discoveries.[1]

My colleagues and I propose a formalization of the detection of bisociations in graph-based databases using exclusively structural information[2]. The proposed approach takes a database represented as a graph as an input and performs the following tasks: (1) identifies a hierarchy of domains within the database, (2) identifies all pairs of non-overlapping bisociation candidates, (3) scores the bisociation candidates according to their potential for being a surprising connection.

Identification of the hierarchy of domains is performed by means of hierarchical clustering based on spreading activation node similarities[3]. Scoring in step 3 is based on three structural properties of bisociation candidates: exclusiveness, size, and balance. The first of the mentioned properties renders the idea that surprising relations between domains should be reflected by a small number of connections. Size and balance are related to the level of abstraction of the domains. More abstract domains tend to be larger, which is the reason why we are interested in possibly large and equally sized bisociation candidates.

A result of applying the above steps is a list of connected domains ranked according to their potential of representing a surprising connection. This is a valuable input for the process of searching for creative discoveries. Naturally, such a process cannot be fully automatized. However, the enormous size of possible solutions space creates a need to eliminate a large number of trivial, uninteresting solutions as well as to point to potentially interesting results.

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[1] Berthold, M.R., *Bisociative Knowledge Discovery.* In: Proceedings of the 10th International Symposium on Intelligent Data Analysis (IDA 2011), Series Lecture Notes in Computer Science (LNCS), no. 7014, pp. 1-7, Springer-Verlag, 2011

[2] Nagel, U., Thiel, K., Kötter, T., Piatek, D., Berthold, M.R., *Bisociative Discovery of Interesting Relations Between Domains.* In: Proceedings of the 10th International Symposium on Intelligent Data Analysis, Series Lecture Notes in Computer Science (LNCS), no. 7014, pp. 306-317, 2011

[3] Thiel, K., Berthold, M.R., *Node Similarities from Spreading Activation.* In: Proceedings of the IEEE International Conference on Data Mining, pp. 1085–1090, 2010

1.14 Real-Time Rendering and Modeling of Vegetation

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The complex visual appearance and the inhomogeneous structure of botanical objects makes rendering of large scenes a challenging task that extends to this day. The obvious main reason is the tremendous amount of geometry that is needed to represent trees and plants. Even though complex virtual environments are routinely used in applications like games, movies or urban visualization, storing as well as rendering such objects with full detail is beyond the capabilities even of modern (graphics) hardware.
The visual appearance heavily depends on the underlying geometry and complex material properties (i.e. translucent leaves). Targeting photorealism requires complex models and algorithms for approximating the transport of light. Shading and shadowing, both by themselves complex areas of interest within computer graphics, need to be adopted and developed for achieving a high level of reality when rendering trees and plants. Especially shadowing is an expensive task in real-time graphics, requiring multiple render passes of the tree's geometry.
Often, vegetation is only a minor, however, important detail when defining virtual scenarios. Content creators like artists, designers or architects are in the need to define these details without spending a majority of their time. Algorithms and models for editing and modeling trees are not yet satisfying these requirements. Complex procedural formalisms (i.e. L-Systems) or tedious modeling by artists are the current approaches for more natural reality in applications.
Animation of vegetation and the interaction of trees and plants with their environment are rather unaddressed. While high level physical interaction models found their way into todays applications (e.g. simple wind animations), more sophisticated approaches are necessary to describe the complex behavior observable in nature.
The simulation and visualization of biological processes - either at microscopic or macroscopic level - of plant behavior and development is yet only in its minority part of computer graphics research.
Especially the real-time domain defines a hard set of constraints expressed by the need to process several frames a second. Modeling and rendering trees in this domain therefore requires efficient algorithms and well defined paradigms within all afore mentioned areas.
The aim of this research project is to contribute to all of the identified areas by proposing solutions to the addressed problems.

1.15 Linear and Non-linear Methods to Analyze Variability and Asymmetry of Indoor Pedaling Kinematics

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Quantitative studies of human motion data and related physiological and neurological signals have typically focused on properties of the average, with fluctuations considered to be noise. Recent publications found evidence that the amount and the nature of the alleged noise contains important information useful to characterize mature motor skills and healthy states . For example, non-linear methods applied to gait motion data have revealed a chaotic structure in healthy subjects, suggesting that the nature of this variation is not entirely random. Furthermore, performance-related and injury-related research have used the concept of variability, based on measures of complexity and predictability, to calculate differences between groups of subjects.

Variability, defined by the amount of variation and its structure, is omnipresent and unavoidable in all kinds of motions. Normally, it is attributed to the ability of the body to coordinate many different physiological systems over many different timescales. Optimal movement variability depends on the level of difficulty and on the number of degrees of freedom necessary to accomplish a task . Lack or excess of variability are understood as a deficiency in motor skills. Less than optimal movement variability characterizes states and behaviors that are overly rigid, whereas greater than optimal variability characterizes states and behaviors that are noisy and unstable. Analysis of kinematic variability has not been reported for pedaling.

Asymmetry is another feature that has been explored for walking but only partially for pedaling. Previous studies of pedaling asymmetry can be extended using the pedal acceleration and new asymmetry indexes.

In this work it will address the question of what algorithms, methods of analysis, and data collection techniques can be implemented to assess the variability and asymmetry present in pedal and leg kinematics during pedaling. The expected scientific output is a theoretical modeling framework for motion analysis of cycling based on non-linear analysis methods, including new definitions of asymmetry indexes. An adaptation of algorithms for non-linear time series analysis suited to the characteristics of pedaling motion will be developed. To evaluate this, a platform with an efficient implementation of the proposed analysis will be provided.

1.16 Exploring Reality- and Proxemic-based User Interfaces for Knowledge Work in Physical Libraries

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Supervisor: Prof. Dr. Harald Reiterer and Prof. Dr. Marc H. Scholl
External Supervisor: Prof. Dr.-Ing. Raimund Dachselt

Digital libraries are growing rapidly, but a huge amount of literature is still available in non-digital form through open access or closed stack libraries. Thus, the physical library will remain as a crucial place for interaction with knowledge, place to learn, or even meeting place. Library users access that knowledge either by searching with traditional terminal-based OPAC interfaces (Online Public Access Catalogue) or browsing the book shelves. Intermixing searching and browsing strategies and switching rapidly between them, however, is not supported by present library systems. Additionally, it is often prohibited by library rules to annotate on printed media once found by the user (e.g. books). This results in a disconnection of source and thoughts and it is even more cumbersome to share the acquired sense-making among different devices or co-workers. Above examples motivate the need for novel knowledge workspaces in physical libraries.
The thesis aims at the development of new user interfaces and interaction styles for supporting research and knowledge work processes in physical libraries with help of emerging information and communication technology (ICT). It addresses the research question of how to inform the design of knowledge work environments based on the theoretical framework of Reality-based Interaction (RBI) [1] and the prospect understandability of Proxemic Interactions (PI) [2]. Further, it needs to be understood in detail how literature research, reading and writing scientific documents is influenced by previous mentioned frameworks. My contributions are divided into three objectives: a taxonomy that connects RBI and PI to the domain of knowledge work, the design and implementation of working prototypes, and the evaluation of concepts using controlled experiments and "living lab" methods.

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[2] Greenberg, S., Marquardt, N., Ballendat, T., Diaz-Marino, R., and Wang, M. (2011). *Proxemic Interactions: The New Ubicomp?*. interactions, 18 (January), 2011, 42-50.

1.17 Integration of Data Mining & Data Warehouse

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Significant research efforts have been made to enable in-database data mining to take advantage of the DBMS's power of handling large volume of data. The integration of data mining algorithms with a relational Database Management System is a challenging issue. Tight coupling of data mining and database systems, however, is - besides improving data mining algorithms - a key issue for efficient and scalable data mining in large databases. Tight coupling means not only to link specific data mining algorithms to the database system, e.g. as stored procedures, but rather to investigate, which salient functionality of key mining algorithms should be integrated to be run as part of the database system kernel, so as to avoid expensive data transport. Basically, the question is whether certain parts of the data mining functionality can only be implemented efficiently inside the DBMS server, because running them outside (i.e., on top) would be too large a performance penalty. Our overall goal is to identify such data mining primitives that need to be included in the low-level DBMS's functional repertoire, pretty much in the same way as some of the OLAP extensions that have already made it into the SQL standard and into the core DBMS algorithms.
We further aim to discover potential computations that can be performed in advance on the ready-to-mine data, which can also be materialized and made part of the database. These computations offer a set of pre-calculated and ready-to-consume values to the data mining algorithms which otherwise would be calculated from scratch. Such pre-computations not only enable data mining algorithms to work efficiently, but also tightly couple data mining with database systems.

1.18 Analysis of Dementia with Structural and Functional Image Data

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Alzheimer's disease (AD) and frontotemporal lobar degeneration (FTLD) are the most prominent types of dementia, a disease which affects the structure and function of the human brain. To improve its diagnosis, data acquired from magnetic resonance imaging (MRI), diffusion tensor imaging (DTI) and positron emission tomography (PET) is analyzed to extract features, align them in a common space and apply statistical analyses for classification.
In the first part of this work, the definition of the common space is addressed which is often accomplished by registration to an atlas image to label main foldings. Statistics applied on average cortical thickness values might obscure information such as higher values in gyri than in sulci. To separate these out- and inward foldings, the segmented white matter (WM) was skeletonized and geodesic distances between feature points on the WM surface were used to establish a continuous pruning function that was thresholded to identify gyral and sulcal regions. With the separation of gyri or sulci, classification of dementia could be significantly improved as shown by logistic regression applied to cortical thickness data of different disease groups[1].
In the second part, complementary features from multiple modalities will be combined as improved discrimination between different types of dementia is expected. From images acquired in a collaborative study, features such as cortical thickness from MRI, WM integrity from DTI, and glucose uptake from PET will be collected. Due to the high variability of AD and FTLD, discrimination of their disease subtypes is a complicated task which requires accurate methods for artifact removal, segmentation and registration to get features in a common space. These will be analyzed by feature reduction methods such as random forests and principal component analysis and classification methods such as LR and support vector machines.
In the last part, an alternative approach to establish gyral correspondences between brains will be developed that is transformation- and template-free. The matching of cortical and subcortical structures will be simplified using different abstraction levels of the WM skeleton and will be guided by geometric and topological similarity features. Designed as an energy-minimization optimization problem, this approach is expected to provide equal or improved robustness as compared to vertex- or surface-based registration.

[1] Mirco Richter, Courtney A. Bishop, Jürgen Dukart, Elisabeth Stühler, Karsten Müller, Matthias L. Schroeter, Dorit Merhof, *Skeleton-based gyri sulci separation for improved assessment of cortical thickness*, IEEE 9th International Symposium on Biomedical Imaging (IEEE ISBI), 2012 (accepted).

1.19 Non-Periodic Tilings in Graphics

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Creating rich and complex content is one of the major problems in computer graphics, especially in interactive applications where large amounts of content have to be produced very quickly and from limited data. Tile-based methods mitigate this problem by synthesizing large amounts of content out of a much smaller data set of tiles by generating a valid tiling. An example is texture synthesis: Once a set of carefully constructed tiles has been generated from a provided input texture, arbitrary amounts of this input texture can be produced at runtime in connection with tile-based texture mapping. So far, research has solely focused on stochastic tilings, i.e. tiles are placed randomly as long as they fulfill certain matching constraints. This has numerous deficits, among them local repetition artifacts due to clusters of tiles showing identical content, and the inability to control the synthesized result. We presented an improved tiling algorithm based on a quasi-Monte Carlo point sequence that produces tilings that are at the same time non-periodic and highly uniform, which noticeably improves the quality of tile-based textures.[1] We also presented a simple extension that allows to control the resulting tilings.
Furthermore, we contributed to the ongoing effort of generating highly optimized point sets.[2] The points are either derived from a special class of centroidal Voronoi diagrams,[3] or by performing a mutual distance optimization.[4] This yields point sets that both have desirable spectral properties as well as superior convergence in a numerical integration setting. Since the underlying optimization is of significant time complexity, a combination with a tile-based approach is necessary in order to make the new schemes beneficial.

[1] Thomas Schlömer, Oliver Deussen. *Semi-Stochastic Tilings in Example-Based Texture Synthesis.* Computer Graphics Forum (Eurographics Symposium on Rendering), Vol. 29, No. 4, 2010.

[2] Thomas Schlömer, Oliver Deussen. *Accurate Spectral Analysis of Two-Dimensional Point Sets.* Journal of Graphics, GPU, and Game Tools, Vol. 15, No. 3, 2011.

[3] Steffen Frey, Thomas Schlömer, Sebastian Grottel, Carsten Dachsbacher, Oliver Deussen, Thomas Ertl. *Loose Capacity-Constrained Representatives for the Qualitative Visual Analysis in Molecular Dynamics.* IEEE Pacific Visualization Symposium (PacificVis 2011), March 2011.

[4] Thomas Schlömer, Daniel Heck, Oliver Deussen. *Farthest-Point Optimized Point Sets with Maximized Minimum Distance.* Proceedings of the ACM SIGGRAPH Symposium on High Performance Graphics, August 2011.

1.20 Quality Aware Visual Analysis of Spatio-Temporal Data

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With the increased availability of spatially referenced data, assessing the quality and credibility of such data becomes vital. With a special focus on volunteered geographic information such as Flicker or Twitter data sources, this thesis deals on the one hand with means to quantify various quality components such as the positional, temporal and thematic uncertainties of these user generated data, and on the other hand explore mechanisms to evaluate the credibility of the data contributor. Humans perceive and express geographic regions and spatial relations imprecisely, and in terms of vague concepts. This vagueness in human conceptualisation of location is due not only to the fact that geographic entities are continuous in nature, but also due to the quality and limitations of spatial knowledge. Therefore, credibility can be expressed as the believability of a source or message, which comprises primarily of two dimensions, the trustworthiness and expertise. Thus, in assessing the credibility of users this thesis considers factors that attribute to this perception of trustworthiness and believability, other than data accuracy itself. Metadata about the origin of volunteered geographic information provides a foundation for judgment on the credibility of the source. As important as it is to quantify these uncertainties of data and credibility, visually analysing these data helps the user in information derivation and decision making. Therefore, this thesis further entails visually analysing these data uncertainties and evaluate these tools on their usability within appropriate user domains.

1.21 Document Structure Analysis for Large Document Collections

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The knowledge about the structure of the documents is of use for many document processing applications. Especially for information retrieval and automatic document analysis the ability to distinguish between the relevant and non-relevant parts of the document is important. For instance, knowing the sender and receiver region on a letter is crucial for distinguishing the sender from the receiver.
The central question of my research is the development of a general structure analysis component that is able to handle large archives with many different types of document. Existing approaches are able to handle single document types such as invoices. They are not able to handle many different document types that can be found in libraries or archives.
A general structure analysis approach is implemented with a combination of machine learning techniques and visualizations. This approach can be adapted to different document types with minimal efforts. Especially, it is adaptable to varying properties of the documents. It could be shown, that this approach achieves comparable or even better results on different document types as the specialized algorithms. The approach was successfully applied to conference proceedings, product manuals, service reports and medical files.

1.22 Column Subset Selection with an Application to Neuroimaging Data.

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Column subset selection requires to identify a subset of the columns of a matrix, such that a norm reconstruction criterion is optimised. Consider for example CX factorisation: Given a $m \times n$ matrix A, select c columns from A into the $m \times c$ matrix C, and choose a $c \times n$ matrix X such that the norm reconstruction error $\|A - CX\|^2$ is minimised [1]. This identifies a subset of columns that can "explain much" of the data matrix. The columns in C can be seen as cluster centers with X encoding cluster membership status. The difference to standard clustering problems is that X does not contain binary cluster membership indicators. Here, X is continuous and encodes mixtures, i.e. each column in A can be approximated by linear combinations of the basis columns in C with the coefficients in X.
CX factorisation lends itself for application to neuroimaging data: Optical brain activity measurements (A: m time points $\times$ n pixels) contain a large number of pixels, many of which are redundant or irrelevant. Only few, those that contain the signals of neural units, should be presented to the data analyst. Ideally, an algorithm for CX factorisation selects one pixel from each (multi-pixel) neural unit into C, and X encodes signal mixtures, e.g. in case the units overlap [2]. For a useful data representation and visualisation, pixels (columns) that contain signal mixtures should not be selected into C.
Empirical evaluation of algorithms for CX factorisation was performed on both real-world brain imaging data and on artificial data generated from a mixture model. Prior algorithms for CX [1 3 4] select columns for C that are by some criterion close to the principal components or singular vectors of A, whereas our algorithm [2] selects column $k+1$ as the column that is least explained by linear combination of the k columns selected so far.
Prior algorithms for CX are randomised [1], which is less suitable for practical data analysis, and they tend to select mixed signal columns on the neuroimaging data source [1 3 4]. In contrast, our algorithm [2] is deterministic, and it successfully selects the signals of distinct neural units and not their mixtures.

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[2] Strauch, M., Rein, J., Galizia C.G., ICCABS, Feb 23-25 2012, Las Vegas, USA, IEEE
[3] Li, X. & Pang, Y., IEEE Trans. Knowl. Data Eng., 22, 145-149, 2010
[4] Çivril, A. and Magdon-Ismail, M., Theor. Comput. Sci., Elsevier, 421, 1-14, 2012

1.23 Advanced Visualizations of Large Document Collections

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Nowadays, large document collections, such as research paper corpora and news feeds, grow at high rate. Many of these documents contain text and images for describing facts, methods, or telling stories. It is an exhaustive task for a user to get an overview of of a larger collection. For instance, search engines usually show the title of a document together with a small context of the query terms. With this representation a user has to read only a portion of the text and is focused on the relevant parts of the documents, which efficiently allows him or her to differentiate between relevant and non-relevant documents. While this representation is efficient to browse through search results, it is not capable to give a quick overview of a document or even a whole document collection. Reducing the document collection to only search-centric results allows only little serendipity, the effect of " acquiring knowledge by accident".
In cooperation with Daniele Oelke, Christian Rohrdantz, and Andreas Stoffel we addressed the problem by finding a suitable representation of each document in a collection. We developed a technique called DocumentCard which we described [1].
The positioning of images and texts in a DocumentCard was originally guided by the goal of compactness. In the reviews of the mentioned paper a more sufficient positioning of terms and images in terms of closeness of related items was mentioned. To investigate this positioning idea, we (cooperation with Iris Adae) extended the well known technology of text clouds to research an approach where position of terms in a text cloud has a meaning. Working on the base of news articles we addressed the tasks of finding good terms, finding good distance measures between terms, and finally finding good projection technologies of high dimensionally data into 2D positions.

[1] H. Strobelt., M. Heilig, O. Deussen *Interactive Demo: Stay in Touch with InfoVis – Visualizing Document Collections with Document Cards*. In VisWeek 2010 Interactive Demos, October 2010.

1.24 Visual Analytics of Patterns in High-dimensional Data

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The extraction of relevant and meaningful information out of high-dimensional data is notoriously complex and cumbersome. The curse of dimensionality is a popular way of stigmatizing the whole set of troubles encountered in high-dimensional data analysis; finding relevant projections, selecting meaningful dimensions, and getting rid of noise, being only a few of them.
Visual exploration of multivariate data typically requires projection onto lower-dimensional representations. The number of possible representations grows rapidly with the number of dimensions, and manual exploration quickly becomes ineffective or even unfeasible. Visual quality measures have been recently devised to automatically extract interesting visual projections out of a large number of available candidates. The measures permit for instance to search within a large set of scatter plots (e.g., in a scatter plot matrix) and select the views that contain the best separation among clusters. Using quality measures, the user is provided with a manageable number of potentially useful candidate visualizations, which can effectively ease the task of finding truly useful visualizations and speed up the data exploration task. We developed measures for class-based as well as non class-based scatter plots and parallel coordinates visualizations[1]. We also provide an overview of approaches that use quality metrics in high-dimensional data visualization and propose a systematization based on a thorough literature review[2].
Interesting patterns may be located in subspaces of a large input feature space. While a rich body of research has been carried out in designing subspace clustering algorithms, surprisingly little attention has been paid to develop effective visualization tools to help analyzing the clustering result. Appropriate visualization techniques could not only help in monitoring the clustering process but, they also enable the domain expert to guide and even to steer the subspace clustering process to reveal the patterns of interest. To this goal we envision a concept that combines scalable subspace clustering algorithms and interactive scalable visual exploration techniques. This work will include the task of comparative visualization and feedback guided computation of multiple alternative clusterings.

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[2] E. Bertini, A. Tatu, and D. Keim. Quality Metrics in High-Dimensional Data Visualization: An Overview and Systematization. Proceedings of the IEEE Symposium on IEEE Information Visualization (InfoVis), 2011.

1.25 Detection of archaeological objects in high-resolution remotely sensed images

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There is some debate whether or not automated procedures of object detection in images can be successfully applied to archaeology. In spite of recent advances of automated object detection in other fields - e.g., detecting people, faces, traffic signs etc. in different kinds of images - little progress has been made in detecting archaeological features in remotely sensed images. While there are some successful case studies, they are few, and are usually limited to particular sites without attempts towards wider application.
Meanwhile, the amount and variety of remotely sensed images of potential interest for archaeology is increasing rapidly. As prices are decreasing, more and more of these images become affordable for archaeological projects. If they are to be efficiently used, visual image interpretation must be complemented by automated procedures for routine tasks, such as scanning large areas for typical, recurrent archaeological objects. Moreover, due to the large amount of the collected data visual interpretation is frequently not feasible to complete.
To explore the potential of high-resolution satellite images for automated object detection, we use, as a case study, recent fieldwork in the Silvretta Alps. To this end, we focus on ruins of huts and cattle compounds. The recorded structures serve as ground truth. While each structure is unique, they share a limited range of geometries in terms of size and shape, making them a suitable test case for automated detection. Our goal is to identify sites highly likely to contain architectural remains of our interest to guide archaeological fieldwork.
In September 2011 we acquired five Geoeye 1 images of our study area, featuring four spectral (VNIR) and a panchromatic band. After pansharpening, all bands have a spatial resolution of 0.5 m. Geometrical and spectral information is used for detection of potential archaeological sites. The first step toward object detection is texture segmentation, i.e. filtering out textural regions. Our target objects occur in open areas, so that filtering out urban, forested and rocky regions greatly reduces the area to be searched. Segmentation is achieved by using mathematical morphology to measure texture evidence. In the second step local image features are extracted from the remaining areas of interest and grouped into larger curvilinear features. To each image point, the following search will assign likelihood values of forming rectangular or convex structures corresponding to archaeological objects of our interest. This likelihood map is then used to visually validate archaeological objects in the images and in the field.

2 GRK 1194: Self-organizing Sensor-Actuator-Networks

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The research focused by GRK1194 is "Self-organizing Sensor-Actuator-Networks". Sensor-actuator-networks consisting of numerous small and autonomous devices can be used to monitor and control physical phenomena. To make sure the requirements can be fulfilled, the system should be efficient, reliable, and cost-effective. Therefore many issues related to hardware, communication, and information processing have to be investigated. Accordingly, three subprojects of GRK1194 emphasize their efforts in tackling research problems within these three areas respectively. These include the whole spectrum ranging from data processing to communication and hardware/software system integration.
Research topics also include distributed information processing, query processing, content-based addressing schemes, energy efficiency, and self- organizing middleware. One strong objective of the Training Group is to obtain integrated solutions that cover several aspects.

2.1 A Meta-Modeling Approach Supporting C2X System Design

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Supervisor: Prof. Dr. Juergen Becker

Embedded applications are steadily growing in complexity and currently causing the usage of Multi-Processor System-on-Chips (MPSoCs) to meet the requirements on performance and energy efficiency at the same time. Basically embedded systems consist of some sensor and actuator entities exchanging information with the environment, one or more computational entities, e.g. MPSoCs, and some networking entities providing communication between MPSoCs. An example of such distributed embedded applications is Car-2-X (C2X). To verify a certain C2X scenario a simulation approach is usually used. Because of the different domains stated above, there is a lot of heterogeneity and several simulation models relying on different data and behavioral models are needed. Additionally, in case of C2X a traffic domain is required. To describe the hardware/software system design SystemC[1] could be used, which has different data and/or behavioral models than a network, traffic or an environmental simulation model.
Regarding C2X environments methods are necessary to manage that heterogeneity in order to obtain trustful and deterministic simulation results. Furthermore, because of the computational complexity of the simulation approach, concepts to provide scalability and acceleration of the overall simulation are needed. That can be accomplished by the usage of multi-resolution modeling and distributed simulation. There exists a lot of research regarding heterogeneous modeling, abstract modeling and distributed simulation. However, questions like how to integrate the above methods into one continuous design flow are still not answered. Therefore the goal is to develop a meta model allowing the configuration of C2X simulation environments with its applications. Existing meta modeling environments, such as the Generic Modeling Environment (GME)[2], address automated generation of domain-specific modeling paradigms and could be reused. The main challenges are to identify how the multi-resolution aspects must be meta-modeled and which parts of the overall C2X simulation are allowed to be modeled more abstractly with less accuracy but also with less simulation time and which parts must be modeled accurately, e.g. to verify real-time requirements. This requires certain constraints in the meta model. Beyond that the heterogeneity, i.e. the synchronisation schemes and data models of the different domains have to be meta-modeled properly to get trustful results regarding a distributed C2X simulation environment.

[1] Standard SystemC Language Reference Manual, IEEE Standard 1666, 2011.
[2] The Generic Modeling Environment, *http://w3.isis.vanderbilt.edu/projects/gme/*.

2.2 Control and Estimation in Linear Networked Sensor-Actuator-Networks

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Networked sensor-actuator-networks with centralized controller and estimator as depicted in fig. 2.1 are often referred to as Networked Control Systems (NCS). The components of an NCS communicate over unreliable networks with stochastic packet delays and dropouts. These systems differ from clas-

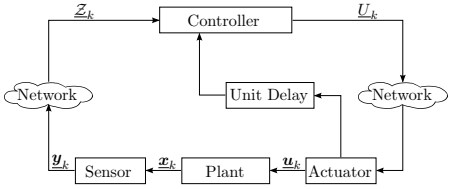

Figure 2.1: Networked Control System with a TCP-like network connecting the controller and the actuator.

sical control and estimation approaches with hard-wired control loops where the information exchange between system components is provided instantaneously and no information is lost, because the employment of unreliable networks can degrade system performance and destabilize it, even if the controller/estimator for an equivalent system with hard-wired connections is optimal. It is therefore advisable to consider the networks between system components when designing estimator and/or controller.
My current research concentrates on sequence-based control of linear NCS. Sequence-based control is an approach to reduce or even overcome network impacts. Every time step, the sequence-based controller transmits not only the current control input but a sequence of predicted control inputs. This way, the actuator can use already received control sequences if a new sequence does not arrive in time. Employing state extension, it is possible to convert such systems into Markovian Jump Linear Systems and hence methods of stochastic programming can be applied.
For future research, I plan to investigate, nonlinear NCSs and distributed NCSs. I also want to extend the already obtained optimal solution to linear NCSs which employ the UDP-like protocol which does not provide any acknowledgments.

2.3 Distributed Algorithms for Scheduling in Wireless Networks

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Supervisor: Prof. Dr. Dorothea Wagner

A network of (micro-)computers capable of wireless communication is often considered to be ubiquitous in future homes, workspaces and cities. However, with such a rise of wireless communication new challenges and constraints are established for distributed computation.
Distributed algorithms have for decades been mostly designed for CPUs and wired networks, while realistic models for wireless communication are only seldom considered so far. In this thesis we consider distributed algorithms for scheduling in the SINR (Signal-to-Interference-and-Noise-Ratio) model, which models wireless interference realistically.
In the context of wireless communication, scheduling solves the problem of media access (i.e., which node is allowed to transmit a signal), which can be seen as node or edge coloring. Node coloring is considered for local broadcast schedules, i.e., each node is required to send a message to all nearby nodes, while edge coloring is considered for link scheduling, where a given set of transmission requests must be satisfied. The focus of this thesis is on node coloring and the local broadcasting problem in the SINR model of interference. Despite initial works, there are still major open problems.
For example whether it is possible the achieve local broadcasting in optimal $\mathcal{O}(\Delta)$ time slots (where Δ is the maximum node degree in the network), how to deal with non-uniform power assignments or how to transform theoretical results into practical solutions.

2.4 Hybrid Localization in Ad-hoc Networks using Inertial Sensors

Tobias Gädeke (tobias.gaedeke@kit.edu)
Supervisor: Prof. Dr. Klaus D. Müller-Glaser

Localization of persons or equipment in ad-hoc scenarios, e. g., after an earthquake still poses many challenges. Especially, when indoor scenarios are considered where Global Navigation Satellite Systems (GNSS) are not usable a robust and alternative localization solution is needed. One way to cope with such situations is to use a wireless sensor network (WSN) with fixed anchor nodes as reference positions and mobile nodes carried by persons and objects to be localized (Figure 2.2).

A popular way to obtain the distance between two nodes is to measure the received signal strength (RSS) of incoming radio packets, which is easy to obtain. However, the needed accuracy is often not sufficient especially if sensor equipment or tools are to be localized in a challenging environment e.g. with non-line-of-sight conditions.

Figure 2.2: Ad-hoc system concept.

On the other hand, time-of-flight (ToF) measurements have shown more accurate results but use two way measurements to avoid synchronization which results in poor scalability. In order to tackle this problem a bi-modal scheme for hybrid RSS/ToF data fusion is used for localization. The main idea of the developed approach is to find the equilibrium between inaccurate but efficient RSS measurements on the one hand and precise but more resource-consuming ToF measurements on the other. The goal is to achieve superior localization accuracy in comparison to the use of one method alone. In order to setup the network and also allow for person localization in areas with low sparse node density data fusion from inertial sensors is used. An iterative position estimation is obtained by the integration of acceleration and gyro-measurements. Current research focus lies on system integration aspects and power consumption improvements with low cost sensors. It can be concluded that the fusion of various different data sources is a key aspect for reliable and efficient positioning systems in challenging ad-hoc scenarios. One of the next steps will be the fusion of ToF-measurements with inertial data based on different ToF methods (WSN, Ultra Wideband, etc.).

2.5 Estimation and Scheduling in Sensor-networks Involving Angular Data

Igor Gilitschenski (gilitschenski@kit.edu)
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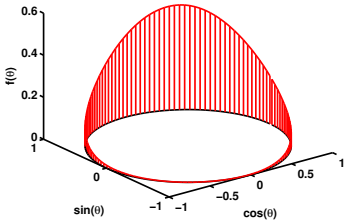
When considering the problems of dynamic state estimation and sensor scheduling in sensor networks, classical methods often rely on assuming euclidean state spaces and Gaussian noise. The Kalman filter presents an optimal estimator in this setting, when a linear system function with additive noise is considered. Extending this approach to nonlinear estimation problems is usually done by Linearization (EKF), Deterministic Sampling (UKF, Gauß filter, Smart Sampling Kalman Filter) or usage of Gaussian Mixtures.



In many estimation and control problems, it is of interest to consider angular data. It naturally appears in sensors with bearings-only measurements and in pose estimation problems. Classical nonlinear estimation techniques and distribution assumptions do not consider the periodic nature of circular data. One of the reasons is that the Gaussian Distribution is not the natural limit distribution for limit theorems on the circle. Thus assuming a Gaussian noise yields suboptimal results for processing noisy angular data.
We focus on developing estimation and control techniques based on circular distributions, like the Wrapped Normal distribution, the Von Mises distribution or the Bingham distribution. This distributional assumptions lead to better estimation results due to consideration of angular nature of the underlying data. Furthermore, the wrapped normal distribution is a limit distribution for a circular equivalent to the central limit theorem.

2.6 Shared Reconfigurable Sensor-Actuator Networks

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After more than one decade of the development, the sensor networks has been extended to the Cyber-Physical-Systems (CPS) and the Internet of things (IOT) where the embedded devices are not only able to manipulate the physical environment but also able to be accessed through the Internet. These extensions imply that the sensor-actuator networks are more capable of processing the environmental phenomena and are better integrated with other networks. Sharing the sensor-actuator network infrastructures become a reasonable solution to save the deployment costs. For example, in the Smart Cities project, the sensors and actuators are virtualized as resources and provide open standard APIs to the middle-ware platform. The developers can use the middle-ware services to build the applications for the citizens (end users) and the city manager (administrators). Since the applications across different domains may share the same set of the sensors/actuators, the sensor/actuator nodes should be able to adapt to the changing requirements of the various application sets. Therefore, the nodes should be capable of adjusting their behaviors according to the application requirements.
On the other hand, due to the recent advance of the Field Programmable Gate Array (FPGA), it is possible to perform the low-power hardware accelerations using flash-based FPGA which consumes power at milliwatt-level in active mode and at microwatt-level in sleep mode. Following this trend, it is foreseeable that the flash-based FPGA will be used in the scenarios where the reconfiguration will be beneficial in terms of the energy efficiency and the flexibility. In shared sensor-actuator network infrastructures, the nodes should adjust their behaviors based on the running applications. Using the reconfigurable nodes can change the hardware configuration at run-time and accelerate certain tasks to improve the energy efficiency.
The focus of this thesis is to bring the reconfigurable accelerations to the shared sensor-actuator networks. To fulfill the changing requirements of the running applications, the sensor-actuator nodes can decide whether to reconfigure the FPGA fabric to accelerate certain tasks in order to improve the performance and the energy efficiency. However, to decide when to reconfigure and which accelerator to use under the resource constraints is challenging. In addition to that, how to disseminate and store the various versions of configuration in the network and how to design a reconfigurable architecture to reduce the reconfiguration overhead are important issues to be solved. In this thesis, we are going to develop a self-organized system in the shared reconfigurable sensor-actuator networks addressing the aforementioned issues to improve the performance and the energy efficiency.

2.7 Anomaly Detection in Sensor Networks

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This subproject considers sensor networks from the point of view of data mining. In particular, the focus is on the topic of anomaly detection, which is one of the major subtopic in data mining. The goal of this research project is to develop novel anomaly detection approaches that are tailored to the specific demands in sensor networks. Compared with other applications, the demands for anomaly detection in sensor networks can be summarized by the issues of (1) the dimensionality of sensor space and (2) the temporal nature of sensor data.

The first challenge, the dimensionality of the sensor space, refers to the fact that in modern sensor applications a sensor typically no longer measures a single quantity; it is more and more common that a sensor gathers several quantities simultaneously and the amount of quantities increases steadily with the complexity of the sensors. The resulting high dimensional feature space is an essential challenge in anomaly detection, subsumed by an effect known as the curse of dimensionality. As a first step to tackle this problem, we identified dependency analysis of sensor readings as promising solution to improve the quality of anomaly detection. We have shown that the existence of non-trivial sensor anomalies, i.e. anomalies hidden in high-dimensional spaces, require dependencies amongst the sensor attributes. To this end, we develop techniques to detect dependencies in sensor attributes.

The second challenge, the temporal nature of sensor data, describes the effects introduced by the infinite stream property of sensor readings. In general, it would be desirable to perform an anomaly detection approach on-line, i.e., directly on the sensor nodes. This has several implications: First, the approach has to deal with the limited resources of a sensor node – access to the whole (potentially infinite) history of sensor readings is not possible. Instead, it is necessary to develop sensor stream summarization techniques, which capture information of the past in a limited way while providing sufficient information to maintain high anomaly detection quality. The second implication is that anomaly detection must be aware of changes in the observed system itself. For instance, there might be seasonal effects in the data, which means that normal/anomalous behavior cannot be modeled statically. Instead the models must be adapted continuously to the observed states of the system.

2.8 Correlation Analysis based on Cumulative Distributions with Applications on Sensor Data

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Correlation analysis is an important task for studying multi-dimensional data where one is interested in mining dependencies among attributes. Such dependencies in turn not only indicate the existence of interesting patterns but also help us compress the data for better storage as well as processing. Despite the importance of correlation analysis, most of existing techniques, however, focus only on linear correlation. While such restriction permits efficient computation of correlation coefficients, it likely misses non-linear and complex dependencies due to its simplified assumptions. While recent methods have been proposed to tackle the issue, they nevertheless are too expensive for very large and high-dimensional data sets. Furthermore, they rely on probability distribution functions (PDFs) which are usually unavailable and need to be estimated. Estimation techniques such as discretization and kernel density estimation in turn are prone to knowledge loss and the curse of dimensionality.
In this work, we focus on correlation analysis for very large and high-dimensional continuous-valued data. Since the data in consideration is continuous-valued, i.e., its PDFs are not available at hand, we propose to use its cumulative distribution functions (CDFs). CDFs have the advantage that they can be computed directly on empirical data. In particular, we aim at devising novel correlation measures based on CDFs that can be practically computed in closed forms. Since real-world data contains complex dependencies among its attributes, we focus on correlation measures that are able to capture both linear as well as non-linear correlation. In addition, we target at developing efficient methods for mining attribute dependencies on very large and high-dimensional data. This is to ensure the applicability of our research to the big data issue that has raised many practical challenges for traditional data analysis techniques. To empirically evaluate our work, we conduct experimental study on data collected from sensor networks in various domains, e.g., energy consumption, chemistry, climate, and physical activity monitoring. Studying such data is beneficial for improving the battery life of sensors as well as amending the process of collecting and storing sensor data.

2.9 Graph Embeddings for Routing in Wireless Networks

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Routing messages is one of the most basic tasks a network must be able to perform. In wired networks, routing typically relies on a hierarchical address space, distinguished router nodes or precomputed routing tables. In ad hoc and wireless networks, however, these assumptions often do not hold, e.g. sensors act not only as origins and destinations of messages, they have to play the role of routers as well.
Geometric routing is a family of methods for routing in wireless networks. It uses geographic coordinates of a node as its address. The easiest strategy is Euclidean greedy routing: a message is always being passed to a neighbor closer to the destination. However, this approach is problematic, since GPS antennae are both expensive and cause high energy consumption. Also, a message can get stuck at a void. Greedy embedding tackles these issues by mapping vertices to a metric space such that greedy routing on these new virtual coordinates always works.
The question about the existence of greedy embeddings for various metric spaces and classes of graphs has attracted a lot of interest from researchers in graph theory and computational geometry. For example, a long-standing conjecture on the existence of greedy embeddings of 3-connected planar graphs in $\mathbb{R}^2$ has been resolved. However, many theoretical questions remain open, e.g.: Does every 3-connected planar graph have a planar convex greedy embedding? Is it possible to characterize all graphs that admit a Euclidean greedy embedding?

2.10 Distributed Kalman Filtering

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Decentralized processing of data is one of the main challenges in today's strongly interconnected world. The collection of data at distributed sensor nodes about a specific phenomenon is an important aspect. Usually, the value of information decreases over time and when information stems from only a few sources, strong dependencies exist between different data sets. Due to these effects, challenges arise that must be taken into account when data sets are fused in order to harvest as much information as possible.
Distributed estimation of a physical phenomenon is one of the main challenges. In this regard, I am concerned with optimizing the processing of measurements at the sensors, minimizing data traffic between the nodes, and finding fusion rules for locally derived information. When a common phenomenon is estimated at spatially distributed nodes, dependencies arise from past data exchanges and/or a common evolution model of the phenomenon. When sensors ignore the correlations, even for linear models, inconsistent and bad estimates are obtained by the sensor network.
Depending on the available information about the models, the complexity of the algorithms, the communication bandwidth in the sensor-network and so forth, different approaches are pursued in literature. In my work, I primarily focus on 1) the fusion of estimates under unknown correlations and 2) strategies for the overall processing of measurements in order to minimize the mean-squared-error at a dedicated sink.
In diverse estimation scenarios such as SLAM or large-scale systems, it is expensive and sometimes even impossible to store dependency information between estimates. When this information is discarded, suboptimal fusion methods that minimize the expected uncertainty are applied. While Covariance Intersection is a popular representative in this category, I pursue the idea of utilizing some (easy to maintain) dependency information in order to yield more precise estimates and bounds.
In the second direction, I proposed an approach that takes into account the dependencies and optimizes the local filtering at the sensors according to an assumed sensor network capacity while consistent quality bounds are provided. This way, the estimation performance is significantly improved compared to state-of-the-art track-to-track fusion approaches.

2.11 Energy Efficiency in Wireless Sensor-Networks

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Wireless sensor networks consist of several small battery-powered sensor nodes which are deployed over geographic areas to sense the environment and transmit the gathered data to a remote receiver. Network lifetime is a primary metric to evaluate the performance of sensor networks and since sensor nodes are often battery powered devices, their lifetime is strongly related to their energy consumption. Hence, reducing energy consumption and distribution of power among nodes is a major concern in sensor networks. Focusing on sensor node (hardware architecture, algorithms, etc), we aim at improving energy efficiency and power reduction in wireless sensor networks. Since wireless sensor network environments are dynamic in nature, the quantity and type of targets may change frequently, requiring many system reconfigurations. This property causes a trend to use reconfigurable (FPGA-based) sensor nodes, especially in computation intensive applications. We aim at exploiting new energy efficient solutions for sensor nodes in wireless sensor networks to reduce the energy dissipation and prolong the lifetime of wireless sensor networks. Using these new technologies in wireless sensor network domain will arise some problems and cause some challenges that should be addressed by researchers. For instance, high energy overhead associated with reconfiguration in FPGA-based sensor nodes is one of those challenges.
Wireless sensor networks are supposed to work in harsh environments under extreme heat and cold which will result in significant change in performance and energy consumption characteristics of sensor nodes. It necessitates using adaptive online approaches rather that static, design-time solutions for energy management in sensor networks. We concentrate on emerging technologies, hardware architectures, online and adaptive algorithms for reducing power or energy consumption in sensor nodes to enhance their battery lifetime and therefore the lifetime of wireless sensor networks.

