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Aims and Scope
The periodical *Dagstuhl Reports* documents the program and the results of Dagstuhl Seminars and Dagstuhl Perspectives Workshops.
In principal, for each Dagstuhl Seminar or Dagstuhl Perspectives Workshop a report is published that contains the following:

- an executive summary of the seminar program and the fundamental results,
- an overview of the talks given during the seminar (summarized as talk abstracts), and
- summaries from working groups (if applicable).

This basic framework can be extended by suitable contributions that are related to the program of the seminar, e.g. summaries from panel discussions or open problem sessions.

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Report from Dagstuhl Seminar 11231

Scientific Visualization

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 11231 "Scientific Visualization".

Seminar 05.–10. June, 2011 – www.dagstuhl.de/11231
1998 ACM Subject Classification I.3 Computer Graphics, I.4 Image Processing and Computer Vision, J.2 Physical Sciences and Engineering, J.3 Life and Medical Sciences
Keywords and phrases Scientific Visualization, Biomedical Visualization, Integrated Multifield Visualization, Uncertainty Visualization, Scalable Visualization
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1 Executive Summary

Min Chen
Hans Hagen
Charles D. Hansen
Arie Kaufman

Scientific Visualization (SV) is the transformation of abstract data, derived from observation or simulation, into readily comprehensible images, and has proven to play an indispensable part of the scientific discovery process in many fields of contemporary science. This seminar focused on the general field where applications influence basic research questions on one hand while basic research drives applications on the other. Reflecting the heterogeneous structure of Scientific Visualization and the currently unsolved problems in the field, this seminar dealt with key research problems and their solutions in the following subfields of scientific visualization:

Biomedical Visualization: Biomedical visualization and imaging refers to the mechanisms and techniques utilized to create and display images of the human body, organs or their components for clinical or research purposes. Computational and algorithmic biomedical imaging is a wide area of research and solution development.The participants presented open problems and some solutions in this research area.

Integrated Multifield Visualization: The output of the majority of computational science and engineering simulations typically consists of a combination of variables, so called multifield data, involving a number of scalar fields, vector fields, or tensor fields. The state of the art in multifield visualization considerably lags behind that of multifield simulation. Novel solutions to multiscale and multifield visualization problems have the potential for a

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large impact on scientific endeavours and defining open problems and ideas in this subtopic was of keen interest to the seminar.

Uncertainty Visualization: Decision making, especially rapid decision making, typically happens under uncertain conditions. Challenges include the inherent difficulty in defining, characterizing, and controlling comparisons between different data sets and in part to the corresponding error and uncertainty in the experimental, simulation, and/or visualization processes. Refining and defining these challenges and presenting solutions was the focus for participants.

Scalable Visualization: The development of terascale, petascale, and soon to be exascale computing systems and of powerful new scientific instruments collecting vast amounts of data has created an unprecedented rate of growth of scientific data. Many solutions are possible such as trade-offs in speed vs quality, abstractions which provide scalability, novel parallel techniques, and the development of techniques for multivariate visual display and exploration.

However, scaling to the next generation (exascale) platforms may require completely rethinking the visualization workflow and methods. Defining how such architectures influence scientific visualization methods was addressed in this seminar.

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3 Overview of Talks

3.1 Visualization of uncertain scalar data fields using color scales and perceptually adapted noise

Georges-Pierre Bonneau (INRIA Rhône-Alpes, FR)

We present a new method to visualize uncertain scalar data fields by combining color scale visualization techniques with animated, perceptually adapted Perlin noise. The parameters of the Perlin noise are controlled by the uncertainty information to produce animated patterns showing local data value and quality. In order to precisely control the perception of the noise patterns, we perform a psychophysical evaluation of contrast sensitivity thresholds for a set of Perlin noise stimuli. We validate and extend this evaluation using an existing computational model. This allows us to predict the perception of the uncertainty noise patterns for arbitrary choices of parameters. We demonstrate and discuss the efficiency and the benefits of our method with various settings, color maps and data sets.

3.2 Visualisation for Computer Assisted Surgery: Open Questions and Challenges

Charl P. Botha (TU Delft, NL)

Joint work of Botha, Charl P.; Kroes, Thomas; Valstar, Edward R.; Preim, Bernhard; Post, Frits

Computer Assisted Surgery, or CAS, refers to the integration of computers in the surgical planning and guidance pipeline. Visualisation plays an important role in presenting patient-specific data, enabling virtual surgery during planning and providing guidance in surgery. In order to study the role of visualisation, we are working on a survey of all research papers, more than 500 at the moment, dealing with examples of visualisation-oriented CAS. In this talk, I give a brief overview of the application areas and classes of techniques that we have identified and discuss five of the more interesting open questions that have come up during the research.

The great majority of all application papers can be classified into one of the following four types: Orthopaedic, neuro, maxillofacial and hepatic. The rest of the work consist of technique papers that we have classified according to the CAS pipeline: Visual representation, interaction, and process and outcome simulation. Furthermore, there are four "transfer modalities" by which planning can be applied during surgery: Image-based guidance, mechanical guidance devices, documentation and mental models.

Five of the more interesting open questions are:

1. What is the role of realism in visualisation for computer assisted surgery? Do the used visualisations need to be as realistic as possible, or is a caricaturistic solution more effective?
2. Related to the previous question, what is the value of simplified visual representations such as reformations (e.g. CPR) and maps (e.g. tumor maps) in surgical planning? How do these influence the spatial recognition of the surgeon?

3. How effective are the various different transfer modalities, especially documentation and mental model? How valuable is planning without any form of explicit guidance?
4. Who or what should be responsible for the segmentation and other processing that is so crucial for performing surgical planning?
5. Is surgical planning and guidance based on population stratification viable? Is it desirable?

3.3 Visual Knowledge Discovery in Neurobiology

Stefan Bruckner (TU Wien, AT)

The rapid evolution of computer technology has stimulated domain researchers from many areas to adopt and develop new techniques for data analysis. Spatial distributions represented by large collections of volumetric data are being generated in fields as diverse as biology, medicine, chemistry, physics, and astronomy. This development, however, means that it is no longer sufficient to provide tools for analyzing a single data set. Instead, many thousands of data points, each consisting of a volumetric representation, need to be investigated. Mapping neural structures in biology, in particular, requires efficient tools to visually query and retrieve data items as well as methods to explore, categorize, and abstract the space. This talk discusses current challenges in visualization systems that can help scientists to uncover how information processing in neural circuits gives rise to complex behavior.

3.4 Hammerspace & Nailspace: Two approaches to multivariate topology

Hamish Carr (University of Leeds, GB)

Joint work of Carr, Hamish; Duke, David

Topological analysis has proven to be a useful set of techniques for both scalar and vector fields. However, much of the development of these techniques has been based on a familiar paradigm in Computer Science: inventing a hammer, then looking for nails. To extend topological analysis to multivariate fields, we therefore start by asking what characteristics of the underlying phenomenon should be used for analysis - i.e. what the characteristics of the nail are. At the same time, however, the hammer paradigm continues to be productive, and we introduce early steps in extending level set (contour) snslysis to multivariate data.

3.5 Simplex, diamond and hypercube hierarchies in arbitrary dimensions

Leila De Floriani (University of Genova, IT)

Joint work of Kenneth Weiss (University of Maryland)

Hierarchical spatial decompositions play a fundamental role in many disparate areas of scientific computing since they enable adaptive sampling of large problem domains. Many approaches in this area deal with hierarchical simplicial decompositions generated through regular simplex bisection. Such decompositions, originally developed for finite elements, are extensively used as the basis for multiresolution models of scalar fields, such as terrains, and static or time-varying volume data. Moreover, the use of quadtrees, octrees, and their higher dimensional analogues as spatial decompositions is ubiquitous, but these structures usually generate meshes with cracks, which can lead to discontinuities in functions defined on their domain.

In this talk, we focus on hierarchical models based on regular simplicial bisection and on regular hypercube refinement and we treat them in a dimension-independent way. We highlight the properties of such hierarchies and discuss a dimension-independent triangulation algorithm based on regular simplex bisection to locally decompose adaptive hypercubic meshes into high quality simplicial complexes with guaranteed geometric and adaptivity constraints.

3.6 Visual Analytics at Scale: Challenges and Directions

David S. Ebert (Purdue University, US)

Enabling discovery and decision making at real-world scale is an interesting and challenging problem. The main focus should be on understanding the science, the user, their questions, tasks, and the context. Given this frame of reference, four challenges to be addressed are the following:

- Creating Computer-human visual cognition environments
- Enabling coupled interactive simulation and analytical environments
- Addressing specific scale (natural scale, physical scale, cross-scale) issues
- Effectively integrating certainty/uncertainty and temporal analysis and visualization

3.7 Displaying Many Pixels and How to Compute Them

Thomas Ertl (Universität Stuttgart, DE)

This talk addresses aspects of output scalability of large-scale visualization environments by reporting on the progress of an infrastructure project at the Visualization Research Center of the University of Stuttgart. When moving into a remodeled and extended building in 2010, the institute had the space and the funding available to build a high-resolution back-projection system. The demand for a wall-size, seamless, bevel-free display allowing for binocular 3D stereo and almost monitor resolution (50 dpi) lead to a design with five stereo pairs of 4K projectors arranged horizontally in portrait mode. This results in an immersive display with only four blending zones with a total of almost 100 megapixels (45 megapixels per eye) of 0.5 mm pixel size. In order to drive such a wall display requiring 40 video-in lines and an aggregate bandwidth of more than 20 gigabyte/s, we propose a two-tier GPU cluster architecture with 20 display nodes attached to the projectors and 64 node rendering nodes all connected by a high-throughput low latency InfiniBand network. The second part of the talk addresses various approaches to generate visualizations for such an architecture. While low-level output driver models are difficult to implement and tend to be as performance-limited as transparent library overloading, applications exploiting the full potential of the system still need to be manually tuned eventually easing implementation efforts by building on a middleware abstracting from the various layers of parallelism.

3.8 Scalable Visualization: Motivation, Issues and Impediments

Kelly Gaither (University of Texas at Austin, US)

As visualization scientists and practitioners, we are faced with increasingly larger datasets generated by increasingly more complex models. To properly handle these resulting massive datasets, we must analyze and understand opportunities to scale our visualization tools, methods, and resources. The computational science and high performance computing communities have addressed many issues with respect to scaling for a number of years. Much can be learned by reviewing what these communities have done to address scaling of resources, algorithms, and accessibility mechanisms. By understanding the mission and the enablers for scaling each of these, we can compare current successes in high performance computing and visualization, and better understand the issues and impediments that must be addressed to respond to the data deluge we are currently facing. Doing so will allow us to formulate strategies going forward to analyze massive datasets.

3.9 Integral Curves on Large Data

Christoph Garth (University of California – Davis, US)

The talk gives an overview of recent effort towards enabling integration-based visualization on large data sets by taking advantage of modern supercomputing architectures. Integration-based visualization has garnered renewed traction in the visualization community and is a feature often needed by domain scientists to facilitate vector field visualization and analysis. Over the past two years, we have investigated parallelization schemes that make use of distributed computation and data to achieve good performance for integral curve computation. Furthermore, by leveraging architectural features of modern supercomputing architectures, such as multi-core CPUs, we achieve further performance improvements. The talk concludes with an overview of open problems and future directions.

3.10 Computational Steering and Interactive Visualization for Large-Scale Simulations

Andreas Gerndt (German Aerospace Center – Braunschweig, DE)

Joint work of Gerndt, Andreas; Wagner, Christian

After submitting a batch job to a supercomputer to simulate large multi-disciplinary flow fields, the user has to wait hours, days or more until it is finished or crashed. With computational steering, it is possible to modify numerical parameters in order to adjust an ongoing simulation. But to identify failures in 3D flow simulations, we propose 3D post-processing in virtual environments. Here, interactivity is a crucial point while the extraction data is computed in parallel on the simulation back end. We can show, that classical extraction approaches can not guarantee interactive response times. However, multi-resolution sampling schemes are very promising. By adding variance information to the cell tree stored at each compute node, the information density for the interactive data exploration can be improved even more.

3.11 The Haunted Swamps of Uniformity

Eduard Groeller (TU Wien, AT)

Dissemination of scientific results in visualization (like in many other disciplines) through papers and talks follow rather standardized styles and procedures. Given that publishing strategies were very different not so much time ago in the past, and given new technological developments like electronic publishing, ideas of possible future developments are discussed. Topics treated include: increased repeatability through augmenting papers with executables, providing more extensive sensitivity and robustness analyses, paper presentation as drama, poem, comics strip.

3.12 Interactive Visual Analysis of Multi-Dimensional Scientific Data

Helwig Hauser (University of Bergen, NO)

One common notion of scientific data is to consider it as a mapping of independent variables – usually space and/or time in scientific visualization – to a set of dependent values, very often resembling some measurements or computational simulation results.

Traditionally, neither the spatiotemporal domain nor the dependent variables were of higher dimensionality. A larger number of dependent values, leading to multi-variate data, however, has lead to interesting visualization research more recently. Very interesting and quite challenging, also, the emergence of higher-dimensional scientific data (higher-dimensional domain) leads to new visualization questions.

Multi-run / ensemble simulation data, for example, includes also parameters as additional independent variables.

The integration of descriptive statistics, both for the representation of trends and outliers, allows to perform a linked interactive visual analysis both on aggregation level as well as on the original multi-run data.

Challenges arise from the larger number of available statistics as well as from the necessary mental reconstruction of phenomena from aggregates.

3.13 Uncertainty Visualization & Display of Probabilistic Isocontours

Hans-Christian Hege (ZIB – Berlin, DE)

Main reference Kai Pöthkow, Britta Weber, Hans-Christian Hege, "Probabilistic marching cubes," Comput. Graph Forum 30:3, pp. 931–940, 2011 (EuroVis 2011)
URL http://dx.doi.org/10.1111/j.1467-8659.2011.01942.x

In the *first* part of the talk I shortly sketch what we
1) need to learn from other fields like probability theory, statistics, statistical graphics, softcomputing and artificial intelligence
2) should explore and develop in our research.

Regarding 1): This includes the various types of uncertainty, causes of uncertainty, mathematical representations of uncertainty, uncertainty quantification, uncertainty propagation, data processing and analysis techniques like ensemble analysis, aggregation, reasoning under uncertainty, as well as defuzzification for decision support.

Regarding 2): This includes practical representations of uncertainty, uncertainty propagation in the visualization pipeline, uncertainty of extracted features, fuzzy analogs of crisp features, visual mapping of uncertain data and of fuzzy features, perception of visual uncertainty representations, visual reasoning under uncertainty, visual support of statistical processing and analysis techniques as well as decision making under uncertainty, methodology for development of visualization and visual analytics applications; furthermore evaluation of particular visualization and visual analytics techniques as well as whole software systems.

Additionally, I discuss the tight relation between visualization of uncertain fields and function field visualization as well as multi-field and multi-variate visualization – due to the mathematical structure that is identical, up to sampling, normalization and grouping of data dimensions.

In the *second* part of the talk I discuss ideas how the display of probabilistic iso-contours of uncertain scalar fields – modeled as discrete Gaussian random fields with arbitrary spatial correlations [1] – can be significantly speeded up.

3.14 3D tensor field exploration in shape space

Ingrid Hotz (ZIB – Berlin, DE)

Joint work of Hotz, Ingrid; Andrea Kratz
URL http://www.zib.de/hotz/publications/paper/kratz_techReport1026.pdf

We present a visual approach for the exploration of stress tensor fields. Therefore, we introduce the idea of multiple linked views to tensor visualization. In contrast to common tensor visualization methods that only provide a single view to the tensor field, we pursue the idea of providing various perspectives onto the data in attribute and object space. Especially in the context of stress tensors, advanced tensor visualization methods have a young tradition. Thus, we propose a combination of visualization techniques domain experts are used to with statistical views of tensor attributes. The application of this concept to tensor fields was achieved by extending the notion of shape space. It provides an intuitive way of finding tensor invariants that represent relevant physical properties. Using brushing techniques, the user can select features in attribute space, which are mapped to displayable entities in a three-dimensional hybrid visualization in object space.

Volume rendering serves as context, while glyphs encode the whole tensor information in focus regions. Tensorlines can be included to emphasize directionally coherent features in the tensor field. We show that the benefit of such a multi-perspective approach is manifold.

Foremost, it provides easy access to the complexity of tensor data. Moreover, including well- known analysis tools, such as Mohr diagrams, users can familiarize themselves gradually with novel visualization methods. Finally, by employing a focus-driven hybrid rendering, we significantly reduce clutter, which was a major problem of other three-dimensional tensor visualization methods.

3.15 Visualization in Developmental Biology

Heike Jaenicke (Universität Heidelberg, DE)

Modern microscopy techniques allow for fascinating new insights into the development of life. They produce digital threedimensional records of living embryos and reveal how a single cell develops into a complex organism. Though all relevant information is contained in such data, the records confront scientists with large challenges when it comes to data analysis. Digital embryo data is very difficult to segment and cell tracking is just as challenging. This information, however, is the key to further analysis and insights into these complex processes.

In this talk, I will present a set of algorithms that enable biologists to track the segmented cell data and assess the quality of the segmentation and tracking. We provide visualization techniques and quality measures for multiple levels of detail, which provide means to interactively dig into the data and find artefacts in the data and shortcoming of the algorithms.

Our methods enable the users to validate terabytes of data and turn them into reliable data sources that can be used for further investigation.

