Report from Dagstuhl Seminar 11231

Scientific Visualization

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Abstract

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

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1 Executive Summary

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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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