3 GRK 1247: Cross-modal Interaction in Natural and Artificial Cognitive Systems (CINACS)

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Natural cognitive systems combine the input of the different sensory systems as each modality provides information about different aspects of the world and as the different senses can jointly encode aspects of events. As each modality uses specific representations, information needs to be transferred into codes that permit the senses to interact. Corresponding problems arise in human communication when information is expressed via formats like language and graphics.

We investigate cross-modal processes in natural and artificial cognitive systems, focusing on phenomena of dynamics, learning, memory and communication. These principles of cross-modal processing are central to understanding and building new cross-modal intelligent systems. Furthermore, we investigate principles for designing and realizing multi-modal environments for human-computer interaction. The research programme aims at understanding the biological mechanisms of cross-modal processing, its role in perception and behavioural control and the use of multi-modal representations in communication and problem solving. We also design models, implement algorithms and investigate architectures for robust artificial systems which facilitate a smooth and efficient cooperation and communication between humans and artificial systems.

Cross-modal Interaction in Natural and Artificial Cognitive Systems (CINACS) combines the relevant methods, in particular behavioural techniques including EEG, MEG, fMRI, cognitive and computational simulation, artefact construction, computer and robot experiments. This is possible because CINACS comprises neuroscience, bio-engineering, psychology, linguistics, computer science and robotics. In the cooperation among CINACS PhD projects, we are focusing on top-down control of cross-modal processing, cross-modal binding, adaptivity of cross-modal processes, cross-modal

representations, multi-modal communication, multi-modal BCI, cross-modal decision making and executive control.

3.1 A Lamprey Spinal Generator with Sensory Feedback for Adaptive Locomotion

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Animals exhibit various highly efficient methods of locomotion, such as walking, crawling, flying and swimming by means of rhythmic oscillation of their articulation. From the morphologcial point of view, their modular topology, featuring an advantageous distribution of body mass and a large amount of contact points, allows them to move adaptively in complex environments. In biology, neurobiological studies have shown that in animals, rhythmic movements are generated by a group of neural networks, called central pattern generator (CPG), which is able to produce coordinated rhythmic signals without any sensory inputs. Although sensory feedback is not necessary in CPGs, it indeed plays a role in altering CPGs to deal with environmental perturbations[1]. In robotics, the CPG-based control method is considered as an elegant solution for online gait generation[2]. It is a decentralized control method that is well suited for robots with a modular implementation. Meanwhile, CPG models typically have a few control parameters for online gait modulation and are able to add sensory feedback. In existing literature, several famous CPG models, such as Ekeberg's model, Matsuoka's model and Ijspeert's model, have been thoroughly studied for locomotion control in robots in the past decade.

In this work, we propose a CPG model derived from the spinal cord of lampreys as the controller of limbless robots. The CPG model not only possesses explicit parameters for modulating the output, including the tuning of amplitude, period, phase difference and offset, but also provides a solution for sensory feedback integration with the help of biological findings in lampreys. Since force sensors are mounted on the bottom of the robot, sensory information is available during the locomotion. We bridge the sensory information and the CPG model by means of additional sensory interneurons. In order to learn the mapping between sensory information and sensory feedback to the CPG model, we use a genetic algorithm to obtain CPG parameters. Simulation results show that after parameter evolution, the sensory information can modulate the CPG model appropriately and thus help the robot to adapt to the environment.

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3.2 The Influence of Pre-Stimulus Oscillatory Brain States on Pain Perception

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The processing of information in natural cognitive systems is closely related to the percept that is created from sensory information originating in the outside world[1]. As for the human brain, the oscillatory brain state at the moment of sensory input has been shown to substantially influence the subsequent perception[2]. The aim of our study is to use visual feedback of selected parameters of oscillatory brain states to enable the participants to voluntarily modulate their brain activity – and subsequently their perception. Other studies were able to show that this approach is viable [3], and using non-invasive brain-computer-interface (BCI) technology to modulate one's own perception can yield valuable insights into the composition of perception, but also possibly bring in suggestions for BCI control of external electronic devices.

In our study we will conctentrate on the perception of pain – being clinically relevant as well as an important factor in behavioural regulation.

In a three step paradigm we will first contrast a pain with no-pain condition and analyse electroencephalography (EEG) data from 64 electrodes in the time-frequency-domain for markers of differential perception. In a second step these preliminary results will then be tested by monitoring the identified EEG markers in real time while presenting painful stimuli of constant intensity upon detection of particularly high and low oscillatory activity in the frequency and spatial region of interest. If the predictive power of the previously identified markers will reflect in the collected behavioural data, we will continue with six consecutive training sessions which are supposed to enable the participants to learn to control their brain activity and thus to modulate their perception of pain. In a pre-post-test paradigm the specifity and success of this training will then be evaluated.

If this series of experiments proves to be successful, we will then try to connect the resulting capability to modulate pain to the underlying neural correlate by re-running a training session in a functional magnetic resonance imaging (fMRI) setting.

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3.3 Three Dimensional Robotic Mapping

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Three dimensional (3D) mapping is one hot topic in mobile robotics which aims to provide the robot 3D maps for localization, path planning and navigation, especially for service robots. A number of objects with planar surfaces can be found in both indoor and urban environments; this thesis deals with the 3D mapping problem based on the surfaces.
The first research question focuses on fast planar patches extraction. Following the route of region growing segmentation in image processing, two region growing based plane segmentation algorithms have been proposed: First, one sub-window based region growing algorithm, i.e., the cloud is divided into sub-windows and coplanar sub-windows are clustered based on region growing, has been published[1]; Second, a hybrid region growing algorithm, i.e., both sub-windows and single points are considered during region growing, has been submitted[2].
The second research question focuses on scan registration, based on attributed planar patches (resulting from the above-mentioned algorithms). Planar segment correspondences between overlapping point clouds are determined by a search algorithm, and are used to compute the transformation. The correspondences are searched globally to maximize a spherical correlation like metric, by enumerating solutions derived from potential segment correspondences. A brief introduction of this approach has been published[3], and a detailed description has been accepted[4].
The third step will focus on closure detection, i.e., place recognition. To deal with this problem, the area of each planar patch will be calculated. The idea is to construct a global descriptor for each point cloud similar to 3D-NDT histogram. The descriptor is a feature histogram which encodes area distributions for selected directions on 2-sphere. Then descriptor comparison is measured as Euler distance between normalized feature histograms.

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3.4 Haptic-sonified Virtuals Environment for Spatial Knowledge Acquisition of Blind and Visually-impaired people

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The spatial knowledge of one's own apartment is crucial for daily life. But for visually-impaired people, to acquire spatial knowledge of such an environment could be frustrating.
Many scientists and researchers have proposed that other perceptual channels could be utilized to compensate the absence of sight for people with these kinds of special needs. Since the end of the last century, a large number of assistance systems and human computer interactions, which communicate and interact with users via the sense of touch and the sense of hearing, have been emerging[1].
This project introduces a haptic-sonified human computer interaction system, which is designed and implemented to help people acquire spatial knowledge of novel small-scale apartments without visual observation. Virtual 2.5-D apartment models are made according to realistic floor plans. Haptic force feedback will be rendered when users touch the virtual model by a joystick. During the exploration, specific auditory assistance information could be invoked in prescribed areas. Categorical knowledge is uttered in the form of Text-To-Speech assistance, while analogical knowledge is represented by sonification. Spatial overlapping constellations involving two or three different types of entities are investigated in detail[2].
Blindfolded university students are invited to explore the virtual models of empty apartments. Reproductions of the floor plans confirm a good performance in spatial knowledge acquisition. Through a focus group study with blind and visually-impaired students, as well as the teachers, at the Shanghai School of the Blind, positive feedback was acknowledged. Furthermore, information about power-outlets and furniture pieces is regarded as critically relevant and expected as adds-on of the current virtual model of empty apartments only with windows and radiators.

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3.5 Evaluating computational models of sensorimotor contingencies

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Cognitive neuroscience plays an increasingly important role in artificial intelligence (AI), for example in the development of new computational models aimed at explaining cognitive behaviour. Consequentially, the field of AI research has adopted a more connectionist and embodied viewpoint. However, the influence of neuroscience on AI is bidirectional, in the sense that AI models provide us with the opportunity to study cognitive processes through the use of computational models. One promising new approach in the field of cognitive neuroscience is O' Reagan and Noe's (2001) Sensorimotor Contingency Theory. In contrast to other established theories of human perception, the authors suggest that perception and action are inseparably linked. More specifically, perceiving is mastering the law-like relations between actions and resulting changes in sensory input. These law-like relations have been termed "sensorimotor contingencies" (SMCs). This approach is not only of great relevance in further understanding what constitutes human perception, but it also suggests an alternative to the "perceive-think-act" control architecture commonly used in the field of robotics for example. Our studies focus on evaluating computational models based on this theory and applying them on a robotic platform to evaluate cross-modal information processing, self-perception and organization of sensorimotor space. One aim of our experiments is to extend the sensory input with visual features to study the effect of multimodal processing on the behaviour of the robot. As a consequence of using vision the need for an efficient feature extraction method arises for compressing this high bandwidth visual information. Therefore, methods for extracting structures from images, like optical flow or color histograms will be evaluated against each other for usefulness in the SMC context. With multimodal sensory input coming from distance sensors as well as camera images, it is planned to investigate the robot acquiring object-related SMCs to distinguish simple objects. This approach will be compared to traditional object recognition techniques. It is expected that the SMC-controller architecture for the robot and the multimodal sensory input will result in a more robust and efficient performance leading to a better recognition of simple objects. For the experiments we will use the robotic platform Robotino equipped with an omnidirectional wheel drive, a webcam, nine distance sensors, and a collision detector. These studies will take place in an indoor environment consisting of a homogenously coloured floor and white walls with relatively few visual salient features.

3.6 Multi-Sensory Integration For Orientation and Action Selection Inspired By The Superior Colliculus

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the In vertebrates, the superior colliculus (SC) is a mid-brain region which receives direct and indirect input from the visual, auditory, and tactile sensory modalities. Together with other brain areas up- and downstream, it localizes sources of cross-sensory stimuli, decides which ones to attend to, and initiates orienting movements accordingly.[1] The SC has been a focus of research in neurophysiology, behavioral psychology, and computational modeling. It is expected that findings about the SC can guide research on other brain regions.[2]
The human brain as an information processing system surpasses the capabilities of today's computers in many ways. One example is sensory-motor processing, where humans and other animals display striking robustness, flexibility, and efficiency. Modeling the SC, which is at the heart of sensory-motor control and multi-sensory convergence in vertebrates, thus promises great insights into ways to improve performance in artificial systems.
We have presented an extension of Kohonen's unsupervised Self-Organizing Map (SOM).[3] This SOM extension learns to optimally combine localizations from different sensory modalities.[4] In as of yet unpublished work, we have developed this idea into a SOM-based unsupervised ANN which learns latent-variable models from high-dimensional input. Given a data point, the network computes a probability density function (PDF) for the latent variables, and represents that PDF in its output. It needs no knowledge of the noise properties of its input. This ANN can be seen as an abstract model of the SC. Indeed, it manages to naturally replicate well-known properties of SC neurophysiology. In the future, we want to validate our model in robotic orientation experiments. We also want to further extend our model to aspects relating to attention and contextual knowledge and study ways of increasing biological plausibility.

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3.7 Investigation of Haptic Graph Comprehension Through Co-Production of Gesture and Language

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Documents combining text and pictorial (re-)presentations, such as graphs, diagrams, or maps, are wide-spread in print media and in electronic media. In addition to text-graphics documents, in many communication settings, e.g., conference presentations or classroom settings, spoken language, depictions and often also gestures, accompany each other forming multimodal communication acts. Various modalities are intertwined in communication settings, including communication through line graphs. The investigation of gestures, eye movements, language and haptic exploration in interaction has the potential to provide insights for human interpretation of the represented information that has a direct contribution on multimedia design. One of the fields, profited by these researches, is multimedia design for blind and visually impaired people. The graphical representations are used as a basic material to elaborate the information, which is hard to express within text only. Therefore, to provide access to graphical representations for blind people is one of the important topics of this field. Haptic graphs are considered as an efficient medium that provides access to the visual representations presented through haptic modality. However haptic representation has lower bandwidth compared to visual modalities, since the haptic exploration is sequential, while visual perception allows the perception of both local and global information about graph at one glance. Therefore, visual representations can be considered as superior in the amount of conveyed information. In order to bridge this gap and present coherent information to the haptic graph readers, haptic graphs should be accompanied by alternative modalities such as verbal/audio modalities.For designing haptic graphs augmented by audio assisitance (sonification or speech) it is necessary to determine, which information depicted by the graph or by segments of the graph, are appreciated as important [1].
To conclude, a systematic investigation of the interaction between modalities in communication through graphs has the potential to contribute to identifying design principles for multimodal communication settings that facilitate efficient and effective communication of information since experiments give evidence about the content relevant to the conveyed information (in particular the question what should be communicated by language).

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3.8 Event Recognition during Exploration of Pictorial Representations in Virtual Haptic Environments

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Pictorial representations are widely used in human problem solving. For blind and visually impaired people, force-feedback devices, such as the Sensable PHANToM, can provide perceptual access to graphical representations like maps, graphs, and diagrams. In contrast to visual perception, haptic perception in virtual environments is local and sequential. The explorer has to integrate local information over the course of an exploration into a coherent 'picture'. This makes exploration of complex spatial arrangements difficult. Verbal assistance and sonification can help to overcome this problem by informing the user of facts that are not easily perceived during exploration[1]. Due to the nature of force-feedback devices, the classical human-computer interaction paradigm WIMP (Window, Icon, Menu, Pointing Device) is not applicable for the proposed interaction scenario, as the pointing device is at the same time used to explore the haptic representation. Instead the computer acts like an intelligent and proactive partner: While the user explores a haptic representation, the system observes the exploration process and builds up a propositional representation of the current exploration situation. Based on these representations the system can interact with the user using speech or non-linguistic sound. The central prerequisite for realizing powerful assistive interaction is monitoring the users' haptic exploration to recognize exploratory events.[2] This is achieved using a rule based approach for complex event detection, based on a qualitative spatial model of pictorial representations.

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3.9 In-hand Manipulation Learning from Human Demonstration

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To manipulate an object with a hand, the object has the leading role; it can be moving, rotating or deforming over a period of time. The driving force in all this is the hand. Resulting from different contact areas or different magnitudes of force at the moment, the object is being handled.
However, in terms of different applications, in-hand manipulation models still require improvement. Even if each state of in-hand manipulation looks easy to our human eyes, they should be converted into an understandable way for a robot. Besides, the information acquired from different sensing channels should be merged as a continuous and reasonable operating sequence, which will instruct the robotic humanoid hand to perform, simulate or refine itself. Nevertheless, the data from different channels are incosistent, so here is another problem that needs to be solved.
The in-hand manipulation model will be presented as "State-Action Transition Network", which can be known as the reaction mechanism during the whole process of manipulation. Then what has been recorded correctly will be integrated into the model and organized after analysis.
Specifically, our solution is named "State-Action Gist". This concept includes the important but compact knowledge of the process of in-hand manipulation. Action gist indicates the key finger moving directions sequentially, and meanwhile state gist describes the corresponding object, hand and the interactive information, e.g. object moving direction, contact state.
After we extract "State-Action Gist", we have the necessary knowledge to teach the robot to train itself to realize the manipulation task. Therefore, the next step is called "motor babbling learning". In this step, the robot hand just needs to find the corresponding parameters to command the finger movement, so as to translate the object state from the beginning to the target state. Because the scale of the parameters is large, we cannot find an absolute optimization algorithm. In stead, we employ a swarm algorithm. Since the algorithm tries and approaches a good solution gradually, we assume the process is a babbling process.

3.10 Statistical Semantic Parsing on Wide-Domain Data

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Supervisor: Wolfgang Menzel

Semantic parsing is the task of constructing a formal meaning representation from a natural language text. This work is concerned with supervised statistical semantic parsing: systems that cast the task of semantic parsing as a machine-learning problem and learn from data annotated with full meaning representations.
One problem that has been limiting research on statistical semantic parsing is the scarcity of such annotated data. This work circumvents this problem by using automatic annotation performed by a (non-statistical) semantic parsing tool called Boxer[1]. Although the annotations thus generated are imperfect, they should suffice to serve as training data for a statistical semantic parser.
Automatic annotation provides the basis for an evaluation of extant statistical semantic parsing methods. As the meaning representations generated by Boxer are considerably more complex than those used in prior research, they may be gradually simplified in order to find the right balance between expressiveness of the meaning representation and performance of the learning algorithm. The results of this evaluation can then inform further research in statistical semantic parsing methods.
Applying statistical semantic parsing to wide-domain data also yields opportunities for new applications. The combination of statistical semantic parsing with parallel (multilingual) corpora may allow for the training of semantic parsers for languages other than English and finally lead to applications in hybrid approaches to statistical machine translation.

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3.11 Neural Sound Source Localisation for Speech Processing Based on the Inferior Colliculus

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Audition, among other perceptual processes, allows animals to generate an internal representation of their environment. From this rich representation vast amounts of noise and persistent information are filtered out. This dynamic process is crucial for animal survival and for spoken communication [1]. The same perception-action loop is important for autonomous robots deployed in dynamic environments and in general for human-robot interaction. In the case of humanoid robotics, we can take advantage of the richer perceptual representations produced by their embodiment and facilitate communication with humans. Particularly, we are interested in the robotic *Cocktail Party* problem, i.e. the segregation of a speech source from a background of noise and concurrent speakers. For this matter, there is evidence that sound source localisation (SSL) can enhance the performance of autonomous speech recognition (ASR) systems [2].

A head related transfer function (HRTF) can be obtained from any humanoid robotic platform. The HRTF describes the influence of the robot's body on the frequency components of sound captured from a set of spatial locations around the robot. In previous work we use the spatial cues produced by the HRTF of a humanoid robot for localising sound sources in space [3]. Such spatial cues are processed with a spiking neural model of the medial and lateral superior olive for estimating interaural time and level differences. Afterwards, both cues are integrated in a model of the inferior colliculus using Bayesian inference. This integration increases the reliability of spatial cues across sound frequency components for SSL.

The following step in our research is to use SSL for the enhancement of ASR systems. When knowing the location of a sound source it is possible to filter out spurious information on different sound frequencies and increase the SNR of speech [4]. Embodied cognition is a powerful computational tool and a promising approach to the robotic *Cocktail Party* problem.

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3.12 Multimodal based Objects Categorization and Recognition

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Supervisor: Jianwei Zhang

The ability of extracting features from objects and classifying objects into different categories plays very important roles in human intellingence. Human beings can easily find unfamiliar objects and relate them with similar object categories. This kind of inference underlies an object through its "understanding". The "understanding" ability is what we want to develop on an artificial intelligent system/robot.

This thesis is an extension of the PhD thesis of Dr. Jianhua Zhang[1], who has graduated from CINACS last year. In his thesis, he proposed a new approach for object categorization which he named "Explore Objects and Categories in Unexplored Enviroments Based on Multimodal Data". The whole object recognition process has been separated into two steps in his approach, object detection and category discovery. During the first step, a set of novel category-independent object features is proposed. Based on these features, a cross modal co-segmentation method is proposed to detect and localize category-independent object instances. After the localization of objects, a dynamic category hierarchy is proposed to improve object recognition.

As mentioned above, this thesis is an extension work of the exsist system. It focusses on two points which can be improved. The first point is that two more modals will be used to improve the accuracy of object localization and description. Audio data will be added to help localize object position and also as a property of an object to expand the hierarchical framework. Haptic information will be added into the features of objects to further extend the attributes of objects, such as material and density. The second point which will be improved is the time cost of the whole process. Currently the system requires a lot of computational reresources to extract features and the process of training SVM classifiers is also a time-consming task. A possible approach of reducing the time-cost will be presented in this thesis.

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3.13 Grasping based on semantic information does not obey Weber's law

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Grasping in humans involves both sensory and higher-level cognitive mechanisms. Advances in our knowledge about these mechanisms can be applied to the development of smart prosthetics and brain-machine interfaces. Here, we studied the mechanisms that guide the formation of grip size in humans. In order to prepare an adequate grip size humans normally use visual information about object size. Recently it has been found that the processing of visual size information during grasping violates Weber's law, a basic psychophysical principle[1]. Weber's law states that the uncertainty of a visual size estimate increases with the size of the object. In grasping, however, the uncertainty of the grip size does not increase with the size of the object. This is a very surprising result and qualitative differences in visual coding mechanisms have been used to account for this dissociation between grasping and perceptual tasks in terms of Weber's law. However, in our previous work we could show that also higher-level, semantic information (e.g. numbers indicating the size of an object) can be used to scale the grip size in an efficient manner even when vision is not available. In this project, we investigated whether the assumed differences in the visual coding mechanisms solely account for the dissociation between grasping and perceptual tasks. Therefore, we compared grasping and a perceptual task (manual estimation) with and without vision. If the visual coding mechanisms solely account for the difference between grasping and perceptual tasks, the dissociation should disappear when there is no visual information about object size. Sixty participants grasped objects or estimated the size of the objects with their finger span (perceptual task) while seeing the object (visual condition) or hearing numbers indicating the size of the object (semantic condition). Interestingly, we found the same dissociation between grasping and manual estimation in terms of Weber's law regardless of whether the object was visible or not visible. Besides a general higher uncertainty and a slightly lower slope of the grip scaling across size in the semantic condition, grasping apparently follows the same principles as in the visual condition. Consequently, visual coding mechanisms cannot solely account for the dissociation between grasping and perceptual tasks in terms of Weber's law. Other, more task specific aspects (e.g. integration of haptic feedback) have to be taken into account to shed light on the violation of Weber's law during grasping.

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3.14 An Affordance-Based Conception of Social Space for Socially-Aware Robot Placement

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Social robotics is concerned with problems related to the acceptability of robots in human-populated environments. As robots become part of human daily life, traditional approaches to robot navigation and placement planning turn out to be insufficient. To model socio-spatial constraints for robot planning, the social science notion of 'social space' has widely been applied. Our conception of social space systematically distinguishes four types of social spaces, i.e., personal spaces associated with persons, activity spaces associated with activities performed either by humans or by robots (or jointly), social affordance spaces associated with affordances, and territories associated with claims of exclusive usage or property. We investigate how these different notions can be based on a common ground by taking affordances and normative facts as primitives. The spatial dimension of social space is axiomatized using mereotopology as a formal mean to qualitatively specify spatial structures.[1] We suggest that a wide range of socio-spatial phenomena can be described using this social space framework. As an example, a personal robot at home should have most reason not to disturb human activities. It should be aware of blocking action possibilities, e.g., when parking in front of a light switch making it impossible for a person to reach it.
Our current investigations are concerned with how these requirements can be met within a unifying ontological framework taking affordances and normative facts as primitives, and how reasons for socially-aware actions can be provided to deliberative decision-making modules.

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3.15 Tactile Perception in In-hand Manipulation System

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Touch perception plays an important role in our daily life. It occurs in human daily life, such as dining, writing, opening a door, putting on clothes etc. Touch perception provides rich information about the world around us. In in-hand manipulation, perceptions employed by humans are classified as touch and visual perception. Visual perception provides an estimation of objects that is necessary for humans to preliminarily plan their hand actions. But it is hard to artificially perceive contact based on vision due to object occlusion and the limits of cameras. Touch perception mainly supplies the force information between fingers and objects. Even if there is a lack of visual perception, it is possible to estimate the state of object by means of touch interaction and prior knowledge.
Inspired from mechanisms of human's manipulation, the two types of perceptions are usually utilized in robotics, such as the application of in-hand manipulation. Considerable research has been done based on these perceptions for in-hand manipulation. However, most of it relies on precise models. As a matter of fact, it is impossible to build such precise models for every object in a realistic manner.
In order to resolve these problems, here a cognition strategy "touch exploration" is presented to help the robot to explore and attain knowledge on the unknown objects within their hands. There are several steps to this strategy: contact point selection, exploring trajectory planning, reward perception and action execution. The contact point selection is the control of grasping. The pushing trajectory planning is a process in which fingers search directions along which the pushing of fingers can produce the expected reward. The rewards perceived show whether the current action is expected. Therefore it concerns two parts. One is the change of the object's movement that includes position and attitude and the other is the change of resistance to the fingers' pushing. The action execution is the action that fingers push along the planned direction with expected rewards. In a word, the touch exploration provides a method that helps robots to understand and utilize tools.

4 GRK 1298: Algorithmic Synthesis of Reactive and Discrete Continuous Systems (AlgoSyn)

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While methods of software validation and verification are by now well established, based on adequate formal models and tested in practical applications, the approach of automatic synthesis of software (and hardware) is as yet only developed in quite rudimentary form. On the other hand, in theoretical computer science as well as in engineering disciplines a rapidly increasing stock of techniques for algorithmic synthesis is emerging, triggered by the demand to decrease development costs by invoking algorithmic methods. However, the approach of program synthesis is only applicable in restricted scenarios, in particular in reactive (multi-agent) systems with low data complexity, such as control systems, and in the transformation and optimization of existing models. Central issues in the area are the establishment of system models which allow for an algorithmic solution of the synthesis problem, the combination of discrete and continuous parameters in hybrid systems (as this is also familiar from verification), and the exploration of the potential of applications. The aim of the Research Training Group is to unify the expertise from computer science, mathematics, and engineering disciplines (embedded systems, automatic control, process control engineering, train traffic systems) and to push forward the desired integration of methods. The research projects are organized on three levels: Theoretical foundations (algorithmic and formal models), model transformations and software engineering, and applications.

4.1 Verification of Code for Programmable Logic Controllers

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Programmable Logic Controllers (PLCs) are control devices used in industry for monitoring and controlling of plants, robots and safety critical infrastructure. Since they are often used in safety critical environments where a failure might have serious effects on human health or the environment, formal verification of their programs is advised. This strive for functional correctness combined with having small, well-structured programs, makes PLCs a very interesting platform for the application of formal methods.
For their operation, PLCs have inputs, which are usually connected to sensors, and outputs, which are connected to actuators. The operation is controlled by a program, which is periodically called at a high frequency to set new output values depeding on the current inputs. The program can access non-temporary variables that retain their value for the next cycle. This allows to select, e. g, different modes of operation. The programs are usually composed of function blocks which can be written in various programming languages.
To analyse and verify PLC programs, this project automatically creates a model reflecting their operation. This model comprises states, which are tuples combing the values of the input, output and non-temporary variables after one execution of the program. A transition between states is assumed if they are reachable within one cycle. This model can then be analyzed using formal methods: We allow for model checking using CTL and past time LTL logic and offer a static analysis to determine ranges of variable values.
Such a model can naïvely be generated by simulating the program for all possible input values and iterating this process for the new states. In general this process is not feasible, since even the state space of small programs comprises too many states. Hence, we use symbolic states which abstract a set of concrete states using, e. g., intervals. To select a suitable abstraction, we start by a very coarse abstraction of the program and then use a counterexample guided abstraction refinement. That is, we analyze counterexamples returned by the model checker for feasibility in the concrete state space. If they are not feasible, we use them as a hint to refine the current abstraction. For this, we can currently use either an own constraint solver or the Z3 SMT solver. To generate the transition relation on the corresponding abstract state space we use an abstract simulator.
The results of this work are implemented in the Arcade.PLC framework, which offers a graphical user interface, the necessary program file parsers and abstract simulators to analyse PLC programs using these techniques.

4.2 Strategy Representation and Complexity

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The aim of automated synthesis is to generate code exhibiting a specified behavior. In order to achieve this goal, methods from game theory are employed. The situation is modeled as a game between two players, *Controller* and *Environment*. The goal of Controller is to ensure that the execution of a software system conforms with the initially specified, desired behavior. The goal of Environment is to thwart that effort. If Controller can find a program to ensure the specified behavior, he wins the game by playing accordingly. Methods to find such a "winning strategy" for Controller exist, but usually generate a "state space" representation of the desired program. This representation can be exponentially large in general which limits the practical use of such methods. The aim of this thesis is to study alternative means of representing and deriving winning strategies in games in order to overcome these limitations.

We address this by representing winning strategies not as state space representations, but as Turing machines. This allows us to find exponentially more succinct representations of winning strategies. At the same time, we obtain a better tool of assessing the quality of a winning strategy as a program to be executed. In contrast to state space abstractions, we can measure runtime, space consumption and program size. Using these measures, we obtain a much finer granularity at which to compare and classify strategies.

Representing strategies in a different formalism must be supplemented by finding such representations. We study ways of synthesis that avoid constructing the large state space abstraction altogether. For several important classes of games (namely Streett and Muller games) we can show that polynomially sized controllers can be directly synthesized.

Possible real-world applications of automated synthesis are often very structured. This structure is usually closely related to a succinct description of the problem instance. For instance, an assembly plant with n conveyor belts has a large number of possible configurations these n belts can have at a given time. Classically, the complexity (size, runtime, etc.) of synthesis algorithms is measured in this large number. It seems more appropriate to instead use the size of the succinct description. To address this problem, we study how structure of this kind in a problem instance can be exploited. We show that, in notable instances, the overall controller can be similarly structured. As a consequence, its runtime and size remain polynomial in the succinct description, rather than in the exponentially larger number of configurations.

4.3 Approximation Algorithms for Combinatorial Auctions

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This research project deals with improved approximation algorithms for combinatorial optimization problems with a focus on randomized methods and online arrival of the input elements. Where previous work is mostly concerned with offline optimization, we deal with the practically more relevant scenario in which the elements arrive one after another. Decisions on how to use an input element must be hit on its arrival, that is, only information about elements seen so far can be taken into consideration. A common example for such an online optimization problem is the well-known independent set problem, where nodes of a graph must be chosen in a way that selected nodes are not connected with each other but form a set of maximal size. In the online variant, nodes arrive after each other and the decision whether a node is selected into the independent set must be hit upon its arrival.
Assuming an adversarial arrival sequence of the input elements turns out to be lower bounded by n, the total number of nodes in the graph. Hence, we investigate the use of randomization in several ways to bypass this bound. Applications for our work can be found in the field of scheduling, e.g., requests. In that context, nodes in a conflict graph correspond to requests and edges in the graph indicate conflicts when scheduling both of the affected nodes. A valid set of requests is then exactly an independent set in the conflict graph.
Another vast area of research connected to our approximation algorithms is the design of combinatorial auctions. In combinatorial auctions, bundles of items are sold to agents which give bids for item sets according to their valuation of these sets. One can take advantage of structural properties of the underlying conflict relations to obtain better approximation guarantees for item allocation. A further challenge in the field of auctions and mechanism design is to use algorithms in a way, such that the obtained mechanism is truthful. This is a desirable property in multi-agent systems to prevent participants from misreporting information in order to give tactical bids.

4.4 Applying Supervisory Control Theory for PLC Software Development

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In the past decades the degree of automation applied to industrial plants has increased significantly. Especially in the domain of process control engineering but also in manufacturing contexts, Programmable Logic Controllers (PLC) play an essential role as reliable platform to host the actual controller software. However, the engineers or technicans who set up and configure the plant do programming work mostly manually and independently from any predefined development process.
The *Supervisory Control Theory* (SCT), which was initially developed and presented by Ramadge and Wonham[1] provides a theoretical concept of synthesizing controllers for *Discrete Event Systems* (DES). Especially the domain of automation engineering could significantly benefit from proper synthesis techniques. When transfering SCT to practice several problems arise[2]. Many of these address the discrepancy between logical events and physical signals that has to be bridged somehow[3]. Another problem is the distinction between events originating from the plant and those generated by the controller[4].
There are several research projects that try to adapt SCT synthesis concepts for PLC languages and systems[5] [6]. However, on the one hand there are still some issues waiting for an adequate solution, e.g. the problem of *interleave insensitive* supervisors (w.r.t. the order of the event occurrence)[2]. On the other hand, SC PLC code synthesis is still far away from being applied in industrial contexts. These are both fields where research work has yet to be done.

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4.5 Unified Runtime Systems for Industrial Automation

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Growing production flexibility and complexity of manufacturing and process plants pose new challenges for engineers and software developers in the industrial automation domain. The strict hardware and software hierarchy known as the automation pyramid becomes increasingly blurry. As a consequence, approved development methods and models cannot be consequently applied any longer. This will be a perfect opportunity of usage of formal methods, if a unified software architecture is used throughout the levels of the pyramid i.e. ranging from field devices like sensors or actuators to servers of the manufacturing execution system of the plant. Until then, heterogeneous systems and underlying models enforce unique solutions that cannot be transferred to further use-cases.
Software architectures that are available in the current standards are not unconditionally suitable for such a wide range of applications. Therefore, we identified a set of paradigms that runtime systems should follow in order to be used across various pyramid levels. A wide range of design decisions has to be met in order to describe a runtime environment. These decisions include software component architecture and communication infrastructure as well as the software development and deployment process. Other aspects from industrial automation including hard real-time compatibility and domain-specific programming languages have also to be taken into account.
As example, we emphasize the programming in the small. For this purpose we propose the widely accepted graphical programming language Function Block Network from IEC 61131-3. The encapsulation of the program logic into well-defined blocks with inputs and outputs allows a better program structuring; program re-usability and effective unit testing (for example, black box testing). Instances of pre-defined function block types can be combined into complex logic networks at runtime. The control flow inside of a function block network can be either task, call or event-driven. The obtained networks can be considered safe in terms of execution time and side effects, as long as the used block types are safe. The reconfigurability of the block networks allows the usage of logic synthesis at runtime (e.g. by a rule-based system). Further aspects of a runtime system design have been outlined in the below-mentioned publication.

4.6 Model Synthesis through Transformations

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Today it is common to use a set of modeling languages to describe different viewpoints of a software system. Within the process of developing, evolving, and maintaining a system, we encounter situations in which models of the system need to be transformed in various ways. Model transformations can be seen as the automatic generation of target models from source models according to transformation definitions[1]. A transformation definition consists of a set of transformation rules which describe how the target model is derived from the source model. These transformations can be, e.g., complex edit operations, structural refactorings or refinements. Beyond model transformations could also be used to model synthesis within code generation[2] or reverse engineering.
Most model transformation approaches use the abstract syntax of the modeling language to define transformations but some approaches also reuse the concrete syntax to allow modeling transformations in a more intuitive way. We call such a transformation language domain specific.
We are interested in the generation of domain specific transformation languages (DSTL). This approach combines the advantages of generating a transformation language and using a domain specific language. A DSTL allows the modeler to model transformations in an intuitive way as he is already familiar with the concrete syntax of the modeling language. Furthermore this language should be generated to prevent the modeler from implementing a transformation language for every modeling language used. A transformation engine to generate a DSTL using the grammar of the modeling language was already developed by our group[3] but up to now it only supports endogenous transformations which means source and target models are defined within the same language.
To model synthesis using model transformations we need to extend this approach such that we could use multiple modeling languages and multiple input or output models possibly in different languages, e.g., to combine class diagrams with the object constraint language and state charts to generate code. This research focuses on the generation of DSTLs for exogenous transformations to allow an intuitive way of modeling (model) synthesis.

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4.7 Logic and Strategy Construction in Infinite Games

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Supervisor: Prof. Dr. Erich Grädel

Infinite games on graphs are a tool that is used in various areas of computer science, including automata theory, verification, and synthesis. Accordingly, it is of great importance to solve such games, i.e. to find winning strategies or optimal strategies. As for most infinite games on graphs, strategies in general are not finitely representable, the existence of simple winning strategies is crucial. Prominent examples of simple strategies are positional strategies, where only information about the current position in the graph is required to produce a next move, and finite-memory strategies, where the necessary additional information can be stored in a finite memory structure.
For several well-known games, the required strategy models are already known, e.g. parity games are positionally determined, while finitely colored Muller games are determined via finite-memory strategies. For other classes of games, e.g. infinitely colored Muller games, Banach-Mazur games on graphs, or several variants of games with counters, no complete characterization has been obtained so far. We thus investigate different models of infinite games, both qualitative and quantitative, with respect to determinacy and memory requirement of winning strategies. As an example, we proved that in second-life games, which are games with a restricted kind of imperfect recall, finite-memory strategies suffice for the player suffering from the imperfect recall, and we used this result to solve counter parity games[1], a special variant of quantitative parity games.
As there are close relationships between logics and infinite games, we also study logics. Since many properties one would like to check in the real world are quantitative, we focus on quantitative logics. For example, we introduced a counting logic[2] based on the quantitative μ-calculus[3] and showed that this logic is decidable on a generalization of pushdown systems. We also investigate how other important logics, e.g. monadic second-order logic, can be lifted to the quantitative setting.

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4.8 Analysis and Synthesis Techniques for the Development of Distributed Interactive Systems

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The development of distibuted interactive hard- and software systems is a challenging task. One way to address the complexity of distributed interactive systems is decomposing the system into subsystems with well defined interfaces. Component and connector (C&C) architecture description languages offer mechanisms to formalize system decomposition to components and their communication via connectors effecting component interaction[1].
We are developing modeling languages, methods, and tools to support the development of distributed interactive systems in various steps from formalizing initial knowledge about the C&C structure of the system to behavior and interaction specification to detailed model-based implementation and code generation.
We have developed a C&C views language to describe design decisions and knowledge available about a system's decomposition in partial C&C views. This language is based on C&C modeling languages and adds powerful abstraction mechanisms for hierarchical containment, connectedness, and interfaces. Multiple C&C views can be combined to Boolean specifications for C&C models allowing to specify valid, invalid and dependent designs. Our analysis method can verify whether a C&C model satisfies a views specification. We have also developed a synthesis method to automatically compute a satisfying C&C model for a given specification, if one exists.
To describe the interaction behavior of components we have developed a modeling language for automata embedded in components interacting by sending and receiving messages via the component's typed input and output ports[2]. This language has various mechanisms for underspecification of component behavior. We have developed tool support to verify the implementation of components and component compositions against their underspecified models to enable incremental development of component behavior based on step-wise refinement.
The complete and checked components with embedded automata are ready for code generation. We have developed a code generation framework and runtime environment for the educational Lego NXT robotics platform to demonstrate our work on the example of robotic systems.

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[2] J. O. Ringert, B. Rumpe, A. Wortmann. A Requirements Modeling Language for the Component Behavior of Cyber Physical Robotics Systems. In: Modelling and Quality in Requirements Engineering, Monsenstein und Vannerdat, 2012.

4.9 Mechanism Design for Combinatorial Auctions

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Combinatorial auctions are a form of weighted set packing problems which is, in general, a hard class of problems. In the problem, bidders assert a valuation to items and there is a constraint on the maximal occurrences of the items. A solution is an assignment of the items to the bidders, so that the social welfare is maximized, while no packing constraint for an item is violated. The social welfare is defined as the total value over all bidders. Now, in mechanism design people go one step further. It is assumed that the valuation functions are only known by the bidders themselves and that all bidders act in a selfish manner. Therefore, if a bidder assumes he can improve his personal outcome by lying about his valuation, then he will do so. In mechanism design, we try to construct the algorithms to be truthful, meaning bidders maximize their outcome by telling the truth about their valuation. This is achieved by introducing prizes on the items, so that any bidder maximizing his utility (the difference between his valuation for a set of items and the prize on this set) also maximizes the social welfare incurred by the mechanism.
In my research, I design and analyze algorithms for various variants of combinatorial auctions. Currently, we work on approximating online combinatorial auctions. In this type of online problem, it is assumed that the items to be sold are known at the start of the algorithm. Then, the bidders arrive at runtime and the algorithm has to allocate them one or more items before the next bidder arrives. In the most simple form, when there is only a single item, this problem is the well known secretary problems. If there are more items, but every bidder is bound to only receive a single item, then the problem corresponds to the bipartite vertex-at-a-time matching problem. Now in the general online combinatorial auction problem, the bidders constraints on the size of the sets of items are lifted and multiplicities on the items are introduced. We develop algorithms for all these types of online auction problems.
Additionally, I work on multi-unit auctions in an offline setting. In such auctions, there is only a single item in an exponentially large quantity compared to the number of participating bidders. I have shown that there is a universally-truthful mechanism for the problem that only requires a very small number of random bits and approximates the optimum arbitrarily good (PTAS). Based on this result, I research if it is possible to achieve the same result with a deterministic mechanism.