3.16 Image space occlusion model

Yun Jang (ETH Zürich, CH)

Understanding and perception of three-dimensional scientific visualizations benefit from visual cues which are available from shading. The prevalent approaches are local shading models since they are computationally cheap and simple to implement. However, local shading models do not always provide proper visual cues, since non-local information is not sufficiently taken into account for shading. Better visual cues can be obtained from global illumination models but the computational cost can be often prohibitive. It has been shown that alternative illumination models, such as ambient occlusion, multidirectional shading, and shadows, can provide proper perceptual cues as well. Although these models improve upon local shading models, they still need expensive preprocessing, extra GPU memory, incur high computational cost, or cause a lack of interactivity during transfer function and light position changes. In this paper, we propose an image space multidirectional occlusion shading model which requires no preprocessing and stores all required information in the output image on the GPU. Changes to the transfer function or the light position can be performed interactively. The approach is based on the insight that image space shading methods can be improved if we store relevant information during the preceding rendering step. Our simple model is capable of simulating a wide range of shading behaviors, such as ambient occlusion, soft and hard shadows, and can be applied to any rendering system such as geometry rendering or volume rendering. We evaluate our approach and show that the suggested model enhances the perceptual cues even though it can be computed efficiently.

3.17 Overview of Uncertainty Visualization

Christopher R. Johnson (University of Utah – Salt Lake City, US)

As former English Statesmen and Nobel Laureate (Literature), Winston Churchill said, "True genius resides in the capacity for evaluation of uncertain, hazardous, and conflicting information." Churchill is echoed by Nobel Prize winning Physicist Richard Feynman, "What is not surrounded by uncertainty cannot be the truth." Yet, with few exceptions, visualization research has ignored the visual representation of errors and uncertainty for three-dimensional (and higher) visualizations. In this presentation, I will give an overview of what has been done thus far in uncertainty visualization and discuss future challenges.

3.18 Bayesian evidence for visualizing model selection uncertainty

Gordon Kindlmann (University of Chicago, US)

Bayesian inference provides a well-known mathematical framework for fitting given models to data, and quantifying the variance of the model parameters.

The variance of the underlying data, and of the model parameters, are two kinds of uncertainty that have been previously studied in visualization.

Bayesian inference also provides a quantity known as "evidence", or the marginal likelihood of the model, which quantifies the quality of a model given the data. Bayesian evidence naturally implements Occam's Razor. We propose that uncertainty in model selection can be parameterized by evidence, and that visualization of evidence can create an effective way of "seeing" where current hypotheses do and do not explain the data. This kind of visualization method may prove especially useful in the context of modern biomedical imaging (such as fMRI and diffusion MRI), which can generate 30-120 values per-voxel, which benefit from some form of model fitting as part of evaluating hypotheses.

3.19 Downscaleable Visualization

Jens Krueger (DFKI Saarbrücken, DE)

In recent years there has been significant growth in the use of patient-specific models to predict the effects of neuromodulation therapies such as deep brain stimulation (DBS). However, translating these models from a research environment to the everyday clinical workflow has been a challenge, primarily due to the complexity of the models and specialized software required to provide the visualization. In this talk I will motivate that an interactive visualization system, which has been designed for mobile computing devices such as the iPhone or iPad, used to visualize models of four Parkinson's patients who received DBS therapy can significantly improve the state of the art and I will make the claim that this is just one of many possible scenarios for successful application of mobile visualization.

3.20 Multifield Data Visualization: Automatic vs. Interactive Feature Extraction

Lars Linsen (Jacobs University – Bremen, DE)

Extracting features from volume data has been one of the main driving goals in scientific visualization.

Many approaches exist that do this automatically or interactively.

For multifield data visualization, interaction in attribute space is less intuitive and the outcome of automatic approaches is harder to interpret.

This talk focuses on discussing advantages and disadvantages of automatic and interactive feature extraction and combined approaches.

3.21 Visualization of Temporal Trends for Time-Varying Data

Aidong Lu (University of North Carolina at Charlotte, US)

The visualization challenges of time-varying datasets with long time durations are different from 2D or 3D large-scale scientific visualization, as temporal features are often abstract and can be easily transformed at different time scales. This talk provides examples of designing new visualization tools to study temporal features with the technique of storytelling. First, a digital storytelling - animation is chosen as it is a natural representation of a time-varying dataset. It describes detailed events computed through features-of-interest. Second, an interactive storyboard is chosen to overview temporal relationships, as it is flexible to describe various trends in an extremely succinct style. Last, temporal histogram is shown to be useful to identify interesting temporal patterns as well. We plan to continue to explore new visualization designs to study large-scale datasets.

3.22 Problem-drive Visualization Research

Miriah Meyer (Harvard University, US)

Problem-driven research in visualization focuses on applying visualization techniques, methods, and algorithms to specific domains and target users. On the micro scale, this approach results in tools and designs that are truly effective for answering scientific questions. On the macro scale, this approach results in new visualization algorithms, methods, and techniques, as well as insight for formulating new methodologies. We are working towards articulating one such methodology, design studies, for conducting problem-driven research.

A design study results in a user-validated design for an existing and reoccurring problem with reflection. This methodology pushes the expectation of visualization beyond just pretty pictures, and towards a deep investigation into task-oriented data analysis.

3.23 The Case for Multi-Dimensional Visual Data Analysis

Torsten Moeller (Simon Fraser University – Burnaby, CA)

In this talk I am trying to summarize my experiences with working with several different input-output systems of which simulations are the majority. I characterize these systems on an abstract level and list and explain the major tasks scientists are trying to accomplish as - a) Optimization, b) Segmentation, c) Fitting, d) Steering, and e) Sensitivity Analysis.

3.24 Can Computers Master the Art of Communication?

Klaus Mueller (Stony Brook University, US)

Visual analytics seeks to conduct a discourse with the user through images. The computer supports the user in this interactive analytical reasoning, constructing a formal model of the given data, with the end product being formatted knowledge constituting insight. Yet, validation and refinement of this computational model of insight can occur only in the human domain expert's mind, bringing to bear possibly unformatted knowledge as well as intuition and creative thought. So, it's left to this human user to guide the computer in the formalization (learning) of more sophisticated models that capture what the human desires and what the computer currently believes about the data domain. Obviously, the better a communicator the computer is, the more assistance it will elicit from the user to help it refine the model. We propose visualization and visual interaction as the prime communication channels between analyst and computer. We look at effective strategies that exist in human-human communication and then identify their corresponding visual counterparts for use in human-computer communication.

3.25 Derived Scalar Fields for Visual Analysis of Multifield Data

Vijay Natarajan (Indian Inst. of Science – Bangalore, IN)

Multifield data is ubiquitous to all scientific studies. In this talk, I will argue that the design of analysis and visualization techniques for multifield data will benefit by studying the relationship between fields as compared to a focused study of inherent properties of individual fields. We have followed this principle to develop a relation-aware method for exploring isosurfaces of scalar fields and a gradient-based derived scalar field that captures the alignment between gradient vectors at a given point. I will briefly describe these methods for visualizing multifield data and outline some interesting and challenging problems that remain open.

3.26 On Visualization of Dense Line Data

Harald Obermaier (University of California – Davis, US)

Joint work of Schroeder, Simon; Obermaier, Harald; Garth, Christoph; Hagen, Hans; Joy, Ken

Dense line data is generated by various scientific simulation and post-processing methods. For visualization purposes, flow fields, for example, are often densely sampled by integral lines. We present novel methods to perform multi-field feature extraction on this dense set of lines to highlight features in the flow field and solve problems of dense line data visualization. Together with a novel ambient occlusion approach, these multi-field properties provide the means for feature-based and interactive visualization of dense line data. We demonstrate, how this implicit flow feature extraction can help provide a fast, feature oriented display of characteristic flow structures such as vortex cores.

3.27 Uncertainty Visualization: Routine for Color Vision Deficient Individuals

Manuel Oliveira (UFRGS – Porto Alegre, BR)

Color vision deficiency (CVD) is a relevant subject in visualization, but one that has not yet received the attention it deserves. Current estimates indicate that approximately 200 million individuals worldwide suffer from some kind of CVD. Due to loss of color contrast, these individuals will not perceive visualizations the way they were intended to be. This leads to uncertainties when interpreting images and videos, forcing them to make important decisions based on ambiguous information, which may have catastrophic implications. This talk explains the causes of the difficulties faced by color-vision-deficient individuals, and describes the main tools available for helping them to recover, as much as possible, the experienced loss of color contrast. Such tools consist primarily of recoloring techniques.

It also discusses the inherent limitations of these techniques, and presents some open questions in this area. It then describes one approach that tries to address these questions, and presents the results of a user study designed to evaluate it. The study was performed with sixteen color vision deficient volunteers and twenty two individuals with normal color vision. Its results show that one can, in certain visualization tasks, improve the performance of individuals with CVD to the levels of a normal color vision person by augmenting the visualizations using relatively simple patterns.

These results show that this technique also improves the performance of normal trichromats on the same tasks, and suggest a fruitful direction for future exploration.

3.28 Uncertainty in Analysis and Visualization: Topology and Statistics

Valerio Pascucci (University of Utah – Salt Lake City, US)

One of the greatest challenges for today's visualization and analysis communities is the massive amounts of data generated from state of the art simulations. Traditionally, the increase in spatial resolution has driven most of the data explosion, but more recently ensembles of simulations with multiple results per data point and stochastic simulations storing individual probability distributions are increasingly common. This paper introduces a new data representation for scalar data called hixels that store a histogram of values for each sample point of a domain. The histograms may be created by spatial down-sampling, binning ensemble values, or polling values from a given distribution. In this manner, hixels form a compact yet information rich approximation of large scale data. In essence, hixels trade off data size and complexity for scalar-value "uncertainty".

Based on this new representation we propose new feature detection algorithms using a combination of topological and statistical methods. In particular, we show how to approximate topological structures from hixel data, extract structures from multi-modal distributions, and render uncertain isosurfaces. In all three cases we demonstrate how using hixels compares to traditional techniques and provide new capabilities to recover prominent features that would otherwise be either infeasible to compute or ambiguous to infer.

We use a collection of computer tomography data and large scale combustion simulations to illustrate our techniques.

3.29 Interacting with our related fields – some observations

Ronald Peikert (ETH Zürich, CH)

The field of scientific visualization is seen differently by communities in some of the more closely related fields, such as applied math, fluid mechanics, or computer vision. After decades of various kinds of exchanges with people from industry partners, met at conferences or even within our institution, some observations could be made repeatedly. Sources of frequent misunderstandings include different notions of scientific exactness, different work flows, different conventions for structuring publications, different terminology, and different understandings on the border between disciplines. In this talk this is illustrated with a number of anecdotic examples.

3.30 The Connectome - Discovering the Wiring Diagram of the Brain

Hanspeter Pfister (Harvard University, US)

Discovering and analyzing the neural network of the brain is one of the great scientific challenges of our times. The Harvard Center for Brain Science and the School of Engineering and Applied Sciences have been working together since 2007 on the Connectome Project. This ambitious effort aims to apply biology and computer science to the grand challenge of determining the detailed neural circuitry of the brain. In this talk I will give an overview of the computational challenges and some interactive visualization approaches that we developed to discover and analyze the brain's neural network. The key to our methods is to keep the user in the loop, either for providing input to our downstream segmentation methods, or for validation and corrections of the segmented processes. The main challenges we face are how to deal with terabytes of image data in an efficient and scalable way, and how to analyze the brain's neural network once we have discovered it.

3.31 Visualization for Urban Environments

Huamin Qu (The Hong Kong University of Science & Technology, HK)

With the advance of technologies, we are now able to collect many different kinds of data related to human behaviors such as mobile phone data and vehicle trajectory data. With these data, we can gain insight into human behaviors and reveal some hidden knowledge in the data. However, real data often contain many errors. In this talk, I will present how visualization techniques can help users detect errors in mobile phone data and fix the errors in the GPS data.

3.32 Ways of Not Knowing

Penny Rheingans (University of Maryland Baltimore County, US)

Visualization draws a picture from data, with the implication that the image shows THE truth. Reality is more complicated, with uncertainty clouding the picture. Visualization researchers have begun to acknowledge the importance of showing uncertainty, but what does that mean?

Uncertainty can mean very different things in different situations. Each type of uncertainty might best be displayed in a different way, depending on the key characteristics and goals. Estimated error from simulations or predictions might be considered to be just another scalar variable, to be displayed alone or in concert with the expected value. Complex models may involve multiple distinct components of uncertainty, with sources in model inputs, parameter selections, and the nature of the mechanisms modeled. Missing data can give rise to measures for confidence that supplements display of expected value. Uncertainty in location, boundary, or shape is most naturally displayed through spatial elements.

With heterogeneous predictions or classifications it may be desirable to show the numerous possibilities and their likelihoods.Other types of potential uncertainty offer new visual representation challenges. These include data that may be out of date or of dubious provenance, residuals of abstraction, distributions of value and uncertainty, variability of relationships, and uncertainty of causation.

Finally, we should understand how the visualization process impacts the propagation, magnification, perception, and impact of uncertainty.

In order to do this, we must understand computational sources and magnifiers of error and uncertainty in input values, perceptual and cognitive influences on the understanding of uncertainty visualization, effects of differences in audience abilities and culture, and competing positive and negative consequences of showing uncertainty.

3.33 Comparing brain networks

Jos B.T.M. Roerdink (University of Groningen, NL)

Nowadays, many neuroimaging methods are available to assess the functioning brain. Of particular interest is the comparison of functional brain networks under different experimental conditions, or comparison of such networks between groups of people. Recent studies on brain network architecture have shown a clear need for methods that allow local differences to be visualized in the original network representation. We discuss some recent methods for comparative visualization of brain connectivity networks obtained from EEG and fMRI data.

3.34 Illustrative Visualization of Probabilistic Tractogramms

Gerik Scheuermann (Universität Leipzig, DE)

Joint work of Scheuermann, Gerik; Goldau, Matthias; Hlawitschka, M.; Tittgemeyer, M.
Main reference Unpublished work under review

Neuroscience uses diffusion weighted imaging for quite some time to get an idea on the large scale connectivity inside the brain. The imaging data is processed to produce connectivity data by tractography algorithms. One class of these algorithms produces probability values for connections between different brain areas. In the talk, an illustrative visualization method is presented showing the connections between different cortex areas. As the technique is motivated by a celebrated book with hand-made illustrations of brain connectivity in the neuroscience community, the technique has found its way into publications of our partners directly.

3.35 Fuzzy Fibers: What Uncertainty Visualization Can and Cannot Achieve

Thomas Schultz (University of Chicago, US)

Despite their immense popularity in visualizing data from diffusion MRI, the interpretability of streamline visualizations in terms of white matter architecture is limited by partial voluming effects. Streamline lengths and trajectories depend on modeling choices, parameter settings, noise and artifacts in the data, as well as preprocessing strategies to address these problems. In this talk, I survey the existing approaches that have aimed at visually conveying the uncertainty that these factors introduce in the visualization, and I will identify open problems in this field. This will lead to some more fundamental reflections on what we can and cannot hope to achieve with uncertainty visualization, and on some more general challenges in uncertainty visualization.

3.36 Augmenting 3D perceptibility of in Data Visualization

Shigeo Takahashi (University of Tokyo, JP)

The Super Real Vision (SRV) is a system for plotting a series of illuminants freely in 3D space, which allows us to observe the target data as real 3D objects from any viewing positions. This new display technology will motivate us to reformulate the conventional data visualization techniques.

The talk presents how we can explore such possibilities to enhance the 3D perceptibility in data visualization, including possible applications to medical visualization as a means of achieving informed consent between medical doctors and patients.

3.37 Exploration of 4D MRI blood flow

Anna Vilanova Bartroli (TU Eindhoven, NL)

Better understanding of hemodynamics conceivably leads to improved diagnosis and prognosis of cardiovascular diseases.

Therefore, elaborate analysis of the blood-flow in heart and thoracic arteries is essential. Contemporary MRI techniques enable acquisition of quantitative time-resolved flow information, resulting in 4D velocity fields that capture the blood-flow behavior.

Visual exploration of these fields provides comprehensive insight into the unsteady blood-flow behavior, and precedes a quantitative analysis of additional blood-flow parameters. The complete inspection requires accurate segmentation of anatomical structures, encompassing a time-consuming and hard-to-automate process, especially for malformed morphologies. We present a way to avoid the laborious segmentation process in case of qualitative inspection, by introducing an interactive virtual probe. This probe is positioned semi-automatically within the blood-flow field, and serves as a navigational object for visual exploration. The difficult task of determining position and orientation along the view-direction is automated by a fitting approach, aligning the probe with the orientations of the velocity field. The aligned probe provides an interactive seeding basis for various flow visualization approaches. We demonstrate illustration-inspired particles, integral lines and integral surfaces, conveying distinct characteristics of the unsteady blood-flow.

3.38 Parallel Extraction of Crack-free Isosurfaces from Adaptive Mesh Refinement Data

Gunther H. Weber (Lawrence Berkeley National Laboratory, US)

Joint work of Weber, Gunther H.; Childs, Hank; Meredith, J.

Adaptive mesh refinement (AMR) is a simulation technique that is used increasingly for phenomena that cover large spatiotemporal scales. Block structured AMR represents the domain as a hierarchy of nested, axis-aligned grids arranged in levels of increasing resolution. Handling this type of data during visualization is a challenge since information in finer resolution levels supersedes that in coarser resolution levels, and it is difficult to handle resolution changes at level boundaries. Isosurfaces, an important building block for many visualization and analysis techniques, pose particular problems since the linear approximation of the surface as triangulation leads to discontinuities (or cracks) between AMR hierarchy levels. Here, we propose an efficient, parallel scheme to extract crack-free isosurfaces from AMR data. Our approach is based on previous work that uses dual grids and stitch cells to define a C^0 continuous interpolation scheme. We extend this approach by simplifying and unifying stitch cell generation in a case-table-based approach and utilize ghost cells to support effective parallelization as well as avoid conversion of dual meshes into unstructured grids.

3.39 On the (Un)Suitability of Strict Feature Definitions for Uncertain Data

Tino Weinkauf (MPI für Informatik – Saarbrücken, DE)

We discuss strategies to successfully work with strict feature definitions such as topology in the presence of noisy data. To that end, some previous work from the literature is reviewed. Also, the concept of Separatrix Persistence is presented, which allows to quantify features - and thereby remove small-scale features induced by noise.