4.10 Online Buffering: Theoretical Results and the Application in a Hybrid Car

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In Online Buffering we assume a decision maker has to purchase a commodity with varying prices over time. In every time step an decision maker is given a price and a demand of the commodity and has to decide how many units he wants to purchase. Units which are not used can be saved in a storage for later usage. We consider this problem in an online setting, i.e., the decisions made cannot based on information about future time steps.
We have studied online buffering using online. In online learning a decision maker is given a set of N experts. Each expert depicts a strategy to manage the buffer. In every time step the decision maker chooses an expert and can observe the performance of all experts afterwards. If the decision maker chooses an expert, it purchases the same amount of units as the expert in that time step and is accounted with the cost of the expert. Objective of the decision maker is to achieve cost which are at most as high as that of the best expert in hindsight, i.e. to the minimize its regret for not choosing that expert in every time step. The buffer makes the problem different from standard online learning, since the algorithm now has an internal state. Switching between experts can then be costly since it means switching between internal states which can cause additional cost.
In stead of choosing the expert independently for each time step which achieves low regret in standard online learning we studied an algorithm where the decision which expert to choose in time step t dependents on the expert chosen in time step $t-1$. The resulting Shrinking Dartboard algorithm studied in[1] only performs a small number of expert switches and achieves a low regret for Online Buffering.
A possible application of Online Buffering is in the management of the battery in a hybrid car. We have adapted the algorithm such that it can be applied in a hybrid car to study its performance in a real world application. To measure the performance of our algorithm the results are then compared to the performance of strategies which are applied in todays hybrid cars.

[1] Sascha Geulen, Berthold Vöcking and Melanie Winkler. *Regret Minimization for Online Buffering Problems Using the Weighted Majority Algorithm.* Proceedings of the 23rd Conference on Learning Theory, 2010.

5 GRK 1324: Model-Based Development of Technologies for Self-Organizing Decentralized Information Systems in Disaster Management (METRIK)

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In its second funding period the graduate school METRIK continues the cooperation of computer scientists and geo-scientists in Berlin and Potsdam by joint exploration of a particular type of wireless communication and cooperation of computer systems. By the implementation of principles of self-organisation and by using inexpensive (but wide-spread) sensors, the graduate school will reach for new horizons in the development of geo-specific monitoring, information and alerting systems to analyse the environmental processes in space and time. The network architectures to be investigated are characterised by the fact that they do not require a (costly) centralised management and adapt to changes in the environment. Both the expansion of such networks as well as a limited failure of computers and sensors do not restrict the functionality of the whole system in principle. The IT technologies that have to be developed in the context of disaster management must take into account not only their functional requirements for correctness, but also reliability and responsiveness. Since its launch in October 2006 about 44 PhD theses have been started, some of which have already been completed. 11 of them came with excellent results and others are nearing completion.
In the first phase of the graduate school a number of technologies developed within METRIK have also been applied to METRIK-related projects (funded by the EU and the BMBF) of the German GeoForschungszentrum Potsdam to implement prototypical monitoring systems. One of the most compelling applications of interdisciplinary collaboration was the model-based development of a new earthquake early warning system for the highly

seismic vulnerable region of Istanbul. In the second phase the METRIK technologies will be consolidated and expanded. Aspects of security, mobility of sensors in form of wireless communicating flying robots, dynamic adjustment of the system in terms of the current traffic flow through intelligent change of frequency bands for data transmission or type of communication and voting rules in the cooperative interaction between the service providers will be investigated. All these questions are related to the potential size of such sensor networks that determine the degree of coverage of an urban metropolis. In addition, solutions for dealing with large quantities of captured sensor data are needed. Comprehensive data collections of specific sensors for temperature, humidity, pollution, traffic congestion, energy consumption, or radioactivity can be compared to other geo-specific data for the monitoring and manipulation of the environment with respect to health, transportation, security and development of a urban metropolis not only in extreme situations. For this reason, the graduate school aims at cooperation with the DFG Research Group “Stratosphere” to investigate how this complex information data management can be implemented using "Cloud Computing".
To investigate environmental processes especially for the city of Berlin the graduate school since 2011 establishes a test network at the Campus Adlershof, Humboldt University of Berlin as a wireless mesh network with 120 indoor and outdoor node computers with various sensors. The integration with the existing sensor network at Freie Universität Berlin, which also consists of 120 sensor nodes, is another challenge that has just begun. The lecture of the last summer semester "Information and communication technologies for a smarter city in the area of transport, energy and the environment" (organized by our graduate school) was the prelude to the thematic specification of the METRIK research topics in the final phase.
To achieve its new goals, METRIK has rejuvenated and extended its supervising faculty member team. Thus, the scientific expertise in the outlined interdisciplinary research fields can be guaranteed by scientists from Humboldt-Universität zu Berlin, Freie Universität, Fraunhofer Institute FIRST, Konrad-Zuse-Zentrum Berlin, Leibniz Institute for Innovative Microelectronics (IHP Frankfurt), the Geographic Institute of Humboldt-Universität zu Berlin and the German GeoForschungs-Zentrum (GFZ Potsdam).

5.1 Robotic Self-Exploration and Acquisition of Sensorimotor Primitives

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Mobile robots are potentially useful components of technical disaster relief systems. They can also be regarded as mobile nodes in sensor networks or smart city scenarios. It is spatial mobility which poses specific problems, depending on accurate sensing and corresponding control policies. Classically, sensing and control can be solved on a per problem basis but it can also be solved on another level.
The problem then can be stated as follows. Considering a robotic system with a given set of sensor and motor capabilities and inherent dynamics, we want to efficiently explore the sensor and motor spaces and identify specific subspaces of reduced dimensionality which are sufficient for purposeful and robust task-dependent behaviour.
The approach combines vision as the prime sensory modality and the use of learning algorithms as the main instrument for establishing sensorimotor mappings. It is oriented towards biological principles of organization. Vision is passive, can be made lightweight, delivers highly redundant data and is fully local. Realizing motion control on flying robots based on vision is feasible [1] Exemplary uses of learning include evolutionary parameter optimization in a flying robot control problem [2], and evolutionary circuit design on self-reconfigurable hardware [3]. Beyond EAs, Reinforcement Learning (RL) with neural networks and directed exploration processes are subject of current work, along with issues of representation, latency in inert systems, and exploration of nonmonotonous performance surfaces.

[1] O. Berthold, M. Müller, V. V. Hafner, (2011), A quadrotor platform for bio-inspired navigation experiments, International workshop on bio-inspired robots, Nantes, France.

[2] V. V. Hafner, F. Bachmann, O. Berthold, M. Schulz, M. Müller, (2010), An Autonomous Flying Robot for Testing Bio-Inspired Navigation Strategies, Proceedings of ISR/Robotik 2010, Joint conference of the 41st International Symposium on Robotics (ISR 2010) and the 6th German Conference on Robotics (ROBOTIK 2010)

[3] O. Berthold, (2012), Self-reconfiguring System-on-Chip using Linux on a Virtex-5 FPGA, Diplomarbeit Humboldt-Universität zu Berlin, http://edoc.hu-berlin.de/docviews/abstract.php?lang=ger&id=39514

5.2 Self-Organization in Networks of Mobile Sensor Nodes

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Self-organized wireless multihop (ad hoc) networks can form an easily deployable, robust and reconfigurable communication infrastructure. These properties are of critical importance in a disaster scenario, where emergency first response teams need to be able to communicate and share information immediately after their deployment. In some situations, robotic agents have to be able to integrate themselves in these and similar wireless networks.
What all wireless network technologies have in common is that they use the air as a shared physical medium. This often leads to very space- and time-varying characteristics with a lot of noise in the parameters (like signal quality etc.) of these networks.
Intelligent robotic network nodes can overcome these problems posed by measurement noise using sensorimotor interaction. By actively shaping the sensory information by means of moving the robot in the wireless environment complexity can be reduced. This means making use of the correlations in the measured data generated by moving the robot.
We chose a flying robot — a multicopter — as a platform because it, in contrast to ground based robots, facilitates easier outdoor experiments since it is not as limited by obstacles and adds an additional movement dimension. Furthermore, we chose of-the-shelf wireless technology working in the unlicensed ISM bands. We use the Humboldt Wireless Lab, which is a large-scale wireless mesh network installed on our campus as a testbed.
As one of our test scenarios, we place the robot in the vicinity of a network node and the objective for the robot is to move to the location of this node. Additional scenarios are network exploration or bridging of partitioned networks. We investigate algorithms inspired by biological problem solutions which make use of their knowledge about the egomotion of the robot. Chemotaxis algorithms are particularly interesting for finding nodes and exploring the network. We focus on the robustness of these algorithms against noise.
After designing and evaluating these algorithms in simulation, we implement them on a real flying robot and test them in the context of our testbed. In order for the algorithms to work on a real robot, robust local localization and positioning is needed, additionally to the algorithms themselves.

5.3 Information Extraction for Disaster Management

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Year after year natural disasters like floods or earthquakes are striking our planet. After such events, decision makers require precise and timely information to assess damages and to coordinate relief operations. Understanding "the big picture" in emergency situations, a construct referred to as situational awareness (SA), is presumably a prerequisite for effective responses. More and more, SA-supporting information can be found in textual form on the Internet, both in conventional sources like newspapers[1], as well as in social networks like Twitter. These sources offer among the most detail information available, but searching them manually is a time-consuming and therefore costly task.
Information Retrieval (IR) deals with the problem of finding documents relevant for a given request within a set of documents. Web search engines are a prominent example of IR-applications today, used to search efficiently the overwhelming number of documents on the Web. While IR searches relevant documents, Information Extraction (IE) studies the problem of automatically extracting structured information from given unstructured text. Methods in IE build on a multitude of different techniques, including pattern matching, natural language processing (NLP) and machine learning.
We suggest treating the problem of finding relevant pieces of information within documents as a combined IR / IE problem. Such information snippets, forming n-ary relationships, may include temporal and spatial attributes. Clearly, this requires specific solutions because those relations typically contain incomplete tuples or ones spanning multiple sentences. Dealing with automatically extracted information also leads to the problem of inconsistent results, due to different sources, points in time or granularities. Furthermore, addressing web content carries the danger of ungrammatical texts, which might break NLP methods.
Considering crisis events like earthquakes, the question arises: How may modern IR and IE techniques contribute to situational awareness? This can be refined as: (I) What methods are best for finding event-relevant documents, especially for Web data sources which are solely accessible by HTML-based search interfaces? (II) Which IE methods are the most appropriate ones to analyze textual messages in the context of natural disasters?
Even though there are established methods for IR / IE, they need to be adapted for the target domain.

[1] Döhling, L. and Leser, U. (2011). EquatorNLP: Pattern-based Information Extraction for Disaster Response. In Proceedings of Terra Cognita 2011 Workshop, Bonn, Germany.

5.4 Optimizing Network Lifetime and Degree of Resilience in Wireless Multi-Hop Networks

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METRIK proposes the application of decentralized information systems using wireless multi-hop networks (WMHNs) for disaster management. Here, different application scenarios ranging from early warning systems to communication infrastructure for the management of rescue operations are envisioned. However, such a WMHN is required to exhibit certain properties and to meet pre-defined criteria for disaster management scenarios. In particular, such a network has to be self-organizing, meaning that there is no central control and nodes only interact by local means. Furthermore, such a network has to be *resilient*, i.e., that the provided disaster management services have to be acceptable in face of faults. The network lifetime defines the time span a network can fulfill a task, whereas we define the degree of resilience as the number of available routes up to a certain point of time. For example, an early warning system requires a high network life time and a high degree of resilience in order to spread the information about an detected event, while the instant communication for on-site rescue operations has a short network lifetime and low degree of resilience as long as at least one route is viable. Flexible adaption mechanism are required in order to cope with the different requirements on the envisioned application scenarios. This leads to the challenging question: How to maximize the network lifetime and control the degree of resilience?

In order to achieve the desired distributed control and operation of WMHNs, we integrate ideas from bio-inspired networking algorithms and control engineering. This class of algorithms is in general self-organizing, scalable and has a low utilization of resources in terms of computational power and memory. However, there is often no full understanding of the observed structures and behavioral patterns of these algorithms, and they are often only stable in certain parameter intervals. In contrast, control loops are well understood, there are plenty of methodological tools to develop appropriate solutions, and they are applicable to many technical systems. Ant algorithms [1] are a representative of bio-inspired networking algorithms and promise all the required properties for the considered scenarios. We focus on ant algorithms and are at present identifying suitable parameter settings for adaption of these algorithms. Here, we are conducting a simulation-based parameter study where the results will be verified within a wireless testbed.

[1] Mesut Guenes et. al., *ARA-the ant-colony based routing algorithm for MANETs* in Proc. of the Intl. Conf. on Parallel Processing Workshops, 2002

5.5 Peer-to-Peer Replication in a Wireless Network

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The METRIK's mission is to enable a wireless network-based support for disaster management processes. Many envisioned applications will depend on the successful temporal in-network data storage and prompt availability of this data.
In the considered applications, disaster may destroy some nodes what results in a loss of a locally stored data and a network partitioning, which lowers data availability even more. As a result, in an irregular and sparse wireless network, the crash of even a small number of nodes may lead to the huge drop in the data availability, if we assume availability as the reachability of every stored data item by every node in the system. The goal of this work is to maximize the number of data that are still available to the requesting nodes, after a partial crash of the network, while we assume only a size of a network damage, but not its location.
An established way to increase data availability is a data replication. The problem is in that at the application design time the data request and location patterns are unknown. In other words, we are dealing with a Peer-to-Peer (P2P) application. In order to serve the application requirements best, all nodes in the underlying system must be ready to take a role of data suppliers and data consumers. Also, we do not know which node or nodes will be used to extract data from the network (there is no static sink, typical in the wireless sensor networks). Further, the envisioned applications should scale with the network- and load size and be self-organized (decentralized and reactive to the changes in the network).
Known P2P replication mechanism are unfeasible. Main reason are huge communication costs connected to the underlay stretch. Another reason is the insufficient improvement in the data survivability in case of a disaster. The reason is, that P2P replication systems work regardless of the geographic location of system nodes, while a disaster tends to destroy nearby laying nodes. In order to find a replica placement that guarantee a minimal improvement in data availability for a damage of a given maximal size, I propose a decentralized replica placement protocol that is based on local knowledge only, and uses geographical positions of nodes. My approach on one hand greatly improves availability of data for the given maximal disaster radius, and on the other hand, it is efficient in replica dissemination and retrieval with regard to the communication costs. Moreover, the Network Area Protocol that determines the geographical shape of the network, designed especially for this replication approach, is a useful building block for future P2P applications for the wireless environment.

5.6 Distributed Channel Assignment in Wireless Mesh Networks

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Multi-radio mesh routers allow the communication over multiple wireless network interfaces at the same time. However, this can result in high interference of the wireless transmissions leading to a low network performance. Channel assignment for multi-radio *wireless mesh networks* (WMNs) attempts to increase the network performance by exploiting the availability of fully or partially non-overlapping channels. By assigning non-overlapping channels to the radios of each mesh router, the network capacity can be increased and data-intensive applications such as audio and video transmissions that are important in emergency scenarios are better supported.
However, existing distributed channel assignment algorithms usually do not consider external co-located networks and devices in the channel assignment procedure, since these devices are not under the control of the network operator and their activity is therefore hard to capture[1]. This applies especially to networks based on IEEE 802.11 technology, since the number of private and commercial network deployments exploded recently in urban areas. These co-located networks compete for the wireless medium and can interfere with each other, thus decreasing the achievable network performance in terms of throughput and latency.
Therefore, it is important for an efficient channel assignment, to consider the activity of such external networks. The main goal of this thesis is to close this gap by developing an external interference-aware algorithm for distributed channel assignment. The detection of external networks and devices is thereby a crucial step. For this task, a software-based *spectrum sensing* component has been developed that measures the local channel conditions at the network nodes. Based on the results, the *channel occupancy interference model* (COIM) has been developed to predict interference relationships between network nodes[2]. The results of the measurements are incorporated into the channel assignment algorithms to make them adaptive to the activity of external networks. The performance of the channel assignment algorithms will be evaluated in the DES-Testbed, a large-scale multi-radio mesh network at the Freie Universität Berlin.

[1] Juraschek et. al. *External Interference-Aware Distributed Channel Assignment in Wireless Mesh Networks*. In: Proceedings of UBICOMM, 2011.

[2] Juraschek et. al. *Measurement-Based Interference Modeling Using Channel Occupancy in Wireless Mesh Networks*. In: Proceedings of The 13th IEEE WoWMoM, 2012

5.7 Privacy aware Data Processing using Ontologies

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Systems such as Intelligent Transportation Systems (ITS) exchange information in order to provide improved functionalities such as enhanced travel services, driving support, and transportation optimization. Services implementing these functionalities impact the privacy of individuals (e.g., vehicle owners and drivers) due to required location information and related personal information. Uncontrolled information flows constitute the potential for privacy infringements (e.g., generating driving/movement profiles).
Existing privacy protection mechanisms exclusively control the event of data access and do not consider individual privacy requirements for a complete data flow within a distributed systems. In contrast, we target to control the complete data flow; i.e., we control additional events such as communicating data and processing data by local applications or remote nodes. For realizing this extended control we introduce a formally defined privacy aware query execution model which we complement by an ontology-based privacy analysis method. Most approaches of protecting privacy implement a centralized data access control or they do not provide a formalization.
Our approach describes a basic query processing model which protects privacy for executing a query. Instead of handling privacy as an add on, we directly integrate privacy aspects as basic concepts into our model; e. g., we introduce privacy constraints as a basic model element. Our goal is to use this model in order to 1.) analyze a given query regarding privacy (aspects); e. g., we check whether the query satisfies given individual privacy criteria or we calculate the expected cost and privacy risk that result from executing the query, and 2.) to extend a given query by introducing privacy operators which enforce the given privacy criteria of individuals. Therefore, we formalize a given query statement using an expression which consists of standard operators of the relational algebra enhanced by privacy aspects. For instance, these privacy aspects may describe constraints on the selection/set of attributes which a join operation may produce. With such a constraint we want to prevent that an expression creates combinations of data that might violate privacy by identifying sensitive information about individuals. Thus, our extensions of the relational algebra introduces new constraints/rules for creating privacy preserving expressions. In addition, we describe and evaluate such constraints based on semantic descriptions using ontologies. Complementary to this passive privacy preserving approach, we actively support the implementation of privacy constraints. Therefore, we adapt the algebra expression; e.g., by introducing privacy operators which anonymize or encrypt data.

5.8 Uncertainty in Land- Use Change Modeling

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Humankind is heavily and rapidly changing the Earth's surface with severe consequences for the human-environment system. One of these is an increasing risk for natural disasters, such as floods and droughts. Land-use change modeling aims at better understanding LUC and developing possible future scenarios that can be an important resource for political and economic decision-making. Modeling results always incorporate uncertainty which can influence the user's reliability of the results. Up to know little effort has been done to connect the different sources of uncertainty, their propagation and the effects on the reliability of LUC scenarios in a generic approach.
I investigate LUC in the central Amazon region, where huge deforestation occurred in the past. Deforestation is analyzed by using several drivers of LUC, comprising biophysical, socioeconomic and accessibility variables, for the time period of 1998-2011. The approach of Bayesian Belief Networks (BBNs) is identified as suitable to construct a reliable LUC model on the one hand and to investigate uncertainty in LUC modeling on the other hand. A BBN is a directed acyclical graph with nodes (variables) and edges (relationships between the variables). The relationships are of probabilistic nature and are expressed in terms of conditional probabilities which can be interpreted as uncertainty. One of the strengths of BBNs is the ability to combine qualitative and quantitative knowledge. The latter one describes the availability of spatially explicit empirical data. It is useful for learning the conditional probabilities connecting the different variables. Qualitative knowledge is often used in terms of expert knowledge to define the network structure. By means of the inclusion of qualitative knowledge, uncertainty related to input data shall be reduced. Especially in natural disaster case studies, missing current and accurate input data can be major problems. Additional qualitative knowledge addresses these problems.
Results for LUC in the Brazilian Amazon region show a solid model fit of BBNs, with strengths in minimizing errors due to the correct quantity of the two different LUC classes 'deforestation' and 'stable forest' and weaknesses due the correct spatial allocation of these classes. Results also show a significant effect of spatial subareas on the occurrence of LUC. Therefore, further effort will be done to refine spatial components of the LUC models. Future work will also concentrate on the creation of plausible scenarios and the investigation of different sources of uncertainty influencing the reliability of these scenarios.

5.9 Reliable Network-Wide Broadcasts for Wireless Mesh Networks

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Wireless Mesh Networks (WMNs) are self-organizing, independent of infrastructure, allow easy deployment and continue operating even if the network is damaged. Therefore, using them in disaster management is promising. Network-wide broadcasts (NWBs) are a fundamental operation in WMNs needed by routing protocols or warning message dissemination.
Flooding, a trivial realization of a NWB, provokes collisions due to many simultaneous transmissions, referred to as the broadcast storm problem. Plenty of NWB protocol proposals have been made to avoid this problem, most of them trying to remove redundant transmission. They can be classified as probability-based, topology-based and position based or a mixture of these. Reliability, in terms of reachability, the percentage of nodes that received a NWB, is often not regarded as high priority. Furthermore, retransmissions and acknowledgements can amplify the broadcast storm problem. However some NWB applications need a high reliability, e.g. the warning message dissemination in the WMN-based earthquake early warning system envisioned within METRIK[1]. Thus, this work explores approaches for reliable NWBs in WMNs.
One key observation is when reliability is needed that lowering the redundancy of a WMN can be harmful since redundancy is also one of its strengths, especially if this is done without considering link qualities. Here, local knowledge about links and nodes is integrated into the forwarder decision process of a NWB to boost efficiency and reliability. NWB protocols, which are based on this and which also consider retransmissions, are evaluated in simulations and testbeds like the DES testbed[2], a heterogeneous wireless testbed which consists of over 100 nodes featuring indoor and outdoor deployment. The goal is a reliable NWB protocol which adapts to the local condition a node experiences.

[1] Joachim Fischer, Jens-Peter Redlich, Jochen Zschau, Claus Milkereit, Matteo Picozzi, Kevin Fleming, Mihal Brumbulli, Björn Lichtblau, Ingmar Eveslage: *A wireless mesh sensing network for early warning*, Journal of Network and Computer Applications, March 2012

[2] Mesut Güneş, Felix Juraschek, Bastian Blywis,and Quasim Mushtaq, Jochen Schiller: *A Testbed for Next Generation Wireless Network Research*, PIK - Praxis der Informationsverarbeitung und Kommunikation, 2009

5.10 Localization in Wireless Sensor Networks

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At the end of the previous century, with the appearance of the **G**lobal **N**navigation **S**atellite **S**ystems (GNSS), a huge step in improving localization precision and availability was made. Today, the spectrum of applications which utilize GNSS is very broad. The use of GNSS in disaster management scenarios is one of those applications and it is playing a quite important role. Tracking rescuers in search and rescue missions, measuring distances between buildings for damage estimation after an earthquake has happened, are only few a applications of localization systems in disaster scenarios.
Even though GNSS have quite good performance, they are still limited in indoor and urban canyon usage. GNSS require a separate radio receiver. In systems, like for example wireless sensor networks (WSN), which already have radio interfaces, this means increased complexity and power consumption.
A solution, proposed in this research, is to use the same radio interface, for data communication and localization. This solution should also enable precise localization in indoor and urban areas. The complexity, should be kept at minimum, since the main idea is to use it in wireless sensor networks for disaster management. Since the WSN nodes are power limited, the power consumption should be also taken into account.
Localization is usually done by doing range measurements. For obtaining precise range measurements, the time of flight (ToF) of radio waves is commonly used. Traditionally, high precision of the time of flight measurement is possible, only if the incoming signal is oversampled[1]. This work addresses the problem of oversampling and proposes a solution using modified equivalent time sampling. For indoor localization, two main problems arise. The first one is the multi-path channel. Finding the shortest path can be challenging in this scenario. The second problem is the non-line of sight (NLOS) propagation between the nodes. In this scenario, the only radio waves that come from one node to another are the reflected ones. A direct method for range measurements would measure the path length of the reflected wave. A possible solution is to use different heuristics to estimate the distance between the nodes, using the reflected waves arriving at the receiver. At the end, having more wireless sensor nodes, means that more range measurements can be performed, which can improve the localization precision of the nodes in the wireless sensor network.

[1] S. Lanzisera, K. Pister, "Burst Mode Two-Way Ranging with Cramer-Rao Bound Noise Performance", Proceedings of the Global Communications Conference, 2008. GLOBECOM 2008, New Orleans, LA, USA, 30 November - 4 December 2008

5.11 Automatic Optimization for Data-Parallel Streaming Systems

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Currently, a new class of sensor-driven applications for so-called *Smart-Cities* is emerging. Those applications enable people, companies, and the authorities to monitor public infrastructures. The aim is to gain insight into the behavior or usage of a city's facilities like streets or power grids and to optimize their usage. An example of a *smart-city-application* is traffic monitoring using either GPS sensors in cars or stationary sensors built into the streets. The live monitoring of the current traffic state allows for redirecting traffic to avoid traffic jams or to balance the smoke level across the city. In the case of a disaster, this sensor infrastructure helps the authorities to coordinate task forces, estimate the damage, and speeds-up the rebuilding of infrastructure like water, gas, and electricity.
Usually, information of different sensors is combined and processed within an application. For example, the current weather situation (wind speed and direction, temperature, humidity) may influence the smog level within a city. For calculating a smog map of a city, the current traffic state and weather information is processed together. Unfortunately, sensors report values at different frequency, send values of different formats, and measurements are error-prone. At the same time, near real-time processing is mandatory for smart-city-application and disaster management. Therefore, processing a large number of sensor streams is a challenging task. Researchers developed prototypes of data-parallel streaming systems in order to process a large number of heterogeneous sensor streams. Prototype examples are Yahoos!'s S4, Twitter's Storm, and Walmart's Muppet. This new systems are able to process data streams with low latency and provide a flexible programming API that allows to handle different sensor rates and data formats. Furthermore, the systems are designed to scale with an increasing input rate.
The manual optimization and tuning of streaming systems requires expert knowledge and is a time consuming process. Therefore, we develop optimization techniques for automatic system tuning. An example parameter that needs to be configured is the *degree of parallelism* (dop) for each step in the data processing chain. If the dop is too small, the system may not meet the required latency constraints. At the same time, there is a limited number of computing resources available and the dop cannot be arbitrary large. Furthermore, data stream rates can be burst and may vary periodically. Thus, we need to adjust the dop during runtime, resulting in an *elastic* system.

6 GRK 1362: Cooperative, Adaptive and Responsive Monitoring in Mixed Mode Environments (GKmM)

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The GRK addresses a variety of fundamental, scientific and technological challenges behind networked autonomous entities which accomplish a common task through actively monitoring the environment with a variety of stationary and mobile sensors, that acquire, manage and disseminate data, and finally utilize the data to react and possibly influence the environment. The problem space is defined along several dimensions including (i) perception abilities of entities like sensor complexity and heterogeneity, ranging from sensors producing simple readings, such as temperature or position, to complex sensors producing images or video, and from environments with many homogeneous sensors to environments with multiple types of interacting sensors, (ii) motion and behavior abilities of entities like sensor mobility, ranging from stationary sensors with known location to highly mobile sensors mounted on autonomous ground or aerial vehicles, (iii) communication abilities of ad hoc wireless networks subject to different constraints on bandwidth, timeliness of data transmission, node mobility, dependability, and quality of service, and (iv) computing and middleware layers of heterogeneous networked entities. Mixed mode environments of networked autonomous entities are characterized by the heterogeneity of resources, capabilities, connectivity and requirements of the system and its components. The resulting, challenging research topics are structured along four main areas: A) Sensing and Monitoring, B) Foundations of Communication, C) Computing and Middleware, D) Cooperative Planning and Control. They require a close, interdisciplinary approach by the participating scientists of the departments of computer science, electrical engineering and information technology, and mechanical engineering. A special strength of the GRK is the evaluation of methodologies developed in areas A-D in joint experimental setups for monitoring and coordination across networked heterogeneous entities including human assistance for task fulfillment.

6.1 Fault-tolerant, cross-layer protocols for enabling automation control over multi-hop networks

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One trend in today's Internet is the autonomous communication of devices without human interactions (machine-to-machine communication). Such devices are, for example, embedded systems, sensors and actuators, spread over a large area and interacting physically with their environment. This concept of machine-to-machine communication enables new application areas such as advanced car assistance, lightweight, wireless planes as well as highly efficient manufacturing plants. In these environments *multi-hop* communication between sink and source is necessary due to the spatial extent of, e.g. a manufacturing plant. In addition with *real-time* communication meaning bounded transmission delays between the end-devices, wireless multi-hop networks enable new critical and safety-related applications.
Current radio transceivers usually operate in the unlicensed 2.4 GHz ISM-band leading to dense radio conditions in areas with a large number of communicating devices. Packet losses caused by interferences of other transmissions may lead to re-transmissions and thus to latencies and jitter. No real-time boundaries are necessary in case sensing devices communicate there readings to one or several remote controllers periodically and aperiodically, respectively. When one or more sensors read an unusual value or a value above or below a specified threshold, in critical and safety-relevant applications this value must be transmitted to the end-device within a bounded latency and without packet losses. However, other traffic might still exist on the wireless medium from other sensing devices that may lead to collisions and interferences.
This thesis concentrates on the realisation of the real-time communication in multi-hop networks with absolute guarantee of the arrival of the packets in time. To achieve this goal, all layers in the OSI-model need to be considered since the communication speed depends on the used protocols in the protocol stack. An investigation is required whether (i) existing protocols can be adapted to fulfil the hard real-time guarantees, or (ii) a protocol switch from an energy-efficient non-real-time communication to a transmission with bounded latencies is the more appropriate solution. Non-real-time traffic is monitored in advance to be able to schedule the fastest path to the destination in stationary networks while in mobile networks a mobility prediction of moving nodes is necessary.
The goal of this thesis is to provide fault-tolerant, cross-layer protocols for enabling real-time communication over multi-hop networks in environments with high communication density.

6.2 Autonomy for Planetary Rovers

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Space robotics, specially Mars rovers have demonstrated that some key technologies are not yet mature. This thesis focuses on one of them, automated planning.

Automated planning is the area of Artificial Intelligence that studies the process of generating plans, while **Temporal planning** is a branch that takes into consideration the time. Planners require two inputs: **model** and **problem** and produce one output, the **plan**. The model contains a formal description of all the systems which activities must be planned. Each system is modeled as an automaton composed of states and relations between the states. Each component has related a timeline that represents a more or less flexible sequence of states that represent the plan. A problem is represented as a graph that contains a set of facts (assumed to be true) and goals which the planner must justify. Both facts and goals are represented as sets of nodes and edges of the graph. In case all goals in the graph are satisfied, the result is called plan.

This thesis presents a temporal, hierarchical, heuristic-driven and domain-independent planner called QuijoteExpress that aims to generate robust plans for execution, that is, responsive to the uncertainty and dynamics of the environment. A second objective is to produce more understandable plans for human experts. It presents the following novelties:

HTLN - Hierarchical timeline networks Quijote uses cyclic hypergraph structures to represent the hierarchical decomposition of goals into sub-goals, allowing the human expert to define a plan in terms of complex goals while the planner is in charge of decomposing them into commands.

Parallelism By reasoning over the underlying graph structure of an HTLN problem it is possible to identify independent sub-problems taht can be planned in parallel. **Sufficient-plan** It represents a problem that has been partially solved, but still represents a valid output of the planner.

Heuristically-based The planner needs to be assisted by heuristics in order to find a solution. Heuristics are used to:

- Choose next flaw to solve: Quijote selects first the most constrained node.

- Choose solution from a pool of candidates: Quijote selects first the solution that imposes less constraints

6.3 Active Intrusion Detection in Self-Organized Wireless Multihop Networks

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The underlying principle of cooperation in Self-organizing Wireless Multihop Networks (WMNs) opens the door to malicious nodes to perform a wide range of attacks. In addition, cryptographic solutions to protect the authenticity of nodes and/or the confidentiality and integrity of messages do not mitigate all possible attacks. By means of an extensive literature study, I found that there exist severe limitations in the field of intrusion detection for WMNs in general. In summary, intrusion detection mechanisms for wireless multihop networks proposed in literature are scarce, and most of the proposed solutions have never been validated in practice. The mechanisms for intrusion detection in WMNs so far have generally two properties: they are distributed, and they use passive eavesdropping. However, existing work shows that the distributed intrusion detection systems overwhelm the limited resources of the constraint network devices. Also, passive eavesdropping of the medium severely limits the number of attacks that can be detected. A number of solutions proposed to modify the existing routing protocols to ease intrusion detection, however, this approach is infeasible in heterogeneous environments.

The fundamental research question of my thesis is to investigate in how to overcome the limitations of existing intrusion detections approaches for WMNs operating in constraint environments.

In particular, the goal is to allow for (1) efficient detection of (2) a wide class of attacks (including advanced attacks). Moreover, the proposed solution needs to be (3) practical for heterogeneous and constrained environments as well as for legacy protocols. My working hypothesis is that active, mobile intrusion detection can overcome the problems of passive and distributed intrusion detection approaches, while being more practical than contemporary approaches to intrusion detection in WMNs. My proposed detection method does not need the modification of the routing protocols. The objective of my intrusion detection technique is to detect certain classes of insider attacks.

6.4 Optimal Cooperative Control of Mobile Sensors for Dynamic Process Estimation

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The use of robotic systems for environmental monitoring has been increasingly considered in recent years. They offer high precision and efficiency and can gather information on environmental phenomena even if the setting is hostile and possibly life-threatening for humans. However, phenomena like oil spills or the propagation of airborne contaminants represent large-scale dynamic spatio-temporal processes, that can hardly be captured by a single mobile sensor platform. Therefore, cooperative monitoring by a group of sensor equipped robots is investigated in this thesis.
So far, research on the modeling and control of cooperative multi-vehicle systems has been emphasized and a decentralized model-predictive control (MPC) approach based on mixed-integer programs has been developed [1]. In order to achieve near-real time numeric efficiency, it employs linear approximations of the underlying motion dynamics and logical rules. Here, the challenge is to balance model approximations and the required accuracy for realistic vehicle control.
The MPC approach has been combined with an adaptive sampling strategy for simultaneous tracking of multiple concentration levels of an atmospheric contaminant plume by a team of unmanned aerial vehicles [2]. The determination of sampling locations is based on uncertainty and concentration estimates resulting from previous measurements. Example plumes could be efficiently reconstructed at high accuracy. However, applicability of the approach is limited to quasi stationary plumes and two dimensions.
Current research activities focus on the model-based determination of ideal spatio-temporal measurement locations for analysing and predicting an atmospheric dispersion process. The objective is to repeatedly solve a parameter estimation problem for a Gaussian puff model based on already gathered data and employ Optimum Experimental Design techniques to determine optimal vehicle trajectories, such that the corresponding measurements continuously improve the estimation. This couples optimal cooperative control and optimal parameter estimation in one problem that yet is to remain solvable in an efficient and decentralized manner.

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[2] J. Euler, A. Horn, D. Haumann, J. Adamy, and O. von Stryk, "Cooperative N-Boundary Tracking in Large Scale Environments", *Proceedings of the IEEE International Conference on Mobile Ad hoc and Sensor Systems*, 2012 (to appear).

6.5 A model-based an Optical Navigation System

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In today's technical applications based inertial sensors are often used, in order to sense 6DoF ego-motion for localization in the three-dimensional space. Due to the random walk behaviour of inertial sensors these are often combined with other types of sensors. For applications without any restrictions of the satellite connection an inertial navigation system (INS) in combination with the Global Positioning System (GPS) represents a state-of-the-art navigation solution. Especially in areas where satellite signals are shaded due to structural conditions, a GPS/INS navigation solution loses its accuracy. Therefore, other localization methods have to be investigated.
In the 1950th James Gibson pointed out that the visual perception is one of the most important sensory cues used by humans to navigate or interact with a dynamic environment[1]. Therefore, Optical Navigation Systems (ONS) are a new promising approach for indoor applications.

My research interests includes optical state estimation as well as model based navigation algorithms to develop a optical navigation system. A first report on this topic has shown promising results for accurate navigation state estimation for indoor applications[2]. Further investigations have also shown quite a big improvement in accuracy if the optical state estimation is combined with a model based state prediction[3].
Currently I am working on a visual self-localizing and mapping (V-SLAM) approach based on a treefocal monocular camera setup combined with a vehicle dynamics model for state prediction as mentioned in Sendobry et. al. [3]. In my approach, the vehicle dynamics is not only considered for the data fusion, but also for feature tracking and selection as well as for detection of dynamic objects.

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6.6 Towards a Benchmark for Wireless Sensor Network Protocols and Applications

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Wireless Sensor Network (WSN) simulators allow studying the performance of protocols and applications (hereafter called system under test, SUT) in a controlled environment. However, their principal limitation resides in the real-world phenomena simplifications and abstractions. It becomes therefore necessary for researchers to evaluate SUTs on realistic, large-scale WSNs. The goal of my dissertation is to architect a generic, real-world benchmark for WSN protocols and applications.

One important step in this direction is the identification of best practices to be followed when conducting WSN experiments. Usually, the higher the number of testbeds against which a SUT is tested, the more significant and trustable the evaluation is considered. However, it is unclear whether the selected environments on which the SUT was evaluated cover significantly different properties to claim the generality of the obtained result. Simultaneously, an evaluation of a SUT against many testbeds is time-consuming and usually requires researchers' knowledge in the operation of these testbeds. Therefore, we propose a methodology to characterize testbeds. As a core component of this methodology, we describe a catalog of quantitive metrics which allows a coherent classification of testbeds. Based on this catalog, we aim at allowing an automatic selection of testbeds, out of a set of testbeds, against which a SUT needs to be tested.

Although there exists a number of approaches around the idea of WSN benchmarks, their core functionality lies in observing the internal metrics of the sensor nodes or different parameters of the wireless communication and the network during the benchmark execution. This has the disadvantage that very often the component responsible for recording the internal metrics of the protocol or the device under test is intrusive and may alter the behaviour of the protocol under test. On contrary, our approach has the goal to allow a fair comparison between generic protocols and applications by evaluating them against the same testbed configurations, part of our catalog of quantitive metrics, collected before the execution of the benchmark experiment. Our catalog consists of not only static metrics (the number of nodes available in a site or their actual position), which change over long periods of time, but also of dynamic metrics such as network diameter and node degree. Therefore, in order to be able to compare the performance of two SUTs, a detailed study on the dynamic metrics, which change much more frequently, and are a result of complex phenomena such as internal or external interference or multi-path fading, has to be conducted.

6.7 Control of Compliant Walking Four-Legged Robots

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Multi-legged locomotion can be considered as the best way of movement in unknown inhomogeneous terrain for a number of reasons. Walking offers many advantages, including the possibility to adapt to various surfaces and speeds while maintaining a high level of agility and dexterity. Especially when looking at search and rescue operations in disaster scenarios with unstructured and rough terrain, a high level of robustness is necessary.
State of the art quadruped walking robots however lack all of these qualities when compared to real animals. One of the possible reasons for the incredible robustness we see in animals, is the mechanical use of their environment. Animals and humans have the ability to not only handle physical effects better than current robots, they actually benefit from it by considering the environment not as interference, but as part of the embodiment.
The general use of the laws of physics as an advantage especially is called *morphological computation* and is far from being sufficiently investigated. In the proposed approach, parts of the control are shifted to the embodiment to increase the systems efficiency, since "physical effects are fast and for free"[1]. The inclusion of the environment to the robots embodiment however, increases the complexity and makes control difficult for current control strategies. A bio-inspired approach to control these highly complex systems and to benefit from morphological computation is to combine a feedback control and a feed-forward control that is based on an inverse dynamics model[2] learned with a non-linear regression algorithm[3].
In the next steps of the investigation, the bio-inspired control approach will be extended for general application with a self adjusting model for increased efficiency.
For the useful exploitation of physical effects appropriate trajectories for the deployed embodiment need to be designed. This problem will be addressed in future studies by again combining concepts from biology. For an efficient application of the proposed control approach the embodiment is planned to be optimized regarding the complexity of the control signal for the selected trajectories.

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6.8 Efficient Spatiotemporal Sampling in Wireless Sensor Networks

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The fundamental function of a Wireless Sensor Network (WSN) is the distributed sampling of a physical parameter of interest in both space and time. Our spatiotemporal sampling techniques are mainly based on the Compressed Sensing (CS) theory that proved to be a very efficient method for acquiring compressible signals in distributed sensory systems [1]. CS allows to recover a discrete signal of size n from $m \ll n$ random linear measurements if the signal vector has a sparse or compressible representation in some fixed orthonormal basis. The key benefit of CS is that the Sensor Nodes (SNs) of a WSN perform very simple arithmetic calculations, while the complex computation for recovering the spatiotemporal signal is performed by a dedicated node called the sink [2]. We enhanced the performance of the CS-based data gathering in WSNs by finding the most compressible permutations of the spatial samples [3]. In an extension of our framework to the temporal domain, we proposed a novel sampling method that is able to gather information efficiently without producing temporal delay. At the same time, if an abnormal sensor reading occurs in the WSN, the location and magnitude of the unexpected value is determined in a timely manner [4]. Currently, we are working on an efficient dissemination method that is based on the probabilistic theory of CS and uses concepts of the weight matrices in Consensus. As a future work, we are going to extend our dissemination techniques to mobile ad-hoc sensor networks with dynamic topologies.