3.40 Multi-field Visualization for Biomedical Data Sets

Thomas Wischgoll (Wright State University – Dayton, US)

There is a multitude of data sets that include additional information other than velocity data. This presentation will discuss two examples of such data sets: medical and insect flight. Based on a CT angiogram data set, the geometry of the vessel boundary can be extracted and then used in order to compute the blood flow inside that geometry assuming an inflow velocity and pressure based on a typical heart rate. The visualization can then be extended by introducing wall-shear stresses mapped onto the geometry using color coding. Similarly, FTLE-based color coding is capable of highlighting similar areas compared to wall-shear stress. The other example included deals with a dragon fly. Using high-speed cameras, a dragonfly can be observed and its geometry reconstructed based on different views generated by a set of three cameras. Using this geometry, a CFD simulation then generates the flow around the dragonfly. Since additional data is computed alongside the flow, the flow can be studied and correlated to the lift generated by the individual wings of the dragonfly, allowing for more insight of the flight characteristics of the dragonfly.

3.41 Asymmetric Tensor Field Visualization from a Multi-Field Viewpoint

Eugene Zhang (Oregon State University, US)

Asymmetric tensor fields often arise as the gradient of a vector field, such as the velocity gradient tensor in fluid dynamics and the deformation gradient tensor in solid mechanics. Visualization of the vector field of interest and its gradient tensor field can provide greater insight than the visualization of the vector field only. This leads to a multi-field framework in vector field visualization. In addition, tensor decomposition implies that the behaviors of a tensor field is a direct result of the interaction of the components in the decomposition. This is another aspect of multi-field in tensor field visualization.

We also discuss future challenges and opportunities in tensor field visualization based on a multi-field framework.

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Report from Dagstuhl Seminar 11241

Design and Analysis of Randomized and Approximation Algorithms

Edited by

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Abstract

The Dagstuhl Seminar on "Design and Analysis of Randomized and Approximation Algorithms" (Seminar 11241) was held at Schloss Dagstuhl between June 13–17, 2011. There were 26 regular talks and several informal and open problem session contributions presented during this seminar. Abstracts of the presentations have been put together in this seminar proceedings document together with some links to extended abstracts and full papers.

Seminar 13.–17. June, 2011 – www.dagstuhl.de/11241

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Edited in cooperation with Mathias Hauptmann

1 Executive Summary

Martin Dyer
Uriel Feige
Alan M. Frieze
Marek Karpinski

Many, if not most computational tasks that arise in realistic scenarios are computationally difficult, and no efficient algorithms are known that guarantee an exact (or optimal) solution on every input instance. Nevertheless, practical necessity dictates that acceptable solutions be found in a reasonable time. Two basic means for surmounting the intractability barrier are randomized computation, where the answer is optimal with high probability but not with certainty, and approximate computation, where the answer is guaranteed to be within, say, small percentage of optimality. Often, these two notions go hand-in-hand.

The seminar was concerned with the newest developments in the design and analysis of randomized and approximation algorithms. The main focus of the workshop was on the following specific topics: randomized approximation algorithms for optimization problems, approximation algorithms for counting problems, methods for proving approximation hardness, as well as various interactions between them. Here, some new broadly applicable techniques have emerged recently for designing efficient approximation algorithms for various optimization and counting problems as well as for proving approximation hardness bounds. This workshop has addressed the above topics and some new fundamental insights and paradigms in this area.

The 26 regular talks and other presentations delivered at this workshop covered a wide body of research in the above areas. The Program of the meeting and Abstracts of all talks are listed in the subsequent sections of this report.

The meeting was hold in a very informal and stimulating atmosphere. Thanks to everyone who made it such an interesting and enjoyable event.

Martin Dyer
Uriel Feige
Alan M. Frieze
Marek Karpinski

Acknowlegement. We thank Annette Beyer and Angelika Mueller-von Brochowski for their continuous support and help in organizing this workshop. Thanks go to Mathias Hauptmann for his help in collecting abstracts of the talks and other related materials for these Proceedings.

2 Table of Contents

3 Overview of Talks

3.1 On the usefulness of predicates

Johan Håstad (KTH – Stockholm, SE)

Joint work of J. Håstad and A. Per

We introduce a notion of usefulness for constraint satisfaction problems. A k-ary predicate P is useful for a k-ary function Q if the following holds. Given a list of k-tuples of literals and a promise that there is an assignment such that P is true on (almost) all of the resulting strings, we can efficiently find an assignment such that when Q is applied to the resulting strings the average is more than the expectation of Q when applied to a random string.

This is an extension of the concept of approximation resistance of standard Max-CSPs in that P is useful for P iff it is not approximation resistant.

A predicate P is useless if it is not useful for any real-valued Q. Among other results we give a simple characterization of uselessness assuming the unique games conjecture: P is useless iff there is a pairwise independent measure supported on the strings accepted by P.

3.2 Counting contingency tables

Alexander Barvinok (University of Michigan – Ann Arbor, US)

Joint work of A. Barvinok and J.A. Hartigan

Let $R = (r_1, \ldots, r_m)$ be a positive integer m-vector and let $C = (c_1, \ldots, c_n)$ be a positive integer n-vector such that

$$r_1 + \ldots + r_m = c_1 + \ldots + c_n = N.$$

We are interested in the number $\#(R, C)$ of $m \times n$ non-negative integer matrices (*contingency tables* with *margins* R and C) with row sums $r_1, \ldots, r_m$ and column sums $c_1, \ldots, c_n$. Namely, we present an efficiently computable asymptotic formula for $\#(R, C)$.

Let us consider the function

$$g(x) = (x+1)\ln(x+1) - x\ln x \quad \text{for} \quad x \geq 0.$$

It is easy to see that $g(x)$ is increasing and concave. We extend g to non-negative $m \times n$ matrices X by

$$g(X) = \sum_{i,j} g\left(x_{ij}\right) \quad \text{for} \quad X = \left(x_{ij}\right).$$

Since g is strictly concave, it attains its maximum on the transportation polytope of all $m \times n$ non-negative matrices X with row sums R and column sums C at a unique point $Z = (z_{ij})$, which we call the *typical matrix*. As is shown in [1], a random non-negative integer matrix with row sums R and column sums C looks more or less like the random matrix of independent geometric random variables with expectation Z. Matrix Z can be efficiently computed by interior point methods.

Let us define a quadratic form $q : \mathbb{R}^{m+n} \longrightarrow \mathbb{R}$ by

$$q(s_1, \ldots, s_m; t_1, \ldots, t_n) = \frac{1}{2} \sum_{i,j} z_{ij}(z_{ij}+1)(s_i+t_j)^2 .$$

Let $u \in \mathbb{R}^{m+n}$, $u = (1, \ldots, 1; -1, \ldots, -1)$, be vector and let $H = u^\perp$, $H \subset \mathbb{R}^{m+n}$, be the hyperplane that is the orthogonal complement to u. Then the restriction $q|H$ of q onto H is a positive definite quadratic form. We define $\det q|H$ as the determinant of $q|H$. Equivalently, $\det q|H$ is the product of the non-zero eigenvalues of q.

We define the Gaussian probability measure in H with the density proportional to e^{-q}. We consider two random variables $f, h : H \longrightarrow \mathbb{R}$ defined by

$$f(s_1, \ldots, s_m; t_1, \ldots, t_n) = \frac{1}{6} \sum_{i,j} z_{ij}(z_{ij}+1)(2z_{ij}+1)(s_i+t_j)^3$$

and

$$h(s_1, \ldots, s_m; t_1, \ldots, t_n) = \frac{1}{24} \sum_{i,j} z_{ij}(z_{ij}+1)\left(6z_{ij}^2+6z_{ij}+1\right)(s_i+t_j)^4 .$$

We compute

$$\mu = \mathbf{E}\, f^2 \quad \text{and} \quad \nu = \mathbf{E}\, h.$$

We note that computing the expectation of a polynomial with respect to the Gaussian probability measure is a linear algebra problem. In particular, given Z, one can compute μ and ν in $O\left((m+n)^4\right)$ time. To describe the range for which our asymptotic formula is applicable, we need one more definition. Given $0 < \delta < 1$, we say that the margins (R, C) are δ-*smooth* if

$$m \ \geq \ \delta n, \quad n \ \geq \ \delta m \quad \text{and} \quad \delta\tau \ \leq \ z_{ij} \ \leq \ \tau \quad \text{for all} \quad i, j$$

and some

$$\tau \geq \delta,$$

where $Z = (z_{ij})$ is the typical matrix. The following result is proved in [1].

Theorem. Let us fix $0 < \delta < 1$. Let (R, C) be δ-smooth margins. Then, for any $0 < \epsilon \leq 1/2$ the value of

$$\frac{e^{g(Z)}\sqrt{m+n}}{(4\pi)^{(m+n-1)/2}\sqrt{\det q|H}} \exp\left\{-\frac{\mu}{2}+\nu\right\}$$

approximates the number $\#(R, C)$ within relative error ϵ, provided

$$m+n \ \geq \ \left(\frac{1}{\epsilon}\right)^{\gamma(\delta)}$$

for some $\gamma(\delta) > 0$.

If

$$r_1 = \ldots = r_m = r \quad \text{and} \quad c_1 = \ldots = c_n = c$$

then by symmetry we have

$$z_{ij} = \frac{rc}{N} = \frac{r}{n} = \frac{c}{m} \quad \text{for all} \quad i, j$$

and the formula of the above theorem transforms into the asymptotic formula of [3], obtained earlier by Canfield and McKay in the particular case when all the row sums are equal and all the column sums are equal.

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3.3 Estimating the partition function of the ferromagnetic Ising model on a regular matroid

Leslie Ann Goldberg (University of Liverpool, GB)

Joint work of L.A. Goldberg and M. Jerrum

We investigate the computational difficulty of approximating the partition function of the ferromagnetic Ising model on a regular matroid. Jerrum and Sinclair have shown that there is a fully polynomial randomised approximation scheme (FPRAS) for the class of graphic matroids. On the other hand, the authors have previously shown, subject to a complexity-theoretic assumption, that there is no FPRAS for the class of binary matroids, which is a proper superset of the class of graphic matroids. In order to map out the region where approximation is feasible, we focus on the class of regular matroids, an important class of matroids which properly includes the class of graphic matroids, and is properly included in the class of binary matroids. Using Seymour's decomposition theorem, we give an FPRAS for the class of regular matroids.

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3.4 TSP on cubic and subcubic graphs

Leen Stougie (CWI – Amsterdam, NL)

Joint work of S. Boyd, R. Sitters, S. van der Ster, L. Stougie

We study the Travelling Salesman Problem (TSP) on the metric completion of cubic and subcubic graphs, which is known to be NP-hard. The problem is of interest because of its relation to the famous 4/3 conjecture for metric TSP, which says that the integrality gap, i.e., the worst case ratio between the optimal values of the TSP and its linear programming relaxation, is 4/3. Using polyhedral techniques in an interesting way, we obtain a polynomial-time 4/3-approximation algorithm for this problem on cubic graphs, improving upon Christofides' 3/2-approximation, and upon the $3/2 - 5/389 \approx 1.487$-approximation ratio by Gamarnik, Lewenstein and Svirdenko for the case the graphs are also 3-edge connected. We also prove that, as an upper bound, the 4/3 conjecture is true for this problem on cubic graphs. For subcubic graphs we obtain a polynomial-time 7/5-approximation algorithm and a 7/5 bound on the integrality gap. Just very recently Mömke and Svensson superseded this result by announcing 4/3 bounds for subcubic graphs. However, the techniques we propose here remain interesting and probably more widely applicable.

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1 Sylvia Boyd, Rene Sitters, Suzanne van der Ster and Leen Stougie, *TSP on Cubic and Subcubic Graphs*, accepted for IPCO 2011

3.5 Approximating Graphic TSP by Matchings

Ola Svensson (KTH – Stockholm, SE)

Joint work of T. Mömke and O. Svensson

We present a framework for approximating the metric TSP based on a novel use of matchings. Traditionally, matchings have been used to add edges in order to make a given graph Eulerian, whereas our approach also allows for the removal of certain edges leading to a decreased cost.

For the TSP on graphic metrics (graph-TSP), the approach yields a 1.461-approximation algorithm with respect to the Held-Karp lower bound. For graph-TSP restricted to a class of graphs that contains degree three bounded and claw-free graphs, we show that the integrality gap of the Held-Karp relaxation matches the conjectured ratio 4/3. The framework allows for generalizations in a natural way and also leads to a 1.586-approximation algorithm for the traveling salesman path problem on graphic metrics where the start and end vertices are prespecified.

3.6 Connectivity in Discrete Random Processes

Po-Shen Loh (Carnegie Mellon University – Pittsburgh, US)

Joint work of E. Lubetzky and Po-Shen Loh

Half a century ago, a seminal paper of Erdos and Renyi launched the systematic study of random graphs. Since then, this direction of investigation has blossomed into a broad field, and the original model has given rise to many useful variants. Of the properties which have received attention, one of the most fundamental has been that of global connectivity.

Recently, motivated by the practical problem of establishing connectivity in peer- to-peer networks, a natural question of similar flavor arose in the analysis of a natural randomized clustering algorithm. Using methods which originated from physics, but now known to be remarkably useful in the study of random graphs, we establish the asymptotic optimality of this algorithm. We also prove the first rigorous lower bounds on the performance of a closely-related algorithm, extending an approach of Oded Schramm.

3.7 A $(5/3 + \epsilon)$-Approximation for Strip Packing

Lars Prädel (University of Kiel, DE)

We study strip packing, which is one of the most classical two-dimensional packing problems: Given a collection of rectangles, the problem is to find a feasible orthogonal packing without rotations into a strip of width 1 and minimum height. In this paper we present an approximation algorithm for the strip packing problem with approximation ratio of $5/3 + \epsilon$ for any $\epsilon > 0$. This result significantly narrows the gap between the best known upper bounds of 2 by Schiermeyer and Steinberg and 1.9396 by Harren and van Stee and the lower bound of 3/2.

3.8 Every Hyperfinite Property is Testable

Christian Sohler (TU Dortmund, DE)

Joint work of I. Newman and Ch. Sohler

A property testing algorithm for a property Π in the bounded degree graph model is an algorithm that, given access to the adjacency list representation of a graph $G = (V, E)$ with maximum degree at most d, accepts G with probability at least 2/3 if G has property Π, and rejects G with probability at least 2/3, if it differs on more than ϵdn edges from every d-degree bounded graph with property Π. A property is *testable*, if for every ϵ, d and n, there is a property testing algorithm $A_{\epsilon,n,d}$ that makes at most $q(\epsilon, d)$ queries to an input graph of n vertices, that is, a non-uniform algorithm that makes a number of queries that is independent of the graph size. A k-disc around a vertex v of a graph $G = (V, E)$ is the subgraph induced by all vertices of distance at most k from v. We show that the structure of a planar graph on large enough number of vertices, n, and with constant maximum degree d, is determined, up to the modification (insertion or deletion) of at most ϵdn edges, by the frequency of k-discs for certain $k = k(\epsilon, d)$ that is independent of the size of the graph. We can replace planar graphs by any hyperfinite class of graphs, which includes, for example, every graph class that does not contain a set of forbidden minors.

We use this result to obtain new results and improve upon existing results in the area of property testing. In particular, we prove that

- graph isomorphism is testable for every class of hyperfinite graphs,
- every graph property is testable for every class of hyperfinite graphs,
- every hyperfinite graph property is testable in the bounded degree graph model,
- A large class of graph parameters is approximable for hyperfinite graphs

Our results also give a partial explanation of the success of motifs in the analysis of complex networks.

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1 Ilan Newman and Christian Sohler, *Every property of hyperfinite graphs is testable*, STOC 2011, pp. 675–684

3.9 Sublinear Algorithms via Precision Sampling

Alexandr Andoni (Microsoft Research – Mountain View, US)

Joint work of R. Krauthgamer, A. Andoni, K. Onak

Suppose we want to estimate a sum of bounded reals $a_1 + a_2 + \ldots + a_n$ with access to only some "limited information" about the a_i's. A classical setting is where we estimate the entire sum by knowing only a random subset of a_i's. Naturally, there is a trade-off between the size of the subset and the resulting approximation.

Motivated by applications where this tradeoff is not good enough, we introduce Precision Sampling, which is an estimation technique that uses more general kind of "limited information" about the a_i's: Instead of obtaining a subset as above, here we obtain a rough estimate for each a_i, up to various "precision" (approximation). The trade-off is then between the precision of the estimates and the resulting approximation to the total sum. We show that one can obtain a trade-off that is qualitatively better in the precision sampling setting than in the aforementioned (vanilla) sampling setting.

Our resulting tool leads to new sublinear algorithms, including a simplified algorithm for a class of streaming problems, as well as an efficient algorithm for estimating the edit distance.

3.10 Lifting Markov Chains for Faster Mixing

Thomas Hayes (University of New Mexico – Albuquerque, US)

Joint work of Th. Hayes and A. Sinclair

Markov Chain Monte Carlo is a powerful tool for sampling from distributions over large sets with combinatorial structure. Generally, the goal is to obtain samples fast, as a function of some parameter that is, say, logarithmic in the space being sampled. In some cases, we know how to sample in say, polynomial time, but really want performance that is a little faster, say $O(n \log(n))$ time or $O(n^2)$. Are there any tools for systematically enhancing the speed of MCMC algorithms?

"Lifting" a given Markov chain produces a new chain, whose ergodic flow projects homomorphically back down to that of the original chain, and hence can be used for sampling the original distribution. We discuss some examples fo which a directed lifting of an undirected original chain gives as much as a quadratic speedup. The main example is a lifting of a tree-structured Markov chain introduced by Jerrum and Sinclair.