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6.9 Real-time Obstacle and Terrain Mapping for Autonomous Micro Aerial Vehicles

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Micro aerial vehicles (MAV) tend to be deployed in obstacle-rich environments like urban or industrial sites for various applications. During autonomous operation obstacle information is used for reactive avoidance maneuvers and as input for strategic path planning. Even when not maneuvering totally autonomously the operator's awareness about the height above terrain and objects in the vicinity is crucial for safety reasons. In comparison with ground robots aerial vehicles make high demands on real-time availability of obstacle information and controller reaction time due to their faster dynamics. As there are no external navigation aids and only limited bandwith available in most real-world settings, information must be gathered and processed onboard taking into account the payload and energy capacity.
Several methods for autonomous obstacle and terrain mapping have been evaluated with respect to their feasibility for UAVs using simulations and real-flight experiments. Light-weight scanning laser range finders (LIDAR) emerged to a state-of-the-art technology for robotic mapping but are limited to a single scan plane at each time step. In contrast image-based obstacle detection through reconstruction of 3D information from motion or using stereo can cover the whole field of view at once and is available at lower weight and cost. A combination of both techniques benefits from the accurate distance information on the one side and good sensor coverage on the other.
For experimental evaluations autonomous ground vehicles and quadrotor UAV have been developed from scratch to demonstrate the results[1][2]. These robots are actively used by the GRK's rescue robot team *Hector* and won several prices in robot competitions. In the team I am responsible for pose estimation and control.
During the last months major parts of the software framework have been published as open source packages for the ROS middleware[3].

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6.10 A General Concept for Human Supervision of Autonomous Robot Teams

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Supervisor: Prof. Oskar von Stryk

Deployment of human-supported autonomous teams of robots can in many situations be beneficial due to several reasons. First, robots can replace humans in the workspace, which is useful especially in dangerous or confined areas. Second, *autonomous* robots can reduce the workload of a human, because they do not require continuous human attention. Third, *teams* of robots allow distributed operation in time and space, and enable to deploy specialized robots with heterogeneous capabilities, instead of a single robot suitable for multiple purposes.

For human supervision of robot teams, high-level overview of the current state of mission and robots is mandatory. Situation awareness (commonly used for teleoperation of robots) is not appropriate for supervision, because it requires too detailed knowledge and does not include team coordination. The concept of *situation overview (SO)*[1] is defined as the combination of information related to the mission progress and of information about each robot in the team. To obtain SO, a new event-based communication concept has been developed[1]. Events that are important for SO are detected by the robots using complex event processing. Queries are used to transfer decisions to the human, to use the supervisor's implicit knowledge and experience. The robots' level of autonomy is adapted using policies, that define if the robots take decisions autonomously, or supported by the supervisor.

Based on SO, the supervisor can coordinate an autonomous robot team by defining goals and modifying plans[2]. The supervisor's commands are matched to modifications of the tasks, and adaptations of the task allocation (TA). To realize the commands independent of underlying algorithms, the TA is influenced implicitly by manipulating the task cost, without requiring to change the TA algorithm. Therefore, different approaches to TA can be exchanged transparently, which enables to apply the new supervision concept to fundamentally different problem classes.

In our group, the methods are used for coordinating urban search and rescue (USAR) robots and for humanoid soccer robots. Other applications like monitoring and surveillance, factory automation, or hazardous waste disposal are also envisioned.

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6.11 Body Sensor Networks with external Communication and Integration with Ambient Sensors

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Recent advances in wearable sensor devices have surged in novel fitness and healthcare systems that monitor the wearer's physiological parameters and physical activities by using body sensor networks (BSN). For healthcare applications, BSNs enable patients to freely move and practice their daily activities in their usual environment while being monitored in real-time. Benefits are more adequate information about a patient's parameters as well as the reduction of hospital stays. By automatically triggering an alarm when vital signs become critical, BSNs allow monitoring less stable patients, first responder teams and elderly.
Most BSN implementations for healthcare and fitness applications as well as first responder monitoring are specialized solutions developed for a specific purpose. Adapting the system for another application or another set of sensor devices becomes costly. My research focuses on the development of a generic BSN middleware that supports a variety of applications and sensors. Since wearable sensor devices have to be small and power-efficient, they are strongly limited in processing power, storage capabilities and networking support. An additional platform for collecting, storing and monitoring sensor data, decision making, and for establishing a network connection to remote devices is desired. Current smartphones fit in the role of such a platform. Therefore, we developed a smartphone-based BSN middleware, *myHealthAssistant*[1], that performs the aforementioned tasks and supports a seamless switching of sensor configurations in order to always provide the best available service. This is demonstrated by a fitness diary application[2] built on top of myHealthAssistant.
Currently we are integrating our system in an environment with ambient sensors. By enabling the system to gather information from a user's surroundings, it can be used for an even broader range of applications such as firefighter warning and elderly people monitoring.

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6.12 Security Quantification in Mixed mode systems

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Mixed mode environments (MME) are characterized by heterogeneity in terms of capabilities, connectivity and resources of their components. Providing secure and dependable communication mechanisms is of significant importance for different mission scenarios in MME. Reasoning about the trust relationships established in this heterogeneous environment should also be taken into consideration. Providing ways to quantify security and dependability can be very beneficial for the choice of communication mechanisms. This quantification can also serve as a basis for establishing trust in MME. However, characterizing trust levels in such a diverse environment is a complex task not only due to the heterogeneity of the system. Additionally, conforming with requirements on the communication mechanisms such as timeliness of data transfers poses challenges on the way. At the state of the art much effort has been devoted to the field of security and dependability quantification. Standalone dependability and security metrics have been identified, but the lack of appropriate quantification mechanisms impedes deriving benefits from their usage. Other open questions in the area are related to trust establishment and trust measuring. Deriving relevant trust metrics, taking into account trust issues in MME as well as considering at what level of the system (OS, middleware, etc.) measuring and providing trust is most advantageous are among my research interests.

7 GRK 1424: Multimodal Smart Appliance Ensembles for Mobile Applications (MuSAMA)

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MuSAMA is based on the hypothesis that ubiquitous machine intelligence, envisioned for our future everyday environments, will be provided by dynamic ensembles: Local agglomerations of smart appliances, whose composition is prone to frequent, unforeseeable, and substantial changes. Members of such ensembles need to be able to cooperate spontaneously and without human guidance in order to achieve their joint goal of assisting the user. The resultant concept of autonomous cooperative assistance poses new challenges for the research on ubiquitous and ambient information technology. Work in MuSAMA concentrates on the investigation of models and algorithms that allow dynamic ad-hoc ensembles to deliver assistance independently of external or global knowledge. Coherent ensemble behaviour emerges from local interaction of individual appliances. The application scenario are instrumented rooms supporting teams in knowledge exploration based on distributed displays. The following research areas are addressed: *RA1. Ubiquitous Context Sensing and Analysis.* Use of distributed sensors and sensor networks to recognise the current context, specifically with respect to the spatial configuration of users and devices. *RA2. Multimodal Interaction and Visualisation.* Information visualisation based on distributed display infrastructures and ubiquitous displays. Adaptive interaction with an ad-hoc ensemble based on explicit task models. *RA3. Intention Recognition and Strategy Generation.* Recognition of user activities and intentions based on knowledge about typical behaviour and explicit interactions. Techniques for the cooperative generation and execution of strategies for assisting user objectives by the ensemble. *RA4. Data Management, Resources, and Infrastructure Management.* Underlying communication and data management services for cooperative strategies. Resource-adaptive communication mechanisms for dynamic ensembles.

7.1 Smart Visual and Interaction Encoding in Smart Meeting Rooms

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Generating visual representations for Smart Meeting Rooms is a challenging task. Various views of information, derived from different sources have to be organized, published and distributed to heterogeneous devices. Previous work at MuSAMA addressed the generation of visual representations, by the development of a service based visualization framework, the adaptation of the visual representations for heterogeneous displays and the information presentation, including the distribution and layout of multiple views on multiple displays for multiple users.
One goal of my work is to develop appropriate visualizations and adapt these visualizations according to the current task and the users' needs. For that, relevant scenarios and user tasks need to be extracted. Based on these, dedicated representations are developed. Fitting interaction techniques are considered to allow user-driven adaptation of the visualization.

7.2 Enhancement of Mobility and Multi-homing in Heterogeneous Network Environments

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Supervisor: Prof. Dr. Djamshid Tavangarian

Mobility and multi-homing are key challenges in current and future networks, since the user mobility and heterogeneity of network environments have been increased rapidly. While mobility support is mandatory for seamless connectivity, multi-homing enhances networking capabilities such as (1) connection redundancy and related availability and reliability improvement; (2) bandwidth increase by simultaneous utilization of multiple network interfaces; (3) mobility support improvement by (soft) vertical handover.
Recent investigations have shown that mobility and multi-homing are closely related and mainly issues of the used IP addressing scheme. Typically, IP addresses are used for two main purposes: (1) node identification and (2) node location determination within the network topology. Since both semantics are jointly embedded into a single IP address, the contradicting requirements of stable indentification and varying location causes serious problems. Additionally, IPs are assigned to network interfaces (NIs) instead of nodes. In that respect, a node with multiple NIs has multiple IP addresses and therefore multiple identities and locations at the same time.
Accordingly, a decoupling of node identification and location is promising to support mobility and multi-homing. Approaches such as Shim6, ILNP and others proposed a separation of IP addresses into two parts: node identity (NID) and location ID (LID). While changing LID is used for routing at network layer, stable NID is used for node identification in upper layers.
However, these approaches offer, among others, insufficient capabilities to select one or multiple NIs for communication process, e.g. to enable load balancing, and provide only partial mobility support. Therefore, we propose a novel concept called *Node-oriented Internet Protocol (NIP)*. Our concept adapts the separation approach and uses a three-tuple addressing scheme composed of NID for global unique node identification, LID that identifies the node location(s) and an additional interface ID (IID) to identify each NI in relation to NID and LID. By introducing IID, we enable network nodes to select a set of NIs to be used for a certain communication process. Building on that addressing scheme, the rest of our concept is based on several pillars, among others, a mapping system, schemes for packet forwarding, enhanced mechanisms for mobility and multi-homing support and strategies to ensure backwards compatibility to IP architecture.
Currently, we specify detailed mechanisms for each pillar of the concept. In our future work, NIP concept will be optimized, analyzed and evaluated. Moreover, we intend to submit our work as an IETF RFC.

7.3 Intelligent Integration and Dissemination of Services in Smart Environments

Philipp Lehsten (philipp.lehsten@uni-rostock.de)
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Mobile internet-enabled devices are part of the every day life in modern universities. They are used by students and staff in a multitude of tasks. These tasks are supported by different stand alone software components like learning management systems, social networks and others. Providing these components as services in a unified context-aware manner is one idea of MuSAMA. The discovery of these heterogeneous components is challenging, because they use different technologies and need to be identified as well as described. An abstract service description language, such as STiL[1] is suitable in environments, where every service is network-based and at least via network technology gateways reachable. But services which are offered as websites are hard to identify and difficult to describe.
The target of this thesis is a concept and prototype for the integration of services in smart environments and the dissemination of these functionalities within large-scale or even urban pervasive environments. Therefore, the first task was to design an infrastructure which can handle generic service descriptions, context facts as well as rules which connect these services to situations described by the context. This was done by the development of the Context-Aware Service Access (CASA) node. These distributed nodes collect the domain specific knowledge and provide service interfaces for consumers. As most services are unable to describe themselves in a semantically consistent manner, a next step is the usage of crowd sourcing as methodology to gather this knowledge from the users themselves as they know best which services they use in specific situations. Here the question of how to describe sufficiently the situation as well as the service arises and is handled with knowledge from different personal, community and public context sources. The user-driven creation of adapters for the sources as well relevance rules is essential for the CASA concept and backed up by its decentralized structure and modular architecture.
The final target of the thesis is the evaluation of existing integration and fusion concepts for heterogeneous services and the comparison to the CASA approach in cross-institutional environments. The focused solutions for communication between services, devices, and applications will therefore be evaluated in the graduate school's reference scenario of a "Pervasive University".

[1] Service Technology-independent Language developed by Raphael Zender. *Service-basierte Infrastruktur für pervasive Lehr- und Lernarrangements.* Dissertation, 2011.

7.4 Coginitive models for intention recognation

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This work is about using cognitive models for intention recognition. The motivation for my work is to build systems, which are human-centric in the sense of taking into account a user's internal state such as intentions, current goals, or the focus of attention. The latter is widely acknowledged as an important factor to be considered in the design of user interfaces, but so far the design principles are largely heuristic. Based on signals collected from various sensors the smart environments can react in a proactive manner in order to assist the user. However, the signals delivered by sensors in smart environments are usually not informative enough to simply read of the internal states of users. Prior knowledge about how humans reason, decide, and act needs to be employed in order to disambiguate the signals and infer intentions with limited amount of data. In my work, this prior knowledge is embodied in the normative models.
I have identified eye movements and the spatial location of visual attention as informative for intention recognition. The existing models for eye movement do not take contextual factors into account. This could be addressed using a systematic machine-learning approach, where user profiles for eye movements are learned from data, but I suggested the modeling of eye movements using first principles from decision making and planing as an alternative. Therefore, the goal of my work is to develop normative models for predicting gaze locations and to compare the predictions with recorded eye movements in smart meeting rooms and predictions from data-driven approaches.
We used a data-driven approach to complement the normative modeling, because this way we can find out which features are predictive under which circumstances, even though we may not have a satisfying model for that, only a working black-box predictor. We also integrate contextual information from other sensors and intention recognition in order to improve prediction of gaze location. We are currently formulating eye movements as a reinforcement learning problem, but we use inverse reinforcement learning to infer the reward function and we compare the prediction with the data-driven approach.

7.5 Efficient Probabilistic Semantics for Symbolic Behavioural Models

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Supervisor: Prof. Dr. Thomas Kirste

Supporting users inside smart environments requires software knowing (i. e. inferring) the users' intentions and planning useful actions. A first step towards this goal is *action recognition*: based on sensory data ascertain what the user has done and is currently doing. To actually support a user, software needs to infer future plans and goals of the user. This task is called *intention recognition*.
Both tasks may be solved in a discriminative or generative way. The discriminative approach learns the user's activities by a comparatively large amount of training data. Generative models of human behaviour use a priori domain knowledge, thus reducing the need for training data. By executing the generative model, it is possible to *predict* future user actions and handle missing sensor data. My research focuses on the generative approach, using a symbolic model of human behaviour.
Efficient reasoning needs well-suited models for describing human behaviour and their interactions with smart environments. A challenge is to efficiently handle complex state spaces induced by real-world applications. Based on an existing modelling and inference tool, investigating how to integrate techniques for reducing the state space complexity and increase the accuracy of inference algorithms will be part of my research.
I study how different levels of abstraction may influence modelling and reasoning. Sub-models using a formalism better suited for the specific subproblem can be used for more efficient and correct inference. For instance, tracking user-positions with a noisy position sensor is usually estimated using Kalman filtering. Although not being general enough for modelling complex human behaviour, it is ideal for location tracking.
My work includes how to integrate such sub-models into a more general modelling language. Speech recognition, as one example, is a discipline where multi-level models are already used successfully. Sub-models not only increase accuracy, but also reduce the state space of the more complex top-level models. I will investigate the applicability of other state space reduction techniques as well, both at the modelling and inference level.

7.6 User-driven visual interfaces for smart meeting rooms

Axel Radloff (axel.radloff@uni-rostock.de)
Supervisor: Prof. Dr. Heidrun Schumann

Smart meeting rooms are used to support users working together to reach a common goal. These environments are physical spaces collecting and processing information about the users and their environment to adapt the environment and its behavior in order to reach an intended state. In such environments users often use their own personal devices and software. However, appropriately presenting information and sharing with other users requires specific effort.
My PhD thesis addresses this problem particularly focusing on presenting visual views. I developed a smart view management that shows views of different applications. For this purpose, the views are adequately combined, automatically mapped onto display surfaces and presented with an automatically optimized layout. Furthermore, I developed an interaction approach (smart interaction management) to interact seamlessly with the displayed information, regardless of the used interaction device and regardless of the view generating application. Moreover, the content of the views is adapted with regard to the users' perceptional capabilities.

7.7 Using BCI techniques for intention recognition in smart environment

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Ubiquitous computing promises the invisible computer, which recognizes activities of users and provides proactive assistance. Estimating the intentions of users, i. e. going beyond the recognition of ongoing activities, is a promising approach to realize such proactive assistive systems. Intentions cannot be measured directly, but have to be estimated from observed behavior. However, in many scenarios the observable physical behaviour is rather limited and restricted to direct human-computer interactions. The key idea of my dissertation work is to use brain signals to improve the estimation of intentions in such scenarios. Research on brain computer interfaces (BCIs) has yielded many analysis techniques and paradigms to estimate the cognitive state of a user via analyzing electrical brain activity measured non-invasively with electroencephalography (EEG).
In my work, I plan to use BCI techniques for intention recognition in situations. However, recording brain signals with EEG has some principled limitations, because the electrical activity is measured outside the head. I will address this problem by i) using contextual information obtained from other sensors about the ongoing activities in the smart environment and ii) analyzing EEG data using cognitive models of decision making under uncertainty and time-constraints. As a consequence, I also need to understand the brain networks for planning and action selection. I focus on the human mirror neuron system and the neural systems for attention and alertness/arousal, because it was shown that they can be measured using EEG.
Currently, I am performing behavioural studies, where I test how humans make decisions when the structure of the environment (the relation between causes and effects) is changing abruptly at so-called change points. I compare human performance with the performance of algorithms for optimal Bayesian decision making. The next step is to determine the EEG signatures of human decision making in these scenarios to use them later as biomarkers for new EEG-based systems to estimate intentions.

7.8 On-Line Simulation

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The increasing ubiquity of computing and communications coupled with advances in sensors and sensor networks have increased interest in the deployment of simulation interacting with operational systems. In such systems simulations are driven by real-time data, and simulation results may be used for purposes such as decision support to optimize system behaviors. This approach has been applied to many applications such as manufacturing, computer networks, emergency response, and transportation.
This type of simulation where physical systems interact with simulation are announced under different terms, e.g., as embedded simulation, in-the-loop simulation, on-line simulation, symbiotic simulation, DDDAS (dynamic, data driven application systems), and cyber-physical systems, to mention a few.
Two basically different questions are supported via this type of simulation. (1) What can be derived about the future behavior of the system given certain data being sensed from the system? (2) How can the observed data be explained (be reproduced), i.e., what does it tells us about the system, about its current parameters, or components?
The first question is a typical "what-if" question and would allow to foresee problems or specific requirements in smart environments. This way, it enables smart environments to be proactive.
The second question is a typical optimization problem (also known as simulation coercion). Here, given the data, the task is to search for a model that allows to generate these data. This approach could be used complementarily to the current approach on inferring user intentions, for instance. It could also be used to identify critical situations that already occurred, thus simulation would allow to provide additional—not observable—information about the state and context of a smart environment.
The planned work will contribute to these areas by methodological research and by applying the developed methods to smart environments. Questions of interest are which specific tasks can be supported by on-line simulation, how on-line simulation can be implemented generically and efficiently, and how well this approach performs in comparison to other approaches.

7.9 Situation-Aware Publish/Subscribe Communication for Ubiquitous Computing

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Smart Environments consist of embedded and mobile computing devices as well as sensors and actuators that interact to cooperatively provide a particular service to the user. Due to cooperation among each other, these ensembles of devices can recognize conditions and intentions more precisely than devices working isolated. Moreover, smart environments are inherently dynamic with components spontaneously joining and leaving the network of devices. For such dynamic environments, a flexible communication is needed. An event-based style of interaction relying on the publish/subscribe paradigm is well suited as it allows devices to communicate any relevant change in state or environment conditions as an event on which other devices can react without obligation.
In this context, *situation awareness* is needed for two reasons. On the one side, applications have to detect environmental situations in order to better tailor offered services to the user. Although single events may trigger a particular action, often, a more complex spatio-temporal pattern of events is required to detect environment conditions as well as user intentions more precisely. By integrating a distributed detection mechanism for composite events directly into the middleware, we are able to detect event patterns and sub-patterns therof very close to their origins. This way, a significant amount of network bandwidth is saved.
On the other side, application and middleware components as well as the publish/subscribe communication itself need to be adapted to the dynamic network environment. In case of the event detection mechanism, for example, event detectors may have to be replicated and migrated or even split and recombined. Similar actions may also be beneficial or even necessary for general application components. To ease their automatic deployment and adaptation, we work on a dataflow-based approach that supplements the business logic of application components with annotations and deployment descriptors.

7.10 Component-based Modeling and Simulation for Smart Environments

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Modeling and simulation (M&S) is an established methodology to study complex systems and their behavior in a controlled and reproducible manner. Thus, it seems to be promising to apply M&S also in the domain of smart environments. For instance, synthetic context information, e.g., sensor data, can be generated by means of simulation instead of gathering it from sensors in a real physical deployment. Testing the behavior and timeliness of context-aware application, such as a system providing assistance by controlling the devices deployed in the environment, in interaction with a simulated environment (in-the-loop simulation) is another example for using M&S in the domain of smart environments.
In the thesis a methodology for modeling and simulating complex adaptive systems, such as smart environments, is proposed, which reflects the characteristics and specifics of those systems and combines a component-based model design and variable structures (composition over time). Furthermore, the proposed methodology allows modeling different levels of behavior and expressing interdependencies within and between those levels explicitly, ranging from direct interaction over indirect interaction to emergence. The model composition and analysis framework COMO (Component-based Modeling) serves as one starting point facilitating the specification of component interfaces and their compositions on the one hand and the analysis of the (syntactic) correctness of compositions on the other hand. The model components are implemented in the modeling formalism ML-DEVS (Multi-Level Discrete Event System Specification) for parallel discrete event simulation. The formalism supports variable structures, multi-level modeling, and an intensional, yet expressive communication mechanism on top of a modular, hierarchical model design. A repository of predefined and customizable model components should foster their reusability in different simulation studies and by different modelers.
The developed concepts and model components are evaluated based on a concrete use case, i.e., the simulation-based testing and evaluation of the robustness of an approach for probabilistic activity recognition in smart environments.

7.11 Secure Web Services for ambient embedded Systems

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The vision of the Internet of Things – which is the fundamental basis for ambient embedded systems – becomes more and more concrete. This development is especially leveraged by a plenty of new emerging protocols. While IPv6 provides a widely accepted way to interconnect countless devices on network level, emerging technologies such as the Devices Profile for Web Services (DPWS) enable features such as dynamic discovery on device- and service level. At the same time, protocols such as Efficient XML Interchange (EXI) and the Constrained Applications Protocol (CoAP) decrease the high protocol overhead inherently included in SOAP and HTTP. However, with these new opportunities, new problems arise regarding security concerns.
On the one hand, providing secure ways of communication between embedded devices is absolutely vital for the feasability and the acceptance of ambient intelligence. On the other hand, it must be ensured that providing an adequate level of security does not decrease usability of these new technologies in a way that leads to a lower acceptance.
For example, when integrating a new device (such as a sun-blind, a smoke detector or a fridge) into the existing network of devices, it must be assured, that these devices cannot be accessed and abused by unauthorized third persons. This issue becomes especially critical when all devices are connected to the internet. At the same time, setting up a secure integration must work as seamless and as easy as possible in terms of usability. Another aspect is the communciational and computational overhead produced by applying security mechanisms. Studies show, that traditional security models such as Public-Key-Infrastructures as well as traditional security algorithms are not suitable for highly resource-constrained devices often found in ambient embedded systems. Therefore, different, lightweight security mechanisms must be evaluated.
It is the goal of this thesis to solve these and other problems to enable secure yet easy to use ambient, embedded intelligent systems.

7.12 Methods and algorithms of multi-dimensional user-localization

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Passive or device-free localization (DFL) of mobile users in intelligent environments with radio frequency is the topic of this dissertation. The method is designated as a device-free method, because the localized or tracked person has not to wear any active or passive hardware. Only the user influence on the environment and the variation of parameters in the environment caused by the user movement provides enough information for deriving the current user position. The localized object or person affects the characteristics of the RF-signals between senders and receivers. A very high accuracy can be reached by increasing the number of multiple sender/receiver-pairs. The idea is to replace additional sender/receiver-pairs with their high installation and energy costs by a wide spread of cheap and passive RFID-tags (Radio Frequency IDentification) and by that increase the precision of the localization approach. These RFID-tags can be placed inconspicuous and without any energy supply for example under the floor covering or under furniture. The tags receive the RF-signal from the sender, are activated and modulate their answer on the received signal (backscatter). They can be interpreted as reflectors, which can be used to increase localization accuracy and efficiency at relevant places in the room. The user moving in the space of the RF-field between RFID-reader and tags affects the RF-communication. From the attenuations and amplifications of the RF-field the position of the 'scatterer' can be calculated. Up to present statistical estimation methods and geometric methods from sensor network research were evaluated for the user localization. This needs to be extended by new approaches.
Central goals of this dissertation are: (1) Evaluation of quality, robustness and applicability of methods for mobile user localization and tracking and (2) the development of new methods for precise determination of user position and orientation. In special device-free approaches should be investigated. (3) The quality of the derived activity information from the elementary phases should be increased by the use of evolutionary algorithms.
Recent research has shown the theoretical and practical feasibility of the basic innovative principle. The topic of this dissertation is to find possibilities for improvement and further development. The developed architecture consisting of a little number of active tags and a high number of passive RFID-tags has to be investigated and improved regarding three-dimensionality and the interference of range, precision and robustness in particular. Therefore the theoretical model needs to be adapted, extensive simulations and an experimental validation has to be performed.

7.13 Estimation of expectable network quality in wireless mesh networks

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The smart environments within the graduate school's scope usually consist of numerous different sensing and acting devices, many of them mobile or portable. These devices need to communicate among each other in order to assist the user. To fulfill this task, a robust and flexible communication layer is needed that does not depend on a central infrastructure, supports device mobility within the network, integrates new devices seamlessly, and allows the discovery of devices and services.
Wireless mesh networks based on IEEE 802.11 Wireless LAN (WiFi) fulfill almost all of the requirements and are therefore well-suited for this task. The technology is commonly available and can provide a throughput which is comparable to Fast Ethernet when using 802.11n. However, the achievable network quality in terms of packet loss, throughput, and latency strongly depends on the quality of the wireless link and varies over time. The main reasons for the variations in link quality are fading due to attenuation and multi-path propagation, interference caused by non-WiFi devices, and transmissions of other WiFi devices within range.
In real-world scenarios, it is not possible to control every influencing factor. Thus, even when prioritization or reservation protocols are used, minimum service qualities cannot be guaranteed. Within the thesis, the communication in wireless mesh networks is therefore considered to be opportunistic. Instead of relying on reservations, the goal therefore is to estimate the short-term network quality from both current link-level measurements and recorded, historic data. By combining data from different nodes within the mesh network, the accuracy of the prediction is further increased.
The estimated network quality is used as an input to the strategy synthesis component of the smart environment. With the help of knowledge about the expectable network conditions, the validation of generated plans can be improved. When for example a deterioration of network performance is expected for the near future, an audio-only transmission could be preferred over a video-chat from the start. Likewise, devices with a low probability for receiving control commands can be skipped in strategy synthesis.
The focus of the thesis is on empirical modeling of spectrum usage, network conditions, and network quality. The entire work aims at a system which is implementable on consumer-grade hardware to allow straightforward prototypic implementations. The developed models are validated in a real-world testbed.

7.14 Engineering Human Behaviour Models for Activity Recognition

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Activity recognition plays an important role in assistive systems where to assist the user, the system has to know her needs and intentions. Basically, there are two research directions for recognising user activities: data-driven and model-driven. While the data-driven are extremely successful for fixed scenarios and settings (especially provided a large enough dataset), they are not robust to changes in the settings or the user behaviour. Additionally, such approaches are costly in terms of training data collection and annotation. To avoid this drawback, I investigate another approach - namely a model-driven one, and more specifically – ways for substituting training data with prior knowledge encoded in human behaviour models.

My topic concerns the investigation of rule-based representations of human actions that can be abstracted from the specific environment and later reused in various settings by parameterising the abstract action templates with concrete values. Furthermore, this representation allows the generation of multiple hypotheses leading from the initial to the goal state without the need of system engineer to model them manually. The models are then used to generate problem-specific probabilistic models such as particle filter or Hidden Markov Models, that given a set of observations, are able to recognise user's current activity and intentions.

Furthermore, my work investigates different problems a designer faces while modelling human behaviour and proposes a novel development process for human behaviour models for activity recognition. The process aims at providing a structured way for creating causal models for activity recognition that could reduce the time needed for building a model, the effort put into backtracking problems and finding alternative solutions, as well as a better documentation accompanying the model.

Additional output of my work is a modelling toolkit that contains templates for modelling solutions concerning different problems or subproblems from the field of activities of daily living. Its goal is to provide a ready made solutions instead of leaving the model designer to build them from scratch.

In conclusion, the model-driven activity recognition approach provides more flexibility and reduces the need of training data while the introduced process gives a valuable help to modelling human behaviour as it allows the early discovery of design and implementation problems, provides better problem documentation and more detailed model evaluation.

7.15 Integration of Patterns into Model-based Specifications of Smart Environments

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The challenges encountered while developing interactive systems have been researched for decades. However, an additional set of requirements that have to be satisfied by an assistive application to be deployed in a given smart environment is imposed. Smart environments are a specific type of ambient intelligent environments in which the main tenet is to provide optimal assistance to resident users while performing their daily life tasks. The main requirements of a supportive system offering the desired assistance are multifold. Briefly, the system needs to be unambiguous (in terms of the way the services are provided to the user), needs to provide personalized assistance and also to be extensible for new kinds of users and devices after the deployment in the room.
A thorough analysis of those requirements makes it clear that a convenient starting point for the development of such an application is a human behavior model providing a holistic understanding of the tasks the system needs to support. Nevertheless, modeling human behavior in smart environments is not a trivial process. For example, in a smart meeting room a usual scenario is the gathering of several actors trying to achieve a common goal while employing a set of stationary as well as dynamic devices. Thus, the tasks cannot be isolated from the environmental context in which they take place. The mutual dependencies between the various entities increase remarkably the complexity of the modeling process of the user tasks taking place in smart environments and hence this process is becoming a burden for the developer and a time consuming activity.
In this thesis, we suggest the extraction of repetitive patterns in human activity which can serve as both, reusable blocks for modeling human behavior as well as a basis for the development of personalized user interfaces through which an access to the services provided by the room is possible. Since we focus on the domain of smart meeting rooms in the context of our work, we compile a collection of activity patterns in this domain. Each pattern is composed of two components, first the descriptive information explaining the context in which the suggested solution encapsulated by those patterns can be used and integrated within the model, and second a machine-readable form of the solution.
Moreover, in the thesis we propose a model-based development flow for the generation of the desired assistive user interfaces based on the collected activity patterns. Our methodology adopts a hybrid interaction technique resulting in an equilibration between explicit and implicit interaction paradigms.

8 GRK 1480: Programm- und Modell-Analyse (PUMA)

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The research training group PUMA brings together the four fundamental approaches of program and model analysis, namely, type systems, theorem proving, model-checking, and abstract interpretation. The Munich universities hosting the program have expert researchers in all of these areas. Our goal is to stimulate cross-fertilization between these approaches resulting in a better understanding of their common basis and their distinctive properties, and leading to better algorithms and tools. Our vision is the Verifying Compiler, i.e., the development of methods and tools that examine not only whether a program or model is syntactically correct, but also whether it behaves according to its specification.
The second funding period has now started where we additionally want to focus on decision procedures which often are at the heart of combining different approaches and also consider verification questions related to assembly lines and autonomous systems.

8.1 Deciding MSO over ω-Words with Finite Automata

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In my thesis I aim for an implementation of a decider for monadic second order logic (MSO) over infinite words. While a possible implementation of this can be done by various ω-regular automata models[1] it has the downside that minimization of most ω-regular automata is NP- or PSPACE-complete. Thus intermediate minimization of the automata in the deciding procedure is barely usable. Thus the implementation would require the runtime of the exponential tower, even if the intermediate automata describe only very easy languages.
Choosing a more appropriate model for representing these languages with easy minimization can therefore dramaticaly enhance the runtime.
Representing the ω-regular languages L by the regular languages $L' = \{u\$v | uv^\omega \in L\}$ and storing these regular languages as DFA seem to be applicable. While this method was already known by Büchi, algorithms for transformation between standard ω-regular automata models and this model were developed in 1994[2]. They did not give algorithms to work directly in this model nor to check whether a given regular automaton even describes a ω-regular language.
Further progress on this automata model could not be found in literature, thus I started to develop algorithms for the necessary transformations to work with this model directly to implement MSO, namely intersection, union, complementation and projection.
Thus this approach indeed allows for deciding MSO over ω-words with the help of finite automata.

[1] On a decision method in restricted second-order arithmetic. J. R. Büchi
[2] Ultimately periodic words of rational omega-languages. Calbrix, Nivat and Podelski

8.2 Decidability of linear tree constraints

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Linear constraints have been introduced by Hofmann and Rodriguez in the context of programme resource analysis. They were able to show that the type inferece problem can be reduced to the satisfiability of these constraints and they gave a decision procedure for an important subcase. But the question of decidability of linear tree constraints in general remained open.
This PhD project is devoted to this latter question. We will try to develop a general decision procedure or try to rigorously prove undecidability. In the latter case or if the question cannot be completely resolved we will refine existing and give new heuristics. Partial results shall be integrated into the existing implementation. Concretely, we will begin by giving an overview of the properties of linear tree constraints and a classification of the solutions they admit. Then, we will consider functions on infinite trees or lists, define operations such as addition, scalar multiplication and composition and analyze their closure properties. Furthermore, we will explore the relationship to convex optimization.

8.3 Constraint-based Transaction Inference for Efficient Verification of Multi-threaded Programs

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Supervisor: Prof. Andrey Rybalchenko

To make efficient use of multi-core systems, which are becoming ubiquitous due to advancements in the hardware industry, more concurrent software systems are being developed and used. The defining property of a concurrent systems is that there are several threads of execution each of which processes its own allocated task simultaneously and in interaction with other threads. However, writing bug-free multithreaded programs is often very difficult, and ensuring certain properties for such programs is extremely challenging due to the need to reason about concurrent execution of statements from various threads. Assuming each thread executes a sequence of statements, ensuring a property may need consideration of each possible interleaving among statements from the interacting threads.
The objective of the work is to automatically filter out a sequence of statements, called transaction, that can only be executed together as a unit by one thread without any interference from another thread. Considering a single transition instead of a sequence of statements reduces the set of possible interleaving among the interacting threads, and enables efficient property checking for the entire program. In this work, constraint solving methods are used to enable efficient property checking for shared variable multi-threaded programs by modeling transaction inference as a constraint satisfaction problem. The reduction is based on Lipton's theory of reduction, and hence, we first define formally the types of movers and mover analysis that enable the reduction. Then, a system of constraint will be given for reducing the original program which is a sequence of statements into the corresponding transactional program. Our system of constraints will be extended later to handle programs with parallel compositions, loops, and procedures.
There are three main challenges in our approach. One challenge has been solving implication constraints with existentially quantified head. The challenge has been successfully solved as shown in[1]. The other challenges are finding a viable heuristics to choose the right location for computing relevant program invariant, and setting a boundary between transactions. During the remainder of the work, we intend to deal with these challenges, and other minor challenges coming on the way. We also plan to implement a prototype of our approach using state of the art constraint solver, and evaluate its performance.

[1] Tewodros Beyene, Corneliu Popeea and Andrey Rybalchenko, Solving Existentially Quantified Horn Clauses(Accepted CAV2013)

8.4 Interprocedural Herbrand Equalities

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In programs without procedure calls, all Herbrand equalities can be computed[1]. In the case of side-effect-free functions all Herbrand equalities can be computed for interprocedural programs which was shown by Seidl et al.[2]. One step towards describing the general effect of a procedure call has been done by Petter[3] where the number of occurring variables is limited to two.
The aim for my thesis is to come up with an interprocedural analysis which infers arbitrary Herbrand equalities. In order to achieve this, we introduce second-order variables in our Herbrand equalities. However, second-order unification is in general undecidable, i.e. we cannot decide in general whether there exists a solution to a conjunction of Herbrand equalities or not. This also means we cannot decide in general if the solution space of a conjunction of Herbrand equalities is the same as the solution space of the same Herbrand equalities plus one additional equality. Though, while solving a constraint system, it is crucial to decide if an equality is subsumed by other equalities if we want to find a fixed point.
To circumvent the undecidability problem we study the domain of Herbrand equalities with second-order variables by examining several restricted cases as e.g. by limiting the number of second-order variables and by allowing that not each parameter of a second-order variable must occur in the resulting term of it. The vision of this is, that we can show compactness of Herbrand equalities and come up with a subsumption test such that we can guarantee termination of a fixed point calculation of a solution of a constraint system. It is still an open question which trade-off we have to do between assuring termination of a fixed point calculation and (best) possible approximation. One basic idea is to limitate the length of terms by switching to top if the length is longer than some predefined value. While this might help to assure termination of a fixed point calculation we would also loose precision. Another idea is to limit the number of disjunctions in order to describe special cases.
All in all, the great vision is to come up with a calculus which infers arbitrary Herbrand equalities of interprocedural programs while we can assure termination without loosing to much precision.

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8.5 Efficient computation of winning strategies in games with ω-regular winning conditions

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Automatic synthesis (generate code satisfying a given specification) is being intensely investigated in recent years. Synthesis problems reduce to computing the winning strategy of a player in an infinite game, and so they can be approached by means of game-theoretic techniques. While algorithms for computing winning regions have been intensively studied in the last decade, much less is known about computing winning strategies. The aim of the thesis is to identify game classes for which winning strategies can be efficiently determined and compactly represented.

8.6 Formalization of Rigorous Numerical Methods and Applications

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Rigorous numerical methods compute guaranteed bounds on solutions of mathematical problems. The proof that the computed bounds actually enclose the solution usually stays on an abstract mathematical level.
The goal of this work is to make the connection between problem, algorithm and proof more tight by formalizing rigorous numerical methods in one (mechanized) logical framework, namely Isabelle/HOL. It is therefore necessary to develop a library that allows to maintain guaranteed approximations of functions.
A basic data structure for guaranteed approximations is interval arithmetic. Interval arithmetic suffers from intrinsic problems like undesired growth of dependent intervals or from the so-called wrapping effect when working in multiple dimensions. A hybrid approach, developed to overcome these limitations is given by symbolic polynomials with an interval remainder term. For the special case where the polynomials are Taylor series expansions up to a certain order, one speaks of Taylor models.
We aim to formalize polynomial approximations and in particular Taylor models in Isabelle/HOL, where we can build on the existing library for multivariate analysis. We want to obtain an executable formalization and generate code for Taylor models with different representations of the coefficients: dyadic rational numbers as well as IEEE floating point numbers.
An example could be the computation of guaranteed enclosures of the flow of ordinary differential equations. As a further application, these enclosures could be used to approximate sets of reachable states of hybrid automata with nonlinear dynamics: checking safety properties of hybrid systems reduces to reachability analysis.

8.7 Verification of Higher Order Functional Programs

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Recent works on verification of functional programs offer methods that overcome the challenge of analyzing higher order procedures. The current methods approach the verification problem in two steps. First, a syntactical analysis generates a set of verification conditions. Satisfaction of the conditions entails safety (i.e. no program assertion is violated) of the input program. Second, a constraint solving method is applied to the verification conditions. The syntactical analysis is usually based on a refinement type system. The refinement type system gives verification conditions in the form of subtyping constraints. The number of subtyping constraints is fixed for a given input program and does not interfere with the precision of the method. Instead, the precision of the method depends on the constraint solving method.
A current problem is verification of program code in the order of hundreds or more lines of code. For imperative programs there are tools that handle program code (Blast, Slam). One approach to scaling verification of higher order programs is to optimize the generation of verification conditions.
In this project we investigate the generation of verification conditions that are amenable to optimization at constraint solving time. We propose a summarization approach to higher order functional programs. Our conjecture is that a summarization approach will provide succint verification conditions that can be efficiently solved. The conditions take the form of Horn-like clauses and can be solved using existing methods, e.g. HSF.
Our summarization method differs from summarization for first order programs in the following two key aspects. First, for first order programs, procedures are summarized as relations over reachable program states. In our summarization method, procedures are summarized as relations over base parameters and the return value. Second, for first order programs, parameter passing happens only on base values. In our summarization method, parameter passing may occur for base values and functional values. We handle passing of function parameters by populating the summaries of the formals with the summaries of the actuals.
We have implemented an initial version of our method in the tool OSummarizer. OSummarizer consists of a frontend written in OCaml using the preprocessor Camlp4 and a backend written in Sicstus Prolog. OSummarizer together with HSF yields a tool chain for verifying higher order programs writen in OCaml. We are currently experimenting with the set of benchmarks from MoCHI.