3.11 Average-Case Performance of Heuristics for Multi-Dimensional Assignment

Gregory Sorkin (London School of Economics, GB)

Joint work of A. Frieze and G. Sorkin

Beautiful formulas are known for the expected cost of random two-dimensional assignment problems, but in higher dimensions, even the scaling is not known. In 3 dimensions and above, the problem has natural "planar" and "axial" versions, both of which are NP-hard. For 3-dimensional Planar random assignment instances of size n, the cost scales as $\Omega(2/n)$, and a main result of the present paper is the first polynomial-time algorithm that, with high probability, finds a solution of cost $O(n^{-1+\epsilon})$, for arbitrary positive ϵ (or indeed ϵ going slowly to 0). For 3-dimensional Axial assignment, the lower bound is $\Omega(n)$, and we give a new efficient matching-based algorithm that returns a solution with expected cost $O(n \log n)$. Neither algorithm extends to 4 or more dimensions, and finding algorithms with the conjectured scaling for d-dimensional Planar and Axial assignment are open problems.

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3.12 Embedding Spanning Trees in Random Graphs near the Connectivity Threshold

Michael Krivelevich (Tel Aviv University, IL)

Joint work of D. Hefetz, M. Krivelevich, T. Szabo

A disconnected graph G does not contain any spanning trees. Thus, a tree T on n vertices typically does not appear in the binomial random graph $G(n, p)$ before the threshold for connectivity, which is well known to be at $p(n) = \frac{\log(n)}{n}$. We prove that a given tree T on n vertices with bounded maximum degree is contained almost surely in $G(n, p)$ with $p(n) = (1 + \epsilon)\frac{\log(n)}{n}$, provided T belongs to one of the following classes:

(1) T has linearly many leaves
(2) T has a path of linear length all of whose vertices have degree two in T.

3.13 Stochastic Knapsack with Correlations and Cancellation and Application to Non-Martingale Bandit Problems

R. Ravi (Carnegie Mellon University – Pittsburgh, US)

Joint work of A. Gupta, R. Krishnaswamy, M. Molinaro, R. Ravi

In the stochastic knapsack problem, we are given a knapsack with size B, and a set of jobs whose sizes and rewards are drawn from a known probability distribution. However, the only way to know the actual size and reward is to schedule the job—when it completes, we get to know these values. How should we schedule jobs to maximize the expected total reward? We know constant-factor approximations for this problem when we assume that rewards and sizes are independent random variables, and that we cannot prematurely cancel jobs after we schedule them. What can we say when either or both of these assumptions are dropped?

Not only is the stochastic knapsack problem of interest in its own right, but techniques developed for it are applicable to other stochastic packing problems. Indeed, ideas for this problem have been useful for budgeted learning problems, where one is given several arms which evolve in a specified stochastic fashion with each pull, and the goal is to pull the arms a total of B times to maximize the reward obtained. Much recent work on this problem focus on the case when the evolution of the arms follows a martingale, i.e., when the expected reward from the future is the same as the reward at the current state. However, what can we say when the rewards do not form a martingale?

We give constant-factor approximation algorithms for the stochastic knapsack problem with correlations and cancelations, and also for some budgeted learning problems where the martingale condition is not satisfied, using similar ideas. Indeed, we can show that previously proposed linear programming relaxations for these problems have large integrality gaps. We propose new time-indexed LP relaxations; using a decomposition and "shifting" approach, we convert these fractional solutions to distributions over strategies, and then use the LP values and the time ordering information from these strategies to devise a randomized scheduling algorithm. We hope our LP formulation and decomposition methods may provide a new way to address other correlated bandit problems with more general contexts.

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3.14 Smoothed Analysis of Multiobject Optimization

Heiko Röglin (University of Bonn, DE)

Joint work of R. Beier, T. Brunsch, H. Röglin, S.-H. Teng, B. Vöcking

A well established heuristic approach for solving various multicriteria optimization problems is to enumerate the set of Pareto-optimal solutions. The heuristics following this principle are often successful in practice, even though the number of Pareto-optimal solutions can be exponential in the worst case.

We analyze multiobjective optimization problems in the framework of smoothed analysis, and we prove that the smoothed number of Pareto-optimal solutions in any multiobjective binary optimization problem with a finite number of linear objective functions is polynomial. Moreover, we give polynomial bounds on all finite moments of the number of Pareto-optimal solutions, which yields the first non-trivial concentration bound for this quantity.

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3.15 k-Means Algorithm Converges

Ravi Kannan (Microsoft Research, IN)

Joint work of R. Kannan and A. Kumar

The k-means algorithm is widely used. It is well-recognized that it does not converge to the desirable answer if we start with a bad set of centers. We formalize a simple geometric condition called proximity under which we show it does converge to the desired result. Many known results which assume a stochastic model of input are subsumed by our purely deterministic result.

3.16 Random Geometric Graphs

Tobias Müller (CWI – Amsterdam, NL)

If we pick points $X_1, ..., X_n$ at random from d-dimensional space (i.i.d. according to some probability measure) and fix a $r > 0$, then we obtain a random geometric graph by joining points by an edge whenever their distance is $< r$.

We give a brief overview of some of the most important results on random geometric graphs and then describe some of my own work on Hamilton cycles, the chromatic number, and the power of two choices in random geometric graphs.

3.17 Hardness of Approximating the Tutte Polynomial of a Binary Matroid

Mark Jerrum (Queen Mary University of London, GB)

Joint work of L.A. Goldberg and M. Jerrum

We consider the problem of approximating certain combinatorial polynomials. First, we consider the problem of approximating the Tutte polynomial of a binary matroid with parameters $q \geq 2$ and γ. (Relative to the classical (x, y) parameterisation, $q = (x-1)(y-1)$ and $\gamma = y - 1$.) A graph is a special case of a binary matroid, so earlier work by the authors shows that for $q > 2$ and $\gamma < 0$ there is no FPRAS unless NP = RP, and for $q > 2$ and $\gamma > 0$, the approximation problem is hard for the complexity class $\#\mathrm{RH}\Pi_1$ under approximation-preserving (AP) reducibility. The case $\gamma = 0$ corresponds to the infinite-temperature limit of the Potts model, and is computationally trivial. The situation for $q = 2$ is different. For graphic matroids, the region $\gamma < -2$ is only known to be as hard as approximating perfect matchings in a graph (a problem whose complexity is open), whereas Jerrum and Sinclair have provided an FPRAS for the region $\gamma > 0$. It is known that there is no FPRAS unless NP = RP in the in-between region $-2 \leq \gamma < 0$, apart from at two "special points" where the polynomial can be computed exactly in polynomial time. We show that for binary matroids there is no FPRAS in the region $\gamma < -2$ unless NP = RP. Also, in the region $\gamma > 0$ the approximation problem is hard for the complexity class $\#\mathrm{RH}\Pi_1$ under approximation-preserving (AP) reducibility. Thus, unless there is an FPRAS for all of $\#\mathrm{RH}\Pi_1$, the graphic case differs in approximation complexity from the binary matroid case at $q = 2$. Our result implies that it is computationally difficult to approximate the weight enumerator of a binary linear code, apart from at the special weights for which the problem is exactly solvable in polynomial time. As a consequence, we show that approximating the cycle index polynomial of a permutation group is hard for $\#\mathrm{RH}\Pi_1$ under AP-reducibility, partially resolving a question first posed in 1992.

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3.18 Computational Complexity of the Hamiltonian Cycle Problem in Dense Hypergraphs

Edyta Szymanska (Adam Mickiewicz University – Poznan, PL)

Joint work of M. Karpinski, A. Rucinski, E. Szymanska

We study the computational complexity of deciding the existence of a Hamiltonian Cycle in some dense classes of k-uniform hypergraphs. Those problems turned out to be, along with the hypergraph Perfect Matching problems, exceedingly hard, and there is a renewed algorithmic interest in them. In this paper we design a polynomial time algorithm for the Hamiltonian Cycle problem for k-uniform hypergraphs with density at least $1/2 + \epsilon, \epsilon > 0$. In doing so, we depend on a new method of constructing Hamiltonian cycles from (purely) existential statements which could be of independent interest. On the other hand, we establish NP-completeness of that problem for density at least $1/k - \epsilon$. Our results seem to be the first complexity theoretic results for the Dirac-type dense hypergraph classes.

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3.19 Distributed Storage Allocation via Fractional Hypergraph Matchings

Andrzej Rucinski (Adam Mickiewicz University – Poznan, PL)

The following model of distributed storage has been studied in information theory [7, 8, 12]. A file is split into multiple chunks, and then it is replicated redundantly and stored in a distributed storage system with n nodes. The amount of data to be stored in each node i is equal to x_i, where the size of the whole file is normalized to 1. We require that the total amount of data stored does not exceed a given budget T, i.e. $x_1 + \cdots + x_n \leq T$. At the time of retrieval, we attempt to recover the whole file by accessing only the data stored in a randomly chosen subset R of nodes. It is known that there always exists a coding scheme such that we can recover the file whenever the total amount of data accessed is at least the size of this file. Our goal is to find an optimal allocation $(x_1, \cdots, x_n)$ to maximize the probability of successful recovery. In [12], R is taken uniformly at random among all the r-element subsets of $\{x_1, \cdots, x_n\}$. Then the problem can be reformulated as follows: *for a nonnegative sequence* $(x_1, \cdots, x_n)$*, let*

$$\Phi(x_1, \cdots, x_n) = \left| \left\{ S \subseteq [n], |S| = r \text{ such that } \sum_{i \in S} x_i \geq 1 \right\} \right|.$$

Given integers $n \geq r \geq 1$ *and a real number* $T > 0$*, determine*

$$F(r, n, T) = \max_{\sum x_i = T,\ x_i \geq 0\ \forall i} \Phi(x_1, \cdots, x_n).$$

If the total budget $T \geq n/r$, by setting all x_i equal to $T/n \geq 1/r$, we can recover the original file from any subset of size r. For the case $T < n/r$, the problem of determining $F(n, r, T)$ is equivalent to that of finding the maximum number of edges in an r-uniform hypergraph on n vertices with fractional matching number at most T. Erdős and Gallai [4] determined the integral version of this problem for graphs ($r = 2$). In 1965, Erdős [3] conjectured for r-uniform hypergraphs that the maximum number of edges without a matching of size $s \leq n/r$ is $\max\left\{\binom{rs-1}{r}, \binom{n}{r} - \binom{n-s+1}{r}\right\}$.

For $r = 2$ and $s = T + 1$, where we assume that T is an integer, an easy calculation shows that the above maximum equals the first term if $\frac{2}{5}n \leq T \leq \frac{1}{2}n$, and the corresponding optimal graph is a clique of size, roughly, $2T$. This means that, asymptotically, an optimal allocation is $x_1 = \cdots = x_{2T} = 1/2$ and $x_{2T+1} = \cdots = x_n = 0$. On the other hand, if $T < \frac{2}{5}n$, an optimal allocation is $x_1 = \cdots = x_T = 1$ and $x_{T+1} = \cdots = x_n = 0$.

We now formulate the fractional version of Erdős' Conjecture.
0.4ex]

Conjecture 1: *For all integers* $r \geq 3$ *and a real* s *such that* $0 \leq s \leq r/r$*, if* $\nu^*(H) < s$ *then*

$$|H| \leq \max\left\{ \binom{\lceil rs \rceil - 1}{r}, \binom{n}{r} - \binom{n - \lceil s \rceil + 1}{r} \right\}.$$

In [2] we proved an asymptotic version of Conjecture 1 for $r = 3$ and $r = 4$, and $s \leq \frac{n}{r+1}$. In the proof we used a probabilistic approach based on a special case of an old probability conjecture of Samuels [10]. Samuels' Conjecture says (in a special case we are interested in) that *for all* $\mu \leq \frac{1}{r+1}$, *and all choices of* r *independent random variables* $X_1, \ldots, X_r$ *with common expectation* μ,

$$P(X_1 + \ldots + X_r < 1) \geq \left(1 - \frac{\mu}{1-\mu}\right)^r.$$

Samuels proved his conjecture for $r \leq 4$ in [10].

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3.20 Universally-Truthful Multi-Unit Auctions

Berthold Vöcking (RWTH Aachen, DE)

We present a randomized, polynomial-time approximation scheme for multi-unit auctions. Our mechanism is truthful in the universal sense, i.e., a distribution over deterministically truthful mechanisms. Previously it was only known an approximation scheme that is truthful in expectation which is a weaker notion of truthfulness assuming risk neutral bidders. The existence of a universally truthful approximation scheme was questioned by previous work showing that multi-unit auctions with certain technical restrictions on their output do not admit a polynomial-time, universally truthful mechanism with approximation factor better than two.

Our new mechanism employs VCG payments in a non-standard way. In particular, the deterministic mechanisms underlying our approximation scheme are not maximal-in-range which, on a first view, seems to contradict previous characterizations of VCG-based mechanisms. Although they are not affine maximizers, each of the deterministic mechanisms is composed out of a collection of affine maximizers, one for each bidder. The composite construction ensures that the mechanism's output for a bidder coincides with the output of the affine maximizer for the bidder. This yields a subjective variant of VCG in which payments for different bidders are defined on the basis of possibly different affine maximizers.

3.21 Smoothed Analysis of Partitioning Algorithms for Euclidean Functionals

Markus Bläser (University of Saarland, DE)

Euclidean optimization problems such as TSP and minimum length matching admit fast partitioning algorithms that compute optimal solutions on almost all of the input points.

We develop a general framework for the application of smoothed analysis to partitioning algorithms for Euclidean optimization problems. Our framework can be used to analyze both the running-time and the approximation ratio of such algorithms. We apply our framework to obtain smoothed analyses of Dyer and Frieze's partitioning algorithm for Euclidean matching, Karp's partitioning scheme for the TSP, a heuristic for Steiner trees, and a heuristic for bounded-degree minimum-length spanning trees.

3.22 Approximating Gale-Berlekamp Games and Related Optimization Problems

Marek Karpinski (University of Bonn, DE)

Joint work of M. Karpinski and W. Schudy

We design a linear time approximation scheme for the Gale-Berlekamp Switching Game and generalize it to much wider class of dense fragile minimization and ranking problems including the Nearest Codeword Problem (NCP), Unique Games Problem, constrained form of matrix rigidity, maximum likelihood decoding, correlation clustering with a fixed number of clusters, and the Betweenness Problem in tournaments. As a side effect of our method we obtain also the first optimal under the ETH (exponential time hypothesis) deterministic subexponential algorithm for weighted FAST (feedback arc set tournament) problem with runtime $n^{O(1)} + O^*\left(2^{O(\sqrt{OPT})}\right)$.

Our results depend on a new technique of dealing with small objective functions values of minimization problems and could be of independent interest.

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3.23 Vacant Set of a Random Walk on a Random Graph

Alan Frieze (Carnegie Mellon University – Pittsburgh, US)

Joint work of C. Cooper and A. Frieze

We consider random walks on several classes of graphs and explore the likely structure of the vacant set, i.e. the set of unvisited vertices. Let $\Gamma(t)$ be the subgraph induced by the vacant set of the walk at step t. We show that for random graphs $G_{n,p}$ (above the connectivity threshold) and for random regular graphs G_r, $r \geq 3$, the graph $\Gamma(t)$ undergoes a phase transition in the sense of the well-known Erdős-Renyi phase transition. Thus for $t \leq (1-\epsilon)t^*$, there is a unique giant component, plus components of size $O(\log n)$, and for $t \geq (1+\epsilon)t^*$ all components are of size $O(\log n)$. For $G_{n,p}$ and G_r we give the value of t^*, and the size of $\Gamma(t)$. For G_r, we also give the degree sequence of $\Gamma(t)$, the size of the giant component (if any) of $\Gamma(t)$ and the number of tree components of $\Gamma(t)$ of a given size $k = O(\log n)$. We also show that for random digraphs $D_{n,p}$ above the strong connectivity threshold, there is a similar directed phase transition. Thus for $t \leq (1-\epsilon)t^*$, there is a unique strongly connected giant component, plus strongly connected components of size $O(\log n)$, and for $t \geq (1+\epsilon)t^*$ all strongly connected components are of size $O(\log n)$.

3.24 On Milgram Routing

Alessandro Panconesi (University of Rome “La Sapienza”, IT)

Joint work of S. Lattanzi, A. Panconesi, D. Sivakumar

We demonstrate how a recent model of social networks (“Affiliation Networks”, [1]) offers powerful cues in local routing within social networks, a theme made famous by sociologist Milgram’s “six degrees of separation” experiments. This model posits the existence of an “interest space” that underlies a social network; we prove that in networks produced by this model, not only do short paths exist among all pairs of nodes but natural local routing algorithms can discover them effectively. Specifically, we show that local routing can discover paths of length $O(\log^2 n)$ to targets chosen uniformly at random, and paths of length $O(1)$ to targets chosen with probability proportional to their degrees. Experiments on the co-authorship graph derived from DBLP data confirm our theoretical results, and shed light into the power of one step of lookahead in routing algorithms for social networks.

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3.25 The Condensation Transition in Random Hypergraph 2-Coloring

Amin Coja-Oghlan (University of Warwick, GB)

Joint work of A. Coja-Oghlan and L. Zdeborova

For many random constraint satisfaction problems such as random k-SAT or random graph/hypergraph coloring the best current bounds on the thresholds for the existence of solutions are derived via the *first* and the *second moment method*. However, in most cases these simple techniques do not yield matching upper and lower bounds. In effect, for most random CSPs the *precise* threshold for the existence of solutions assignments remains unknown. Examples of this include random k-SAT, random graph k-coloring, or random k-uniform hypergraph 2-coloring ($k \geq 3$). Here we discuss the example of random hypergraph 2-coloring, a case in which the second moment analysis is technically quite simple. We present an approach to improve slightly over the naive second moment argument. But more importantly, we establish the existence of a phase transition below the threshold for the existence of solutions poses a genuine obstacle to the second moment argument. The existence of this so-called *condensation transition* was hypothesized on grounds of non-rigorous statistical mechanics arguments [3].

To define the *random hypergraph 2-coloring* problem, let $V = \{1, \ldots, n\}$ be a (large) set of vertices, and let $H_k(n, m)$ be a random k-uniform hypergraph on V obtained by inserting a random set of m edges (each containing k vertices). A 2-*coloring* of H is a map $\sigma\colon V \to \{0, 1\}$ such that no hyperedge e is monochromatic. We let $m = \lceil r \cdot n \rceil$ for some fixed number r (independent of n). Friedgut's sharp threshold theorem implies that there *exists* a threshold $r_{col} = r_{col}(n)$ such that for any $\varepsilon > 0$ the random hypergraph $H_k(n, m)$ of density $m/n < (1 - \varepsilon)r_{col}$ is 2-colorable with high probability, while in the case $m/n > (1 + \varepsilon)r_{col}$ w.h.p. no 2-coloring exists. The first and the second moment methods can be used to estimate the threshold [1]:

$$r_{second} = 2^{k-1} \ln 2 - (1 - \ln 2)/2 \leq r_{col} \leq r_{first} = 2^{k-1} \ln 2 - \ln 2/2. \tag{1}$$

As observed in [1], for $r > r_{second}$ we have $\mathrm{E}\left[Z^2\right] > \exp(\Omega(n)) \cdot \mathrm{E}\left[Z^2\right]$, i.e., the second moment method fails dramatically. But why? First, it could be the case that the *expectation* $\mathrm{E}\left[Z\right]$ is driven up by a tiny fraction of hypergraphs with excessively many 2-colorings, and thus $Z \ll \mathrm{E}\left[Z\right]$ w.h.p. Second, it could be that Z is 'close' to $\mathrm{E}\left[Z\right]$ with high probability, but without being sufficiently concentrated for the second moment method to apply. The following theorem, which improves the lower bound in (1) by an additive $(1 - \ln(2))/2 \approx 0.153$, shows that the second scenario is true.

▶ **Theorem 1.** *There is a sequence $\varepsilon_k \to 0$ such that for*

$$r \leq r_{enhanced} = 2^{k-1} \ln 2 - \ln 2 - \varepsilon_k$$

the random formula $\vec{\Phi}$ is NAE-satisfiable and $\ln Z \sim \ln \mathrm{E}\left[Z\right]$ w.h.p.

Even the enhanced second moment argument from Theorem 1 does not give the precise threshold for 2-colorability. The intuitive reason is that for $r > r_{enhanced}$, the expected number $\mathrm{E}[Z]$ is indeed dominated by a tiny fraction of hypergraphs with an abundance of 2-colorings.

▶ **Theorem 2.** *There exist $\varepsilon_k \to 0$, $\delta_k > \varepsilon_k$, and $\zeta_k > 0$ such that the following two statements are true.*

1. *The 2-colorability threshold satisfies $r_{col} > 2^{k-1}\ln 2 - \ln 2 + \delta_k$.*
2. *For any $2^{k-1}\ln 2 - \ln 2 + \varepsilon_k < r < r_k$ we have*

$$\ln Z < \ln \mathrm{E}[Z] - \zeta_k n \qquad \textit{w.h.p.} \tag{2}$$

The first statement shows that indeed $H_k(n,m)$ remains 2-colorable w.h.p. for (at least a small range of) densities $r > r_{enhanced}$. Moreover, the second statement asserts that for densities between $r_{enhanced}$ and the true threshold r_k for 2-colorability, the *expected* number $\mathrm{E}[Z]$ of 2-colorings exceeds the *acutal* number Z by an exponential factor $\exp(\zeta_k n)$ w.h.p. This constrasts with Theorem 1, which shows that below $r_{enhanced}$, Z is of the same exponential order as $\mathrm{E}[Z]$ w.h.p. This so-called *condensation transition* at density $2^{k-1}\ln 2 - \ln 2$ was hypothesized on the basis of non-rigorous statistical mechanics arguments [3].

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3.26 Linear Index Coding via Semidefinite Programming

Eden Chlamtac (Tel Aviv University, IL)

Joint work of E. and I. Haviv

In the index coding problem, introduced by Birk and Kol (INFOCOM, 1998), the goal is to transmit n bits to n receivers (one bit to each), where the receivers reside at the nodes of a graph G and have prior access to the bits corresponding to their neighbors in the graph (side information). The objective is to find a code word of minimum length which will allow each receiver to learn their own bit given access to the code word and their side information. When the encoding is linear (this is known as linear index coding), the minimum possible code word length corresponds to a graph parameter known as the minrank of G.

In this talk, we will describe an algorithm which approximates the minrank of a graph in the following sense: when the minrank of the graph is a constant k, the algorithm finds a linear index code of length $O(n^{f(k)})$. For example, for $k = 3$ we have $f(3) \approx 0.2574$. This algorithm exploits a connection between minrank and a semidefinite programming (SDP) relaxation for graph coloring introduced by Karger, Motwani and Sudan.

A result which arises from our analysis, and which may be of independent interest, gives an exact expression for the maximum possible value of the Lovasz theta-function of a graph, as a function of its minrank. This compares two classical upper bounds on the Shannon capacity of a graph.

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4 Informal Session

4.1 Geometric MAX-CUT Problem

Marek Karpinski (University of Bonn, DE)

We raise an open problem on computational status of exact geometric MAX-CUT problem on a real line and the plane. Polynomial time approximation schemes are known for arbitrary metric MAX-CUT problems. The status of the exact geometric MAX-CUT eludes us however completely for both NP-hardness or existence of exact polynomial time algorithms.

4.2 Streaming algorithms for the analysis of massive data sets

Christian Sohler (TU Dortmund, DE)

Massive data sets occur in many applications of Computer Science. Examples include the WWW, internet traffic logs, and operating system calls. Often data is read sequentially in the form of a data stream, which is too large to be stored in main memory and sometimes even too large to be stored at all. If we want to analyze such massive data sets to, say, build a search engine, detect spreading viruses, or optimize a system's performance, we need special algorithms that use only little memory and process the input sequentially. Such algorithms are called streaming algorithms. In this talk I will give an introduction to streaming algorithms and explain the two major algorithmic concepts used in this area. I will discuss their applications in the development of streaming algorithms for data analysis and close with a discussion of future directions of research.

5 Open Problem Session

5.1 Star Cover Problems

R. Ravi (Carnegie Mellon University – Pittsburgh, US)

Given a set of points S, a distance function d, an integer k and a bound B on maximum load of any facility, the problem is to decide whether we can select k facilities in S and serve other points by these facilities such that the maximum load of any facility is B. The load on a facility f is the sum of distances to the clients it serves. Alternately, since an open facility together with the assigned clients, forms a star and its load is exactly equal to the cost of the star, we can call this the Star Cover Decision Problem (SCDP). We consider two optimization versions of the above stated decision problem:

- Minimum Load Star Cover or MLSC : Given S, d and an integer k, minimize the maximum load on each facility.
- Minimum Cardinality Star Cover or MCSC : Given S, d and a bound B on maximum load, minimize the number of facilities to be opened, such that the load on each facility is at most B.

We can also consider a bicriteria approximation for the decision problem i.e. given S, d, k and B find an (α, β)-approximation, such that at most αk facilities are opened and maximum load on a facility is at most βB.

Known results:

Arkin, Hassin and Levin consider the Minimum Cardinality Star Cover problem, where distance d is a metric and give a $(2\alpha + 1)$-approximation for the problem, where α is the best approximation ratio of the k-median problem.

Even, Garg, Konemann, Ravi and Sinha give a bicriteria approximation of $(4, 4)$ for the case when d is a metric i.e. for given k and B, their algorithm opens at most $4k$ facilities and the completion time is at most $4B$. This is improved to a $(3 + \epsilon, 3 + \epsilon)$ approximation by Arkin, Hassin and Levin.

The star cover decision problem (SCDP) is NP-complete, even when the distance function d is a line metric or a star metric. Furthermore, the problem remains hard even if the facilities to open are specified. The proofs of hardness for line and star metrics are by reductions from 3-PARTITION and MAKESPAN respectively.

The Minimum Cardinality Star Cover or MCSC problem is $\Omega(\log n)$-hard to approximate if the distance function, d, is not a metric, by a reduction from set cover, where $|S| = n$. A similar analysis as that of greedy algorithm for set cover, gives a $\log n$-approximation for the MCSC problem in the general case. There is a 2-approximation for the case when the distance function is a line metric.

For the Minimum Load Star Cover or MLSC problem, the LP relaxation of a natural IP formulation has a large integrality gap. There is a 3-approximation when the distance function is a star metric. In the case of distance function being a line metric, it can be shown that if every point is assigned to either the closest facility to the right or closest facility to the left then the maximum load can be a factor k times worse than the optimum.

Open Problem: Give a nontrivial approximation for the MLSC problem or show a lower bound for the approximation factor. Even the case when the input is a line metric is open.

References

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5.2 Approximating the Euclidean TSP cost in a data stream

Christian Sohler (TU Dortmund, DE)

Assume you are given access to a stream of points from a discrete space $\{1, \ldots, \Delta\}^d$, i.e. the data points arrive sequentially in worst case order. A streaming algorithm is an algorithm that processes the stream of points and uses space polylogarithmic in Δ and the number of points. Is it possible to approximate the cost of the minimum Euclidean TSP problem within a constant smaller than 2 in this model (possibly even upto a factor of $1 + \epsilon$)? It is known that one can approximate the cost of a minimum spanning tree upto a factor of $1 + \epsilon$ [1], so a $(2 + \epsilon)$-approximation of the TSP cost is possible.

References

1 G. Frahling, P. Indyk and Christian Sohler, *Sampling in Dynamic Data Streams and Applications*, Int. J. Comput. Geometry Appl. 18, 1/2, 2008, pp. 3–28,

5.3 Probabilistic Analysis of Local Search for the Max-Cut Problem

Heiko Röglin (University of Bonn, DE)

In the max-cut problem we are given an undirected graph $G = (V, E)$ with a weight function $w : E \to \mathbb{R}_{>0}$ and we want to compute a partition of the vertices into two classes such that the total weight of the edges crossing the cut becomes maximal. We consider a simple local search heuristic that starts with an arbitrary cut and improves this cut by moving one vertex from one side of the cut to the other as long as such a local improvement is possible.

We are interested in the number of iterations until a local optimum is reached. In the worst-case this number can only be bounded by $\Theta(\sum_{e \in E} w(e))$. We suspect, however, that the expected number of steps is polynomial in the size of the graph if every edge weight is chosen uniformly at random from the interval $[0, 1]$. So far, we have not been able to prove this conjecture. We even conjecture that also in the framework of smoothed analysis the number of iterations becomes polynomial in the size of the graph and the perturbation parameter.

5.4 Approximation Hardness of TSP

Marek Karpinski (University of Bonn, DE)

We discussed approximation hardness results for (metric) TSP as well as asymmetric TSP and raised a question on an existence of direct PCP constructions for those problems for proving stronger approximation hardness results.

5.5 Questions about permantents of nonnegative matrices

Alex Samorodnitsky (The Hebrew University of Jerusalem, IL)

We present two conjectures, which, if true, might be useful for approximate counting of some classes of contingency tables (following joint work with Alexander Barvinok).

Conjecture 1: Let $A = (a_{ij})$ be an $n \times n$ stochastic matrix, such that $\sum_{i,j} a_{ij}^2 \leq K$ (think about K as a constant). Then

$$\text{per}(A) \leq n^{K'} \cdot e^{-n},$$

where K' depends only on K.□

Conjecture 2: (This was also independently conjectured by Caputo, Carlen, Lieb and Loss.)

Let $1 \leq p \leq \infty$. The maximum of the permanent of $n \times n$ matrices whose rows are unit vectors in l_p^n attained either at the identity matrix, or at the matrix all of whose entries equal $n^{-1/p}$.

5.6 Understanding the approximability of Graph Balancing

Ola Svensson (KTH – Stockholm, SE)

One of the most prominent open problems in scheduling theory is to understand whether Lenstra, Shmoys, & Tardos' beautiful 2-approximation algorithm for scheduling jobs on unrelated machines to minimize the makespan can be improved. This problem has been open for more than two decades with little progress. Researchers have therefore started to work on improved algorithms for special cases with the hope to shed light on the more general problem.

It was with this motivation Ebenlendr, Krcal, and Sgall introduced a natural special case, named *Graph Balancing*, defined as follows: given an undirected graph $G = (V, E)$ with weights $w : E \mapsto \mathbb{R}_+$ on the edges, find an orientation of the edges so as to minimize $\max_{v \in V} \sum_{e \in \delta^-(v)} w(e)$ where δ^- denotes the edges directed towards v in the given orientation. In their paper, they give an 1.75-approximation algorithm for Graph Balancing and they show that it is NP-hard to approximate within a factor less than 1.5 (which is the same lower bound as known for the general problem of scheduling on unrelated machines).

n order to obtain their 1.75-approximation algorithm they strengthen the linear program used by Lenstra, Shmoys, & Tardos by adding certain linear inequalities. They then show that the strengthened linear program has an integrality gap of at most 1.75 and they also give instances where this gap is achieved. In order to improve the approximation guarantee further one needs thus an even stronger lower bound. One promising strong lower bound is given by a certain strong linear program known as configuration LP. The configuration LP is believed to be strong but our understanding of it remains rather weak although it has been successfully used to obtain better bounds for the more general restricted assignment problem and for the Santa Claus problem.

The worst case integrality gap instances known for the configuration LP for the restricted assignment problem (and thus Graph Balancing) achieves a gap of 1.5. I strongly believe that this is also the upper bound of the integrality gap and the first step would be to prove this for the Graph Balancing problem. I therefore think progress on the following open problem would be valuable for increasing our understanding of this kind of linear programs and also for developing tools for a better understanding of assignment problems.

Open problem: Show that Graph Balancing has a 1.5-approximation algorithm. In particular, it would be interesting to prove an upper bound of 1.5 on the integrality gap of the configuration LP.

5.7 Random TSP

Alan Frieze (Carnegie Mellon University – Pittsburgh, US)

Let $C[i, j]$ be an $n \times n$ symmetric matrix where the $C[i, j], i \leq j$ are independent uniform $[0, 1]$ random variables. Let F be the minimum weight 2-factor using C as weights. How any cycles $\sigma(F)$ does F have w.h.p.? It is known that w.h.p. $\sigma(F) = O(n/\log n)$. Can this be improved to $o(n/\log n)$? On the face of it, this should be easy. The number of cycles in a random 2-factor on n vertices has $O(\log n)$ cycles. A positive result will simplify algorithms for finding low cost traveling salesman problems with these weights.

References

1 Alan Frieze, *On random symmetric travelling salesman problems*, Mathematics of Operations Research (2004) 878-890.

5.8 Perfect Matchings in k-Uniform Hypergraphs

Andrzej Rucinski (Adam Mickiewicz University – Poznan, PL)

Let $k \geq 2$ and n be divisible by k. We denote by $m(k, n)$ the minimum m so that for every n-vertex k-uniform hypergraph H, $\delta(H) \geq m$ implies that H has a perfect matching. It is easy to show that $m(2, n) = \lfloor n/2 \rfloor$. It has been conjectured in [6] and again in [3] that $m(k, n) \sim \left(1 - \left(\frac{k-1}{k}\right)^{k-1}\right)\binom{n-1}{k-1}$. The conjecture has been proved for $k = 3$ in [3], [7], and [4], for $k = 4$ in [5], [8], and [2], and for $k = 5$ in [1]. The proof of this last result is based on a lemma which says that $m(k, n) \sim f(k, n)$, where $f(k, n)$ as the minimum m so that $\delta_d(H) \geq m$ implies that H has a *fractional* perfect matching. (Observe that trivially $f(k, n) \leq m(k, n)$.) That lemma reduces the task of finding (asymptotically) $m(k, n)$ to showing a presumambly simpler conjecture that $f(k, n) \sim \left(1 - \left(\frac{k-1}{k}\right)^{k-1}\right)\binom{n-1}{k-1}$.

Problem: Determine, at least asymptotically, $f(k, n)$ and thus $m(k, n)$ for $k \geq 6$.

References

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7 D. Kühn, D. Osthus, and A. Treglown, *Matchings in 3-uniform hypergraphs*, submitted.