8.8 Static Analysis of Binaries

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The security and integrity of commercial software is asserted through manual inspection of the machine code–the program's binaries. Finding errors that compromise the security of a system by analyzing the binaries is comparable to searching the needle in the haystack. However, there are plenty of needles in software nowadays, hence finding *one* needle is just a matter of time and resources that can be afforded by an attacker. On the other hand finding and eliminating all such vulnerabilities to secure a system requires program analysis employing automated complex tools to be able to perform the task exhaustively. This project eases the task by providing tools for a security engineer to automatically classify binary code as free of memory related bugs and to expose found bugs by providing a program input that triggers them.
The work so far consists of implementing a Static Analysis Framework for binary code[1]. The framework solves the problems of disassembling binaries and reconstructing the control flow[2] of the program even in the case of obfuscation as introduced by reverse engineering protections. We apply known techniques of abstract interpretation (fixpoint computation and abstract domains[3]) to the execution model of machine code and improve on state of the art code analyses to solve the challenges given by analyzing low level code.
To not be bound to a specific hardware platform but be able to analyze the most common processor architectures we designed a platform independent machine language that is used in our analyses. Translating from a processor architecture to our intermediate language is simple and we can reuse the remaining static analysis stack to perform the more complex analysis as e.g. reasoning about the memory correctness of a program. We do this by employing abstract domains that perform a bounds analysis and summarize arrays or heap data structures.
In a next step we want to combine the methods of static analysis with the dynamic execution of the program. This will provide us with a more flexible and scalable approach to binaries that have a footprint of several megabytes as it allows us to focus our complex analyses only on interesting parts of the program.

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8.9 Computational Irrelevance and Dependent Types

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Dependent types provide a strong system to enforce properties of objects and functions while keeping the focus on the actual algorithms, employing the duality between proofs and programs. However, much of the type information provided is solely for the purpose of ensuring conditions that can be checked at compile time, but not needed at runtime, therefore computationally irrelevant. Several solutions take this into account, like the prop-types in Coq or irrelevant quantification in Minlog. However, the coarse distinction between relevant and irrelevant information is not sufficient in any case. For example, in many cases information is not computationally irrelevant, but provably known to the compiler in any case that can occur. Furthermore, there are limitations one has to oppose to pattern matching and type inference to ensure soundness and program termination, which can be loosened when allowing a finer distinction between kinds of irrelevance. Our goal is to extend the notion of irrelevance to a reasonable elaborateness to both solve the theoretical problems and make them usable for actual programming, as a step towards the practical usability of dependently typed programming languages. As a first step, in our current paper-draft, we introduce shape-irrelevance, which is a kind of irrelevance that lies inbetween relevance and irrelevance, and a purely syntactic solution to make use of values that are automatically known to the compiler.

8.10 Verified Decision Procedures Based on Regular Expressions

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Monadic second-order logic on finite words (MSO) is a decidable yet expressive logic into which many decision problems can be encoded.
Since MSO formulas correspond to regular languages, equivalence of MSO formulas can be reduced to the equivalence of some regular structures (e.g. automata). However, formal verification of automata is a difficult task. Instead, the recursive data structure of regular expressions simplifies the formalization, notably by offering a structural induction principle.
Decision procedures of regular expression equivalence have been formalized before, usually based on Brzozowski derivatives. Yet, for a straightforward embedding of MSO formulas into regular expressions an extension of regular expressions with a projection operation is required. We prove total correctness and completeness of an equivalence checker for regular expressions extended in that way. We also define a semantics-preserving translation of MSO formulas into regular expressions. Our results have been formalized and verified in the theorem prover Isabelle. Using Isabelle's code generation facility, this yields a formally verified algorithm that decides equivalence of MSO formulas.
Several related decidable logics can be formalized and verified using similar technology. The closest relative of MSO on finite words is WS1S. The minor modifications of the above semantics-preserving translation of formulas into regular expressions required to support WS1S are again formalized and verified in Isabelle.
Another related logic is MSO on infinite words (also called S1S). The current work focusses on formalizing a procedure for deciding equivalence of ω-regular expressions without constructing ω-automata. This decision procedure will serve as the workhorse for deciding equivalence of S1S formulas by translating them into ω-regular expressions.
A more distant goal is to move from (ω-)words to (ω-)trees and decide equivalence of MSO formulas on (in)finite trees (or alternatively (W)S2S formulas) by translating them into (ω-)regular tree expressions.

8.11 Verification of Industrial Production Plants

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Modern production plants are highly automated complex systems consisting of several robots and other working machines. Errors leading to damage and stop of production are extremely expensive and must be avoided by all means. Hence, the state of practice is to test control programs in advance which implies high effort and comes with high costs. To increase the confidence into the control systems and to reduce the necessary effort, I try to use model checking and auxiliary formal methods to verify certain properties.
A typical production cell consists of up to 12 robots, a PLC and other process devices. To create a model of the control programs, I created a compiler that can transform the industrial robot programs into PROMELA models. Since the statements of the robot programming language can not be mapped directly into PROMELA statements and to reduce model size, compiler optimization techniques are used to close the semantic gap. The PLC and constraints are modeled by using generators that create the necessary parts of the model. The different parts of the model are then linked together into the final model which can then be verified.
In case of an error being found in the model, the error-path gets projected back on the original robots programs. A stand-alone web-application is generated from the trace which resembles a replay-debugger so that a robot programmer can reproduce the error found.
With the developed tools I and my students were able to detect several errors in the control software of plants being build by Audi. We were able to detect several errors: They ranged from simple programming errors like unintialized variables to a severe bug in the standard library used at Audi and VW that could have led to sporadic deadlocks in several plants. The involved robot programmers were able to quickly understand the error and correct their programs.

9 GRK 1487: Self-organized Mobile Communication Systems for Disaster Scenarios (MOBICOM)

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Todays mobile communication systems are highly static and inflexible with regard to changes. This prevents the fast implementation of innovative ideas as well as the fast adaptation to changes of the environment, e.g. to changing service demands, changing traffic loads or traffic distributions in mobile environments.
Our research goal is to develop mechanisms for the autonomous, dynamic and distributed coordination (self-organization) of future mobile communication systems. We apply self-organization to the radio system, to protocols and the network as a whole. Our specific application scenarios are disaster networks, requiring an aggressive approach to network operation. The coordinated adaptation of radio, protocols and network aspects is essential to provide communication services in disaster scenarios.
Important topics addressed by our research are:

- Decentralized Information Management, focusing on the reliable and robust provision of information in mobile communication networks as the base for self-organized decision making,
- Self-organized Service Recovery, focusing on mechanisms to recover from the failure of services,
- Cognitive Management of Transport Resources, focusing on mechanisms to provide transport resources, comprising wireless as well as wired links, and
- Reconfigurable Radio Interfaces, focusing on fundamental issues and basic requirements.

Common to all these topics is their requirement for an autonomous and distributed coordination.

9.1 Localization in Wireless Networks: Improvement of Localization Techniques

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Wireless communications have already become a very important part of our everyday life. According to this, hundreds of new applications emerge every week defining higher and higher requirements on hardware and software. Localization is one of the most crucial issues for many such applications. To keep it simple and cheap, but nevertheless accurate and robust, is still a big challenge for thousands of researchers all over the world.
Disasters represent one of the special scenarios with high requirements on localization results. Uncertainties in the working environment, only few data available, and tight time constraints are only some problems that emerge thereunder. Much scientific research has been conducted in the area of localization techniques. However, none of them may be applied to our disaster scenario with no or little modification. Are there any other ways leading to a solution?
One of possible solutions can be represented by the combination of well-known localization approaches and some improvement schemes that can provide sufficient location estimation results. This work focuses on the investigation and development of methods that deal with improvement of results during (pre-improvement) and after (post-improvement) the main localization process. New methods are being developed, implemented, simulated and evaluated experimentally in the real environment.
According to the pre-improvement, we present different improvement strategies in selecting the most efficient constellation of reference information out of the redundant data available for localization. The developed methods, called *Optimum Anchor Selection algorIthmS* (OASIS), are being evaluated on the real data sets that were collected in our outdoor experiment using an unmanned aerial vehicle (UAV). The obtained results show significant improvement which can be achieved with OASIS schemes.
For the post-improvement, this work proposes to use additional information available during the localization. One concrete solution can be represented by distances between couples of mobile nodes being localized. Based on this information, we introduce a novel improvement technique called *Universal Improvement Scheme* (UnIS). A corresponding mathematical model is being developed and simulated on the appropriate simulation platform. Additionally, we use the empirical results obtained in a deployed wireless sensor network for further validation. We show that the average localization error can be improved significantly using UnIS approach.

9.2 Reliable Multicast in Mobile Ad-hoc Networks Using Delay Tolerant Networks

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MANETs have been confirmed to be suitable for disaster scenarios. In these circumstances, different groups of first-aiders are involved in helping activities, e.g. fire-fighters, policemen, or paramedics. Often, messages need to be sent to a complete group, therefore multicast messages can be used to economize resources. To keep up communication in disaster scenarios, Mobile Ad-hoc Networks (MANETs) can be used to substitute failed infrastructure. If there is a big area to cover, several separate MANETs could be built or they could merge and split frequently. If messages need to be exchanged between different networks having no constant connection, Delay Tolerant Networking (DTN) can be used. Messages like rescue request or warnings should reliably reach their destinations. Therefore, using DTNs is an appropriate way to ensure delivery even if there is no current network connection. Unmanned aerial vehicles (UAVs) like multicopters could be used as ferries to transport the messages in a delay tolerant way.
Traditional multicast approaches developed for infrastructure-based networks are not suitable for MANETs, because they do not perform well in a dynamically changing ad hoc network environment. Additionally, typical multicast trees usually require a global routing substructure such as link state or distance vector. The frequent exchange of routing information, initiated by continuous topology changes, produces high management and processing overhead. Due to the special properties of mobile ad-hoc networks, e.g. dynamic topologies, limited energy resources, variable bandwidth, and limited physical security, it is important to develop protocols that consider these properties.
In this reseach, a new reliable multicast protocol RMDA (Reliable Multicast over Delay Tolerant Mobile Ad hoc Networks) is proposed. This includes an efficient group management approach and a new method for reliable multicast delivery over Delay Tolerant Networks. RMDA is adaptive to different kinds of MANETs, e.g. with or without clusterheads, respectively.

9.3 SEREMA - Self-organized Routing in heterogeneous MANETs

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The performance of wireless ad-hoc networks is mainly affected by the used routing protocol. Therefore it is a main task of the routing protocol to find suitable routes for data forwarding in a fast and efficient way. For the route discovery in wireless ad-hoc networks are different routing protocols available. However, these protocols do not cope with highly dynamic mobile ad-hoc networks (MANETs), because they are not able to adapt to major changes in the network topology. To overcome this drawback we consider highly dynamic MANETs whose size can vary from a few nodes to hundreds of nodes and the movement of the nodes can vary widely from static nodes to highly mobile nodes. Our new framework SEREMA is able to switch between multiple routing protocols during runtime to reconfigure the network. This allows us to get the best routing performance in different network constellations. For switching the routing protocol SEREMA uses an adaptive way like in existing approaches[1][2][3] but overcomes the drawbacks of these approaches like that the used routing protocols have to be modified or that network monitoring is done in a centralized way. SEREMA monitors the state of the network in a decentralized way and makes also a decentralized protocol switching decision based on determined network parameters. Since the SEREMA framework is designed in a modular way different routing protocols can easily be used in the framework without much effort.

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9.4 Self-Organized Coverage and Capacity Optimization for Cellular Mobile Networks

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Radio Access Network's (RAN) performance is sensitive to environmental changes and user behavior. For example, seasonal changes or construction work could alter the radio coverage whereas the dynamic user behavior could result in network congestion. Therefore, RANs have to be optimized from time to time. But currently this optimization process is quite manual and time consuming, where, optimization engineers adjusts the network parameters based on the detailed radio surveys of the environment in which the network is operating. This makes it quite difficult for the network to be responsive to the continuously changing environment and the user behavior. For these reasons, an interest is growing to introduce self-organization into the RANs, where the network, itself, reacts to the changing environment in order to optimize the network resource utilization and enhance the user experience. To achieve these targets in a self-organized manner the network relies on the measurements provided by the mobile users as well as its own measurements about the radio environment and the user behavior. Using these measurements the network can exploit intelligent optimization algorithms and adjust its radio parameters to match the current user demands and the resource utilization policies of the operator. Antenna tilt adaptation is very promising in this regard as they affect the coverage as well as the capacity of the network. Moreover, they can be updated in an automatic manner without any human involvement and thus can reduce the operational expenditure (OPEX), as well as, speedup the optimization process. Therefore this study focuses on identifying the useful measurements which can help to automatically detect coverage and capacity problems in the network, as well as, the optimization algorithms to adjust the radio parameters to overcome these problems.

9.5 Distributed Resource Map for Cognitive Radio Ad hoc Networks

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Cognitive Radio (CR) provides an alternative to the fixed radio spectrum allocation strategy that creates the problems of spectrum scarcity and under-utilization. A CR is a self- and network-aware radio that can make optimized decisions relating to radio spectrum access and management. To develop such an intelligent behaviour in a CR ad hoc network and attain environment awareness, the network needs to have a specific mechanism of knowledge aggregation and utilization. We propose "Distributed Resource Map (DRM)", which is a distributed knowledge aggregation and awareness framework specially suited to CR ad hoc networks. The DRM is a database-driven network-wide support architecture for CR ad hoc networks which not only facilitates the network optimization from an application's quality of service perspective but also supports networks co-existance in the same operational environment.

The DRM aims to exploit the distributed sensing capabilities of the nodes of a CR ad hoc network. A CR node has to perform continuous spectrum sensing in order to identify and utilize radio spectrum opportunities and avoid interference with other radio entities. In a DRM driven CR ad hoc network, each node maintains an individual database for aggregating high level historic information from its own sensing capabilities. The level of awareness which a CR can obtain on its own largely depends on its environment sensing capabilities. To support resource constrained CR nodes, other neighbor nodes in the vicinity can contribute to increasing the awareness of the constrained node by sharing their knowledge of radio spectrum. To acquire environment awareness from spectrum sensing, each nodes employs knowledge abstraction techniques based on statistical approaches.

To facilitate the use of the aggregated knowledge for network optimization and quality of service, the DRM is tightly integrated with a cross-layer learning and decision making component called "Cognitive Engine (CE)". The CE can optimize the behavior of a CR node in a particular environment state by exploiting the knowledge in the DRM and using Artificial Intelligence techniques.

9.6 Self-Organized Placement of Services in Networks suitable for Disaster Scenarios

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Autonomously acting networks are required to keep their administration overhead low. If communication infrastructure is broken it has to be repaired. On the one hand mobile nodes that act as relays might be required to reestablish the connectivity of partitioned networks. On the other hand services (that could consist of either one instance - one central server - or multiple instances - a distributed service) required within that network have to be placed such that the traffic is as low as reasonably achievable. That is the problem of Service Placement. In order to accomplish that task, services do not only have to be initially placed but migrated or replicated. Or maybe an interface to that service by a relay or proxy entity has to be initiated.
How and where to place services is not only considered for mobile networks that are required for disaster scenarios. In the context of Cloud Computing, service placement is discussed. However, the services that have to be placed in a cloud are installed in a rather static network. Here it is necessary to act on changing demands. For mobile ad-hoc networks, the possible instability of the network has to be taken into account, fast reactions upon changes in the network are necessary. Furthermore the impact of the environment is of interest here. Therefore an appropriate mobility, link, interference, energy, communication, capacity and resource model influence the placement.
In this work an approach that consists of two phases that are executed periodically is developed and evaluated based on simulations. To solve the subproblems of service placement, k-Median and the Facility Location Problem are points of interest. There are many algorithms to solve those (e.g. structured algorithm or linear optimization). However, a self-organizing or at least distributed algorithm has to be applied. That solution places agents that keep track on the nearby network. Those agents optimize the solution derived from the structured algorithm via soft-computing methods (e.g. mutation based approaches like genetic algorithm).
There are various services that might be required in disaster scenarios. For the purpose of surveillance it can be necessary that videos from drones or satellites have to be broadcasted to mobiles. Because the network might not always provide the bandwidth required by the stream it can be necessary that the bitrate of the video has to be decreased. The resulting problem includes the application layer multicast. Another deployable service is a map service that helps the relief forces to orient in the area. Among the services required in disaster scenarios is also a directory service that keeps track on the position of the participants in the network service.

9.7 Robust and Flexible Link Layer for Cognitive Radio Ad-hoc Networks

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Cognitive Radio (CR) is a new paradigm of designing intelligent, flexible and self-adaptive wireless communication systems. One of the main motivation behind CR is the scarcity and the underutilization of available radio resources. Through using a *Software Defined Radio* (SDR) which allows to reconfigure and adapt the operating parameters of communication node, CR aims at enhancing the efficiency of today's communication systems. The intelligent adaptability is achieved by using software-controlled signal-processing in combination with the ability to observe, learn, self-optimize and to make decisions.
Analyzing, designing and implementing cognitive communication systems requires multi-disciplinary knowledge. Many different research questions arise in all layers of the communication systems. While physical layer challenges are often related to signal processing, research in higher layers such as the link layer of a radio node addresses questions related to self-organization and multi-objective optimization.
Besides providing traditional *Medium Access Control* (MAC) functionality, the link layer of a CR node has to consider aspects which are unique to this new technology and not present in conventional communication systems. Moreover, ad-hoc networks introduce further challenges. To give an example: CRs in an infrastructure-less environment require protocols to establish network connectivity when they are initially turned on (rendezvous) or moved and thus lose their connection. Furthermore, they might have to vacate the channel currently in use due to primary user activity in the region (spectrum mobility).
The goal of this thesis is to investigate link-layer aspects of a CR operating in an ad-hoc network environment. Thereby, we aim at developing a flexible software and protocol architecture capable to combine MAC, rendezvous and spectrum mobility issues. Thereby, the research focuses on the development of an operational implementation which supports the successful deployment of a highly flexible CR ad-hoc network demonstrator within the Graduate School.

9.8 Robust, Decentralized Information Management

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During the response and recovery phases after a disaster, various working levels produce and require an immense amount of information. In order to ensure efficient disaster management, this data must be reliably available to a quickly growing group of users, despite possible breaks in network links or node failures due to, for example, power loss or mobile devices that have moved out of broadcast range. Increasingly, large amounts of data are being stored in a distributed manner over wide area networks using distributed hash tables (DHTs), which essentially map data to network nodes and provide routing algorithms for lookups. A DHT's structure provides users with guarantees on data availability while its randomness provides the necessary scalability and robustness. The aim of this work is to develop a highly robust, scalable DHT protocol that integrates nodes' locations and resource availabilities (such as power availability) in order to obtain improved data availability and resource usage.
Typically, DHTs fail to incorporate information about nodes' locations or resource availability, both of which have heightened importance in disaster scenarios where nodes are often mobile with limited power and bandwidth availability. Node location is ignored twofold in standard DHTs: Firstly, messages are routed on roundabout underlay, or physical, paths and secondly, data is stored independent of the actual physical locations at which that data is most needed, so that network failures, partitioning, or overloaded links can lead to inaccessible data. Meanwhile, the lack of attention to resource availability can lead to unnecessary node delays or failures. This work uses two main approaches to integrate location and resource awareness in DHTs:

- **Location and resource aware network overlay design:** The network connections are designed such that nodes with high resource availability receive higher routing and maintenance load (thus relieving lower resource nodes) with physically short routing steps. With high resource nodes' lower failure rates, this increases data availability.

- **Location aware replication:** Data replicas are placed physically near to where they are needed and in a manner that anticipates the dynamic changes in the network, increasing availability when nodes fail.

These approaches, combined with the development of measures for comparing systems' robustness with regard to their location and resource awareness, lead to a better understanding of how the integration of node information influences data availability in highly dynamic systems.

9.9 Self-Organizing Energy Saving for Future Radio Access Networks

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Energy saving for future radio access networks (RANs) becomes an increasingly significant factor for wireless network operators, not only regarding costs reduction, but also for meeting the environmental challenges. The energy costs are affected by sharply raising energy prices due to the shortage of non-renewable resources as well as the partial phasing out of nuclear energy. Furthermore, the predicted exponential growth of mobile data volume requires a significant increase of base stations, which consume by far the largest energy fraction within a mobile network. Both factors, the increasing number of base stations and the raising energy prices contribute to the increasing percentage for energy costs regarding the overall mobile network operational expenditure (OPEX). The goal of this work is to minimize the power consumption of future radio access networks by dynamically adapting the network capacity to the current traffic volume. Self-organized network procedures are used to ensure fast reacting and optimal network adaptation by switching off and on the appropriate cells. The switch off procedure can be performed autonomously by the cell. However, the identification of the most needed cell to be switched on is seen as an open complex problem. A new method is introduced to identify the best fitting cell using the fingerprinting method for cell localization. This work is a part of a joint project between the Graduate School on Mobile Communications and Alcatel-Lucent Bell Labs Germany and is closely related to research topics of Self-Organization in Future Radio Access Networks such as coverage and capacity aspects or mobility load balancing. During disaster scenarios causing restricted power supply, self-organized energy saving can be used to maintain a basic mobile communication network by allowing to switch on base stations on demand only. However it still needs to be investigated, whether and to which degree self-organized energy saving impacts the network quality and performance. Both may be affected by the timing delay until a switched off base station becomes fully operational as well as scenarios when inappropriate cells are selected. Multiple further complex scenarios have to be observed, such as fast moving UEs, short term data or periodically data boosting UEs as well as the different network technologies and configurations. Possible improvements could be achieved by combining the switch off / on procedures with tilt or power modifications used by self-organizing coverage and capacity procedures.

9.10 Self-organized Naming and Address Resolution in Heterogeneous Networks

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In disaster scenarios, communication networks usually consist of heterogeneous nodes with different abilities to forward information to the destination. While some of these nodes have several working communication interfaces and are thus able to couple different subnetworks, others operate with one interface only and can thus communicate directly merely with nodes supporting the same technology.
Due to this heterogeneous scenario, different types of addressing can occur as well as different topologies and routing mechanisms. Additionally, high mobility is assumable. Nodes probably join and leave networks frequently. With every network change, the nodes get a new local IP address. Thereby, they are no longer reachable under their old address even if there is a connection between the old and the new subnetwork. To deal with that problem, a logical addressing scheme must be applied on top of the IP addresses. Nodes should be identified by logical addresses that remain the same, no matter where these nodes are located or which network access technology they are using. In a rescue team, for example, the members have different roles and should be addressed accordingly. As Layer 3 communication must be established based on the still changing IP addresses, the logical identities have to be mapped to them dynamically, and this mapping must be available all the time.
Name resolution can be classified in Application Layer approaches, like the well-known Domain Name System (DNS) or its multicast-based adoption mDNS, and Network Layer approaches where the name resolution is included in the routing. We developed a routing-based hostname mapping system and combined it with an adaptive routing framework. This provides the possibility to adapt the routing and therefore the name resolution to the current network scenario. The addressing scheme with a working name resolution adapted to the Mobile Ad-hoc Network scenario can be extended by introducing service discovery based on service names or by combining the geographical position with the logical address, which leads to a geographical anycast. Therefore, one can send an emergency call *to the closest ambulance team*, no matter where this service is located.
To reach the goals, a deep literature research is fulfilled to gather the state of the art. The routing-based name resolution mechanism is designed, implemented, and validated. The simulation of the approach is done in the Network Simulator 3 (ns-3) in combination with the Click Modular Router.

9.11 Self-Organized Unmanned Airborne Message Ferries for Delay Tolerant Networks

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In major disaster scenarios like earthquakes or floods, huge parts of the existing terrestrial network infrastructure are functionally degraded or destroyed. Since search and rescue management relies on a working communication infrastructure, a fast and robust network reconstruction is essential. Adding mobile, UAV-based network nodes to the damaged network is a promising approach for repairing and augmenting such a disaster network.
Basically, UAV's could create multi-hop networks but if the amount of network resources is too low, the last possibility for communication is physical message transport. That means, a UAV will more or less periodically visit nodes which want to communicate, pick up their messages and deliver them. It is clear that the system needs to distinguish between important and less important messages since movements implies a lot of energy consumption.
This thesis focuses on a self-organized message-ferrying algorithm called SOFCOM, which solves the next-hop decision problem in mobility-controlled message ferrying networks. It provides an analytic model for the single-ferry scenario, in which multiple static network nodes require transient connectivity for message exchange. Relaxing the system's state complexity allows to compare this approach with an optimal guessing oracle, with random-walk, and with a standard TSP-based approach. Based on the computed candidate solutions, the type and the parameters of the solution space density function are identified in order to judge the location in the global fitness context. Is is shown that SOFCOM can performs often as good as a TSP-based approach, although only local decisions are conducted. Important qualitative properties of the algorithm are discussed and a performance comparison is provided.
The algorithm is not only simulated but also deployed on a real UAV hardware. Thus, I am also involved in defining the hardware and software architecture of our ARCADE (Airborne Robots for Communication and Autonomy in Disaster Environments) robotic system. This Linux-based system is currently being developed as a prototyping platform for current and future UAV-based communication research.

9.12 Participatory Sensing in Disasters

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The response to natural or man-made disasters has always been a great challenge. With governmental agencies and relief organizations being constrained in their operational resources, help can often not be provided to all those affected by the incident within the first critical 72 hours. Therefore, careful mission planning and coordination is vital for effective response. However, with parts of the communication infrastructure potentially being inoperable as a result of the disaster, strategic decisions have to be made without detailed knowledge about the situation at hand.
While providing relief forces with communication tools is of great importance and has therefore been the focus of several research efforts in the past, the vision of employing techniques of participatory sensing as a tool in disaster response has emerged recently[1]. This vision is based on the observation that more and more people are actively participating in online social networks and are in possession of increasingly powerful mobile devices like smartphones which are capable of providing GPS coordinates, as well as access to the Internet.
Several information and communication services can be envisioned for public participation[2]. One of the most fundamental services is to enable citizens to share their needs and knowledge about the current situation. In order to prevent injection of false and misleading information, such a reporting service has to consider potentially malicious participants. Therefore, this work aims at providing the fundamentals of a privacy-aware spatiotemporal multicast [3] that can be used to implement a witness-based voting scheme for verification of user-collected information in large-scale disasters [4]

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9.13 Self-Organized Mobility Load Balancing for Future Radio Access Networks

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The introduction of self-organization in future radio access networks (RANs), e.g. Long Term Evolution (LTE), offers a great potential, for network operators to reduce operational costs and enhance resource efficiency, and for users to experience high quality of service (QoS) at lower prices. Therefore, future RANs will exhibit a significant degree of self-organization, as also recognized by 3rd Generation Partnership Project (3GPP) [1] and Next Generation Mobile Networks (NGMN) [2].
In cellular networks, changes in users' mobility and traffic patterns over time and space result in imbalanced load distribution among the cells. This load imbalance is more prominent in LTE which allows different classes of users [3] to access the network resources at the same time. Due to this load imbalance, some cells can become overloaded, i.e. they do not have enough resources to satisfy the QoS requirements of all the users present in their coverage area, and at the same time some cells in their neighborhood can be less loaded, i.e. they have free resources to satisfy the QoS requirements of some more users apart from those that are already present in their coverage area.
Mobility load balancing (MLB) deals with balancing the traffic load among neighboring cells by adapting the mobility parameters, i.e. handover (HO) parameters, in particular time-to-trigger and cell individual offset [4], of a cell in a self-organized manner. Thus each base station automatically adapts its own parameters depending upon the load conditions in itself and the neighborhood cells but still achieves the overall network performance targets. Depending on the load in the cells involved in the HO, the HO has to be either advanced, i.e. a user remains in the coverage area of the source cell but it uses the resources of the target cell, or delayed, i.e. a user enters the coverage area of the target cell but it still uses the resources of the source cell. After load balancing a gain is achieved with respect to the overall system throughput and users' QoS.

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10 GRK 1564: Imaging New Modalities (INM)

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Imaging technologies are one of the most important cross-cutting technologies for national and international research activities, high-tech industries and information societies. This is especially true for civil security applications. Here, the primary challenge is the development of highly automated systems, which take the result of the ongoing ethical and legal discussions regarding this topic into account. The field of research within the Research Training Group 1564 is structured according to application scenarios and fundamental techniques. There are close methodological interconnections and significant synergies between the individual projects which obey this structure.

Civil Security Applications
New civil security applications require enhanced imaging functionalities, which, as a consequence, require more powerful and efficient concepts regarding both sensor concepts and sensor data processing methodologies. The focal idea of the Research Training Group is to seize recent developments in imaging for different modalities in order to facilitate innovative approaches to the field of civil security applications. The focused civil security scenarios include person detection and biometry, material detection and analysis, as well as scene observation. The targeted enhancements of civil security systems addresses further functionalities and increased robustness which can be achieved due to the particular orthogonality and redundancy of the information delivered by the individual sensor modalities.

Fundamental Methods
Sensor data processing is the focal point for the Research Training Group, bringing together the potentials of the new sensor technologies and the specific needs of the targeted civil security application. Within this scope, different data processing and information extraction concepts will be compre-

hensively investigated. Sensor models, as part of the sensor development, deliver essential sensor characteristics as a basis for developing efficient sensor data processing techniques.

Sensor Deployment and Sensor Systems
The Research Training Group addresses new sensor concepts, especially distance range sensors based on Photonic Mixing Device (PMD) technology, enhanced THz-sensors and multi-spectral VIS-sensors (colorimetric arrays).

Mono- and Multimodal Methods
For efficient and robust information extraction for new sensor modalities, new mono-modal techniques will be developed. Multi-modal approaches, on the other hand, aim at the registration, merging and representation of data delivered by several diversified sensors modalities. This also covers cross-modal methods which are dealing with the relation of specific information between different modalities. For many of the research projects specific illumination setups and their influence on imaging are important issues. Furthermore, the addressed civil security applications often require fast processing of large amounts of data.

10.1 Terahertz detector arrays in silicon technologies

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Supervisor: Prof. Ullrich Pfeiffer

There is an increased interest in terahertz technologies for emerging applications such as airport security screening, firefighting equipment for gas sensing, medical imaging, pharmaceutical applications, astronomy, communication, biological and material analysis. In this application space, very-large-scale integration (VLSI) in silicon process technologies is becoming a cost-efficient alternative to technologies such as Schottky barrier diode (SBD), high electron mobility transistor (HEMT), vacuum electron devices (VED), bolometers, micro and nanobolometers. Furthermore, the high-frequency capabilities of silicon technologies steadily improve through scaling, which enables high integration levels and low power consumptions at higher frequencies. However, the technology f_T/f_{max} are still a limiting factor for terahertz applications.
Electronic detection methods in the terahertz range are commonly divided into two main categories: coherent (heterodyne) detection and incoherent (direct) detection methods. Below f_T/f_{max}, where transistors exhibit power gain, silicon-based circuits may be operated fundamentally with reasonable RF circuit performance. Above f_T/f_{max}, where transistors exhibit power loss, circuits may be operated sub-harmonically to further extent the RF operation region. Despite their increased receiver noise figure (NF), such circuits prove to be useful for emerging terahertz applications. Unlike heterodyne detection, incoherent (direct) detection favors multi-pixel imaging applications such as focal plane arrays (FPAs), where the power consumption per pixel needs to be small to enable large pixel arrays.
The purpose of the thesis is to integrate high performance and large scale terahertz detectors in silicon technologies. A contribution in a collaborative work on the first CMOS camera prototype has been presented at the 2012 International Solid-State Circuit Conference in San Francisco, California, USA. The terahertz camera consists of a 1-k pixel array. It has shown real time imaging capabilities from 0.6-1 THz with an average power consumption of 2.5 μW per pixel. Further work on terahertz detector arrays has been done on SiGe process technology.

10.2 Constrained Up-Scaling for Direct and Global Image Components

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The separation of direct and indirect illumination[1] in a scene is an interesting task for both, Computer Graphics and Computer Vision domains. Having the direct component, one can obtain the distribution of reflected light in a scene. For instance, this can be used to derive a model for the bidirectional reflection distribution function (BRDF)[2]. Also, 3D reconstruction methods are more robust when working only on the direct component[3]. The global component gives insight into the scattering behaviour between one or more objects in a scene. This is useful to achieve more photo-realistic renderings of a scene by observing the complex light flow. Also, object recognition benefits from such approaches as the scattering of an object highly depends on the material[4].
However, in order to separate full-resolution images, a large number of coded images have to be acquired. For many interactive applications, such as the acquisition of dynamic scenes or video capturing, this is not feasible. In my research, a new constrained up-scaling technique for separated direct and global illumination images is proposed which requires two to three coded input images, only. Our approach imposes the boundary condition that the sum of the direct and global components equals the fully illuminated image. We work in a predictive-corrective manner where we first use a single-image up-scaling method in order to predict the higher resolution images. Afterwards, the missing higher frequencies are determined using a fully illuminated image. As the distribution of the higher frequencies differ among the various frequency bands, we apply our approach in an iterative way for small up-scaling steps distributing the missing information by minimizing the overall frequencies.

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10.3 3-D synthetic aperture processing algorithms with application in THz imaging

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Supervisor: Prof. O. Loffeld / Prof. P. H. Bolivar

2-dimensional Synthetic Aperture Radar (SAR) techniques have been filling numerous journals for decades. The 2-D radar imaging restricts the radial wavenumber on the radar imaging plane, and maps the 3-D objects into the 2-D radar coordinates range and azimuth. The imaged real scene is definitely 3-dimensional, and hence the 2-D radar imaging is simply a limiting form of the more general 3-D scenario. I have worked in the area of 3-D radar imaging with an emphasis on focusing algorithms and its implementation.
On the other hand, there has been increasing interest in THz imaging with 3-D capability. In a traditional imaging approach, the highest achievable resolution is defined by the relation of the wavelength to the dimension of the implemented imaging optics. The inevitable large numerical aperture of a system implies unpractical dimensions for the optics. SAR achieves its 3-D imaging capability by using signal processing techniques, rather than building large aperture antennas (or lens at THz range). Therefore, we started a research project within DFG-funded program of GRK1564 to investigate the 3-D SAR imaging techniques at THz frequency, attempting to efficiently focus the THz data with SAR algorithms. I am developing a very efficient processing approach for 3-D SAR THz imaging. At the same time, the published materials have revealed efforts in the processing algorithms of 3-D SAR that operates at microwave frequency, and to our knowledge, a comparison of these algorithms is missing so far, not to mention there comparative behaviors over THz data. I am additionally working towards fitting this gap. My thesis is about 3-D synthetic aperture imaging algorithms and their implementations.

10.4 Analysis and Visualization of Multispectral Data

Björn Labitzke (bjoern.labitzke@uni-siegen.de)
Supervisor: Prof. Dr. Andreas Kolb

In the last years, multi- and hypespectral sensors have been applied in a growing number of application areas. Thus, spectral data analysis is increasingly applied on both, macroscopic, e.g. remote sensing, and also microscopic scales like Raman spectroscopy. Nowadays, spectral imaging therefore also gains more popularity in applications such as agriculture, medical, food safety and biometrics. The increasing popularity requires tools for analyzing and processing of multi- and hyperspectral data. In the following, for the sake of simplicity, multi- and hyperspectral image data are referred to as multispectral image data.
In general, multispectral imaging yields an image series of a specific range of frequencies across the electromagnetic spectrum. Commonly, these data are often referred to as multispectral image cubes that have three dimensions, two spatial dimensions and one spectral dimension. Typically, multispectral image cubes represent high-density spectral information. The interpretation of these data on the one hand, is complex for humans and on the other hand, is time-consuming for computers. Thus, the challenging task of interpretation consequently requires support in order to improve the understanding of the data.
This thesis addresses the development of an efficient, intuitive and generic visual analytics[1] approach for multispectral image data, in order to facilitate the interpretation. Here, the human expertise plays an important role in the exploration process to close the gap between the limits of automated algorithms and appropriate visualization techniques with domain-based expert knowledge. Such an interactive exploration system poses the main objectives in the areas of data analysis, scientific visualization, interaction and processing speed. Therefore, this work focuses on the evaluation of appropriate data analysis methods and spectral metrics in order to discover characteristic spectra of an individual dataset. Visualizing these spectra in a comprehensive way is helpful for a deeper understanding of the data. Here, appropriate visualization techniques are developed and combined to show the aspects of the individual data as efficient and intuitive as possible. In addition, an appropriate feedback-time of all components is required to allow interactive exploration. Therefore, CUDA-based implementations are developed for time-consuming methods, if suitable.

[1] D. Keim, G. Andrienko, J.-D. Fekete, C. Görg, J. Kohlhammer, and G. Melançon, "Information visualization," A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds. Berlin, Heidelberg: Springer-Verlag, 2008, ch. Visual Analytics: Definition, Process, and Challenges, pp. 154–175.

10.5 Object Recognition in Multimodal Sensory Data

Christian Feinen (christian.feinen@uni-siegen.de)
Supervisor: Prof. Dr. Marcin Grzegorzek

Object recognition is a popular research topic in many applications. Although there is considerable progress, 3-D object recognition is still a challenging task. Many researchers try to approach this problem in 2-D. This is reasonable regarding the fact that one of the most important object similarity features considered by humans is the object's shape[1]. However, caused by perspective distortions, it happens that important parts of an object do not appear in the image and consequently the recognition process fails.
To increase the robustness and accuracy of 3-D object recognition systems, this project focuses on the use of multimodal sensory data. For the time being, the following information are taken into account: (i) Depth, (ii) RGB and (iii) Multispectral data. This is highly sophisticated since the descriptors of each (sensory) feature space have to be prioritized regarding their strength of discrimination. Moreover, all features have to be assigned to a certain weight according to their significance. Therefore, smart and adaptive systems are necessary. Finally, all information have to be represented by an efficient and well-defined model.
In the past, our research was focused on depth devices. In this context, we investigated issues like (i) depth acquisition, (ii) object detection, (iii) feature extraction and representation as well as (iv) matching possibilities. Latter was accomplished by adapting and merging two novel graph matching algorithms[2,3]. In case of feature extraction and representation, skeleton- and contour-based approaches have been considered. Altogether, promising results have been achieved in this area.
At the moment, we are working on registering and fusing depth with multispectral data. Our aim will be the use of both modalities in order to improve the accuracy of object recognition in case of (mostly) textureless 3-D objects. Simultaneously, we investigate the use of surfaces directly for the feature extraction and matching process. It is planed to combine these three geometry types (skeleton, contours, surfaces) to provide an appropriate depth representation. However, the overall objective is to fuse all descriptors into only one model. Both points are part of our future work. In addition to this, state-of-the-art methods and novel appearance-based features will be added to the system as well as incorporated into our model.

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10.6 Representation and Recognition of Articulating Objects in Dynamic Environments

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Supervisor: Jun.-Prof. Dr.-Ing. M. Grzegorzek / Prof. Dr.-Ing. D. Paulus

An interesting research topic in computer vision is how objects can be represented and subsequently measured and computed. This determines the classes of features that could be used, how they are grouped, and how they are matched. Currently object representations span from prototypical (high abstraction level, used mainly for generic object recognition) to exemplar-based (low abstraction level, used mainly for recognizing particular instances). A major research goal is how to eliminate this representation gap. Recognition, manipulation and representation of visual objects can be simplified significantly by the process of abstraction. By definition abstraction extracts essential features and properties while it neglects unnecessary details[1]. Furthermore, the tendency of combining different imaging sensors into one device is increasing and leads to a new information density. Today, state of the art imaging techniques can capture simultaneously depth and color information of a scene. Due to this variety of imaging domains the capabilities of combining different representations is increasing, too. However, view-based object representations and recognition methods are characterized by a non-geometric modeling of the intensity values of an imaging sensor. Instead of using an abstract geometric object model, multiple views are exploited, whereas the view point and the illumination is variable[2]. The research focus of this work relies on how articulating objects in dynamic environments can be generically represented and recognized, by exploiting a multimodal sensory setup. Therefore, one assumption is that objects with a fast articulating movement are based on a skeleton or a skeleton like structure. 2-D Skeletons can be directly learned by observing the movement of an object. Ross et al. uses 2-D feature positions to estimate the objects skeleton by its motion[3]. For matching Bai et al. introduced a technique based on a path similarity skeleton measurement and a graph matching algorithm[4]. 2-D skeletons are view-dependent and one open question is how those skeletons can be projected into 3-D and how this topological structure can be efficiently combined with other representations.

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10.7 Analysis and Visualization of Multispectral Data

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Supervisor: Prof. Dr. Andreas Kolb

In the last years, multi- and hypespectral sensors have been applied in a growing number of application areas. Thus, spectral data analysis is increasingly applied on both, macroscopic, e.g. remote sensing, and also microscopic scales like Raman spectroscopy. Nowadays, spectral imaging therefore also gains more popularity in applications such as agriculture, medical, food safety and biometrics. The increasing popularity requires tools for analyzing and processing of multi- and hyperspectral data. In the following, for the sake of simplicity, multi- and hyperspectral image data are referred to as multispectral image data.
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[1] D. Keim, G. Andrienko, J.-D. Fekete, C. Görg, J. Kohlhammer, and G. Melançon, "Information visualization," A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds. Berlin, Heidelberg: Springer-Verlag, 2008, ch. Visual Analytics: Definition, Process, and Challenges, pp. 154–175.

10.8 Long-Range 2D/3D Segmentation and Super-Resolution

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Supervisor: Prof. Loffeld, Prof. Kolb, Dr. Hartmann

How can color image segmentation and background subtraction, two standard computer vision and image processing tasks in the broader area of scene analysis, be improved by including depth information in addition to color images? In our research project we develop a multi-modal sensor system to perform airfield safety surveillance. Each sensor system consists of the ZESS MultiCam, a monocular depth and color camera, a thermal camera and radar. The goal of the project is to detect objects by change detection based on the segmentation of multi-modal data (color, infrared intensity, modulation amplitude, depth, thermal data and radar measurements). The observation area has a diameter of up to 200 meters and the system has to operate even under difficult lighting and weather conditions, which lead to extreme levels of noise and invalid measurements.

Many image processing algorithm can be easily extended to multi-modal data as long as all images have similar lateral resolution. But typical depth maps gained from Time-of-Flight (ToF) depth cameras and thermal images are of significantly lower resolution than the images common color cameras are able to provide. To cope with the lower resolution several Super-Resolution methods dealing with high quality ToF range data have been proposed. Therefore, important research topics for wide area scene analysis are how to perform super-resolution based on noisy range data and how to include quality measures in the segmentation task.

In a recent paper[1] we utilized depth information to enhance standard background subtraction for color video. Afterward, 2D/3D still image segmentation was a research topic, for which standard feature space methods such as DbScan and Mean-Shift have been extended. Based on these experiences more sophisticated approaches came into the focus and especially how to apply them under difficult circumstances is currently researched.

Super-Resolution algorithms for Time-of-Flight depth and color cameras utilize the high resolution color image to generate an depth map of equal resolution by assuming that color and depth coincide. We analyzed several Super-Resolution methods in theory as well as in practice[2].

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10.9 Processing and Fusion of 2D and 3D sensor data

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Supervisor: Prof. Dr. Andreas Kolb

Real-time (or online) 3D reconstruction has wide applicability and receives further interest due to availability of inexpensive consumer depth cameras (such as time-of-flight cameras or kinect). Many 3D systems assume static scene to reconstruct the surface environment and/or cannot handle scene motion. The current research addresses this limitation using robust segmentation of dynamic objects in order to avoid possible misleading reconstruction. In fact, the camera pose estimation (or camera tracking) based on point-to-surface ICP is greatly improved on scene in motion if a robust segmentation of dynamic objects is provided.
Another important point which highly influence the quality of the surface reconstruction is the measurement uncertainty of specific sensors. The current research also concentrates on different calibration models in order to improve depth measurement of sensors. For example, ToF cameras are well known for their wide variety of measurement errors such as wiggling error or intensity-related depth error. Thus, 3D reconstruction pipeline needs to take into account anisotropic noise of depth sensors in order to reconstruct a more realistic surface model. An highly precise surface reconstruction could later on be used for groundtruth generation which is a real problem in current computer vision and graphics system. The problem lies on the definition of groundtruth data and methods to generate them in a proper way in order to evaluate new algorithms.
The last topic of the current research is concerning post-processing of range data acquired from ToF cameras. Due to the principle of phase modulation based method, motion blur or motion artifacts are present in the depth measurement which greatly decrease the quality of range data in dynamic scenes. Several ways already exist in the literature to handle such kind of errors. But correction of motion artifacts is still not efficient and fast enough to improve depth data at real-time rate. Finally, ToF sensors are also subject of another error which is caused by the mixing of different phase signal. This effect only occurs on specific observed scene where light scattering is stronger enough to influence the direct reflected signal of the illumination. The current research is investigating ways to detect and/or correct errors caused by multi-path problems in real-time.

10.10 Processing and Visualization of THz-Data

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Supervisor: Prof. Dr. Andreas Kolb

The THz-range is a promising new part of the electromagnetic spectrum for getting additional information from a scene or an object that cannot be gained from imaging techniques working in or near the visible spectrum. Non-intrusive security screenings or material detection are possible applications. As a use case, the data of a hybrid synthetic aperture scanner is used. The acquired data needs to be reconstructed in a mechanically scanned dimension and two synthetic aperture dimensions. The object is screened from different acquisition directions. The acquired data needs to be combined to a consistent representation of the screened object for visualization. Therefore, a framework consisting of the modules reconstruction, volume fusion and visualization was implemented.

The reconstruction module needs the most calculation time and was accelerated by an implementation on the GPU in a first step. Depending on the scanner properties (number of antennas, number of acquisition directions, etc.), it allows a real-time processing. The current focus on the reconstruction modules lies in the improvement of the image quality. The mechanical scanning introduces a blurring in this scanning direction. Therefore, a 1D point-spread-function (PSF) was measured and used for deconvolution with the reconstructed image. The achieved results look good but can be improved further with a model of a space-variant PSF. Furthermore, it is planned to improve the reconstruction model by considering the orientation of surfaces.

In the volume fusion module the discrete individually reconstructed synthetic aperture images are combined to recover a 3D representation of the scanned object. A geometrical configuration allows to place the images geometrically correct. The intensities of these images are interpolated into a uniform volume grid to allow a fast visualization.

A volume-raycasting is used for visualizing the fused dataset. Since an additional optical camera captures the scene as well, a multi-modal approach for combining THz and optical data is necessary. Therefore, a calibration was introduced that allows a transformation between the coordinate systems of the cameras. This allows a matched projection of the optical image into the THz dataset. An intensity threshold is used for the decision if the THz data of the scanned object is overlayed with the optical data for the visualization. It is planned to work on an improved material detection that allows a more sophisticated visualization with multi-modal approaches.

10.11 Age prediction and simulation

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Since most of the currently existing face recognition algorithms are developed and optimized for adult faces, those algorithms do not yield convincing results for children's faces. Therefore on the one hand the main goals of this research topic are to regard the characteristics of children during the development of recognition algorithms and on the other hand to build an automatic growth simulation system which is primarily used for children and their faces. Presumably this will finally allow face recognition techniques which are widely independent of facial aging.
The challenge in creating such a system is that the individual aging trajectories might be quite different from each other depending on the respective external influences[1] of each individual person. Furthermore all these trajectories are non-linear[2] and in the majority of all cases no longitudinal data is available whereby a solid training set is hard to achieve.
But nevertheless to find a proper solution it is necessary to acquire a firm data set for faces of children first. Therefore we acquired several hundred photos and 3D scans of children of different ages. This also includes a proper labelling of the data, so that each photo and scan is tagged with a specific age, gender and some other information which can be helpful during the fitting process.
Another important aspect of this labelling is that all the different data which has been acquired for each person can be set into correspondence, to extract as much information as possible. For example the photos provide high resolution textures from different viewing angles of each person but to extract the texture for the whole face it is necessary to usefully combine these single images. And last but not least it is necessary to combine the facial texture with the facial shape which has been extracted from the 3D scans.
Finally on that basis already existing algorithms can be improved in robustness and effectiveness as well as new algorithms can be developed to provide a robust prediction and simulation of aging for children.
As a fundament of this research the *3D Morphable Model*[3] is being utilized.

[1] N. Ramanathan, R. Chellappa and S. Biswas, *Age progression in Human Faces: A Survey*, Accepted for publication in Journal of Visual Languages and Computing, 2009

[2] K. Scherbaum, M. Sunkel, H. P. Seidel and V. Blanz, *Prediction of Individual Non-Linear Aging Trajectories of Faces*, Computer Graphics Forum 26(3), 2007

[3] V. Blanz, K. Scherbaum and H. P. Seidel, *Fitting a Morphable Model to 3D Scans of Faces*, Proc. of Int. Conf. on Computer Vision ICCV, 2007

10.12 Learning a Statistical Model of Thermal Infrared Facial Appearance

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In the last years, images of persons acquired by thermal infrared sensors have become an encouraging topic in medicine and computer vision. Especially the analysis and interpretation of facial thermograms seem promising for a large number of applications.
One of these is face recognition, a topic that belongs to the most highly researched fields in the computer vision domain. Despite the enormous effort, that has been made in this direction, current algorithms still lack the robustness and accuracy required of a field deployable system. Some of the drawbacks arise out of the fact that the methods based on RGB images strongly depend on comparable and favorable acquisition condition. An attempt to circumvent these disadvantages is to use a multimodal facial recognition approach that employs the mentioned thermal infrared spectrum besides the visible one.
This work adresses the acquisition and analysis of thermal infrared textures extracted from the face with the purpose of a better assessment and evaluation of the advantages by using the thermal spectrum for face recognition and a wide range of different applications. A first step to achieve this is the development of an appropriate measurement setup and a procedure to acquire the thermal texture. For this purpose, an uncalibrated acquisition system containing a RGB camera besides the infrared sensor is proposed. The following processing steps employ the 3D Morphable Model[1] to transform the acquired face thermogram with the help of the RGB image into a 3D representation similiar to a RGB texture of a face model. By this form a correspondence of the thermal textures is created that enables a correct and pixelwise comparison of face thermograms for example of one person under changing conditions or of several persons exposed to the same external factors.
On the basis of a so processed infrared dataset a statistical model should be learned that is able to describe the influence of external and internal factors on the infrared texture of a person. The goal behind this is to develop a preprocessing step, for example for recognition methods, in which the acquired thermal data is brought into a uniform status. This would support the analysis of the data and made the algorithms more robust against disruptive influences.

[1] V. Blanz and T. Vetter, "A Morphable Model for the synthesis of 3D faces", *Computer Graphics Proc. SIGGRAPH '99*, pp. 187-194, 1999.

10.13 Improvement and Evaluation of the 3D Morphable Model for Faces

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The main advantage of the 3D Morphable Model[1] (3DMM) in contrast to 2D Face recognition methods is the identification of faces in very difficult conditions (e.g. high rotation angles, different illuminations/exposures). To improve the universality of the model it was neccessary to include more types of image artefacts and acquisition circumstances. The influence of image resolution, defocus, coding artefacts, noise and extreme illumiations on the model had not been researched.
Hence one essential goal was the evaluation of this influence and the gain of additional information in "corrupted" images. The main intention is the reconditioning of faces in images with high varying qualities to improve the recognition of faces for human observers.
One goal was the improvement of the universality of the 3D Morphable Model to include more types of image artefacts and acquisition circumstances. Therefore the influence of different types of image artefacts have been researched.
The influence of image resolution, defocus, coding artefacts, noise and extreme illumiations on the model had not been researched yet.
An idea/goal is the fusion of artefact reduction methods from classical 2D image processing as well as the adaption and extension in the 3D Morphable Model.
One approach, for instance, is the application of contrast enhancement methods (one simple example: histogram equalization) to become independent of extreme illumination scenarios. It is also feasible to add noise reduction mechanisms to the Morphable Model. The question remains how to combine 2D methods with 3D methods: One possibility is to include the 2D image into the 3D Model. Another option is to work on the 2D image itself. To accomplish this, the first step is the estimation of the boundaries considering noise, resolution, exposure, mentioned above.

[1] V. Blanz and T. Vetter, "Face Recognition Based on Fitting a 3D Morphable Model", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 25 (9), pp. 1063-1074, 2003.

10.14 Face Recognition in Unknown and Difficult Lighting Conditions

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Lighting can severely change the appearance of the face of a particular person, thus face recognition systems need to be stable against differences in illumination. Yet, the illumination is not only influenced by the existing light sources but also by the existing objects in the environment, which reflect light on the face; objects such as walls, ground, cloths, etc. With the goal of illumination invariant face recognition, I am going to modify the existing face recognition systems so that they can work more accurately on single images which have been taken under unknown and difficult lighting conditions. Estimating the 3D geometry and the light effects on a surface is an ill-posed problem in computer vision that can only be solved with prior knowledge about the scene. The algorithm uses a 3D Morphable Model and an analysis-by-synthesis approach to reproduce and analyze an image of a face. One goal of this project is to develop new methods and models that cover sophisticated illumination and shadowing effects and material properties. This result provides a more realistic estimation of light and shadow effects than previous algorithms.

10.15 Robust Skin Detection with an Active Near-Infrared Camera System

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Contactless detection of human limbs at manually-fed machines or robot workplaces is a desirable feature for safety applications, as they are often equipped with potentially dangerous moving parts that are difficult to shield off from the reach of the user, rendering them very prone to accidents. A reliable detection of human skin is also very interesting for security applications, as it allows the detection of fakes at biometric recognition systems.
This work analyses robust skin detection and localization methods in real time using a near-infrared camera. It's focus is on the scientific research of the problem, as well as the development and evaluation of possible approaches using a prototypical implementation of a respective camera system.
The concept of a fast and reliable LED-based scanning sensor using several LEDs of distinct wavebands within the near-infrared (NIR) spectrum has been researched for several years at the University of Applied Sciences Bonn-Rhein-Sieg.[1,2] The LEDs sequentially generate short strobe pulses to illuminate objects in front of the sensor, which measures the remission intensity for each waveband. This so-called *spectral signature* is used to classify the object's surface material. The wavebands are chosen based on the characteristic remission properties of human skin in the NIR spectrum, which are widely independent of skin tone, gender and age.
This research investigates the use of an imaging sensor instead of single point sensors in order to widen the applicability of the sensor system. An active NIR camera system has been developed, using an InGaAs camera in conjunction with a custom-made ring flash light. The ring light is synchronized with the camera, allowing to take images with illumination in just one specified waveband and to combine these single images to a multispectral image. Upcoming problems such as optical distortions, noise and motion artifacts have to be solved and algorithms for the calibration and correction of these problems, as well as suitable classification algorithms for the robust distinction of skin and other materials have to be developed.
The first results of the camera system show that the approach is feasible and very promising. With reliable and sensitive classification algorithms, more complex safety applications can be addressed as well as new applications in the area of security can be opened up.

[1] O. Schwaneberg et al, "A near-infrared led-based material classification sensor system," in Optical Sensors. Optical Society of America, 2011, p. SMD4.

[2] O. Schwaneberg et al, "Material classification through distance aware multispectral data fusion," in Measurement Science and Technology, 24(4):045001, 2013.

11 GRK 1651: Service-oriented Architectures for the Integration of Software-based Processes, exemplified by Health Care Systems and Medical Technology (SOAMED)

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Service orientation is a promising architectural concept to quickly and cost efficiently couple encapsulated software components (*services*), and to adapt them to new requirements. It has mainly been suggested for co-operating business processes. Recently, its application in embedded systems as well as in complex information systems is increasing. As service orientation has evolved from very pragmatic problems and backgrounds, little attention has been directed towards theoretical and conceptual problems. Furthermore, only rudimentary software technology methods for services are available. Examples of systematically constructed service-oriented architectures are presently visible only to a minor degree.

Informatics is a key technology for innovative organization of health care systems and for medical technology. Compared to processes from other areas, medical processes are more versatile, and the reliability and correctness requirements are higher. Further, they are usually loosely coupled. Their integration is as much difficult as important. Theoretical and methodological foundations of both the design process and the structure of service-oriented systems might substantially improve the support of medical processes by information technology.

The core idea of this graduate school is to underpin the currently pragmatically focussed service-oriented approach with theoretical foundations by integrating established as well as emerging software engineering procedures.

This approach aims at a decisive improvement of concepts, methods, and tool support for service-oriented system construction.
The scope of innovation of this graduate school is far reaching: health care systems as well as medical systems are presently dominated by structures and processes that can substantially be improved by the concepts and methods developed by this graduate school. As working groups of medical researchers are incorporated, practical relevance of the the concepts developed in the graduate school is assured.

11.1 Foundations of Dynamic Coalitions Formalizing Dynamic Coalition Formation with Event Structures

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Dynamic Coalitions (DCs) is a term denoting some entities cooperating temporarily to achieve a common goal, and then such coalitions resolve. The key feature of a dynamic coalition is that they evolve over time, where members can join and others can leave until the goal is achieved. That's what gives it its dynamicity. Others call it the membership problem, but we call it here by a broader term: Dynamic-Coalition Formation phenomenon, which holds all the dynamicity details and membership events. There is still no clear formal definition of such phenomenon, and thus we are working on that. This formation problem can be seen as a process consisting of events with concurrency. Besides, there might be conflicts in-between these events like conflicts in membership, in addition to causality and dependency.
For that reason we have found that the simplest match or formalization tool to apply is Event Structures (ESs). ESs are concerned directly with events and their relations like causality and conflicts. An ES is a set of constraints and relations defined between a set of events, defined statically, and then many runs are possible to derive out of that structures, all fulfilling the defined constraints and reflecting some runtime or dynamic scenarios. By that we can give a formal definition to our problem. But the question comes: is that enough, to use this native simple form of ESs to define precisely the problem? Or new extensions and ideas should be added?
In fact the medical sector which inspires this work, has its own kind of requirements and criteria. For example the concept of priority is needed when members compete on resources, like doctors try to work together on a patient. Other extensions that might be needed is the concept of evolution over time for the structure representing the coalition. As the coalition evolves over time, the ES should not be static and defined since the very beginning of the coalition. Rather it should itself be flexible and changeable so that it evolves over time. By that, we will be able not only to represent the scenarios possible to have for the formation of a coalition, but also to reflect the evolution.
We have worked on the concept of priority and defined that as an extension to different available event structures, but we are still working on the second idea, and that would be our future work.

11.2 Synthesis of Behavioral Adapters for the Composition of Data-dependent Services

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Service-oriented architectures (SOAs) have been introduced as a paradigm that allows for the creation of sophisticated functionalities by composing different services. Hereby, services interact with the environment and with each other through interfaces. Due to the independent development of such services by different service providers, several incompatibilities between their interfaces arise. Because services cannot be changed internally the synthesis of adapters becomes necessary to enable their composition. However, the manual development of such adapters makes the service composition error-prone, time consuming and increases the development costs unpredictably.
Thus, the aim of this dissertation is to allow for a (semi-)automatic behavioral adapter synthesis. Currently, there is no approach regarding data dependent behavior and its integration in the adapter synthesis process. Hence, new methods representing data types and analyzing data dependencies are needed to ensure a verifiable, reliable and data dependent adapter synthesis process.
For that reason, this dissertation uses the wide range of illustration and analysis facilities of algebraic and coloured Petri nets to enable the representation of data types and data dependencies and aims to develop theoretical fundamentals that can be used in the adapter synthesis process. In particular, the analysis facilities allow for the verification regarding important properties like deadlock- and livelockfreedom on the base of invariants and reachability analysis.
Thus, we achieve a reliable adapter, so that the composed system is correct with respect to safety-critical requirements. This constitutes the base for an application in the medical domain such as an automated and safe integration of medical devices. This kind of integration constitutes a major challenge, especially if complex communication and, accordingly, data dependent behavior occurs between the devices. To demonstrate the correctness and applicability of our (semi-) automatic adapter synthesis, we apply it to a case study from the medical domain where data dependencies are key factors.

11.3 Adaptive Scheduling of Scientific Workflows

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Over the last two decades, scientific workflow management systems (SciWMS) have emerged as a means to facilitate the design, execution, and monitoring of reusable scientific data processing pipelines. At the same time, the amounts of data generated in various areas of science outpaced enhancements in computational power and storage capabilities. This is especially true for the life sciences, where new technologies increased the sequencing throughput from kilobytes to terabytes per day. This trend requires current SciWMS to adapt: Native support for parallel workflow execution must be provided to increase performance; dynamically scalable pay-per-use compute infrastructures have to be integrated to diminish hardware costs; adaptive scheduling of workflows in distributed compute environments is required to optimize resource utilization.

In this dissertation, we develop a heuristic algorithm for adaptive scheduling of data-intensive scientific workflows executed on shared computational infrastructure such as computational clouds. We intend to consider and exploit several characteristics inherent to cloud computing: (1) elasticity, which denotes the possibility to provision additional resources at runtime; (2) heterogeneity of computational resources; (3) dynamic changes of performance characteristics at runtime; (4) substantial data transfer times between cloud instances.

We then conduct a comparative analysis of the developed algorithm with implementations of scheduling in well-established SciWMS. We examine the runtime characteristics and performance requirements of data-intensive scientific workflows, mostly from the field of bioinformatics. The feasibility of our approach towards adaptive scheduling will then be elucidated by simulating the execution of aforementioned workflows on cloud infrastructure. Subsequent to further refinement of the algorithm, a prototypic implementation will be developed and evaluated on actual cloud infrastructure, such as Amazon EC2.

11.4 Operating Guidelines for Timed Services

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Service-oriented computing (SOC) aims to build complex systems from less complex, loosely coupled building blocks called services. A service is a self-contained unit of functionality with a well-defined interface that is used to communicate with other services. The key feature of SOC is the compositionality of the services: The result of a service composition is a new service which can again be composed with other services until the service composition has the desired functionality.
Functional correctness of a service composition is critical for a service-oriented system. We say that a service composition is functionally correct if it satisfies a functional correctness criterion such as deadlock freeness. Health care systems and medical devices are an example domain where functional correctness is particularly important because defects may lead to increased costs or even injury. Functional correctness is often verified by model checking techniques using formal models of the participating services.
But to facilitate the flexibility offered by SOC, functional correctness must be verified whenever a service-oriented system is changed, i.e. at runtime. This is however not always possible due to two reasons: First, detailed formal models of the behavior of the participating services must be available at runtime. Second, the correctness verification methods must be efficient enough to be performed whenever the system is changed. Consequently, the development of verification methods for behavioral correctness that satisfy these two requirements is an important area of research.
Time is an important concept for many service-oriented systems. It is usually introduced by adding time constraints to the formal models representing the service's behavior. Formal correctness verification becomes more challenging when such time constraints must be considered. Thus, the goal of this thesis is to develop a method to verify the functional correctness of a service composition at runtime in the presence of timing information. To this end, we extend the operating guideline approach to support the specification and analysis of services with time constraints. Our method allows to verify not only whether the composition of a set of such timed services is functionally correct, but also whether a given timed service is controllable at all.

11.5 A Formal Framework for Mobile Service-Oriented Sensor-Actuator Networks

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Mobility, self-determination and independence are some of the major factors defining the quality of life. With rising age people often develop physical and mental diseases of different degree influencing their options for an independent and mobile life style. Service-oriented sensor-actuator networks (SOSANETs) employed as assistant systems at home and en route can support the user by securing their everyday life. These networks are highly dynamic. New communication channels are built on-line, connecting the system with other previously unknown SOSANETs. These systems are health-critical and have to fulfill strong safety requirements. Up to now, there exists no formal modeling framework for the verification and analysis of SOSANETs. The common approach is to evaluate network behavior by running test scenarios on prototypes or simulations. These tests do not cover the whole state space of the network and cannot ensure correct system behavior.
In this dissertation, we are going to develop a framework for modeling, analysis and verification of SOSANETs. First we are going to adapt and extend an existing formal language to suit our requirements. Afterwards, we set our focus on the ability to verify correct network behavior after topology changes. Especially, the interaction with components, which were unknown at design level, has to be representable. With that, it is possible to model and verify the functional correct interaction of services of independent SOSANETs. Furthermore, we need to model the sudden disappearance of existing communication channels due to the breakdown or movement of a node. In this regard, we are going to invest the fault-tolerance of our system. Finally, we will prove the applicability and correctness of our approach using a case study from the medical domain.

11.6 Process Architectures in Healthcare

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The healthcare domain is highly regulated but at the same time volatile. It is characterized by a plethora of actors, both private and public. Many business processes of different kinds (regulation, administration, financing, medical treatment, etc.) executed by various entities need to interact to achieve the desired outcome, a functioning healthcare sector. To some degree this already becomes apparent on the level of a hospital, which takes part in many of the overarching processes and therefore constitutes a subject of this dissertation.
Bottlenecks in medical treatment often stem from poor interplay between processes realized in different functional units of the hospital, leading to prolonged stay of patients and higher costs. Doctors spend a lot of time entering data into information systems, documenting treatments and encoding diagnoses for reimbursement. This time could be better spend caring for patients. Such overhead often is caused by insufficient integration of clinical processes with each other and with supporting IT systems. Additional challenges are posed by the fact that business processes do not end at the boundaries of the hospital, but extend to external healthcare actors, like rehabilitation facilities, ambulance operators, resident physicians or health insurance companies.
The goal of this dissertation is to develop a framework that allows to model and analyze interrelated processes, specifically the interplay of treatment, documentation, and accounting processes in hospitals. Business Process Architectures (BPA), which capture the interrelations of business processes in an organization, could be a viable approach. They not only enable a better understanding of the process interplay through visual presentation but also provide the basis for validation and formal analysis. BPA models for a hospital (or parts thereof) could point out bottlenecks in business processes and identify interfaces with external actors. Enriching BPAs with information about IT systems and regulations would possibly allow to check for compliance, as well as find process activities, that would benefit from IT support and automation, thus leaving doctors more time to attend to their patients.

11.7 Privacy Protection in SOA-based Medical Applications

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Health care providers use Hospital Information Systems (HIS) to manage patient data. In the course of a patient's treatment, various health care providers, e.g., hospitals or medical laboratories, collect lots of medical data. In general, the HIS of these providers are not connected. Every provider manages a separate database to store the patient records.
Some medical treatments may involve the cooperation of several health care providers. Therefore, the involved health care providers exchange the required medical data, e.g., access blood analysis data from medical laboratories. In general, regulations of privacy protection define strong constraints for exchanging such personal data within a distributed system. Privacy-preserving query protocols provide mechanisms for implementing and maintaining these privacy constraints.
In this thesis, we introduce a new two-phase protocol for protecting the privacy of patients. The first phase implements a private record linking. Thereby, the queried data provider links the received query with matching records in his database. In the second phase, a requestor and a data provider perform an authorized exchange of matched patient data. Thus, our protocol provides a method for health care providers to exchange individual medical data in a privacy-preserving manner. In contrast to other approaches, we actively involve patients in the exchange process. We apply the honest-but-curious adversary model to our protocol in order to evaluate our approach with respect to complexity and the degree of privacy protection.
Furthermore, we provide a general methodology to add Privacy-Enhancing Technologies (PETs) to services. Usually two services use messages to interact, e.g. XML-massages. These messages match a concrete schema. Based on the attributes contained in the schema we select adequate PETS to generate special adapter-services called privacy facades, which can be composed to the original services. Thus, we provide a method to include new privacy-constrains into existing services without changing the internal behavior of these services.

11.8 Canonical Partners for Services

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Service-oriented computing (SOC) is based on the interaction of loosely coupled software components called services. A *service* encapsulates functionality behind a well-defined *interface*. For two services to interact, their interfaces must be compatible. In this case, we call them *partners*. We may further impose *requirements* on their interaction. For example, we may require the absence of deadlocks. Requirements can be expressed in terms of temporal logic, specifically CTL*. For a requirement R, a partner U of T is *R-respecting* if and only if the interaction of T and U fulfills R. T has either infinitely many R-respecting partners or none.
We aim to finitely represent the infinite set of all R-respecting partners. To this end, we utilize the concept of *canonical* R-respecting partners. Intuitively, no R-respecting partner exhibits more behavior than a canonical R-respecting partner. Depending on R, there are finitely many canonical partners. Then we call R *finitely representable*.
Canonical partners tackle problems involving functional correctness. Notable applications of canonical partners include service discovery, service substitution, service adaptation and service correction. Ensuring functional correctness is imperative in complex domains like health care systems. For instance, deviations may lead to increased costs or legal claims.
Recently, canonical partners were developed for bounded communication, deadlock freedom, weak termination and strong termination. Thus these requirements are finitely representable. These four requirements are fundamental but not sufficient for expressing correctness in complex domains.
Instead of examining another individual requirement, we study classes of requirements with regard to finite representability. The goal of the thesis is (1) to characterize classes of finitely representable requirements, and (2) to find a method for constructing canonical partners for finitely representable requirements.

11.9 Conformance Checking for Open Systems

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Best engineering practices suggest *specifying* a system before actually *implementing* it. Both the implementation as well as its specification have *behavioral properties*. *Conformance* checking is deciding whether the implementation of a system preserves a certain behavioral property of its specification. This is the central scientific problem of this thesis.
Over the past years, there has been a shift in systems engineering from monolithic, closed systems to distributed systems, composed of *open systems*. Therefore, our research centers around conformance checking for open systems. An open system interacts with other open systems—that is, its *environment*. Of particular interest are environments in which a certain behavioral property holds. We refer to such an environment as a *partner*. For an open system, conformance checking translates to deciding whether each partner of its specification is a partner of the implementation. The relation of conforming implementations and specifications may be *compositional*—that is, conformance is preserved under open system composition. In this thesis, we consider both conformance as well as compositional conformance, as they generally differ.
We consider conformance checking for open systems in two distinct scenarios. In the first scenario, the *model-model scenario*, we assume the specification and the implementation of an open system to be given as formal models. We characterize (compositional) conformance of open systems according to five relevant behavioral properties, and show its (un-)decidability.
In the second scenario, the *log-model scenario*, we assume the specification of an open system to be given as a formal model, but this time no formal model of the implementation is available. However, most implementations provide some kind of observed behavior, commonly referred to as *event log*. The idea is to use an event log to check conformance of the unknown implementation to its known specification. We consider conformance checking for the same five behavioral properties as in the first scenario. We analyze whether there exists a conforming implementation which can produce the event log. Furthermore, we study whether we can discover a formal model of the unknown implementation from the event log, assuming the implementation conforms to its specification.
Finally, we implement the decision algorithms from the first scenario and show that they can be applied to examples of industrial size. Using the decision algorithms from the first scenario, we develop algorithms for both questions in the second scenario. Again, we evaluate the implemented algorithms with industrial-sized specifications and event logs.

11.10 Quantitative Analysis of Security- and Reliability-Properties in Service-based Software Systems

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Providing and maintaining effective healthcare is among the most important, costly and complex challenges of public administration. It is characterized by a high degree of integration and cooperation between many public and private institutions, companies and people - each covering aspects of patient treatment, billing and research. Therefore, healthcare is especially dependent on the availability and exchange of information between institutions and departments. Service-oriented architectures are a well-suited software paradigm to encapsulate data sources and functionality in services and build complex software systems on top of these.
The advent of cloud computing enables outsourcing such services to cost-effective, scalable and powerful infrastructure. Cloud infrastructures provide good accessibility of information which needs to be accessed by and shared between many different parties.
However, the user of cloud services usually has little control over the used infrastructure: The hardware is not under his physical control, legal implications unclear and terms of services are usually not negotiable. Hence, new methods are required to consider the security and availability properties of cloud infrastructures in software design.
The goal of this dissertation is to develop quantitative analysis methods for availability and security properties of service-based software systems. The structure of service-based software systems and its security and availability properties are represented in a system design model. Based on this model, quantitative analysis methods are used to derive stochastic measures, which allow the evaluation of different design alternatives regarding their security and availability properties. Different security mechanisms are developed and analyzed, which can improve security and availability. The application of these mechanisms is illustrated in case studies and their influence on the systems security properties is analyzed using the developed analysis methods. Use cases requirements are derived from the real-life scenario of the newborn hearing-screening program in cooperation with Charité hospital.

11.11 Scenario-Based Design of Data-dependent Services

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A designer of a *service-oriented architecture* (SOA) faces the problem that the design of a single service may succeed quite easily, but the interactional behavior of all services may be hard to assess. One approach to tackle this problem is to model the behavior of services by *scenarios*. A scenario describes a part of the behavior of many services that may be interactional and that can occur (and repeat, respectively) if a distinguished precondition is satisfied. In this way, the behavior of all services of a SOA can be described. Scenario-based modeling is assumed to be a more intuitive and comprehensible way to describe interactional behavior of services than modeling each single services separately in one model.
Yet, analyzing and verifying the behavior of one or many services, as well as implementing the single services on the basis of the model, still requires a model of each single service. The aim of *scenario-based design* is to automatically derive a model of each single service out of a set of scenarios. The models of the services must *satisfy* the set of scenarios: Each run that is specified by the scenarios must also be exhibited by a service model or by the composition of service models. Further, if synchronization between services is allowed that is not specified in the scenarios, the service models should exhibit exactly the runs specified in the scenarios. If no additional synchronization is allowed, in general the service models exhibit more runs than specified in the scenarios. In this case, the set of additional runs exhibited by the service models compared to the set of scenarios should be preferably small.
For reasons of practical applicability, a scenario-based modeling language should provide means to explicitly represent data, as well as to abstract from concrete behavior. Representing data provides the opportunity to model big systems in a compact way, as well as to express data-dependent behavior. By means of abstraction the modeler can keep the scenarios small and manageable and can still express causal dependencies accurately.
The aim of this thesis is to develop a method for scenario-based design such that (1) the scenario-based modeling language provides means to represent data and abstraction, and (2) models of services where data is explicitly represented can be automatically generated from the set of scenarios such that they exhibit no additional runs which are not necessary.

11.12 Probabilistic Estimation of Unobserved Process Events

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Business process management strengthens a company's competitiveness and provides means to control and improve the efficiency and quality of processes. A part of managing processes is process monitoring, i.e., keeping track of the activities in a process. Monitoring is essential to detect bottlenecks and react to deviations from the expected or guaranteed performance of a process. The focus of this thesis is on scenarios, where monitoring information is sparse, i.e., not all relevant process activities can be monitored.
When part of this important execution information is missing, we can rely on probabilistic methods to estimate the probabilities of the activities, i.e., when will an activity probably start, or when will it finish? In this thesis, we propose a method to perform probabilistic inference based on Bayes' theorem, in particular we use Bayes networks to capture the dependencies dictated by the process model. The motivation is to use all information that is available, i.e., the process model that is enriched with stochastic information and all the runtime monitoring information captured by events, to reason about the unobserved process events probabilistically.
The motivating use case is that of a hospital, where documentation of treatment steps is done manually, which is prone to errors. Moreover, there exist dependencies between activities in the process model, e.g., a patient has to enter the operating room before surgery. In this case, even if a documentation entry for the "enter surgery" event is missing, this does not indicate that it was not done in reality. Here, if the entry is missing, it is assumed that the documentation is faulty, i.e., the nurse forgot to document the time. In such scenarios, estimation of unobserved process events can bring valuable insights into the process.
Additionally, we use the the developed approaches to provide estimations of remaining process durations. Furthermore, we reason about the effects on estimation quality of the positioning of documentation steps in a process. Latter technique can be used to provide an optimal strategy for good predictability of a process' duration in terms of cost-efficient documentation. The methods are evaluated in hospital settings, and their applicability to other domains is investigated in additional industry case studies.

11.13 Formal Modelling Guidelines for Dynamic Coalitions in Medical Scenarios

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Modern technologies such as service-oriented architectures enable companies and organizations to form dynamic coalitions across system borders. Dynamic coalitions may be defined as (temporary) groups of autonomous agents sharing resources or information through means of network technologies, in order to achieve a common goal. Common aspects of these coalitions are a dynamic nature of membership, information transfer and authorization structures. Examples for dynamic coalitions may be business alliances between companies in order to respond to a market opportunity or disaster response scenarios in which government, emergency services, police etc. must work together to overcome an imminent threat.
In those dynamic coalitions questions like security and privacy are of high relevance. The need for verifiable modeling concepts is obvious. Still, developers today often lack a formal basis on which to evaluate certain policy decisions concerning dynamic coalition architectures. In recent years certain efforts have been made to formally model dynamic coalitions so that they may become verifiable. This PhD-work is meant to be one important step into that direction explicitly dealing with dynamic coalition concepts in the medical sector.
Acknowledging those requirements the goal of my thesis is to provide a formal modeling framework, which captures the various important aspects in privacy-sensitive dynamic coalitions and allows software developers to test, simulate and verify their architectures before implementing them.
Up to this date I have created a set of formal models (using the ASM-formalism) for different perspectives or dimensions of privacy in dynamic coalitions. Different access control concepts have been modeled in order to grasp the various privacy needs. The designer may now choose between different levels of user-centered, role-based, attribute-based or trust-based access control mechanisms and then test or simulate the scenario in question.
In the course of this thesis a tool for the visualization of the simulation traces has been created. The tool is essentially a GUI which allows to browse ASM simulation traces and explore the evolution of the universes and entities in such simulation traces, thereby being able to understand how policies evolve and why certain access requests are permitted and others denied. With this tool it will be possible to discover the sources of unwanted behavior of the simulation.

11.14 Transformation of BPMN-Treatment Models into Constraint Satisfaction Problems

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In recent years the cost pressure in public health care services has been increasing constantly. With the introduction of Diagnostic Related Groups in 2004 hospitals are paid a flat charge corresponding to each patient's diagnosis instead of billing based on their duration of stay. These and further changes lead to the need for greater efficiency without reducing the quality of treatments and patients safety. Thus, methods from business process management have been introduced into public health care[1].
Medical treatments can be modelled in workflow languages. The main goal of my dissertation is a transformation that converts these process models into *Constraint-Satisfaction-Problems*[2] (CSPs), which a constraint-solver can solve to generate plans that allocate the process activities to the available medical staff and resources in an optimal way, thus helping in the coordination and daily operation of the medical facilities. Schedules can be optimized for different goals like minimal waiting times or maximal throughput of patients even with a reduced staff during holiday times.
The CSPs for existing planning systems are usually modelled by IT-experts. Medical staff are rarely able to adapt these constraint models by themselves when requirements or processes change. However, graphical notations exist with which medical treatments can be described as workflows. The *Business Process Model and Notation*-language (BPMN) offers a simple and easily understandable notation that can be comprehended even by non-IT-experts. An automatic transformation from BPMN-treatment models intro constraint problems would thus be a reasonable and useful extension of existing planning systems, allowing domain experts like physicians and hospital organizers to adapt their medical processes on their own.
Alongside the conception and realization of the transformation, it's verification is also an important part of this work. The semantics of the BPMN-models have to be preserved by the transformation and respected by the generated plans. Furthermore, the heuristics for variable and value selection, which control the constraint-solver when exploring the search space, significantly influence the speed in which a solution is found. Therefore, I plan to investigate, to what extend optimized search heuristics can be inferred from the BPMN-model and how they perform compared to strategies automatically chosen by constraint-solvers.

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11.15 Similarity Search for Scientific Workflows

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In recent years, scientific workflows have been gaining an increasing amount of attention as a valuable tool for scientists to create reproducible in-silico experiments. For design and execution of such workflows, scientific workflow management systems (SWFM) have been developed, such as Taverna, Kepler, and several others[1]. They enable the user to visually create pipelines of data processing tasks, including both local scripts and, especially, web-service calls. Scientific workflows are used in a variety of domains, including biology, chemistry, geosciences, and medicine.

Creating scientific workflows using an SWFM is still a laborious task and complex enough to prevent non computer-savvy researchers from using these tools. Thus, there has recently been growing interest in sharing, reusing and repurposing such workflows. This is reflected by the emergence of online repositories for scientific workflows[2]. The increasing number of scientific workflows available in these repositories raises the question of how to best enable both manual and automatic discovery of those workflows which suit a given task. The ultimate goal is to allow scientists to use scientific workflows without detailed knowledge of the process of their creation. For instance, given a workflow they have used before, similar (or complementary) workflows could be suggested which would be instantly executable on the data at hand. An important step towards such scientific workflow discovery is the investigation of workflow similarity and the establishment of adequate similarity measures.

Thus, the overall objective of this thesis is the development of methods and algorithms in support of the discovery of shared workflows. In this, we pursue four consecutive research tasks. First, we closely investigated the available workflows to determine whether further investigation of similarity measures is promising[3]. Second, we are developing a library of similarity measures based on different workflow properties to assess scientific workflow similarity. Third, the results of the second step will be evaluated. And fourth, it is planned to integrate the established methods for similarity search into existing repositories to improve workflow discovery.