8 A. Lo and K. Markström, *F-factors in hypergraphs via absorption*, submitted

6 Seminar Schedule

Tuesday, June 14th, 2011

09:00–09:10	Opening
Chair:	Marek Karpinski
09:10–09:40	Johan Håstad: *On the Usefulness of Predicates*
09:40–10:10	Alexander Barvinok: *Counting Contingency Tables*
10:10–10:40	Leslie Ann Goldberg: *Estimating the Partition Function of the Ferromagnetic Ising Model on a Regular Matroid*
Chair:	Uriel Feige
11:00–11:30	Leen Stougie: *TSP on Cubic and Subcubic Graphs*
11:30–12:00	Ola Svensson: *Approximating Graphic TSP by Matchings*
Chair:	Martin Dyer
15:00–15:30	Po-Shen Loh: *Connectivity in Discrete Random Processes*
15:30–16:00	Lars Prädel: *A* $(5/3+\epsilon)$*-Approximation for Strip Packing*
Chair:	Alan Frieze
16:30–17:00	Christian Sohler: *Every Hyperfinite Property is Testable*
17:00–17:30	Alexandr Andoni: *Sublinear Algorithms via Precision Sampling*

Wednesday, June 15th, 2011

Chair:	Mark Jerrum
09:00–09:30	Thomas Hayes: *Lifting Markov Chains for Faster Mixing*
09:30–10:00	Gregory Sorkin: *Average-Case Performance of Heuristics for Multi-Dimensional Assignment Problems*
10:00–10:30	Michael Krivelevich: *Embedding Spanning Trees in Random Graphs near the Connectivity Threshold*
Chair:	Michael Paterson
11:00 –11:30	R. Ravi: *Stochastic Knapsack*
11:30 –12:00	Heiko Röglin: *Smoothed Analysis of Multiobject Optimization*
13:30–17:30	Excursion
20:00	Open Problem Session
Chair:	Uriel Feige
Speakers:	R. Ravi, Christian Sohler, Heiko Röglin, Marek Karpinski, Alex Samorodnitsky, Ola Svensson, Alan Frieze, Andrzej Rucinski

Thursday, June 16th, 2011

Chair:	Leslie Ann Goldberg
09:00–09:30	Ravi Kannan: *k-Means Algorithm Converges*
09:30–10:00	Tobias Müller: *Random Geometric Graphs*
10:00–10:30	Mark Jerrum: *Hardness of Approximating the Tutte Polynomial of a Binary Matroid*

Chair:	Alan Frieze
11:00–11:30	Edyta Szymanska: *Computational Complexity of the Hamilton Cycle Problem in Dense Hypergraphs*
11:30–12:00	Andrzej Rucinski: *Distributed Storage Allocation via Fractional Hypergraph Matchings*

Chair:	Michael Krivelevich
15:00–15:30	Berthold Vöcking: *Universally-Truthful Multi-Unit Auctions*
15:30–16:00	Markus Bläser: *Smoothed Analysis of Partitioning Algorithms for Euclidean Functionals*

Friday, June 17th, 2011

Chair:	Johan Håstad
09:00–09:30	Marek Karpinski: *Approximating Gale-Berlekamp Games and Related Optimization Problems*
09:30–10:00	Alan Frieze: *Vacant Set of a Random Walk on a Random Graph*
10:00–10:30	Alessandro Panconesi: *Milgram Routing*

Chair:	Ravi Kannan
11:00–11:30	Amin Coja-Oghlan: *The Condensation Transition in Random Hypergraph 2-Coloring*
11:30–12:00	Eden Chlamtac: *Linear Index Coding via Semidefinite Programming*

Participants

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- Markus Bläser
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- Eden Chlamtac
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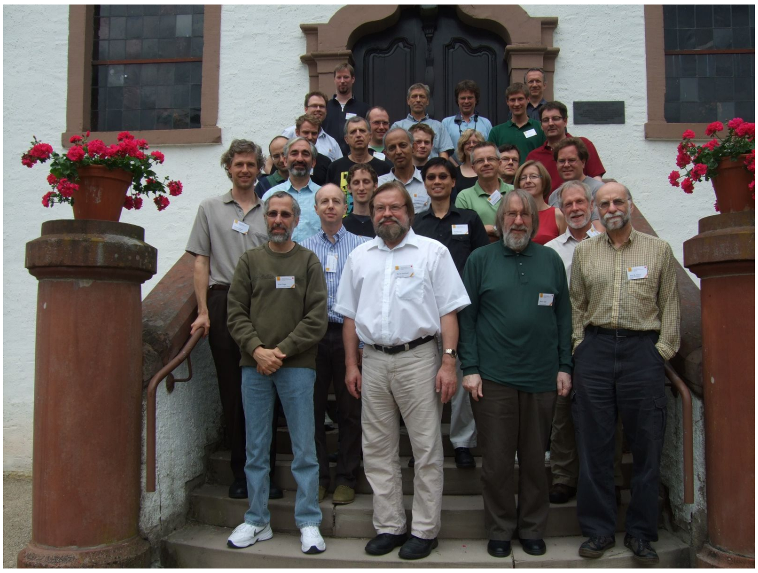

Report from Dagstuhl Seminar 11261

Outdoor and Large-Scale Real-World Scene Analysis. 15th Workshop Theoretic Foundations of Computer Vision

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 11261 "Outdoor and Large-Scale Real-World Scene Analysis, 15th Workshop Theoretic Foundations of Computer Vision". During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general, followed by the scheduled programme.

Overall, the seminar was a great success, which is also reflected in the very positive feedback we received from the evaluation.

Seminar 26. June–01. July, 2011 – www.dagstuhl.de/11261
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Edited in cooperation with Laura Leal-Taixé

1 Executive Summary

Frank Dellaert
Jan-Michael Frahm
Marc Pollefeys
Laura Leal-Taixé
Bodo Rosenhahn

The topic of the meeting was *Large-Scale Outdoor Scene Analysis*, which covers all aspects, applications and open problems regarding the performance or design of computer vision algorithms capable of working in outdoor setups and/or large-scale environments. Developing these methods is important for driver assistance, city modeling and reconstruction, virtual tourism, telepresence, and outdoor motion capture. With this meeting we aimed to attain several objectives, outlined below.

A first objective was to take stock of the performance of existing state-of-the-art computer vision algorithms and define metrics and benchmark data-sets on which to evaluate them.

It is imperative that we push existing algorithms, which are currently benchmarked or tested with artificial or indoor set-ups, towards *real* applications. Methods of interest are 3D reconstruction, optic flow computation, motion capture, surveillance, object recognition, and tracking. These need to be dragged out of the lab and into the real world. Over the last years the computer vision community has recognized this problem and several groups are increasingly concentrating on the analysis of uncontrolled scenes. Examples include reconstructing large city models from online image collections such as Flickr, or human tracking and behavior recognition in TV footage or video from arbitrary outdoor scenes. An outcome we envision is the definition of appropriate metrics, benchmark sequences, and the definition of a *grand-challenge problem* that exposes algorithms to all the difficulties associated with large-scale outdoor scenes while simultaneously mobilizing the research community.

A second objective, then, was to define what the open problems are and which aspects of outdoor and large-scale scene analysis make the problem currently intractable. In uncontrolled, outdoor settings many problems start to arise, among them harsh viewing conditions, changing lighting conditions, artifacts from wind, rain, clouds or temperature etc. In addition, large-scale modeling, i.e. spanning city-scale areas, contains difficult challenges of data association and self-consistency that simply do not appear in smaller data-sets. Failure of basic building-block algorithms seems likely or even inevitable, requiring system-level approaches in order to be robust to failure. One of difficulties lies in the fact that the observer looses complete control over the scene, which can become arbitrary complex. This also brings with it the challenge to describe the scene in other than purely geometric terms, i.e., perform true scene *understanding* at multiple spatial and temporal scales. Finally, outdoor scenes are dynamic and changing over time, requiring event learning and understanding as well as integrating behavior recognition. In this, we brought in participants from industry in order to ground the challenges discussed in real-world, useful applications.

The third and final objective was to discuss strategies that address these challenges, by bringing together a diverse set of international researchers with people interested in the applications, e.g. arising from photogrammetry, geoinformatics, driver assistance systems or human motion analysis. Though these people work in different fields and communities, they are unified by their goal of dealing with images and/or video from outdoor scenes and uncontrolled settings. In the workshop we allowed for an exchange of different modeling techniques and experiences researchers have collected. We allowed time for working groups during the workshop that connect people and whose goals are to develop ideas/roadmaps, additionally we allowed young researchers to connect with senior researchers, and in general allow for an exchange between researchers who would usually not meet otherwise.

The seminar schedule was characterised by flexibility, working groups and sufficient time for focused discussions. The participants of this seminar enjoyed the atmosphere and the services at Dagstuhl very much. The quality of this center is unique.

There will be an edited book (within Springer's series on LNCS) following the seminar, and all seminar participants have been invited to contribute with chapters. The deadline for those submissions is in November 2011 (allowing to incorporate results or ideas stimulated by the seminar), and submissions will be reviewed (as normal). Expected publication date is the end of 2012.

2 Table of Contents

3 Overview of Talks

3.1 Bundle Adjustment in the Large

Sameer Agarwal (Google – Seattle, US)

Main reference C. Wu, S. Agarwal, B. Curless, S. Seitz, "Multicore Bundle Adjustment," CVPR 2011.

I will describe the design and implementation of a new Inexact Newton type bundle adjustment algorithm, which uses substantially less time and memory than standard Schur complement based methods, without compromising on the quality of the solution.

Along the way we will revisit the Schur complement trick and see that its use is not limited to factorization-based methods. How it can be used as part of the Conjugate Gradients (CG) method without incurring the computational cost of actually calculating and storing it in memory, and how this is equivalent to the choice of a particular preconditioner. The resulting algorithm is highly parallelizable, and I will describe our multicore CPU and GPU implementations of it.

3.2 Achievements and Challenges in Recognizing and Reconstructing Civil Infrastructure

Ioannis Brilakis (Georgia Institute of Technology, US)

The US National Academy of Engineering has identified restoring and improving urban infrastructure as one of the grand challenges of engineering for the 21st century. Part of this challenge stems from the lack of viable methods to map/label existing infrastructure. For the computer vision community, this challenge becomes "How can we automate the process of extracting geometric, object oriented models of infrastructure from visual data?" Existing methods for object recognition and reconstruction have been successfully adapted to answer this question for small or linear objects (columns, pipes, etc.). However, many civil infrastructure objects are large and/or planar objects without significant and distinctive texture or spatial features, such as walls, doors, windows, floor slabs, and bridge decks. How can we recognize and reconstruct them in a 3D model? In this talk, the speaker will present strategies for infrastructure objects recognition and reconstruction, to set the stage for posing the question above to the audience and initiating the discussion for featureless, large/planar object recognition and modeling.

3.3 I see bad pixels, and they don't even know they're bad!

Gabriel Brostow (University College London, GB)

The limitations of pixel-samples can be viewed from an application-specific perspective. Should this pixel be trusted in the hands of algorithm X? This talk explores how simple supervised learning and computation of everything-we-can-think-of features enables bespoke assessment, measuring the confidence we should have about a pixel's suitability.

Suitability only makes sense when a specific application is defined. To encourage further research into this family of "smart pixels" algorithms, I'll illustrate how we do confidence-assessment for evaluation of i) interest point descriptors, ii) optical flow, iii) Time of Flight , and iv) occlusion regions, as example applications.

3.4 Modeling Temporal Coherence for Optical Flow

Andres Bruhn (Universität des Saarlandes, DE)

Joint work of Volz, Sebastian; Bruhn, Andres; Valgaerts, Levi; Zimmer, Henning
Main reference S. Volz, A. Bruhn, L. Valgaerts, and H. Zimmer, "Modeling Temporal Coherence for Optical Flow," Proc. International Conference on Computer Vision (ICCV), 201, accepted for publication

Despite the fact that temporal coherence is undeniably one of the key aspects when processing video data, this concept has hardly been exploited in recent optical flow methods.In this paper, we will present a novel parametrization for multi-frame optical flow computation that naturally enables us to embed the assumption of a temporally coherent spatial flow structure, as well as the assumption that the optical flow is smooth along motion trajectories. While the first assumption is realized by expanding spatial regularization over multiple frames, the second assumption is imposed by two novel first and second order trajectorial smoothness terms. With respect to the latter, we investigate an adaptive decision scheme that makes a local (per pixel) or global (per sequence) selection of the most appropriate model possible. Experiments show the clear superiority of our approach when compared to existing strategies for imposing temporal coherence. Moreover, we demonstrate the state-of-the-art performance of our method by achieving Top 3 results at the widely used Middlebury benchmark.

3.5 Convex Relaxation Techniques for Geometric Optimization

Daniel Cremers (TU München, DE)

I will present recent advances in convex optimization methods for estimating geometry from images. In particular, I will discuss convex formulations of multi-view reconstruction, convex constraints for silhouette consistency and convex formulations for stereo reconstruction. Furthermore I will discuss recent extensions of these optimization techniques to minimal partition problems and to piecewise smooth signal approximation.

3.6 Subgraph Preconditioning: The revolutionary new way of using direct graph-based solvers to speed up conjugate gradient

Frank Dellaert (Georgia Institute of Technology, US)

Direct methods have been very successful in solving large scale, sparse SFM problems. However, when scaling up to graphs with densely connected cliques, the classical "Eiffel-tower" problem, no ordering heuristics can make variable elimination (the basis of all direct methods) fast enough. Based on very recent developments in the theory community, as well as seeing preconditioning as re- parameterization, we now use direct methods to pre-condition the method conjugate gradients. We see this as the way of the future for large-scale, urban structure from motion problems.

3.7 Towards Feature-Based Situation Assessment for Airport Apron Video Surveillance

Ralf Dragon (Leibniz Universität Hannover, DE)

Joint work of Dragon, Ralf;Fenzi, Michele; Shoaib, Muhammad; Rosenhahn, Bodo; Ostermann, Joern
Main reference R. Dragon, M. Shoaib, B. Rosenhahn, and J. Ostermann, "NF-features – no-feature-features for representing non-textured regions," Proc. ECCV 2010
URL http://www.tnt.uni-hannover.de/papers/view_paper.php?id=842

In this talk, I will give an overview on a project in which we work on a pure feature-based reasoning in an airport apron scenario. Such a medium traffic scenario is hard to assess as background knowledge is crucial (e.g., a car may only pass the runway if no airplane is scheduled). I will explain how a feature-based approach, which is used to extract the current state, is easy to combine with an inference system for large-scale analysis.

I will show, that in feature-based surveillance, the ideas from image-based approaches can be re-used. For example: Foreground or object detection is performed using motion instead of pixel-wise foreground segmentation [1, 2]. Further, methods for feature-based pixel-wise segmentation have been developed [3, 4]. Feature-based object classification can be performed with state-of-the-art object detectors which have high performance for airport apron objects like airplanes, cars or persons [5].

Last but not least, I will discuss the problem of not detecting enough features in a pure feature-based approach. I give an overview on no-feature (NF) features –a feature-based approach to describe non-textured objects– and demonstrate how they improve feature-based background modeling.

References

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5. Felzenszwalb, Girshick, McAllester: Object Detection with Discriminatively Trained Part Based Models, TPAMI 32(9), 2010-10

3.8 Homogeneity and inhomogeneity of geometric quality in large scale bundle adjustments

Wolfgang Foerstner (Universität Bonn, DE)

Main reference Richard Steffen, Jan-Michael Frahm and Wolfgang Förstner, "Relative Bundle Adjustment based on Trifocal Constraints," ECCV 2010.
URL http://www.ipb.uni-bonn.de/uploads/tx_ikgpublication/steffen10_RelativeBundle_RMLE_ECCV2010.pdf

Large scale data acquisition for 3D outdoor scenes requires a homogeneous geometric quality of large areas. This is a severe problem as terrestrial mapping systems need to follow roads, which induce inhomogeneity of the geometric reconstruction as a function of the distance to the acquisition path, a situation known from loop-closing and when including points very far from the sensor path. We discuss means to handle inhomogeneous geometric situations within bundle adjustment (BA), how to specify homogeneity of large BA results using Gaussian processes and to evaluate the geometric quality of BA results.

- http://www.ipb.uni-bonn.de/uploads/tx_ikgpublication/dickscheid08.benchmarking.pdf
- http://www.ipb.uni-bonn.de/uploads/tx_ikgpublication/laebe08.quality.pdf
- http://www.ipb.uni-bonn.de/uploads/tx_ikgpublication/foerstner10_Minimal_Representation_for_Uncertainty-ACCV2010.pdf

3.9 Egomotion estimation and mapping for autonomous systems

Friedrich Fraundorfer (ETH Zürich, CH)

Egomotion estimation and mapping are key tasks for autonomous systems. In this talk I will discuss egomotion estimation and mapping for two examples of autonomous systems, an autonomous car and an autonomous micro aerial vehicle (MAV). In the car example I will discuss egomotion estimation using a monocular camera. I will show how assuming the Ackerman steering model can be used for extremely efficient and robust egomotion estimation and how even absolute scale can be recovered for this monocular case. In the MAV example I will discuss how tight coupling of IMU measurements and visual features lead to extremely efficient and robust egomotion estimation and how the MAV maps its environment for autonomous navigation and obstacle avoidance.

3.10 Objects are More Than Bounding Boxes

Juergen Gall (ETH Zürich, CH)

The goal of object detection is to locate and identify instances of an object category within visual data like images, videos, or 3d data. The location is commonly described by a bounding box and the object categories are based on the human categorization system, e.g., car, bus, pedestrian, etc. For some applications, however, reducing objects to a bounding box and instances of these human categories does not seem to be optimal. In some cases, the task to be solved is more complex. For instance, questions like “Are all cars in this image parking in the right direction?" or “Where can I sit?" cannot be easily answered by classical object detection methods. In this talk, I want to discuss the relevance of object properties for object detection.

3.11 Challenges for Camera-Based Driver Assistance

Stefan Gehrig (Daimler Research – Stuttgart, DE)

One of the many applications of Computer Vision is Camera-Based Driver Assistance. While (almost) every human that owns a driver license is able to perform this task with fault rates of less than 1 accident in 10 years, this simple task becomes extremely challenging for Computer Vision Algorithms. Lanes and objects must be detected and measured at all times, even under adverse weather conditions (rain, snow, backlight, ...). This imposes a high robustness on the algorithms and hence many algorithms developed for controllable environments are deemed inappropriate for such environments. This talk gives an overview of the challenges at hand and shows some directions of how to tackle and solve these challenges. In addition, different ways on how to evaluate the algorithms against‘ ‘weak" ground truth are presented.

3.12 Working with Real-World Data

Michael Goesele (TU Darmstadt, DE)

Joint work of Ackermann, Jens; Curless, Brian; Fuhrmann, Simon; Goesele, Michael; Haubold, Carsten; Hoppe, Hugues; Klowsky, Ronny; Ritz, Martin; Seitz, Steven M., Steedly, Drew; Stork, Andre; Szeliski, Richard

As computer vision researchers, we now enjoy (or fear?) an abundance of real- world data. Well known examples are the billions of images and millions of videos available online. In this talk, I will first present our multi-view stereo and photometric stereo systems able to operate on such real-world data. I will then introduce ambient point clouds as a way to provide a 3D visualization even based on incomplete and uncertain image-based reconstructions of real-world scenes. Finally, I will discuss some challenges, thoughts, and consequences for future work.