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11.16 Automated Composition of Timed Services for Synchronizing Medical Devices

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The development of controller programs coordinating distributed components in safety and time-critical environments is a very complex task. On the one hand, the correctness with respect to functional and non-functional properties, like timed behavior, has to be assured, which significantly increases the length of development cycles. On the other hand, development time has to be short to achieve a small time-to-market. In this thesis, we address the problem of closing the gap between these opposites with automated development methods assuring correctness by construction.
We lift the problem of creating a controller model to the problem of automated service composition. Our method shall be able to generate controller models for a given set of timed services with respect to functional and non-functional (especially timed) requirements. We describe the behavior of the services as *timed i/o automata* (*TIOA*) and the composition requirements in the temporal logic *Timed CTL* (*TCTL*). The generated controller, which is an orchestrator in the context of service-oriented computing, is a TIOA handling the input and output actions of the individual automata. To realize our approach, we adapt the concept of model checking for identifying action sequences leading to correct behavior. Furthermore, we provide an efficient symbolic implementation of our methods.
Current approaches considering real-time properties only offer limited possibilities for expressing composition requirements. In particular, for *Timed CTL* (*TCTL*) goals, only a small subset of TCTL is supported. In many practical applications, e.g. in medical systems, we need to perform an action infinitely often while ensuring that a certain amount of time passes between each action. Such requirements cannot be expressed by the above-mentioned approaches, but are indispensible for said device control problems. The methods we develop support these requirements, by allowing arbitrary nesting and the conjunction TCTL formulas.
A particularly interesting domain for our approach is the synchronization of medical devices. Here, functional and real-time requirements have to be met in order to guarantee the patient's safety. We show the applicability of our approach through case study where a health-monitoring driver assistant system supporting elderly people has to be controlled. Finally, we evaluate the performance of our implementation with larger case examples.

11.17 Approach to an Individualizing, Adaptive Prediction System

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The subject of this work is an approach, where the adaption of a medical treatment process should be realized according to the criteria individuality, flexibility and predictability: The process should be customized to requirements of the individual (individuality), react on certain external influences (flexibility) and learn the adaptions, which were necessary to meet the patients needs, to predict them for new patients (predictability).
The aim is to analyze and to extend existing methods of information technology, which can be utilized for the adaption of treatment processes to dynamic changing requirements according to the mentioned criteria. It is about an agile kind of process adaptation to changing conditions and requirements, which are newly appearing or were not considered before- all on basis of treatment data. For the information technological conception, methods of the areas Data Mining, Machine Learning and Business Process Management should be chosen, examined, combined and extended such as this work could contribute to an IT-assisted solution to the mentioned problem statement. The challenges in this are the handling of the dynamics of the considered treatment data.
Finally the achieved findings should be applied to an amount of data to evaluate the results. For this purpose two case studies will be considered one of which could be the following: The medical treatment of stroke patients poses high demands on healthcare actors. These include interdisciplinary cooperation in treatment teams across institutions, generally working over months or years. At the centre of the treatment is the stroke patient, who is in consequence of versatile attributes like the severity of stroke, the parallel existence of other diseases, etc. characterized by individual factors, which have an influence on the treatment paths. Those individual characteristics of the Patient have to be considered in the treatment, as otherwise the success of therapy will be jeopardized or made impossible. Thus, the treatment process has to be adapted to the individual requirements of the patient and to changing real-life terms and conditions of the treatment to assure a chronological and content-sensitive dynamic sampling.
After the conceptual arrangement of the work, an exemplary application of this approach should be executed on anonymous treatment data. Furthermore another case study, which has yet to be defined, should be arranged to make a statement on the possibilities of generalizing the method.

11.18 Running Data-intensive Services on Multicores Architectures

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Today's Database Management Systems (DBMS) are based on hardware resources of the 80's. The migration of single-core architectures to present-day multi-core architectures can be automated only to a limited extent. The migration provides opportunities as well as challenges for data-intensive applications. Especially databases, that process multiple queries in parallel might potentially benefit from this fundamental change in hardware architecture. A data-intensive service using databases as the primary data sources relies mainly on two different types of parallelism to reduce processing time. First, *data-parallelism* appears due to the independence between data items. Second, the processing itself can be parallelized on multi-core or many-core systems, so-called *thread-parallelism*. Therefore, the incoming data items are distributed among the available computing units. This further speeds up the processing of independent data items. The main research goal in this area is to design algorithms that exploit such massive parallelism.
The current multicore architectures result from the continual increase in processor clock speed in the last 35 years which ended around 2005 due to physical limitations. To enhance the performance of existing and future applications, processor vendors started to build CPUs with more than one core at lower clock speeds. Furthermore, vendors offer chipset extensions like *Single Instruction Multiple Data* (SIMD) that are able to run one operation simultaneously and very efficiently on multiple independent data items.
As Sutter et al. announced, "*the free lunch is over*", which means that there is less speedup for applications expected in the future based on faster processors. Therefore, a *fundamental turn towards concurrency* must take place to further increase the performance of existing and future applications. Developers are encouraged to shift their efforts from speedup of sequential execution to enable parallelism. Furthermore, the utilization of chipset extensions like SIMD will be crucial for future application performance. To support this major change in software engineering, our work attempts to contribute concepts for efficient data-intensive services utilizing modern chipset extensions as well as multi-core and many-core architectures. Our goal is to explore concepts for massively parallel processing of large data sets. Our approach provides a central service instance as the main entrance point for any data request. Starting at this entrance point, we process the requested data massively parallel and transparent for the user. We choose the medical IT applications as our application example with their huge amount of sensitive data.

12 GRK 1765/1: System Correctness under Adverse Conditions (SCARE)

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The Research Training Group (RTG) SCARE addresses computerized systems that are placed in an environment with which they cooperate. System correctness means that the cooperation between environment and system satisfies desired behavioural properties. SCARE systematically investigates the problem of system correctness under adverse, only partially predictable conditions which can in?uence the behaviour of the system, the system context, and the assumptions made for verifying correctness. The RTG will consider three aspects of adverse conditions, both individually and in their combination: * limited knowledge, * unpredictable behaviour, * changing system environment and system structure. The main aim of SCARE is research into notions of system correctness that guarantee robustness of the system behaviour under such adverse conditions.

12.1 Design and analysis of power conservation techniques for maximizing the lifetime expectancy of tiny sensing devices

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The main goal of our work is to maximize the lifetime expectancy of special purpose wireless sensor networks (WSNs). In particular, we focus on exploiting the trade-off between reducing certain quality-of-service (QoS) measures to a degree still tolerable by the application (such as, for example, accuracy of measurement) and maximizing the application's lifetime expectancy. These objectives will be achieved through the following sequential steps.
First, the power consumption of the different subsystems inside sensor nodes as well as the power consumed by particular external sensors will be investigated. Second, novel techniques will be developed for minimizing the power consumption such as utilizing software sensors instead of hardware sensors, or utilizing Cognitive Radio to adapt the subsystems according to the workload and the residual energy. Third, the management of the hardware components (among them sensors and actuators) by the operating system will be investigated and, based on this analysis, novel energy-saving approaches for their use will be developed. In a subsequent step, different solutions will be proposed for the power consumption problem from the network point of view such as minimizing the transmissions and scheduling long sleep. We plan to test our techniques on a suite of WSN sample applications. Where suitable, Identified beneficent techniques will be applied on smartphones in order to maximize their lifetimes while still offering acceptable QoS to the user.

12.2 Verification Techniques for Dynamically Typed Programs

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For internet programming often script languages like JavaScript, Python, or Ruby are used, which are object-oriented and dynamically typed, i.e. the type safety of method calls can be checked only at run time. On the one hand, these languages enable programmers to write elegant, reusable and extendable programs, on the other hand, they create challenges to software verification. In the sense of the correctness relation (1) the methods of the program represent a system Sys that has only limited knowledge of the way how it will be used by the environment Env in the form of method calls. Additionally, some of these languages offer more advanced dynamic features like reflection, method update or code generation, allowing the type system, the program or even the language itself to become the object of runtime manipulations. Techniques for establishing the correctness of programs in such dynamic environments Env under an appropriate set of assumptions Asm shall also be investigated.

12.3 Structure-Changing Petri Nets as a Model of Adverse Conditions

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A large class of discrete, concurrent systems can be modelled with Petri nets. When the system structure is not fixed but subject to change, extended formalisms are required. Graph transformation systems are among those formalisms that extend Petri nets to allow the explicit representation of structured states, and a dynamic connectivity. The expected operational behaviour (Sys) is described as a set of firing rules resp. graph replacement rules for the firing of transitions. Beyond that, adverse conditions by the action of the environment (Env) reflect the fault model. They can be modelled by structure changes in the net, and also represented as a set of rules. The goal of the proposed thesis is to provide a theoretically founded formalism for specifying properties of such systems subject to adverse conditions, and ways to prove or disprove the satisfaction of these properties.
To this aim, we plan to build on, and extend in several directions, the existing body of work on the correctness of graph transformation systems and graph programs. Correctness here is understood with respect to specifications consisting of pre- and postconditions in the form of graph conditions. Graph conditions, which exist in several variants, are graphical / algebraic expressions akin to formulae of graph logics. An important part of the thesis will be dedicated to the examination of the expressivity of new kinds of spatio-temporal graph properties, and the decidability of classes of properties that are interesting from a modelling point of view, i.e. whether a given system model, under a set of assumptions (Asm), satisfies (sat) a given specification ($Spec$) of correct system behaviour. There may be grades of correctness, and under certain adverse conditions it may be permissible to relax a specification. To address adverse conditions, it is further important to understand how to present an integrated view of the interplay of the environment and the system. It would not be reasonable to impose a sequentialisation or alternation on system operation and faults, as this does not do justice to the distributed functioning of large systems. Env and Sys can be understood as actors playing an asynchronous game. Both parts are composed in parallel ($\|$) and interact via a shared state.
Case studies could include an example for weak or graded correctness in a railway system, for our purposes modelled in a simplified discrete way as a system where trains move on a network graph, carrying passengers (tokens) from one station node to another: under particularly difficult conditions, it might be weakly correct behaviour to accept a re-routing of passengers, but it is under no circumstances correct to permit a crash.

12.4 Processing the Uncertainty: Gathering and processing quality in multi-sensor data stream processing for dynamic context models

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Due to the fact that currently operating autonomous vehicles can observe only a limited area with their onboard sensors, safety regulations often dictate a very slow speed. However, as more and more sensors in the environment are available, we can fuse their information and provide extended information as a shared context model to support the autonomous vehicles. In my thesis, I consider a scenario with a publicly accessible area that is populated with autonomous transport vehicles, human guided vehicles like trucks or bicycles, and pedestrians. I analyze requirements and challenges for highly dynamic context models in this scenario. Furthermore, I propose a comprehensive system architecture that can cope with these challenges, namely deterministic processing of multiple sensor updates with high throughput rates, prediction of moving objects, and on-line quality assessments, and demonstrate the feasibility of this approach by implementing the generic system architecture with sensors for object detection and tracking.
To this end, I leverage concepts from data stream management technologies and complex event processing engines to perform the sensor fusion and dynamic context generation. Furthermore, I extend these technologies by a probabilistic approach for on-line quality assessment. This includes new operations and data types in the mentioned technologies and data structures to represent the a priori knowledge about sensors, sensor data, and context quality and techniques to estimate the quality of sensor data streams.
To evaluate my approach I will concern two application scenarios: The first scenario is a logistic area in which vehicles are using the dynamic context model for path planning. The path planning algorithm uses the quality information about the position and the direction to find the best way to avoid collisions with these obstacles. The evaluation will show the benefit of quality information in this kind of application through a smaller search tree for possible safe trajectories for the vehicles and thus, a faster processing. The second evaluation scenario will be an intersection to record possible accident. In this scenario an intersection that is equipped with different kinds of sensors is used to detect possible accidents. In this scenario the quality of data is necessary during the detection of such situations. To evaluate the scenario a false-negative and a false-positive evaluation of the correct processing will be performed.

12.5 Graph Conditions with Variables and their Application in Metamodel Instance Generation

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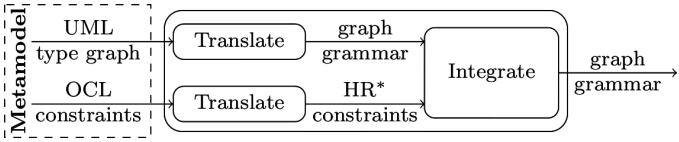
Increasing complexity in software systems calls for design concepts that allow an intuitive overview of a system. We model states by graphs and state changes by graph transformation systems. Structural system properties can be described by nested graph conditions [1].
Nested graph conditions cannot describe non-local properties (connectedness, circle-freeness). We propose HR* *conditions* [2], an extension of nested graph conditions by variables in the form of hyperedges, which can be replaced by graphs, according to a hyperedge replacement system.
The expressive power of HR* conditions lies between counting monadic second-order and second-order logic [3]. Thus, it is possible to express properties like the existence of paths, circle-freeness, or that a graph has as many a-labeled as b-labeled nodes.
We apply HR* conditions in the generation of UML metamodel instances. A type graph, specifiecd by an UML diagram, can be transformed into a graph grammar. HR* conditions can be used as application conditions for graph grammar rules. Our goal is to transform the OCL constraints attached to the UML model into HR* constraints and further to application conditions, allowing easy generation of metamodel instances.



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12.6 Information Flow Security

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One of the main concerns in the field of security is confidentiality. All parts of a system and its users should only be able to access information present in the system according to the *security policy* imposed by the system's designer. This security policy is designed to guarantee the confidentiality of information and governs the flow of information between so-called *security domains* A security domain can be thought of as a level of confidentiality when applied to information or as the privilege to access information at a certain level of confidentiality when applied to users. Information and users of the system are assigned security domains like **confidential** or **public**. For example, a typical demand of a system is that there should be no flow from the confidential domain to the public domain, i.e. that no confidential information is leaked to the public.
One of the questions in modelling systems for information flow analysis is which part of the system's state or behaviour should be considered as relevant information. A common approach is to view the set of actions a system may execute as this information and partition it according to the assignment of security domains. One very basic property in this setting is *non-interference*. A system satisfies this property if the confidential behaviour does not interfere with the publicly visible behaviour, i.e. from observing the public actions of a system we should not be able to deduce anything about the occurrence or non-occurrence of confidential actions. As this is a rather restrictive property, in practise we need ways of allowing controlled information flow between security domains. Customarily this is modelled by an intermediary domain that performs the declassification. Because in this case information may flow from the confidential domain through the declassification domain to the public domain but not directly from confidential to public such a security policy is called *intransitive*.
Another question is whether the system and the security property only have to cope with passive observers who can only see public information or must in some way defend against active attacks by users bent on altering the system's behaviour, and how to deal with the composition of systems against this backdrop.
The aim of this thesis is to investigate information flow security properties for (non-deterministic) infinite-state discrete event systems and corresponding verification procedures. A related goal is to propose security policies amenable to formal verification taking into account the different degrees of freedom in the interpretation of the system model as outlined in this abstract.

13 GRK 1773: Heterogeneous Image Systems

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Image systems are systems for processing, generating, and transmitting digital images. Typical examples are medical image processing, video games and video compression. The heterogeneity of these image systems is twofold: Firstly, the computation is spread over several components within a system. Secondly, there are numerous heterogeneous sets of architecture on which different image applications are executed.
Within the Research Training Group, three major interdisciplinary topics are investigated in 11 subprojects (A1-A3, B1-B4, C1-C4), integrating approaches from computer and electrical engineering sciences: In Area A, novel dedicated hardware for capturing and encoding image and video data is explored and developed. The subprojects consider the direct processing of image data on a photo sensor (A1), analog image processing and AD-conversion on a photo sensor (A2), and the optimized compression of image and video data (A3). In Area B, methods and tools for the efficient development and testing of applications on different platforms (product lines), as well as techniques for applications to configure themselves depending on the underlying hardware are investigated. The subprojects concern the examination of the use of the modeling standard UML2 for system design, considering (non-)functional demands and abstracting from application and system aspects (B1), the modeling for the abstraction of hardware (B4), the interface between application and hardware (B2), and consistent methods for the mapping of algorithms to heterogeneous architectures (B3). In Area C, adaptions of the used algorithms for the dedicated image hardware are investigated. The aim is to restructure applications in such a way that the hardware can be utilized as good as possible and to examine which core functionalities can be executed efficiently on dedicated hardware. Within this area four typical image applications are selected: the processing of medical image data (C1), multispectral data analysis (C2), mobile scanners (C3), and global illumination methods (C4).

13.1 3D-Processor Architectures

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Supervisor: Prof. Dr. Dietmar Fey

One general important goal of the whole research training group is to find flexible, compact and compute performant embedded hardware structures e.g. to use them in smart cameras for various image processing algorithms. This subproject will investigate the technological possibilities to realize all stages of the image processing pipeline as a 3D-processor architecture. Image sensors of today capture the incoming light in parallel, also many image processing algorithms can be optimized for parallel usage. But the readout from the sensor is still performed serially, as a result of the limited bus widths of the processing units. Since there are many applications in image processing, where high frame rates are necessary, optimizing the readout is an important issue in this field. One possibility to overcome this bottleneck will be the use of new rising "3D-chip stacking technologies" for chip design. Several advantages are promised by these technologies. First, by working with the third dimension, interconnections between the units can be reduced. Also by stacking analog and digital circuits of the image chip, signals pass information vertically and the readout can be heavily parallelized. The realization becomes possible by using new manufacturing processes like the TSV technology[1]. Thus, new parallel processor architectures are necessary, which have to be tailored to consider both, mounting and assembly technology and the image processing algorithm to solve.
Besides the chip design of an image processor, image preprocessing will become another important factor in this subproject. Operations like denoising and edge detection are predestined to be processed right after image capturing, since they can be performed on the input pixel stream. Implementing these filters can be realized with the help of full buffering, which stores only a few image lines, depending on the window filter size. This processing technique can be built into a special image processor that contains optimized instructions for streaming applications. As a result image data will be reduced and post processing hardware like regular CPUs will be unloaded.
In general the main object of this subproject is to define new processor architectures, which are able to exploit the parallelism of image sensor structures and are optimized for image preprocessing close to the sensor itself. Moreover, a flow should be created to automate the generation of such architectures by a given abstract definition as it is realized in subproject abstract machines.

[1] Cadence: 3D integrated circuits (ICs) with through-silicon vias (TSVs)

13.2 Analog Signal Processing and Ad Hoc Implementation for Heterogeneous Image Systems

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Modern image processing mechanisms demonstrate a great deal of complexity. Since the dimensions of image sensors are shrinking, it grants a possibility of very dense integrity. On one hand very high resolutions can be yielded, whereas on the other the amount of image data to be processed increases by order of magnitude.
The sub-project A2 is targeted to improve the image sensor signal processing as well as to reduce the complexity and amount of involved hardware. A concept of image sensor signal pre-processing on analog basis is going to be introduced and assessed. This concept has its high potential towards increasing the efficiency and speed of high resolution, complex sensor signal processing. The amount of digital logic needed to process such signals can be significantly reduced by performing algorithms such as tone mapping, denoising, color reconstruction and others on the analog basis. Such algorithms have the potential to be implemented and designed with much less hardware and thus significantly reduced energy consumption on the analog basis rather than on digital. Furthermore the analog circuits are not predetermined in speed by propagation delay; therefore higher speeds and better processing concurrency can be obtained.
Efficient analog to digital conversion techniques will be adapted to the pre-processed analog sensor signal. These tasks will be carried out within the sub-project A2, which gives a good move in efficient ultra-HD and 3D signal processing circuit design.

13.3 Efficient Coding of Non-Conventional Video Data Structures

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Despite ever increasing capacities in both available bandwidth and storage space, video compression remains an indispensable step for the efficient transmission and storage of video data. For high-definition (HD) and higher-resolution progressive-scan video, additional compression is desirable compared to what can be achieved by the widely used H.264/Advanced Video Coding (AVC) standard, particularly with regard to streaming and displaying via mobile devices. The recently standardized video compression scheme, High Efficiency Video Coding (HEVC), offers double the coding efficiency of its predecessor, H.264/AVC, at the same visual quality, and further work is invested with regard to extensions for scalable as well as multiview video coding.

Typically, the input material to such a video coder is comprised of frames, the inherent temporal and spatial correlations of which are then exploited to reduce the bitrate needed to represent the original video signal. Apart from conventional image and video data that is processed and coded in a frame-wise manner, less common data structures may occur for more specialized application areas such as video surveillance, multiview recording, high dynamic range imaging, or light field photography.

In the context of this project, new ways to efficiently code such special data structures by extending the HEVC standard shall be investigated. In light field photography, for instance, *plenoptic* cameras incorporate a microlens array that is attached in front of the photo sensor. Each microlens records a tiny 2D image of part of the main lens aperture, the resolution of which depends on the dimensions of the microlenses. Using such an array, directional information contained in the light rays is preserved, since adjacent microlens images basically contain the same part of the scene viewed from a slight perspective shift. The resulting correlations between neighboring microlenses are not explicitly considered by the video coder, thus causing an according decrease in coding efficiency.

Another interesting application area is video surveillance, where the security cameras employ *fisheye* lenses that produce strong visual distortions to enable a wide-angle panoramic view of the scene to be surveyed. The non-rectilinear characteristics of such imagery causes classical motion estimation and compensation to degrade, as radial distortions are not taken into account in the block-based motion estimation process. Ways to exploit knowledge about such lens distortions to more efficiently code the input data shall be investigated in this project.

13.4 Energy Consumption of Video Coding Systems

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Supervisor: Prof. Dr. André Kaup

In recent years, the use of video services has increased tremendously. Encoding and decoding systems are used in a high variety of applications like streaming, recording, or gaming on heterogeneous platforms like mobile devices, desktop computers, TVs, or cameras. State-of-the-art decoding standards like the upcoming HEVC[1] provide sophisticated tools to encode videos with very low bitrate and at the same time high visual quality. Unfortunately, these tools are often of very high complexity, resulting in a considerable amount of consumed energy for the en- and decoding processes.
This project aims at analyzing and optimizing video coders on different platforms with respect to their energy consumption. If the amount of energy a certain coding tool requires is known, it is possible exploiting this information in order to build efficient video encoders and decoders.
One goal of this project is to find a simple and practical method to derive the energy consumption. Potential indicators can be processing time or complexity profiles, where it has to be investigated how they correlate with the consumed energy. Another approach can be the measurement of voltage and current during coding processes.
A possible field of application is online platforms providing video services like YouTube. Especially on mobile devices that suffer from limited battery capacity, using these services requires a significant amount of energy, shortening the time until the battery has to be recharged. Hence, research on videos that are coded in a way such that decoding energy is minimal is a valuable task.
The second application aims at online gaming services. In online games, artificial worlds in which gamers can act and interact in real time are rendered. Classical approaches require the gamer to provide hardware that can perform the rendering. To allow taking part in these games using devices with lower performance like mobile phones, a possible solution would be to code the scenes as a video and send it to the gamer's device. Hence, encoding needs to be performed on the server side. Since classical rate-distortion optimization is highly complex, the energy consumption as well as the encoding time can be strongly diminished by exploiting scene information that is inherent in the rendering process.

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13.5 Predictable Resource Management for GPU-centric Many-core Systems

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Graphics processing units (GPUs) have become a very powerful platform to speedup specific applications dedicated to the system. However, due to a lack of system software support, GPUs pose a challenge in achieving a predictable run-time behavior as required for a (soft, firm, or hard) graphics real-time environment. For example, current GPU scheduling is managed via first-in-first-out fashion by the device driver. Once GPU kernels are launched, the operating system cannot enforce real-time scheduling decisions due to the risk of priority violation, for example. That is to say, high-priority tasks could be blocked by the preceding executions launched by some low-priority tasks. Moreover, memory transmissions between host and device plays a crucial role in performance and responsiveness of involved application. However, the device driver does not provide any way to preempt data transfers once they are launched. Though GPU tasks can be reordered by the device driver, the non-preemptive nature of GPU processing is difficult to be addressed.

The goal of this project is to provide a time-predictable run-time system for GPU-based application processing. To bound the response time, we mainly consider effects of non-preemptive kernel execution and data transfer. The possible solution to data transfer could be dividing a memory copy transaction into a series of copies of smaller data chunks, and in the same way preemptive kernel execution can be supported by dividing one GPU kernel into a set of sub-kernels which provide a preemption point after each finishes. Another way to enforce prioritization and isolation is to schedule GPU commands based on execution costs. However, due to the overhead of the command-driven scheduler, a tradeoff between throughput and response times should be elaborated according to application requirements.

My current research is focused on GPU command dispatching that controls data transfer and kernel launching. By exercising experiments with real-time graphics applications for GPU-centric many-core systems, we aim at improving GPU response and resource management as well.

13.6 A Memory-centric Run-time Executive for Heterogeneous Many-core Systems

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In heterogeneous systems employing a potentially high number of diverse processing elements, memory is by necessity also a heterogeneous and diverse resource. Examples of such hardware environments are traditional computer systems with GPU, FPGA or other accelerator cards, networked embedded control and display systems such as in-car-systems or novel many- and multicore architectures with large numbers of cores.
Memory may be distributed over various parts of a system such that access characteristics may vary in several dimensions: Access limitations for memory on local and remote device parts may apply, depending on device topology, direction of access and memory layout of accessing and accessed process. Also, cache and bus topologies induce performance characteristics depending on distance as well as relative temporal position. Furthermore, varying addressing models for different memory systems require the dynamic or static adaption of data structures containing references or pointers. Access modi for local and remote accesses differ, such that the use of different processor instructions or dedicated DMA engines makes it necessary for a programmer, operating system or compiler to employ knowledge about the physical memory location of data. Interaction and overlap between memory, synchronization and communication infrastructure compound this complexity.
Traditionally, adapting software to heterogeneous scenarios is a task for the application programmer. Application software needs to be tailored to requirements of the application as well as the hardware environment. This leads to memory management, access, protection and transformation components being bespoke software. Thus such bespoke software is expensive and complex to develop, limited in portability and hard to maintain.
The goal of this work is to research better approaches to the memory-related challenges posed by heterogeneous systems with a special emphasis on image systems.

13.7 Consistent Programming Models and Tools for Designing Heterogeneous Image Systems

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The variety of different image systems and their requirements has led to the need for various architecture types. Many compute-intensive image processing applications can be sped up by running them in parallel on special graphics processors (GPUs), massively parallel processor fields or reconfigurable hardware, in contrast to conventional processors (CPUs). State of the art parallel programming models (e. g., CUDA, OpenCL) enable efficient programming and optimization on a low abstraction level, which is time-consuming and does not cover the need for performance portability.
In this project, we research methods and tools to efficiently map a wide range of image processing algorithms to heterogeneous architectures. Inspired by domain-specific characteristics, the programming takes place on a higher abstraction level. Using this approach, efficient implementations can be created without the need for an architecture expert and therefore increases the productivity and flexibility for writing algorithms. Knowing existing approaches, for example the HIPA^{cc} framework[1]for medical image preprocessing, and efficient techniques[2]is essential for the development of future methods.
To achieve the aims of a) a consistent programming of heterogeneous image systems, b) the related improvement of productivity as well as flexibility, and c) the efficient mapping to a specific target architecture, this project is structured as follows: Imaging applications within the different GRK projects are analyzed and certain reoccurring tasks are reduced to their core functionality. With respect to a specific application domain, a domain-specific language can be designed, which allows to easily express an algorithm by using a common description in a succinct and readable way. Hereby, the algorithm is decoupled from any architecture-specific characteristics, which ensures a high productivity and flexibility. Furthermore, methods for an efficient mapping of the core functionality to a specific target architecture can be developed by utilizing the knowledge of the specific domain and the given architecture characteristics.

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[2] R. Membarth, J.-H. Lupp, F. Hannig, J. Teich, M. Körner, and W. Eckert, "Dynamic Task-Scheduling and Resource Management for GPU Accelerators in Medical Imaging," *Proceedings of the 25th International Conference on Architecture of Computing Systems (ARCS)*, pp. 147–159, 2012

13.8 Abstract Machines for Embedded Heterogeneous Image System Architectures

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The use of smart sensors and heterogeneous image processing architectures has many advantages such as an efficient image pre-processing. Formerly, special hardware for these sensors were designed first and software was developed afterwards which results in high development times. A common problem by implementing image processing software is that unfortunately the algorithm developing or implementing has to start from the scratch when the underlying hardware changes. Consequently hardware changes or analysis of the algorithm with several architectures is very time consuming and difficult to realize.
The idea of this subproject is to find a way to abstract the hardware of image processing systems. Though of the architecture diversity, there are also commonalities because the single steps in the image processing are always similar. Therefore, a general image processing pipeline can be defined: getting images through sensor, A/D-converter, image pre-processing based on local operators which has low complexity but much data, post-processing with high complexity and reduced data, and output of the results. Many of these steps can be parallelized to improve processing speed and efficiency. The goal is to develop a generic multicore computer architecture in software, called abstract machine, for image systems, where applications can be tested independent of the target hardware platform and without having a specific hardware to test on.
This abstract machine can be seen as an interface between the algorithmic level of the applications and the hardware design level. Another advantage is, that utilizing the abstract machine, a developer can find the perfect architecture including the best matching amount of parallelism for his application without having the time consuming task of developing and verifying actual hardware. Also inefficiencies and bottlenecks can be found.
As a first step, a processor model of an already existing multi-processing architecture was developed and a functional test was executed by evaluating several applications on this model[1]. With the help of the model, rough estimations of non-functional properties, e.g. time, area, power, shall be made possible.

[1] S. Berschneider, "Modellbasierte Hardwareentwicklung am Beispiel eingebetteter Prozessoren für die optische Messtechnik," Master thesis, University of Erlangen-Nuremberg, 2013

13.9 Improved C-arm Computed Tomography for the Early Diagnosis of Osteoarthritis

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Osteoarthritis (OA) is one of the leading causes of functional decline and disability in aging populations[1]. However, the current state-of-the art methods in OA imaging are insensitive to early changes or are challenging for the patient workflow and limited by expense and long scan times.
The goal of this project is to develop a weight-bearing computed tomography (CT) procedure that allows a "stress test" of the knee joint. This test is then used to estimate the risk for OA, by measuring the deformation of the articular cartilage using different weight-bearing scenarios.
The standard application area for C-arm CT is in the interventional suite, where it usually acquires images using a vertical trajectory around the patient. For this project we use a C-arm device in a horizontal trajectory, which is necessary to acquire volumes while the patient is standing upright or in squatting position. The acquired volumes will then be aligned to each other and geometric properties of the knee joint will be measured.
Increasing the number of projections acquired per scan and simultaneously keeping the overall dose constant, leads to decreased view aliasing[2]. However, the quantity of projections per scan is limited by the bus architecture. One goal of the project is to investigate compression techniques executed on the detector to reduce data transfer and allow for more projections.
Currently filtered backprojection (FBP) is still the method of choice in C-arm CT reconstruction[3]. Therefore we plan to investigate if it is possible to move the filtering step of the FBP onto the detector, which could lead to a significantly faster reconstruction. This can also be combined with the data compression of the previous project goal.
The standing position results in increased motion artifacts in the reconstructed volume. To improve image quality, we will also investigate methods that give additional information about patient motion. For example metallic markers that encode the object's position in the different detector images or range imaging cameras which keep track of the motion during a scan.
The project is in collaboration with the Department of Radiology, Stanford University, Stanford, CA, USA.

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13.10 Multi-material Beam Hardening Artifacts Reduction in Computed Tomography

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In the last decade, cone-beam X-ray computed tomography (CBCT) has become a widely-used imaging technology with various applications in the medical field as well as in non-destructive testing. Standard reconstruction techniques are generally based on the assumption that the X-ray beams are monochromatic and the measured projection images contain line integrals through the objects. However, in practice, the X-rays are polychromatic and lower energy photons are more easily absorbed than the higher energy photons, resulting in nonlinear characteristics of the X-rays which is the so-called beam hardening phenomenon[1]. Consequently, severe artifacts such as cupping and streaking artifacts appear in the reconstruction, which degrade the reconstruction quality and diagnostic accuracy. Therefore, an effective beam hardening correction approach is important to improve image quality. Current correction approaches used in clinical CT are mainly based on water-equivalent calibration and recent scientific researches published an extension of including dense bones in the scan field. Other correction techniques are limited in correction effectiveness and computational complexity on cone beam geometry, when scanned objects consist of more than one material[2]. The aim of this project is to effectively reduce beam hardening artifacts with datasets consist of multi-materials with different spectral properties. Prior art on this topic requires segmentation of the attenuation image, which results from a single energy CT scan, into different materials. A major limitation of these techniques is either the computational complexity which renders them unsuitable for practical usage, or a limitation of the objects regarding the number or the shape of different materials. The high computational load of these methods is often caused by mis-segmentation of materials in early iterations, which slows down the convergence and may result in unfamiliar image impression and additional artifacts. Investigation and evaluation of the algorithms in terms of correction accuracy and computational efficiency are performed using simulated and real CT datasets. Furthermore, we will develop algorithms with consideration of inhomogeneous density objects and achieve GPU acceleration for 3D reconstruction geometry.

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[2] G. V. Gompel, K. V. Slambrouck, M. Defrise, K. J. Batenburg, J. de Mey, J. Sijbers, and J. Nuyts, "Iterative correction of beam hardening artifacts in CT," *Medical Physics 38 (S1)*, pp. S36–S49, 2011

13.11 Interactive Multispectral Image Visualization and Analysis

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Multispectral imaging is an important tool for better understanding of image formation and reflectance phenomena. For this, a multispectral (or, hyperspectral) image combines the benefits of spectroscopy with the topological information of a two-dimensional image. Captured data is complex and often imperceptible by the human eye. Its interpretation can be more robust and happen in a broader scope in comparison with a regular color image. Research on computer vision methods that interpret, or rely on, scene reflectance often profits from analyzing this data.
To process this amount of high-dimensional data we need more sophisticated procedures for image analysis as well as efficient ways of handling the large amounts of information and visualization in an intuitive way. In this thesis, we evolve on the workflow of multispectral data inspection by introducing the novel visualization and analysis framework *gerbil*[1].
While previous work on multispectral data inspection is focused on dimensionality reduction and classification, our goal is inspection of the data prior to any further processing (e.g. application-dependent data reduction). For this, a visualization method is developed that efficiently presents the raw image data with parallel coordinates. Furthermore, we adapt segmentation and clustering methods that are state-of-the-art in traditional computer vision applications to the multispectral domain. The focus lies on algorithms that are computationally feasible in an interactive setting.
To provide a comprehensive framework, the work conducted in this thesis further incorporates data pre-processing, namely denoising and edge detection, and other means of data presentation, namely false-color image computation based on unsupervised dimensionality reduction. Introduced methods are tested on publicly available multispectral image datasets from reflectance analysis and remote sensing applications as well as newly captured images.
The introduction of algorithms that process multispectral data in interactive time constraints is the first step in the departure from static analysis of image data towards real-time processing of video data.

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13.12 Mobile Scanning

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Today, consumer electronics, for example cameras, smart phones, game consoles and infotainment- systems are equipped with a variety of optical sensors including sensors for capturing color- and depth information. With the ever-increasing processing power of these devices, a portable everyday use of a whole new class of applications will soon be available for the end-user. Example applications include 3D-Object Reconstruction, Classification and Analysis using mobile devices. In the past, such applications required expensive special-purpose devices and hardware. This opens up two research directions: The first deals with the reconstruction, classification and analysis of static objects or complete environments. In the past, we focused on the automatic reconstruction of personalized virtual avatars[1] using depth sensors. Applications range from entertainment to teleconferencing. In the future, we plan to create digital models of complex environments, e.g. the own living room, using low cost depth sensors. The second part deals with dynamic objects. In this scenario, both the static geometry and the dynamic movement have to be reconstructed. The applications range from motion capturing to gesture and mimic control of devices. For dynamic objects the key ingredient is a real-time capable non-rigid registration to compute a dense set of frame-to-frame correspondences in the time-varying input sequence. Therefore, a real-time capable deformation model[2] is required. We also developed a method for animation transfer to retarget an animation to a static target object[3]. To allow a mobile use of such applications, new algorithms have to be developed in a hardware-oriented way to deal with the inherent hardware constraints of such devices.

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[2] M. Zollhöfer, E. Sert, G. Greiner, and J. Süßmuth, "GPU based ARAP Deformation using Volumetric Lattices," pp. 85–88, EG 2012 — Short Papers, 2012

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13.13 Scalable Global Illumination

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In this subproject techniques for global illumination on heterogeneous image systems are to be investigated. These systems can range from smartphones over current high-end desktop systems to even high-performance computer clusters. At first an algorithmic base is to be developed which supports different kinds of global illumination techniques in variable quality settings on highly diverse hardware and software configurations.
Another focus of the project is it to combine conventional rasterization techniques, well supported by current graphics hardware, with ray tracing based illumination computation methods. The basic idea here is that even very complex scenes can be rendered in real-time on current consumer hardware using GPU-based rasterization at high frame rates. It is to be investigated to which degree the visual quality of the renderings can be improved by incorporating global illumination effects.
Often global illumination effects require expensive ray tracing techniques, which can be integrated using available GPU and CPU resources (e.g. using NVIDIA OptiX[1]). The methods developed in this part of the project shall use the remaining CPU/GPU and memory resources to incrementally improve the visual quality. Also temporal and spacial image filtering techniques are to be investigated in this context (e.g. À-Trous Wavelets[2]).

[1] S. G. Parker, J. Bigler, A. Dietrich, H. Friedrich, J. Hoberock, D. Luebke, D. McAllister, M. McGuire, K. Morley, A. Robison, and M. Stich, "OptiX: A General Purpose Ray Tracing Engine," *ACM Transactions on Graphics*, 2010

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13.14 Efficient Visibility Estimation

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The central component of any global illumination simulation is the determination of visibility between scene positions. With this information diffusion of light can be computed. This is a global problem and as such computationally very intensive. The lack of such global illumination strongly decreases visual quality. Searching for efficient solutions is, since long, an active area of research.
Using Ray Casting visibility is determined by accessing the scene geometry, augmented by an acceleration structure which speeds up spatial queries. These methods are accurate, but computationally expensive. Recent advances improve performance by better adaption to hardware, both on CPUs[1] and GPUs[2], as well as by algorithmic considerations[3]. Schemes based on Shadow Mapping are mostly useful to estimate visibility between scene positions and a light source. The intermediate representation is a discretized subset of the scene visible from the position of the light source. This discretization is the cause for a number of artefacts and the conservative nature of the algorithm. It is, however, a very fast method. Beside the basic algorithm many variations on the theme do exist, e.g. to counter aliasing problems or to approximate soft shadows, for a survey see Eisemann et al.[4]. Another, more recent, branch of visibility estimation is the use of a voxel based scene representation[5][6]. Employing such a representation relations of scene points can be queried quickly. The voxelized scene representation, however, suffers from discretization artefacts.
The objective of our efforts will be to improve upon existing algorithms and devise new solutions to the visibility problem that allow to scale the quality of results to the level provided by a given target platform.

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14 GRK 1780: CrossWorlds: Connecting Virtual And Real Social Worlds

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The Research Training Group "Connecting Virtual and Real Social World" addresses the increase in digitization and its resulting virtualization of processes, communication, environments, and finally of the human counterparts. The nature and the degree of virtualization vary significantly, and they depend considerably on the context of application. In addition, media-mediated communication is always restricted in comparison with real-world communication.
Our goal is to overcome the current constraints of media-mediated communication. In doing so, we will study which new ways of interaction and communication are offered by the connection of virtual and real social worlds in comparison with the experience of immediate real interaction and communication. The research program subdivides the connection between virtual and real social environments into the fields of: communication, emotions, sensomotorics, and learning. Research in these areas is performed within interdisciplinary research tandems consisting of computer scientists and social scientists on a doctoral, postdoctoral, and on the supervisory level.
The qualification program is based on the objective of the Research Training Group, which is explicitly focused on joint technology-oriented and social-scientific-oriented media research. Seminars and workshops, some of them to be organized by the fellows, are focused on the research topics of the fellows. Furthermore, tutorials prepare the fellows for the challenges of the national and international scientific community. The qualification program is completed by visits of designated guest scholars.

14.1 Potentialities for Intertwinements of Interactive Systems and Cultural Spaces

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The work presented situates itself at the crossings between informatics, philosophy and the cultural sciences. Their interpenetrations are explored within the concrete context of developing interactive technology to be deployed in *museums*.

Production of digital technology is based on a limited set of ideas concerning the relationship between artefacts developed and the life-worlds they are employed in. These ideas, as well as methodologies informed by them, often are not well suited for addressing the contexts of cultural education. Geared towards product development, they typically aim at producing artefacts amenable to concepts such as efficiency, effectiveness and usability. The museum, however, represents a space which is neither governed by the requests of work or formal education while at the same time not being part of the undemanding sphere of recreation. Hence, it lends itself to be explored in a playful way, creating an unqiue ensemble of interactional-communicative situations, thereby facilitating specific forms of experience.

Supporting these forms of experience calls for a reevaluation of existing theories and methodologies. Consequently, paradigms such as Embodied-Interaction[1], Value-Sensitive-Design[2] Critical Technical Practice[3,4] and Interface Ecology[5] are examined from a systematic philosophical perspective in order to identify connecting factors for the development tasks at hand. As none of the isolated disciplinary perspectives is able to account for the full range of concepts encountered, the approach outlined calls for an unusually tight linkage of the disciplines involved. Therefore, the project seeks to position itself as a communicative hub within the network formed by individual projects within the RTG. Antagonistic viewpoints are not sought to be integrated or covered up. Rather dynamic frictions are rendered productive by means of poietic practices, thereby translating differences and strife into digital artefacts.