3.13 Cross-modal Motion Analysis and Reconstruction

Thomas Helten (MPI für Informatik – Saarbrücken, DE)

Joint work of Tautges, Jochen; Zinke, Arno; Krüger, Björn; Baumann, Jan; Weber, Andreas; Helten, Thomas; Müller, Meinard; Seidel, Hans-Peter; Eberhardt, Bernd
Main reference J. Tautges, A. Zinke, B. Krüger, J. Baumann, A. Weber, T. Helten, M. Müller, H.-P. Seidel, B. Eberhardt, "Motion Reconstruction Using Sparse Accelerometer Data," ACM Transactions on Graphics (May 2011), 30:3, pp.18:1–18:12.
URL http://doi.acm.org/10.1145//1966394.1966397

There are many ways for recording human motion sequences, including optical, inertial and mechanical motion capture (mocap) systems. In particular, optical mocap systems, which provide very rich and easy to interpret data, have been widely used in movie and game productions. However, such systems impose strong restrictions concerning the size of the capture volume and lighting conditions making them difficult to use in outdoor and large-scale real-world scene analysis. Avoiding such restrictions, inertial-based sensors, which have been increasingly used in entertainment and monitoring applications, have become a low-cost alternative for capturing motion characteristics. As a drawback, inertial systems typically deliver rather abstract data such as accelerations and angular velocities, which are prone to noise and difficult to handle. In this contribution, we compare various sensor modalities discussing their strengths and weaknesses. In particular, we address the issue on designing suitable feature representations that allow for cross-modal comparison of motion data. Exemplarily, we illustrate these aspects by means of two application scenarios. Firstly, we describe a method for automatically classifying large-scale trampoline motions on the basis of inertial sensor input. Secondly, we sketch a data-driven approach for reconstructing 3D motions from sparse acceleration data.

3.14 Structure in computer vision and pattern recognition: Why doesn't it really fly high?

Vaclav Hlavac (Czech Technical University, CZ)

Structural pattern recognition has been highly popular in 1960-1970s with seminal contributions from Kung Su Fu. The later interest in it faded with the rise of statistical approaches which penetrated even mathematical linguistics where structural analysis was originally started by Noam Chomsky in 1950s. With images, the failure of structural method was glaring. Recently the structural methods have been mostly understood as the graph embedding (H. Bunke's K.S. Fu Award lecture at ICPR 2010).

In the talk, I will talk about my view of the subject originating from methods from our book Schlesinger M.I., Hlavac V.: "Ten lectures on structural and structural pattern recognition", Kluwer 2002. The structure is also needed for a large scale outdoor scene analysis. I will explain the topic and relate it to my own work and the work of my collaborators: (1) Repetitive structures in house facades, (2) in using structure (pose primitives) in analysis of human activity from video; (3) in using 2D context-free grammars for analysis of mathematical formulae, etc.

3.15 Pyramid Transform Revised: Pyramid Transform on the Manifold

Atsushi Imiya (Chiba University, JP)

Joint work of Imiya, Atsushi; Michizuki, Yoshihiko;Fan, Ming-Ying
Main reference Yoshihiko Mochizuki, Yusuke Kameda, Atsushi Imiya, Tomoya Sakai, Takashi Imaizumi, "Variational method for super-resolution optical flow," Signal Processing, Vol. 91, Issue 7, July 2011, pp. 1535–1567.

The pyramid transform was first proposed in image processing to compress of images preserving global features such as edges and segments.

The transform reduces the size of image data preserving the global features of images by combining shift invariant smoothing and downsampling. Then, the transform provides an efficient strategy for multiresolution image analysis in computer vision.

Multiresolution analysis using pyramid transform allows to unify local and global features on images, which are extracted from low- and high- resolution images, respectively. The pyramid-transform-based method is efficiently used in optical flow computation from planar images captured by pinhole camera systems, since the propagation of features from coarse sampling to fine sampling allows to compute both large-displacement in low-resolution images sampled by a coarse grid and small-displacement in high resolution images sampled by a fine grid. Resizing of an image by downsampling after smoothing by convolution with the Gaussian kernel achieves the image pyramid transform. Since convolution with the Gaussian kernel for smoothing is derived as the solution of diffusion equation, the pyramid transform is achieved by downsampling to the solution of diffusion equation. This separation property of the pyramid transform derives the general pyramid transform on Riemannian manifolds by using downsampling on the manifolds and diffusion equation on manifolds.

As an application, we introduce the Gaussian pyramid transform on the sphere using spherical scale-space analysis and derive a numerically stable optical flow computation algorithm for images on the spherical retina.

There are two typical methods for optical flow estimation for pinhole images; the Lucas-Kanade (LK) method and the Horn-Schunck (HS) method which are based on template matching and the variational minimisation, respectively.Image pyramid technique is commonly used to improve the accuracy of stability of optical flow.For instance, the LK method with pyramid-based multiresolution optical flow computation (LKP) method is derived to guarantee the accuracy and stability of the solution for image sequence using the pyramid transform which detects large-displacement and small-displacement motions. The Gaussian kernel for the pyramid transform is numerically expressed as a discretised small kernel for an planar image, for example, the five times five window is typically selected as the kernel size. For images on the unit sphere, since the grid points of the spherical coordinate are uniformly located,the LKP method is not suitable for optical flow computation on the sphere. However, since variational method such as the HS method only depends on the differentials of a function, the method does not require a uniform grid. Therefore, variational method is suitable for the optical flow computation on the spherical coordinates.

We develop a spherical version of the pyramid-based optical flowcomputation for omni-directional images, since the images captured by any omni-directional imaging system can be transformed to images on the unit sphere.

3.16 Stereo and motion analysis for vision-augmented vehicles

Reinhard Klette (University of Auckland, NZ)

The talk starts with showing current results of stereo and motion analysis for video sequences recorded within a driver assistance project at Auckland university. It points out that data used for performance evaluation do have different properties (e.g. quantified by a SIFT-based measure, see [Haeusler&Klette, Benchmarking Stereo Data – not the Matching Algorithms, DAGM 2010]). Traffic video sequences may be classified into a space of 'situations', defined by combinations of 'events', see[Klette et al, IEEE Trans.

Vehicular Technology 2011]. Trinocular recording [Morales&Klette, Ground truth evaluation of stereo algorithms for real world applications, ACCV workshop, 2010] or approximate modeling of road geometries are options to obtain 'ground truth' for real-world video data.

See www.mi.auckland.ac.nz/EISATS for video test data with various kinds of supporting data towards ground truth.

3.17 Outdoor Ground Truth for Optical Flow?

Daniel Kondermann (Universität Heidelberg, DE)

Creating ground truth for optical flow in natural outdoor environments seems almost impossible. In this talk, I will propose two approaches we are currently investigating.

The first approach is to use semi-automatic vision algorithms as is done for example in movie postproduction to create "pseudo" ground truth. The second approach is to evaluate the properties of today's computer graphic rendering systems with respect to their ability to generate images close to the real world.

Finally I will discuss the problem of defining performance measures and benchmarking with respect to correspondence estimation and related algorithms.

References

1 S. Meister and D. Kondermann. Real versus realistically rendered scenes for optical flow evaluation. In *Electronic Media Technology (CEMT), 2011 14th ITG Conference on*, 2011.

3.18 Two disturbing Remarks on Visual Representations: Hierarchies and Semantics

Norbert Krueger (University of Southern Denmark – Odense, DK)

The advantages of hierarchies with explicit semantics in human and computer vision are discussed. The usage of such hierarchies in today's computer vision is reflected about and a concrete hierarchical system is briefly presented.

3.19 Microscopic vs. Macroscopic crowd analysis

Laura Leal-Taixé (Leibniz Universität Hannover, DE)

Methods for the analysis of crowd videos are usually divided into microscopic and macroscopic. Microscopic methods deal with semi-crowded videos, and the goal is mainly to track each individual over time. Most of these methods are divided into object detection and track linking and occlusions and false alarms are usually the main concerns. On the other hand, what happens when the crowd grows bigger and individuals can no longer be detected? Heavily crowded scenes are handled by macroscopic methods, which have a different goal: finding the general flow of the crowd, preferred paths in a scene, entrances and exits and even panic analysis.

The question that arises is: Can we mix both methods in order to obtain more robust trackers?

3.20 From Image Orientation to Buildings and Trees

Helmut Mayer (Universität der Bundeswehr – München, DE)

The basis of our work is the orientation of images taken from the ground or from small (around 1 kg) unmanned aerial systems (UAS). We employ SIFT points (Lowe 2004), but find correspondences via cross-correlation and least squares matching to obtain highly precise points also for wide baselines and different scales.

Corresponding points are input to Nister's (2004) five point algorithm embedded into a expectation maximization (EM) based robust highly accurate orientation procedure (Bartelsen and Mayer 2010). The procedure can also integrate GPS information for absolute orientation.

Orientation is the basis for object extraction. Our approach for 3D facade interpretation (Reznik and Mayer 2008) based on implicit shape models (Leibe et al. 2004) finds rows or columns of 3D windows. Generative stochastic modeling is at the core of our approach to extract unfoliaged trees from terrestrial images (Huang and Mayer 2009).

3.21 Biologically Inspired Spatiotemporal Saliency Processing for a Computational Model of Visual Attention

Baerbel Mertsching (Universität Paderborn, DE)

In studies of attention, the bottom-up conspicuity of a visual feature is known as *saliency*, describing the level of difference of a feature compared to its spatial neighbors regarding a certain dimension. Common dimensions are color, orientation or size. Traditional, computational models generate saliency maps for these dimensions and combine them into one master map of saliency from which spatial positions with high bottom-up conspicuity can be extracted. Watanabe and Shimojo have shown that in auditory attention saliency exists with temporal aspects: In their setup a single sound can help solve a visual ambiguity while it loses this ability when embedded in an temporal sequence of similar sounds, losing its saliency. In modeling attention, temporal dynamics appear in mechanisms like inhibition of return, which keeps the system from analyzing the same part of the scene again. Mechanisms like that can bee seen as top-down interaction within the model. This work proposes that temporal aspects could already start at the bottom of the system, at the point of saliency processing.

Temporal saliency in vision could work similar than the previously described temporal auditory saliency. It is observable in biological vision, that temporal events like the onset of a stimulus attract attention. Also, it is plausible, that the same onset loses this ability when embedded in a temporal sequence of similar onsets.

3.22 Towards an integrated approach to motion analysis and segmentation

Rudolf Mester (Universität Frankfurt, DE)

What is needed today for advancing further towards practically useful systems for dynamic scene analysis is essentially twofold:

On one hand, the rich repertoire of available techniques for tasks such as optical flow estimation, stereo, segmentation etc., has to be reviewed from the point of view of theoretical sustainability: are all the criteria used in current algorithms solidly based on physical reality, and do they consider 'quality' and 'reliability' as a statistical concept? This necessarily leads to a statistical and signal-theoretic derivation of the optimization target functions ('energy functions') which characterize contemporary algorithms.

It implies also that we need to model images and sequences as the result of a compound process of objects (or regions) where the processes of object (or region) generation, their motion, and the mapping from scene to image are described in a physically realistic way.

The result is a rich, generative 'forward model' which is conceptually built on likelihoods and model parameters learnt from reality, and less on ad hoc energies.

Secondly, the inverse process of inferring from observed images onto the real composition and evolution of the scene, should be addressed in a recursive, Bayesian-filter-like manner, where at each time instant the complete state of information obtained in the past is fused with current observations.

3.23 Realtime 3D Motion Reconstruction from Depth Camera Input

Meinard Mueller (MPI für Informatik – Saarbrücken, DE)

Joint work of Baak, Andreas; Müller, Meinard; Theobalt, Christian; Seidel, Hans-Peter

The reconstruction of human motions from sensor input constitutes a challenging problem in computer vision with numerous applications in biomechanics, medicine, and computer animation. While marker-based approaches constitute a reliable and well understood technique to obtain high-quality motions, they require a significant amount of expensive hardware and intrusive equipment to be attached to the actor's body. On the other side, markerless human pose estimation from multiple video streams becomes extremely difficult when using only few cameras or when tracking outdoor scenes. Recently, depth cameras such as the Microsoft Kinect have shown great potential for obtaining reasonable 3D pose estimates even from a single depth image stream. In this contribution, we describe a method that allows for tracking full-body human motions from a single depth image stream captured in natural, non-intrusive settings. We present a hybrid strategy where the tracking is driven by local optimization component and stabilized by a global data-driven retrieval component. Our experiments show that one obtains stable pose estimation results even for fast and complex motions at real-time frame rates.

3.24 Outdoor Human Motion Capture with Data-Driven Manifold Sampling

Gerard Pons-Moll (Leibniz Universität Hannover, DE)

Joint work of Pons-Moll, Gerard; Baak, Andreas; Gall, Juergen; Mueller, Meinard; Seidel, Hans-Peter; Rosenhahn, Bodo
Main reference Pons-Moll G., Baak A., Gall J., Leal-Taixé L., Mueller M., Seidel H.P, Rosenhahn B, "Outdoor Human Motion Capture with Data-Driven Manifold Sampling," International Conference on Computer Vision, 2011

Human motion capturing (HMC) from multiview image sequences constitutes an extremely difficult problem due to depth and orientation ambiguities and the high dimensionality of the state space. In this paper, we introduce a novel hybrid HMC system that combines video input with sparse inertial sensor input.

Employing an annealing particle-based optimization scheme, our idea is to use orientation cues derived from the inertial input to sample particles from the manifold of valid poses. Then, visual cues derived from the video input are used to weight these particles and to iteratively derive the final pose. As our main contribution, we propose an efficient sampling procedure where hypothesis are derived analytically using state decomposition and inverse kinematics on the orientation cues. Additionally, we introduce a novel sensor noise model to account for uncertainties based on the von Mises-Fisher distribution. Doing so, orientation constraints are naturally fulfilled and the number of needed particles can be kept very small. More generally, our method can be used to sample poses that fulfill arbitrary orientation or positional kinematic constraints. In the experiments, we show that our system can track even highly dynamic motions in an outdoor setting with changing illumination, background clutter, and shadows.

3.25 Affine-invariant diffusion geometry for the analysis of deformable 3D shapes

Dan Raviv (Technion – Haifa, IL)

Joint work of Raviv, Dan; Bronstein, Alexander; Bronstein, Michael; Kimmel, Ron; Sochen, Nir
Main reference IEEE Computer Vision and Pattern Recognition (CVPR) 2011

We introduce an (equi-)affine invariant diffusion geometry by which surfaces that go through squeeze and shear transformations can still be properly analyzed.

The definition of an affine invariant metric enables us to construct an invariant Laplacian from which local and global geometric structures are extracted.

Applications of the proposed framework demonstrate its power in generalizing and enriching the existing set of tools for shape analysis.

3.26 Large Scale Traffic Scene Analysis with Multiple Camera Systems

Ralf Reulke (HU Berlin, DE)

The use of camera systems for traffic monitoring is obvious and already in use for about 20 years. However, most of the cameras are operated locally (similar to an induction loop). It has been shown that the two-dimensional areal data analysis offers new possibilities for the determination of traffic parameters.

These presentations discuss a trajectory based recognition algorithm for atypical event detection in multi object traffic scenes and to obtain area based types of information (e.g. maps of speed patterns, trajectory curvatures or erratic movements). Different views of the same area by more than one camera are necessary, because of the typical limitations of single camera systems, resulting from occlusions by other cars, trees and traffic signs. Furthermore, distributed cooperative multi-camera system (MCS) enables a significant enlargement of the observation area. The fusion of object data from different cameras is done by a multi-target tracking approach. This approach opens up opportunities to identify and specify traffic objects, their location, speed and other characteristic object information. The use of wide baseline stereo methods can improve object detection and the tracking accuracy. An approach, which describes the interaction of traffic objects, will also be presented.

3.27 Towards Fast Image-Based Localization on a City-Scale

Torsten Sattler (RWTH Aachen, DE)

Joint work of Sattler, Torsten; Leibe, Bastian; Kobbelt, Leif
Main reference T. Sattler and B. Leibe and L. Kobbelt, "Fast Image-Based Localization using Direct 2D-to-3D Matching," ICCV 2011 (to appear).

Image-based localization via pose estimation constitutes an important step in many interesting Computer Vision applications such as tourist navigation, augmented reality and incremental Structure-from-Motion. With the advent of large scale reconstructions, computing correspondences between 2D features and 3D points in the model quickly becomes the main bottleneck in the pose estimation pipeline. Current state-of-the-art localization methods thus try to leverage the structure of the models in order to limit the search space. In this talk we present a simple method that directly established 2D-to-3D correspondences without needing to exploit those structures. Using a prioritization scheme based on visual words allows our method to efficiently handle large, (nearly) city-scale models while outperforming the more complex current state-of-the-art methods both in terms of speed and accuracy.

3.28 Semantic Structure from Motion

Silvio Savarese (University of Michigan, US)

We propose a new framework called Semantic Structure from Motion (SSFM) for jointly recognizing objects as well as reconstructing the underlying 3D geometry of the scene (cameras, points and objects). In our SSFM framework we leverage the intuition that measurements of keypoints and objects must be semantically and geometrically consistent across view points. Our framework has the ability to: i) estimate camera poses from object detections only; ii) enhance camera pose estimation, compared to feature-point-based SFM algorithms; iii) improve object detections given multiple uncalibrated images, compared to independently detecting objects in single images. Extensive quantitative results on three datasets 'LiDAR cars, street-view pedestrians, and Kinect office desktop" verify our theoretical claims.

3.29 Measuring and Modeling the World – Bayes and Analysis by Synthesis

Andreas Schilling (Universität Tübingen, DE)

Computer Vision deals with modeling from images. This goal can be defined as finding the most probable of all models that could have produced the measured data, i.e. the taken images. A generative approach to reaching this goal consists in minimizing the distance between the input images and images rendered from the model. This is the classical analysis-by-synthesis approach which can be considered optimal in the sense that this image distance is inversely related to the likelihood of the data.