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14.2 A Framework for Interaction in a Virtual 3D Stereoscopic Environment for Multiple Persons

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Supervisor: Prof. Dr. Guido Brunnett

I am working on the development of a framework for interaction in a virtual 3D stereoscopic environment for multiple persons. Although there is extensive research that explores the matter of interaction in "conventional" virtual worlds, the addition of a stereoscopic view to this scenario has not been a focus of research yet, especially from a technical point of view. The integration of several stereoscopic viewports and the possible new interaction types like swapping views together form interesting research topic.
Two main approaches may come into play in this area of application of virtual realities: cooperative interaction and competitive interaction. Currently, my work concentrates on the former. It will be important to explore an array of different methods to realise the interaction with the virtual world, so that it synergises with the user interaction in the real world. Apart from the standard keyboard/mouse input, the system can be operated with a Novint Falcon, an input device with three degrees of freedom and the ability to emulate haptic forces (the sense of touch). Furthermore, I will be exploring the possibility of gesture-based input. My research partner, Daniel Pietschmann, will conduct studies about examining input types.

14.3 Agent supported Mobile Learning

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Supervisor: Prof. Dr. Wolfram Hardt

During the last five years "smart" mobile devices have reached a significant market share[1]. These devices are characterized by high computing power, a high resolution display, permanent online access and several specific interaction mechanisms like a touchscreen and an accelerometer. This leads to new possibilities in the field of e-learning and encourages scientists to research the possibilities of mobile devices in the learning context. These devices can be used for ubiquitous, highly efficient information access, a personalization oft the learning environment and the learning resources and the usage of context sensitive information like location, weather, temperature, camera and microphone data.

In the context of the RTG mobile devices can be seen as highly adaptable interfaces between the real and virtual worlds.

Visual representations of virtual agents or avatars are beneficial for the personalization of information, the interaction with the learning environment and the learning motivation[2]. An agent can give hints to solve learning problems, remind on doing tasks and provide reaction to context information.

The focus of this work is to evaluate existing mobile learning applications, derive aspects to improve and to develop an own framework for mobile e-learning applications enhanced by an agent, specifically designed for the mobile environment. In a prototype the evaluation of fields like agent interaction, learnability, efficiency, simplicity, memorability, readability, learning performance and satisfaction should be conducted.

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14.4 Robot Companion – Sensor-based Perception of Human Body Behaviour

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Supervisor: Prof. Dr. Wolfram Hardt, Prof. Dr. Maximilian Eibl

At this time there are many kinds of robot devices in some public and private places. The robots work in different situations with very different behaviours. In the mobile sector a robot does heavyweight work or constantly recurring topics. This robots are specialised for precise and recurring work. The interactivity of this kind of mobile robot is restricted to warning signals.
A part of these robot devices are mobile service robots. They use some kinds of perception, present information and entertain the users. A robot like that is the darling of the public. A mobile robot perceives the environment in order to find the path, avoids obstacles and also human beings. The interaction with people reaches from human avoidance to ball playing and a general welcome to the visitors. Social robots can help, accompany and monitor visitors but they can't react individually to actions performed by humans.

The aim of the project is an individual reaction to human activities.
The human is detected by infrared sensors, a Kinect and a HD camera. Depending on the distance human-robot, the robot reacts with movements, path changing and the implemented human voice. The robot monitors two perimeters. The inner one is the safety distance. A person who is detected at this distance is an intruder. The robot switches into the self protection mode. If a person enters the second distance the robot activates the interaction mode. Depending on the body posture it interacts with the human beings. Two contrasting examples are: the shy person and the experienced person. Both of them exhibit different patterns of body language. With the help of the sensors the system perceives the body posture and reacts with individual appropriate activities. The shy person needs words of encouragement and explanatory clues. A experienced person wants a description of the possibilities, i.e. what can I do next. An other point of view is the detection and differentiation of one person or two persons and groups of people. They exhibit different group dynamics. A third possible application is the assistance to visitors.
This communicative behaviour expected reduce the inhibition threshold. It increases the enjoyment and willingness to interact. These points improve the access to the additional information and create a added value for the users. The central point is the human being. Some robots have facial expressions but how can a robot react to human expression!? Perception of body posture and appropriate action is the focus of this project.

14.5 Making Multi Touch Tables perceive their Users

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Supervisor: Prof. Dr. Maximilian Eibl

Focus of my project is the application of object recognition techniques on multi touch tables (MTT). MTTs are new interaction devices which allow several users to interact on the same display simultaneously. This property is a great potential for collaboration between users, but also leads to challenges for interface design. Since the usage context of the MTT will be a local museum, user attraction and the design of simple and understandable interfaces is a priority. In addition, the MTT is supposed to supplement the museum environment and its exhibits shown in a playful way, following the Blended Museum approach[1]. Object recognition techniques will be used to adapt the interface based on the estimated properties of its users. This will be done by analyzing the surroundings of the MTT using four cameras situated in the corners of the table construction. Image processing technology currently developed at the Technische Universität Chemnitz at Chair Media Informatics [2] will then be applied to the gathered data to make a basic classification of MTT users (young, old, single user, multiple user, etc.). Having this knowledge the user interface of the MTT can adapt its content and react to changes of the usage situation.

The design and evaluation of the MTT and its applications are done in collaboration with my research partner Kalja Kanellopoulos, a social scientist focusing on the analysis of processes of interaction with and around multi touch interfaces in museums by means of ethnography.

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14.6 Modeling Vision

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Supervisor: Prof. Dr. Fred H. Hamker

Research summery. Understanding the human visual system and the underlying learning mechanisms is a vital need for computational models of perception. Indeed, the processing in the visual system can not considered as an isolated process as different brain areas can influence it. Indirect pathways via the thalamus, especially over the pulvinar, and direct pathways, as feedback connections from the amygdala, involved in emotional processing, can be identified. Feedback signals can be interpreted as source for attentional guidance of vision, in the case of the amygdala emotional relevant stimuli are attended.
Hence, requirements for our intended computational model of the visual system are at first the ability to recognize different object categories. Secondly, the integration of feedback signals from different areas to guide the processing. Finally, the biological plausibility of the processing in each stage.
Our first research question was how the visual system achieves its ability to recognize objects invariant to various transformations. To study potential mechanisms for learning this invariant processing, we created a model of the primary visual cortex (V1), simulating the so-called simple-layer (V1-layer 4), and complex-layer (V1-layer 2/3). We found that trace learning is a suitable mechanism for learning the responses of V1 complex cells[1]. Subsequently, we show that a single learning rule can account for the development of simple- as well as complex-cell properties. We apply this learning rule to exploit the temporal continuity of the visual input, using a short-term trace for neurons in the simple layer and a longer-term trace in the complex layer. We show that neurons in the simple layer develop receptive fields comparable to monkey data, while neurons in the complex layer exhibit phase invariance. To build more plausible and more advanced networks, we are extending them from monocular isochromatic vision to color[2] and stereo vision. Beside biological plausibility, we are evaluating the object recognition performance and the robustness to occluded stimuli[3]. For the last building block, modeling the feedback signals of other brain areas, my collaborators are developing a model of the amygdala to learn the emotional value of facial expressions.

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15 HPI Research School on Service-oriented Systems Engineering

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Design and implementation of service-oriented architectures impose numerous research questions from the fields of software engineering, system analysis and modeling, adaptability, and application integration.
"Service-oriented Systems Engineering" represents a symbiosis of best practices in object orientation, component-based development, distributed computing, and business process management. It provides integration of business and IT concerns.
Our research school devotes to current topics in the field of IT systems engineering with high potential in academic research as well as in industrial application. Supported by an internationally renowned grant, PhD students at our school participate in joint activities such as lectures, seminars, winter schools, and workshops. The professors of the HPI, each one having an own research group, are the supporting pillars for our research school. With its interdisciplinary structure, our school interconnects the HPI research groups and fosters close and fruitful collaborations.
In context of the research school, the different groups at HPI work on the following topics: Human Computer Interaction and Computer Vision as Service (Prof. Dr. Patrick Baudisch), Service-oriented Geovisualization Systems (Prof. Dr. Jürgen Döllner), Modeling and Verification of Self-adaptive Service-oriented Systems (Prof. Dr. Holger Giese), Tools and Methods for Software Engineering in Service-oriented Systems (Prof. Dr. Robert Hirschfeld), Security Engineering of Service-based IT-Systems (Prof. Dr. Christoph Meinel), Service-oriented Information Integration (Prof. Dr. Felix Naumann), Evolutionary Transition of Enterprise Applications to Service-Orientation (Prof. Dr. h.c. Hasso Plattner), Operating System Abstractions for Service-oriented Computing (Prof. Dr. Andreas Polze), Services Specification, Composition, and Enactment (Prof. Dr. Mathias Weske), Quanti-

tative Evaluation and Optimization of Service-oriented Systems (Prof. Dr. Werner Zorn).

15.1 Association Rule Mining on RDF Data

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Association rule mining has been widely studied in the context of basket analysis and sale recommendations. The increasing amount of Linked Open Data in the World Wide Web raises new opportunities and challenges for the data mining community. Linked Open Data is often represented in the Resource Description Framework (RDF) data model. Thus, data can be represented as a graph or as a set of triples consisting of subject, property, and object. The URI representation of resources and objects and their triple relations harbor many implicit and semantic relations that might lead to new insights about the data and its domain. Therefore one of the major challenges is to define reasonable grouping concepts of the data in the sense of identifying the targets (items) of mining and in an appropriate context view (transactions).
There is already some domain-specific work where correlated ontological concepts are respectively chosen as the targets and context of the mining application. E.g., generating rules between drugs and diseases by looking at their co-occurence towards patients. In this example, the concepts of drugs and diseases constitute the targets where the concept of person defines the context of the mining. This is a very specific use case within RDF-data and requires domain-specific knowledge, which is probably not always available. Our approach is based on a subject-predicate-object view of the data. Any part of the RDF statement can be regarded as the context used for grouping one of the two remaining parts of the statement as the target for mining. Thus, there are six different configurations to derive target values and contexts. As a conceptual task, it is necessary to identify the actual meaning and use-case of each configuration. Rules between properties, such as $name \rightarrow age$, can be used for schema discovery that enable data-driven ontology adjustments and property suggestion for data publishers. Other configurations still need further examinations for identifying their application domains.
To this end, we applied our methodology to several use cases that detect and can prevent inconsistency in RDF data. We show how one configuration can be used for predicate suggestion and how we extend this approach for generating completely new triples by combining two different configurations. Further we developed a predicate mining approach for reconciling data and its ontology. Last but not least, we combined two configurations to discover synonymously used predicates in a dataset, which are important for data consumers.

15.2 Graph Transformation Systems and Invariant Checking with k-Inductive Invariants

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Invariant checking is a static analysis technique related to model checking. Based on a formalization of a system's behaviour, it is possible to show or disprove the validity of certain properties of the system. An existing technique[1] is focused on the special kind of *inductive invariants*. An inductive invariant is a property whose validity is not violated by a change of the system's state, shifting the corresponding analysis from the states to the nature of the system's transitions between states. Inductive invariants do not take initial states into account, making reachability checks for states obsolete. Furthermore, a change to the system's initial state does not compromise the validity of properties proven to be inductive invariants. As a means of specifying properties and system behavior, the abstract and expressive concepts of graphs and graph transformations are employed.
However, properties shown to not be inductive invariants do not automatically imply an unsafe system, as the counterexamples to the properties may not consist of actually reachable states, i.e. states in the system's state space. Consequently, a more detailed analysis is often desirable, taking reachability into account and thus avoiding false negatives.
Instead of applying the time-consuming and possibly non-terminating approach of state space generation, we propose the notion of *k-inductive invariants*, relating to the concepts of k-induction[2]. The idea is to analyse not only a single transition between states and its capability to violate a property, but to take a path of transitions into account. Analysing additional transitions increases the chance of encountering an incorrect state (more precisely, its representation) prior to our incorrect state violating the property. This may allow us to discard counterexamples (false negatives) because they are not reachable from a correct state, thus integrating a certain concept of reachability into our analysis while keeping our symbolic representations instead of employing state space generation or the similar concept of bounded model-checking. Even the system's initial state may be taken into account, if, for example, a transition path is shown to include said initial state.

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15.3 Unified Execution of Imperative and Declarative Code for Loosely Coupled Implementations

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Supervisor: Prof. Dr. Robert Hirschfeld

In a number of domains, such as user-interfaces (UIs), musical applications, program configuration, and simulation, expected program behavior is specified in terms of constraints. Such constraints may be (in-)equalities or invariants, such as minimum and maximum distances between widgets in a UI that have to be considered when resizing. Imperative object-oriented programming languages are ill-suited to describe relations and constraints between objects, because they require programmers to express constraints implicitly through assignments and control flow, rather than declaratively. For some specific problem domains, such as UI definitions or automatic harmonization, specialized constraint libraries and extensions for imperative languages provide solutions to this issue.

However, current approaches result in unsatisfactory trade-offs between constraint-oriented and object-oriented programming. For example, they violate object encapsulation by defining constraints only on state, do not integrate constraint solving and the object-oriented behavior definition, and are limited to specific domains. Consequently, current approaches increase coupling in the system, duplicate definitions of relations across behavior as well as constraint-expressions, and are not reuseable for new domains.

Our approach to eliminate these trade-offs focuses on extensions to object-oriented language runtimes to accomodate declarative extensions such as constraint solvers or prepositional logic systems without compromising the object-oriented design. We provide such extensibility with multiple interpreters that cooperate on the same object space via clearly defined interfaces to exchange informations between the different execution models. We have built a multi-interpeter virtual machine that combines constraint-oriented and object-oriented interpreters under the following working hypotheses: (1) imperative object-oriented programming will remain the primary paradigm to implement service-oriented applications, and (2) relative performance remains a reason for programmers to choose a less expressive paradigm over one that offers worse performance.

In our protoype, both interpreters construct their own interpretation of and operate on the same data. Programmers can use both object-oriented constructs or declaratively define constraints on the data, and refactor one expression into the other without touching other parts of the system. The interface to the constraint-interpreter allows them to choose different constraint solvers for different domains, and a just-in-time compiler provides performance close to equivalent purely imperative programs.

15.4 Towards Aligning Software Development Processes and Model-Driven Development of Service Oriented Enterprise Systems

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To cope with the complexity of today's software and to achieve an efficient development three different techniques are employed together today: service oriented system design, model-driven engineering (MDE) and sophisticated software development processes. However, a combination of different techniques that aim at similar goals might increase positive effects as well as compensate the same.
Already the design of MDE itself can influence productivity (see Hutchinson et al.[1], Mohagheghi et al.[2], or Konrad et al.[3]). Therefore, this research aims at providing support for analyzing influence of MDE on productivity aspects such as changeability.
We introduced a modeling notation that integrates the process view with model management aspects[4]. Based on this notation we developed a pattern language that allows for identifying changeability risks for a given MDE approach[5].
However, knowledge on the interrelation of MDE and software development processes is still rare. Therefore, we currently invest research efforts in identifying MDE phenomena that affect classical issues of software development processes. For example, within an MDE approach transformation chains can include manual activities and, thus, might lead to long cycle times. This however can affect the applicability of agile processes.
Goal of this work is to provide guidance for design of MDE approaches as well as the alignment of MDE approaches and software development processes, in future.

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15.5 Mining and Predicting Opinions on the Web

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Supervisor: Prof. Dr. Felix Naumann

Nowadays, user-generated content receives ever-more importance on the web. The "Web 2.0", or "Social Web", gives users the possibility to publishown content and become authors instead of being mere consumers of information. Information can take on many forms, ranging from the expression of personal opinions and remarks, e.g., on blogs or forums, to the stating or debating of facts, e.g., as it is the case for product reviews, feedback in forums or in Wikipedia articles. Furthermore, the knowledge of multiple users can be combined, assessed and corroborated by the wisdom of the crowds.
Information therefore does not solely lie in the hand of a few companies or interest group anymore, but can be processed, edited, remixed, remarked on, and distributed by any Internet user. Additionally, users have the possibility to establish social contacts and collaborate with each other, resulting in the creation of social circles and interaction within those.
An interesting research topic is the way in which individual views and opinions evolve on social web platforms, e.g., how they are influenced by and fused with each other and can finally even contribute to the social consensus. Opinions can be shaped by high-profile articles about topics that receive an increased general interest, but also in a less drastic way, for instance through independent product reviews on blogs or shopping portals that in total give a good impression about the public point of view on and opinion about the discussed objects.
Going even further, it would be of great value to develop methods that can model and predict such processes of how opinions change and develop. Such models could be applied to blogs, social networks, news portals and the like and gain further insights into the formation of opinions on the web.
To this extent, I currently focus my research on two aspects:

- Firstly, I aim to define and capture the "reliability" of users in the web, i.e., to what degree users' opinions lie within the concensus of their social peers. The concencsus of the peers is calculated by the peers' relabilites.

- Secondly, I am currently working on methods to analyze a posts from the Web 2.0 and recommend similar posts from other websites or posts from similar users, which could prove useful for further opinion-forming on a topic. Different similarity measures will employ a variety of user-, site- and post-specific features and will be compared with each other based on a real-world dataset.

15.6 Heterogeneous Computing for Memory-bound Algorithms

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In recent years, research community in the High Performance Computing (HPC) and Scientific Computing sectors has witnessed an increasing application of Heterogeneous Computing (where Heterogeneous Computing refers to the design of applications that can harness the power of both the CPUs and accelerators such as GPUs).
Many scientific applications comprise of computational kernels that benefit significantly from a processor's capability to perform a large number of arithmetic operations at high speeds. Such kernels are typically *compute-bound* i.e. the performance bottleneck lies in the complexity of arithmetic operations (e.g. dense matrix-matrix multiplication). Accelerator architectures such as GPUs dedicate most of the chip area to arithmetic processing units. This makes it possible for properly tuned compute-bound kernels to perform at levels close to the peak performance offered by the underlying architecture.
There is however another set of kernels, where the performance bottleneck is dictated by the frequency of memory access operations. Such kernels are termed *memory-bound*. These kernels typically have a low arithmetic intensity (i.e. a low compute to main-memory access ratio). A common example for such a kernel is Sparse Matrix-Vector Multiplication (SpMV), which is the foundation for linear solvers. In addition, certain combinatorial algorithms are memory bound as well. As stated earlier, accelerator architectures favor compute-bound kernels. This raises the following questions:

- *"Is it possible to effectively utilize Heterogeneous Computing for algorithms with low arithmetic intensity? Or must such algorithms be executed on CPU-only systems?"*

As a first step towards exploring the above mentioned research question, a method termed *Heterogeneous Software Pipelining* has been developed. In this method, a highly memory-bound kernel is split into two parts; one with high arithmetic intensity and the other with very low arithmetic intensity. Then, the part of the kernel with high arithmetic intensity is executed as GPU kernel, while the part with low arithmetic intensity is executed on the CPU (since CPUs tend to perform better on such kernels). The complete algorithm then executes as a software pipeline that spans both the CPU and the GPU. The *Heterogeneous Software Pipelining* approach has been validated against a simulation kernel from the domain of Systems Biology.

15.7 Interactive Service-Based Visualization of Virtual 3D City Models

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Virtual 3D city models integrate massive, heterogeneous 2D and 3D geodata. Existing geometry-based approaches for remote 3D visualization usually implement most stages of the visualization pipeline on client-side, which makes implementation of cross-plattform clients that provide a homogeneously high graphical quality to users of all platforms is a challenging task. Recent developments towards standards and service-based 3D geovisualization systems enable a deployment of interactive, high quality 3D visualization of 3D city models on devices that where otherwise capable to retrieve, process and render the massive amounts of geometry, textures, and semantic data included in virtual 3D city models. Image-based solutions that are based on 3D portrayal services encapsulate the complexity of processing and rendering massive amounts of geodata on server-side. In this way, geodata processing and rendering techniques are implemented independently from the hard- and software capabilities of client platforms and applications. This image-based approach forms the basis of this thesis.
The main contribution of this work is an approach for cost-efficient distribution of 3D content to a large user basis is introduced. The approach allows for delivery of homogeneously high-quality graphics to a set of thin-client applications running on strongly heterogeneous hard and software platforms (e.g., smartphones, tablet PCs, low-end workstations web browsers). We utilize an image-based portrayal service to generate a graphical representation (g-buffers, e.g., color image, depth image, object id image, etc.) of the source 3D data that can be configured freely with regard to data selection, stylization and rendering effects. There are two types of thin-client applications each using special kinds of image-based representation. First, a fully interactive client that allows to freely explore the underlying server-side 3D model by creating a lightweight reconstruction server-side model from the generated g-buffer images. Second we present client applications that utilize pregenerated, tiled g-buffers datasets can be served by simple HTTP servers that do not require special hardware or software capabilities for 3D rendering. Compared to the first type of client applications, this approach provides a far better scalability in terms of the number of users that ca be served in parallel. The generation of tiles image data sets is highly automated, making the process of 3D content distribution very cost effective. The generated client applications are able to connect the underlying semantic objects with their visual appearance. This allows for a tight integration of 3D content into work processes.

15.8 Storing and Provisioning Linked Data as a Service

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In recent years, the semantic and technical foundations of Linked Data have been widely studied and formalized. Well-known technologies, such as the Resource Description Framework (RDF) model for representing structured linked information or the SPARQL Protocol and RDF Query Language (SPARQL) for retrieving this information, have been established. Whereas in principle Linked Data allows leveraging information from multiple different providers quite easily, real-world applications oftentimes only rely on a single dataset or a handful of RDF data sources as it is cumbersome for developers to discover and consume relevant resources.
In our work, we argue for a Linked-Data-as-a-Service approach combining aspects of data warehousing and distributed query processing. Both these techniques can be considered advantageous in some scenarios, while not optimal or impractical in others. Hence, we introduce a hybrid approach to store and provision Linked Data for application developers. Using a Cloud infrastructure, our framework allows for scalable processing of large-scale RDF dumps. In addition, a mediator-based architecture enables ad-hoc integration of new data sources by continuously materializing SPARQL query results. Here, we do not make any assumptions on the quality, quantity, or format of the underlying data.
In our system, we maintain a lightweight metadata catalogue that is iteratively extended and updated with information generated within our architecture and gathered from outside sources. Leveraging this metadata collection, users can deploy customized SPARQL endpoints suitable to their information and scalability needs, which are then populated using publicly available data dumps and results retrieved from SPARQL endpoints.
In previous work, we focused on metadata generation and ontology reconciliation for this Data-as-a-Service approach. These steps are necessary prerequisites for our hybrid framework where data from different sources may be added ad-hoc to a deployed endpoint and the metadata catalogue itself. Currently, we are analyzing real-world SPARQL query logs to identify typical human and machine agent query sequences. Our goal here is to deduce suitable caching strategies to store frequently accessed data. Moreover, we want to identify resources related to requested data and store this information for subsequent queries. Additionally, we hope that automating this process can assist in determining conceptual gaps between different datasets and ontologies by comparing user behavior.

15.9 The Use of Data Objects in Business Process Engineering

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Supervisor: Mathias Weske

Business process management (BPM) is an important approach to manage work in organizations with process models being the key artifacts. Process models describe the partial ordering of tasks, the resources responsible for executing a task, and the data objects manipulated in the course of process execution. Traditionally, the focus was set to activities and the according control flow view on business processes. In recent years, especially data objects received much attention resulting in a new modeling paradigm focusing on data objects and their life cycles, which represent allowed data manipulations by data state transitions. Indeed, this paradigm has advantages if the process flow follows from objects, e.g., in manufacturing processes, but it also requires new methods, tools, and analysis techniques although the general benefit have not been proven yet. Therefore, we decided to elaborate on the traditional activity-centric modeling paradigm as, for instance, supported by BPMN the industry standard in business process management.

Our work consists of several contributions to the field of enabling data-awareness for the activity-centric paradigm. First, we extend existing business process model abstraction approaches with capabilities to also abstract data objects instead of keeping all of them resulting in unreadable process models or suppressing with the consequences of losing information about data manipulations. Process model abstraction is a technique to reduce the complexity of process models with respect to the needs of a specific stakeholder. Manager like to get a quick overview about the process model – including information about read and written data objects. Thus, the consideration of them is mandatory. Further, each stakeholder requires a different view on the process model. These are provided by means of abstraction criteria. While many control flow specific abstraction criteria have been identified, data object relevance criteria have not been worked on. We change this by introducing a first set of data object relevance criteria, which can directly be used for data abstraction.

Process model abstraction requires correct process models, whereby correctness refers to safe execution. In this respect, we introduce the notion of weak conformance, which refines the existing notion of conformance to be applicable to underspecified as well as already abstracted process model. Furthermore, we incorporate data into complex event processing, and therefore indirectly to related fields such as process mining and business activity monitoring, by deriving events from data state transitions, which increases the number of events being available for analysis.

15.10 JIT-like Optimizations for Data Structures in Language Implementations

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One of the goals of language implementors is to reflect a programming language's semantic as close as possible when implementing it. However, the performance of the implementation is very important, too. To achieve both goals, techniques such as JITs, method inlining, or meta-tracing have gained popularity in the last twenty years. These techniques mostly focus on optimizing the execution of code. Nevertheless, program language semantics typically include data access, too, which seldom can be optimized using those techniques without sacrificing either performance or accuracy regarding the language's semantics.
Functional languages like Lisp or ML have a strong focus on collection types represented as linked lists of so-called *cons*-cells. Access to list elements is exclusively possible through traversing the list; no direct, index-based access is possible. When implementing this semantics of list access, language implementors can choose to either accurately represent the *cons*-cells as individual entities in memory ; or focus on performance and represent such a list as one consecutive entity in memory. However, the traversal that is necessary to access list elements in the *cons*-cell case has to be emulated; also, dynamic creation of or insertion into such lists is cumbersome to support. This does not only apply to the case of binary *cons*-cell structures but also to *constructors*, i. e., n-ary structures like trees.
To overcome this situation, we combined the recognition of patterns in data structures with meta-tracing JIT compilers . Often occurring patterns of nested constructors are recognized and subsequently replaced with internal data structures that use longer array-based storage. Nested elements are reified upon access.
On its own this approach is suboptimal but combined with a meta-tracing JIT the performance is substantially better than of either approaches given above. Constructor reification and shape maintenance introduce an overhead, nevertheless, a meta-tracing JIT can recognize accesses to reified objects and shapes and eliminates them. This effects that operations on constructors with recursive structures becomes very efficient. Considering the list in the figure, a tail-recursive implementation of list reversal would be traced to the direct creation of one constructor with the three elements in reverse order, as opposed to the creation of six constructors in the default case. For six-level-deep recursive shapes, the execution speed of said list reversal was six times faster compared to an implementation in *Standard ML*.

15.11 Multi-Perspective Exploratory Visualization of 3D Building Models

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Virtual 3D building models, represent core components of virtual 3D city models, which are used in various application domains (e.g., analysis, planning and management of urban regions). Typically, virtual 3D building models are explored and modified using interactive visualization and modeling tools, which often depict the models with a central or orthographic perspective in a single 3D viewport. Both perspectives have the inherent property that they introduce occlusion, i.e., only parts of the virtual 3D building are visible at once. A exploration of the complete model (e.g., all building façades) requires a user to change the position and viewing direction of the virtual camera multiple times. Further, the user has to memorize different images to construct a complete mental image or overview of the virtual 3D building model. This demands attention of a user, which implies an increased cognitive workload.

A common approach to cope with this challenge is applied in 3D modelling tools: multiple 3D viewports depict the virtual 3D model from different viewpoints, slightly reducing occlusion. For the exploration of massive and complex scientific data, detail+overview visualization is an established approach. Detail+overview visualization systems typically consists of two separated, but linked, viewports: one viewport depicts data on a larger scale offering overview of the complete dataset; a detail viewport facilitates in-depth exploration.

We present a multi-viewport detail+overview visualization that combines a 2D multi-perspective image with a 3D perspective view. The multi-perspective building panorama seamlessly and simultaneously depicts all façades of a virtual 3D building model, providing overview and reducing occlusion. By linking the overview and detail viewport, the building panorama can be utilized as interaction proxy, i.e., click, hover and sketch interactions in the panorama modifies the virtual camera of the 3D viewport. For example, a mouse click in the overview centers the detail view's virtual camera on the corresponding position.

This work introduces a novel multi-perspective visualization technique as part of an detail+overview visualization. The multi-perspective building panorama facilitates exploratory visualization of virtual 3D building models by providing overview and thus reducing a user's cognitive load. Further, it can reduce interaction overhead by facilitating fast and direct interaction techniques.

15.12 Towards a Secure Multi-Tenant SaaS Environment

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Software-as-a-Service (SaaS) is emerging as a new model of delivering a software, where users utilize software over the internet as an on-demand service rather than an installable product. To reduce *Total Cost of Ownership (TCO)*, SaaS providers utilize the concept of multi-tenancy, where they consolidates multiple companies (tenants) into a shared infrastructure.
SaaS and multi-tenancy provides major advantages to both service providers as well as consumers. Service providers can provision a single set of hardware to host their applications and manage thousands of clients (tenants). As for the consumers, they can use the application anywhere and anytime, they are relieved from maintaining and upgrading the software (on-premises scenario), and benefit from cost reduction by following the pay-as-you-go model.
Although providers are attracted by the benefits of SaaS and multi-tenancy, the consumers are still concerned about the confidentiality of their data. Such a challenging trade-off must be managed by the provider to lower operational cost without compromising security and privacy. We address this challenge in the thesis by proposing two approaches. First, securing tenant's data by preventing a tenant from accessing others data. Second, securely isolate tenants on separate DB instance; a secure placement-algorithm that selects the most secure DB instance to assign the tenant to will be developed.
Securing tenant's data will be accomplished through the usage of a signature to sign the tenant's request, so the SaaS system can recognize the requesting tenant and make sure that the data to be accessed is belonging to this tenant.
Machine learning techniques and usage patterns will be used to achieve the security isolation between tenants. A secure placement-algorithm will be developed based on several parameters, such as the tenant business domain, number of users, and the usage of the system.
An extension to the aforementioned approaches that focuses on hybrid environments might be also discussed, where the tenant connect internal applications with the SaaS provider system, in such scenarios, the privacy and security has an additional perspective that need to be taken into account.

15.13 Visualization of Software System Evolution

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The huge number of artifacts in software systems, e.g., packages and classes, as well as the fact that these artifacts do not have an obvious geometrical or graphical representation, complicate the effective visualization of the hierarchical structure of those systems, including the relations among their artifacts. In addition to that, the possibility of visualizing specific snapshots of those systems becomes more and more important for software developers to fully understand changes in software systems and enable the comparability of different development versions. These changes can affect the hierarchical structure, e.g., by adding new classes to packages, as well as the meta data of the artifacts itself, e.g., code complexity or the number of lines of code. Nevertheless, understanding complex software systems that consist of millions of lines of code and thousands of classes is an essential requirement for the maintenance of these systems, one of the major software-engineering challenges required due to the "aging" of software systems, in particular, in the case of legacy software systems. One approach to create software visualization that, in particular, facilitates the creation of mental models of the underlying data hierarchy, is the use of real-world metaphors, e.g., "software cities". Although these visualization techniques create a specific 2D, 2.5D or 3D visual mapping between abstract artifacts of a software system they are faced with a huge limitation. The techniques use naive layout algorithms to place the nodes of the mapped hierarchy elements, e.g., basic treemaps or fractal solutions. These algorithms, which are suitable for the visualization of a snapshot of the hierarchical structure, are less suited to provide coherent depictions of a software systems throughout its life-cycle because they do not achieve so called "stable layout". For example, a treemap-based visualization of the next release might have almost no visual similarity to that of the previous one. To create pictures of comparable snapshots, or even better, show animated transitions between them, layout algorithms must be used in which local changes in the data only cause local changes in the resulting layout. For it, we use voronoi treemaps, which recursively subdivide a free-formed convex polygon by creating voronoi cells for specially distributed points (or in the case of a used mapping to the resulting cell area, discs of different sizes) in the area of the polygon. The distribution of the points/discs therefore results in the n-body problem which can be solved in O(n log n). Even though the use of voronoi treemap comes up with higher calculation costs it results in a more stable layout. For it, we use hardware accelerated approaches to reduce the calculation time and investigate level-of-detail algorithms suitable for the visualization of software systems.

15.14 Concurrent Programming Activities in Integrated Environments

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Programmers perform multiple activities concurrently when modifying service-oriented software systems. In fact, programming does not just involve writing new or changing existing code, but exploring an extensive informational space to ensure one's efforts will not break the system. Thus, a stack of commenced activities emerges while accessing and understanding pieces of available information. To support this process, programmers benefit from using integrated tools that ease exploration and support putting relevant information together. Having this, environments—such as Eclipse—support exploring the system structure by means of extracting semantics from plain text, accessing run-time by means of supervised program execution, or reading external documentation by means of embedded Web resources.

With tools affecting programming activities and hence programmers' efficiency, tool designers need to carefully assess the expected scenarios: Which questions will programmers ask? How to access answers? How to reduce mental effort when combining multiple answers? However, tools will be used in many, maybe unknown, scenarios. Thus, tool designers use exemplary working patterns to infer generic ones. To compensate for inappropriate generality, they offer options for configuration and extension. Hence, programmers should accommodate tools to domain-specific scenarios, which the designer could not think of in advance, by themselves.

Unfortunately, programmers tend to not accommodate traditional programming environments to domain-specific scenarios. On the one hand, there is the phenomenon called "active user paradox", which means that users will just try out a new tool without reading manuals or consuming other elaborate advice. On the other hand, once an appropriate workflow is found, users are often not interested in optimizing their usage behavior. Even if options are known, they have difficulties to estimate the accommodation effort and the benefits gained for future activities. In the end, the tool cannot be mastered in terms of the specific usage scenario. Thus, activities may need more time than necessary.

Our approach to solve these problems is called VIVIDE—an integrated environment that supports programmers' concurrent programming activities. A small set of primitive features allow for accessing, understanding, and modifying the informational space relevant for shaping the software system in question. Then, using semi-automatic mechanisms, programmers should accommodate the environment by making estimation of costs and benefits easier. Thus, programming activities should be accomplished faster.

15.15 Robust Proactive Capacity Planning and Reactive VM Consolidation for Virtualized Data Centers

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Virtualization is the key enabling technology for Cloud Computing paradigm that provides computational and storage resources as a service over the Internet. Cloud computing as a consolidation environment assists in reducing energy consumption by computing services. Cloud's providers provide on-demand computing services where customers pay based on the actual resource usage. In this context, An efficient resource management should handle the trade-off between performance and energy.
To this end, we propose two level of resource management including capacity planning and VM consolidation. Our approach includes a robust proactive capacity planning and reactive VM migration and consolidation.
The robust proactive capacity planning is capable of predicting the number of the required VMs and determining the number of the required servers for hosting these VMs. Unlike deterministic optimization, the robust optimization approach considers the uncertainty of demand predication. The principle of robust optimization considers point prediction meaningless and it is replaced by range prediction. Thus, robust optimization addresses data uncertainty by assuming that uncertain parameters belong to a bounded range. For exploiting robust optimization, we implemented an adaptive range-based workload prediction approach.
The reactive VM migration and consolidation allow further optimization to achieve energy savings. As we take into consideration the costs of VM migration and server power-state change, we find that inefficient usage of them can be very expensive and cause a reverse effect on energy savings. To efficient handling of VM migration and consolidation, we implemented a robust CPU-utilization state change detection that keeps balancing of resource utilization of servers.
Further research will consider the VMs communication dependent where an application consists of multiple VMs. The placement of these VMs affects on the performance of the application. To achieve efficient placement for these applications, it requires online determining the communication patterns among the VMs, which is the next our objective.
To evaluate our approach, we implemented the proposed algorithms into CloudSim simulator. This allows comparing our approach with other approaches proposed by researchers that also use CloudSim.

15.16 Self-Adaptive Data Quality Services

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Data quality is a crucial factor for entrepreneurial success. In general, it is a statement about to which extend data are fit for use (e. g., up to date, relevant, accessible, or consistently represented). Deficiencies in representation can lead to store several different representations of the same real-world object. This in turn might result in, e. g., too large item counts, missed joins, and waste of memory or processing time. Many different technical actions can be taken to increase data quality regarding this representation errors, among which duplicate detection is the most important part. It employs well-established algorithms and heuristics, which – in short – search through a database and estimate the similarity of pairs of tuples based on data type, value, and additional information to identify these pairs as possible duplicates. Selecting these algorithms and providing them with reasonable parameters is a huge manual effort requiring human and time resources.
Web Services are a versatile yet powerful approach to allow ad-hoc and bargain data cleansing means. In contrast to monolithic stand-alone systems, they offer their capabilities on a pay-as-you-go basis. Moreover, they are exhibiting well-understood and standardized interfaces (SOAP or RESTful) and are thus easy to integrate in the existing IT landscape.
Duplicates are hard to find in databases, because it is unclear which attributes of the tuples to compare and how. The schema can be re-constructed by inspecting values and value distributions, functional dependencies (e. g., zip code and city), or header information and combining this with reference data (if available).
The number of comparisons can quickly become prohibitively large, because each record has to be compared to each other record. Techniques to reduce this number and to exclude most of the futile comparisons usually partitions the dataset according to some key into partitions and performs the actual duplicate detection only within those partitions. The definition of the partitioning key is the important part in this step and has to be done thoroughly.
I aim for creating a data cleansing web service that requires minimal user interaction and expert knowledge, i. e., is especially easy to use. In a first step, I developed a technique to automatically assign fine-grained datatypes to unclassified relational data in the address domain using machine learning algorithms. Secondly, I created a technique to learn good partitioning keys (for discarding irrelevant comparisons) for a given dataset. These partitioning keys can then be used for other datasets which allows for quick and configuration-free processing.

15.17 Understanding Code with Execution Traces

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Most developers spend much time understanding existing code. Especially in large systems, another important task is finding the code in the first place[1]. Programmers search code for various reasons, for instance, finding code that implements a feature, finding existing solutions to similar problems, or understanding how a code unit is used.
A lot of implicit information is not available at development time, but at runtime only. For instance, in a well-tested system, the tests can provide relevant information of common executions paths, as well as anticipated excpetional cases, that can answer typical questions about a program's behavior.
By storing execution traces (of automated tests or other sources) in a database, it is possible to immediately search in multiple traces for possible answers to a question. Modern database technology can allow fast response time even for complex queries on large amounts of data[2].
An extension to the developer's IDE can allow searching this data in a meaningful way. It does not seem reasonable to expect the developer to formulate an exact query (e.g., in an SQL-like language) of what she is looking for. Instead, a graphical interface can help with the construction of the query. The developer begins with browsing the results of a very broad query, which then can be refined incrementally, until the result set is small enough so that each result can be examined individually. Using an in-memory will ensure the fast response time that is necessary for performing incremental searches. The research will show which data layouts are optimal for efficiently answering developers' questions, how user interfaces can be designed to incrementally formulate queries on execution traces, and how complex queries are that developers want to ask. Once a prototype is implemented, user studies will have to show which questions are asked, how the construction of queries can be supported, and to which extend this helper can increase developer productivity.

[1] Oleksandr Panchenko, Hasso Plattner, and Alexander Zeier. *What do developers search for in source code and why*. Proceeding of the 3rd international workshop on Search-driven development: users, infrastructure, tools, and evaluation - SUITE'11, pages 33–36, 2011.

[2] H. Plattner and A. Zeier. *In-Memory Data Management: An Inflection Point for Enterprise Applications*. Springer, 2011

15.18 Adaptation in Cyber-Physical Systems

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Today, software has to meet high demands concerning the ability to change its behavior in order to achieve altering business goals. Modern software engineering approaches help design software systems that are able to adapt their pool of functional behavior to reach these goals. The service-oriented architecture (SOA) provides an architectural description and the handling of a large distributed IT landscape to cover modern software demands.
Combining the idea of independent, reusable services in SOA with different development paradigms of the model-driven architecture (MDA) fits into an adaptive, highly variable software infrastructure, which enables the execution of modern business processes.
Most of today's software runs on embedded systems. Those are hidden from the user in most cases and realize control, monitoring and regulation tasks. Additionally, these systems are characterized by limited resources and other non-functional properties, like hard real-time constraints or limited memory capacity. Cyber-physical systems are a new generation of such embedded systems that arise from the integration and composition of more and more components as well as from the interaction with the physical environment.
This research topic is about the dynamic reconfiguration and adaptation of such embedded and cyber-physical systems. Existing approaches do not fully consider the required hard real-time constraints or make unrealistic and to strict assumptions.
Instead of a given fixed hardware configuration and software setting, the possibility to exchange the underling components and system parts in a SOA environment to handle even higher flexibility is key. Using the SOA paradigm, future embedded software must be able to adapt its execution characteristics at runtime. Furthermore, all non-functional constraints must be guaranteed.
The evaluation of my research is done on the basis of the AUTOSAR standard, which is the new de facto standard of the automobile industry. Additionally, the research results are evaluated in the HPI CPS robot laboratory (http://www.cpslab.de). It consists of three robots, several sensors and actuators as well as of a variable, adaptive environment, which simulates a production scenario.