Bayesian reconstruction tries to maximize the posterior probability of the model which is the product of the likelihood and a prior probability of the model. An impressive example for the power of the analysis-by-synthesis approach is the reconstruction of textures from several obliquely taken images. Important open questions concerning analysis-by-synthesis methods include: 1.) finding good models and representations, that allow for good regularization techniques in the case of ill posed vision problems (bringing in prior information about the model probability), 2.) efficient optimization techniques and initializations, as well as 3.) finding filters or transformations, that remove information from the images to be compared that is a consequence of effects not modeled by the class of models under consideration.

3.30 Segmentation, Classification and Reconstruction of Surfaces from Point Clouds of Man-made Objects

Falko Schindler (Universität Bonn, DE)

Joint work of Schindler, Falko; Förstner, Wolfgang; Frahm, Jan-Michael
Main reference Falko Schindler and Wolfgang Förrstner, "Fast Marching for Robust Surface Segmentation," to appear in: Lecture Notes in Computer Science, 2011.

We present a surface model and reconstruction method for man-made environments taking into account prior knowledge about topology and geometry. The model favors but is not limited to pairwise orthogonal vertical and horizontal planes. We do not require one particular class of sensors, as long as a triangulated point cloud is available. The reconstruction method delivers a complete 3D segmentation, parametrization and classification for surface regions and their inter-plane relations. Starting with a curvature adaptive pre- segmentation we reduce the computational cost and are more robust to noise and outliers. All reasoning is statistically motivated, based on only a few decision variables. We demonstrate our reconstruction method for multi-view stereo and structured light reconstructions as well as for laser range data.

3.31 Non-Perspective Camera Models in Underwater Imaging – Overview and Error Analysis

Anne Sedlazeck (Christian-Albrechts-Universität, Kiel, DE)

Joint work of Sedlazeck, Anne; Koch, Reinhard

When capturing images underwater, image formation is affected in two major ways. First, the light rays traveling underwater are absorbed and scattered depending on their wavelength, creating effects on the image colors. Secondly, the glass interface between air and water refracts the ray entering the camera housing because of a different index of refraction of water, hence the ray is also affected in a geometrical way. This paper examines different camera models and their capabilities to deal with geometrical effects caused by refraction. Using imprecise camera models leads to systematic errors when computing 3D reconstructions or otherwise exploiting geometrical properties of images. In the literature, many authors have published work on underwater imaging by using the perspective pinhole camera model (single viewpoint model – SVP) with a different effective focal length and distortion to compensate for the error induced by refraction at the camera housing. On the other hand, methods were proposed, where refraction is modeled explicitly or where generic, non-single-view-point camera models are used. In addition to discussing all three model categories, an accuracy analysis of using the perspective model on underwater images is given and shows that the perspective model leads to systematic errors that compromise measurement accuracy.

3.32 Outdoor Image-based Motion Capture and Reshaping of Humans

Thorsten Thormaehlen (MPI für Informatik – Saarbrücken, DE)

Joint work of Thormaehlen, Thorsten;Rosenhahn Bodo; Halser Nils; Wand Michael; Gall Juergen; Jain, Arjun, Kurz, Christian; Theobalt, Christian; Seidel, Hans-Peter
Main reference N. Hasler, B. Rosenhahn, T. Thormaehlen, M. Wand, J. Gall, H.-P. Seidel, "Markerless Motion Capture with Unsynchronized Moving Cameras," IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR 2009), Miami Beach, Florida, June 2009.
URL http://www.mpi-inf.mpg.de/resources/MovieReshape/

In this talk I will present techniques to capture the motion of human subjects, which are recorded with multiple unsynchronized moving cameras in an outdoor environment. If multiple moving cameras record the same scene, a camera is often visible in another camera's field of view. This poses a constraint on the position of the observed camera, which can be included into the camera motion optimization process. In cluttered outdoor scenes, silhouettes for human motion estimation are difficult to obtain. We show that reliable estimates are nevertheless possible, if the parameters of the background segmentation are simultaneously updated. Once the camera motion and motion of a human subject has been established, semantically meaningful attributes of body shape, such as height, weight, or waist girth, can be interactively modified. This enables spatio-temporal reshaping of human subjects in outdoor video.

3.33 Inverse Procedural Modeling

Michael Wand (MPI für Informatik – Saarbrücken, DE)

In this talk, I will discuss how to automatically infer rules to build shapes from examples. Given some exemplar geometry, we want to construct a shape grammar that describes a class of objects that are all similar to the input. As a model of similarity, we use local similarity, i.e., local pieces of the output must match the input (as in texture synthesis). The key idea is to examine the symmetry structure of the data in order to find an explicit set of rules that provably constructs only geometry that is similar to the input exemplar.

I will show some result on synthetic 3D meshes as well as scanner data, and conclude the talk with some ideas potential generalizations of the presented framework.

3.34 Implicit scene context for object segmentation and classification

Jan Dirk Wegner (Leibniz Universität Hannover, DE)

Joint work of Wegner, Jan Dirk; Rosenhahn, Bodo; Soergel, Uwe
Main reference Wegner, J.D.; Rosenhahn, B.; Soergel, U., "Implicit scene context for object segmentation and classification," 33rd Annual Symposium of the German Association for Pattern Recognition (DAGM), 2011, accepted for publication.

Our aim is to segment and classify objects in remote sensing images for automatic mapping. A class label is assigned to each pixel. In complex scenes with lots of different object categories like urban areas contextual knowledge may add valuable information if local object descriptors deliver ambiguous results. We learn object-context from the background class of partially labeled images and introduce it as a prior. Local object descriptors and contextual knowledge are combined in a Conditional Random Field framework to label each pixel with the most likely object class. Experiments with simulated data and images of computer vision benchmark data sets, representing context of low and medium complexity, lead to promising results. Context learned from patterns in unlabeled subcategories significantly improves results. Tests with remote sensing data of urban scenes, including context of very high complexity, indicate need for further refinements. More sophisticated contextual learning is necessary to capture complex patterns.

3.35 Inference methods for structure and motion computation: avoiding mistakes before it is too late

Christopher M. Zach (ETH Zürich, CH)

Repetitive and ambiguous visual structures pose a severe problem in many computer vision applications. For instance, erroneously estimated poses between unrelated images with visually similar content can lead to severely distorted 3D models. Our goal is to identify incorrect geometric relations from a set of hypothesized ones, which are typically given as fundamental matrices, homographies, or absolute orientations. Identification of such erroneous relations solely based on low level and local information, e.g. by robust matching techniques and bundle adjustment, is not always possible. The following two cues are helpful to detect incorrect visual relations: (i) determining undetected but predicted visual structures given hypothesized relations, and (ii) verifying the internal consistency of estimated visual relations on a non-local scale. We propose to incorporate these cues particularly into a structure-from-motion framework in order to detect incorrect visual relations, and state this task as Bayesian inference problem. Unlike traditional SfM approaches, where only evidence for the validity of an estimated visual relation is collected, our framework additionally uses indicators explicitly assessing the incorrectness of putative relations. The ultimate goal of this work is obtain a truly incremental, efficient, and fault-tolerant SfM approach.

3.36 Freehand HDR Imaging of Moving Scenes with Simultaneous Resolution Enhancement

Henning Zimmer (Universität des Saarlandes, DE)

Joint work of Zimmer, Henning; Bruhn, Andres; Luxenburger, Andreas; Weickert, Joachim
Main reference H. Zimmer, A. Bruhn, and J. Weickert, "Freehand HDR Imaging of Moving Scenes with Simultaneous Resolution Enhancement. Computer Graphics Forum," Proc. of Eurographics, vol. 30 (2), pp. 405–414, 2011.
URL http://dx.doi.org/10.1111/j.1467-8659.2011.01870.x

We show how a modern energy-based optic flow method can be used for aligning exposure series used in high dynamic range (HDR) imaging. The main advantage of our approach are the resulting dense displacement fields that can describe arbitrary complex motion patterns, caused by severe camera shake and moving objects.

Additionally, it benefits from several advantages over existing strategies:

(i) It is robust under outliers (noise, occlusions, saturation problems) and allows for sharp discontinuities in the displacement field.

(ii) The alignment step neither requires camera calibration nor knowledge of the exposure times.

(iii) It can be efficiently implemented on CPU and GPU architectures as well as on modern smartphones, e.g. Android phones.

After the alignment is performed, we can additionally use the obtained subpixel accurate displacement fields as input for an energy-based, joint super-resolution and HDR (SR-HDR) approach. It introduces robust data terms and anisotropic smoothness terms in the SR-HDR literature.

4 Working Groups

4.1 Workgroup Summary on Performance Analysis in Dense Correspondence Problems

Daniel Kondermann

The aim of the working group was to discuss how meaningful, objective and accurate information about the performance of dense correspondence methods (DCM) such as optical flow and stereo estimation can be obtained. The group met two times and consisted in total of fourteen members.

Staring out with a brainstorming about applications for DCM, the group quickly found three problem domains.

In the first domain *algorithm characteristics* are of interest. They describe general properties of algorithms such as accuracy, number of parameters, time- and space complexity, graceful degradation, parallelization possibilities, engineerability (ease of full system implementation), confidence estimation and information about alternative solutions in the case of multiple local extrema.

The second problem domain is about *input characteristics*. Any DCM can be applied to any kind of image data. It seems unlikely that an algorithm tuned for particle image velocimetry is capable of dealing with traffic scenes or cinematic movies. On the other hand it is problematic to describe each possible image sequence based on the application it was intended for. Therefore, it would help to find more general descriptors for input data. Two approaches could be of interest: first, global approaches could be used to characterize the similarity of a given scene compared to scenes with known ground truth. This would facilitate the choice of benchmark data to predict the accuracy of a DCM given new data. The second approach could be local: for each finite spatio-temporal neighborhood in a scene, a small dataset such as a structure tensor or any feature descriptor (HoG, FFT-coefficients, SIFT, ...) could be used to characterize the quality of each pixel individually to characterize the scene and possibly predict the quality of the outcome.

The third problem domain being discussed was about publications. Many members of the group agreed that the community currently mainly focuses on accuracy and innovation of DCM. Most other algorithm characteristics and the study of input characteristics are mostly treated with low priority. Based on this "research bias", it seems difficult to advance this field of research. The working group agreed that it would be helpful if the awareness about this bias were increased within the community. This could for example be achieved by conference workshops focusing performance analysis in image processing.

The working group showed great interest in addressing these three problem domains in the future. We hope to establish improved performance analysis methods including more detailed algorithm specifications and new benchmark datasets.

4.2 Workgroup Summary on Challenges in Structure From Motion

Marc Pollefeys

The aim of this working group was to explore open challenges in structure from motion. Structure from motion is the problem of recovering the relative motion/position of the camera(s) as well as the (sparse) 3D structure of the observed scene. While our understanding of this problem has tremendously progressed in the last two decades there are still significant challenges to achieve reliable results on many real world data sets.

First, some argued that the main challenge was to reliably find corresponding points between images. It can indeed often be very difficult to match feature points between images that differ in viewpoint, lighting and camera parameters. This also often depends on the scene which can have limited texture or repeating elements which can lead to a large number of incorrect matches or outliers. The argument was that once potential correspondences had successfully been filtered using multiple view relations, the structure from motion problem itself could be solved.

However, several argued that this was not the case and that state of the art algorithms were often still struggling to achieve good results. Three different types of approach have been proposed. First, sequential structure from motion starts building up the reconstruction by sequentially extending the reconstruction starting from a pair of images and adding images in some order. This approach is often dependent on a good choice for the initial pair of views. To avoid errors accumulating too much, the solution is often globally refined after each new view is added which is very inefficient (and essentially turns the problem from being $O(n^3)$ to $O(n^4)$ with n being the number of images. The second type of approach is hierarchical structure from motion where pairs and triplets of views are first assembled and then further grouped and merged in larger and larger reconstructions. These type of approaches can be more efficient, but also can face challenges when inconsistencies appear between sub-models. The third type of approaches aims to perform batch processing of all the images at once. Factorization approaches are a good example of this. In this case a globally optimal solution can be achieved, but the camera model is strongly simplified and outliers can not be handled. More recent approaches are more general and enforce more robust costfunctions (e.g. L_1), but often face significant computational challenges to scale to large-scale data sets. People also mentioned the recent discrete-continuous approach proposed by Snavely et al. which seemed very promising, but also faced problems of scale and efficiency. This approach alternated between solving a coarse structure from motion problem globally using discrete optimization and refining this solution using non-linear continuous optimization. This was seen as a very promising route, although the current formulation still suffered several important limitations.

All in all, the conclusion of this working group was that although great progress had been made in the last decade or two, no reliable general purpose structure from motion solver that could handle any image collection, even if given potential correspondences containing a reasonable number of correct matches, was yet available.

5 Schedule

Monday, June 25th, 2011

09:15–10:00	Bodo Rosenhahn: *Opening* 2-Minute Self-Presentations
Chair:	Felix Klose
10:15–10:40	Henning Zimmer: *Freehand HDR Imaging of Moving Scenes with Simultaneous Resolution Enhancement*
10:40–11:05	Andres Bruhn: *Structural Prediction for Optical Flow*
11:05–11:30	Daniel Kondermann: *Outdoor Ground Truth for Optical Flow?*
11:30–11:55	Jan Dirk Wegner: *Implicit scene context for object segmentation and classification*
Chair:	Henning Zimmer
14:00–14:25	Stefan Gehrig: *Challenges for Camera-Based Driver Assistance*
14:25–14:50	Friedrich Fraundorfer: *Egomotion estimation and mapping for autonomous systems*
14:50–15:15	Reinhard Klette: *Stereo and motion analysis for vision-augmented vehicles*
Chair:	Falko Schindler
16:05–16:30	Radek Grzeszcuk: *City-Scale Landmark Identification and Text Detection*
16:30–16:55	Torsten Sattler: *Towards Fast Image-Based Localization on a City-Scale*
16:55–17:20	Meinard Mueller: *Realtime 3D Motion Reconstruction from Depth Camera Input*
17:20–17:45	Thomas Helten: *Cross-modal Motion Analysis and Reconstruction*

Tuesday, June 26th, 2011

Chair:	Gerard Pons-Moll
09:15–09:40	Laura Leal-Taixé: *Macro vs micro*
09:40–10:05	Juergen Gall: *Objects are more than bounding boxes*
Chair:	Jan Wegner
10:40–11:05	Ioannis Brilakis: *Achievements and Challenges in Recognizing and Reconstructing Civil Infrastructure*
11:05–11:30	Ralf Dragon: *Towards Feature-Based Situation Assessment for Airport Apron Video Surveillance*
11:30–11:55	Ralf Reulke:*Large Scale Traffic Scene Analysis with Multiple Camera Systems*

Wednesday, June 27th, 2011

Chair:	Jan-Michael Frahm
09:15–09:40	Jan-Michael Frahm: *Efficient Robust Large-scale Reconstruction*
09:40–10:05	Tinne Tuytelaars: *From the lab to the real world: two tales from the road*
Chair:	Ralf Dragon
10:40–11:05	Sameer Agarwal: *Bundle Adjustment in the Large*
11:05–11:30	Frank Dellaert: *Subgraph Preconditioning: The revolutionary new way of using direct graph-based solvers to speed up conjugate gradients*
11:30–11:55	Wolfgang Förstner: *Homogeneity and inhomogeneity of geometric quality in large scale bundle adjustments*
14:00–15:15	Frank & Jan: *Working Group Definition* *Working Group Meetings*
Chair:	Torsten Sattler
15:40–16:05	Silvio Savarese:*Semantic Structure from Motion*
16:05–16:30	Vaclav Hlavac: *Structure in images: Why doesn't it really fly high?*
16:30–16:55	Andreas Schilling: *Measuring and Modeling the World – Bayes and Analysis by Synthesis*
16:55–17:20	Helmut Mayer: *From Image Orientation to Buildings and Trees*

Thursday, June 28th, 2011

Chair:	Thomas Helten
09:15–09:40	Rudolf Mester: *Towards an integrated approach to motion analysis and segmentation*
09:40–10:05	Bärbel Mertsching: *Biologically Inspired Spatiotemporal Saliency Processing for a Computational Model of Visual Attention*
Chair:	Laura Leal-Taixé
10:40–11:05	Michael Goesele: *Workin with Real-World Data*
11:05–11:30	Jean-Sebastian Franco: *Probabilistic methods for shape and motion*
11:30–11:55	Falko Schindler: *Segmentation, Classification and Reconstruction of Surfaces from Point Clouds of Man-made Objects*
Chair:	Dan Raviv
14:00–14:25	Daniel Cremers: *Convex Relaxation Techniques for Geometric Optimization*
14:25–14:50	Christopher M. Zach: *Inference methods for structure and motion computation: avoiding mistakes before it is too late*

Chair:	Christopher Zach
14:50–15:15	Gabriel Brostow: *I see bad pixels, and they don't even know they're bad!*
15:15–15:40	Johan Hedborg: *Rolling shutter video*
16:05–16:30	Dan Raviv: *Affine-invariant diffusion geometry for the analysis of deformable 3D shapes*
16:30–16:55	Michael Wand: *Inverse Procedural Modeling*
16:55–17:20	Gerard Pons-Moll: *Outdoor Human Motion Capture using Data-Driven Manifold Sampling*
17:20–17:45	Thorsten Thormaehlen: *Outdoor Image-based Motion Capture and Reshaping of Humans*

Friday, June 29th, 2011

Chair:	Michael Wand
09:15–09:40	Atsushi Imiya: *Pyramid Transform Revised for Large Sparse and Fast Images and Image Sequences in Real World*
09:40–10:05	Tomas Pajdla: *Robust and Scalable Multi-View Reconstruction*
10:05–10:40	Norbert Krüger: *Two disturbing Remarks on Visual Representations: Hierarchies and Semantics*
10:40–11:05	*Working Group Meeting*
11:05–11:30	*Working Group Meeting*
11:30–11:55	Marc Pollefeys: *Working Group Get Together and Summary of each Group*

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