Report

of the 2nd Dagstuhl Seminar on

Scientific Visualization

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Organized by

Hans Hagen, Universität Kaiserslautern
Gregory Nielson, Arizona State University
Frits Post, Delft University of Technology

Scientific Visualization is currently a very active and vital area of research, teaching and development. The success of Scientific Visualization is mainly due to the soundness of the basic premise behind it, that is, the basic idea of using computer-generated pictures to gain information and understanding from data (geometry) and relationships (topology). This is an extremely intiutive and very important concept which is having a profound and wide spread impact on the methodology of science and engineering.

This third Dagstuhl Seminar on Scientific Visualization brought together researchers from USA (26), Germany (11), Great Britain (1), The Netherlands (5), France (2), Austria (1), Switzerland (1), Spain (1), Japan (1), Czech Republic (1) and Russia (1), the contributions reflected the heterogenous structure of the whole area of ScientificVisualization. One of the important themes being nurtured under the aegis of Scientific Visualization is the utilization of the broad bandwidth of the human sensory system in steering and interpretating complex processes and simulations involving voluminous data sets across diverse scientific disciplines. Since vision dominates our sensory input, strong efforts have been made to bring the power of mathematical abstraction and modelling to our eyes through the mediation of computersgraphics. This interplay between various application areas and their specific problem solving visualization techniques was emphasized in this seminar.
Reflecting the heterogeneous structure of Scientific Visualization we concentrated on:

- vector- and tensorfield visualization
- volume visualization
- interactive steering and exploration
- multiresolution techiques

It was a pleasure to see the always well occupied audience and to follow the surprisingly extensive and intensive discussions after the talks.
The occasion of the Dagstuhl Seminar was taken to start the initiative for another book on Scientific Visualization edited by the organizers and contributed by the participants of the seminar. The idea is not to produce a

proceedings volume but an edited book containing tutorial-like sections as well as recent original work. One intention of the book is to use it as material in courses and seminars on Scientific Visualization.

Participants

Chandrajit Bajaj, Purdue University, USA
Polly Baker, University of Illinois, USA
David C. Banks, Mississippi State University, USA
R. Daniel Bergeron, University of New Hampshire, USA
Georges-Pierre Bonneau, LMC-CNRS, France
Kenneth Brodlie, University of Leeds, Great Britain
Pere Brunet, Universitat Politecnica de Catalunya, Spain
Brain Cabral, Silicon Graphics Computer Systems, USA
Herbert Edelsbrunner, University of Illinois, USA
Thomas Ertl, Universität Erlangen-Nürnberg, Germany
Thomas Frühauf, Fraunhofer-Institut, Germany
Richard Franke, Naval Postgraduate School, USA
Issei Fujishiro, Ochanomizu University, Japan
Martin Göbel, GMD, Germany
Sarah Gibson, MERL, USA
Markus Groß, ETH Zürich, Schwitzerland
Eduard Groeller, TU Wien, Austria
Hans Hagen, Universität Kaiserslautern, Germany
Stefanie Hahmann, Laboratoire LMC-IMAG, France
Bernd Hamann, University of California at Davis, USA
Patrick Hanrahan, Stanford University, USA
Chuck Hansen, University of Utah, USA
Andrew Hanson, Indiana University, USA
William Hibbard, University of Wisconsin–Madison, USA
Ken Joy, University of California at Davis, USA
David Kao, NASA Ames Research Center, USA
Daniel A. Keim, Universität München, Germany
Stanislav Klimenko, Institute for High Energy Physics Protvino, Russia
Heinrich Müller, Universität Dortmund, Germany
Nelson Max, University of California, USA
Jörg Meyer, Universität Kaiserslautern, Germany
Robert Moorhead, Mississippi State University, USA
Gregory M. Nielson, Arizona State University, USA
Hans-Georg Pagendarm, DLR, Germany
Alex Pang, University of California at Santa Cruz, USA
Frits Post, Delft University of Technology, The Netherlands
William Ribarsky, Georgia Institute of Technology, USA
Alyn Rockwood, Arizona State University, USA
Ari Saderjoen, Delft University of Technology, The Netherlands
Gerik Scheuermann, Unviersität Kaiserslautern, Germany

Multiresolution Compression and Reconstruction

Markus Groß
Swiss Federal Institute of Technology (ETH), Switzerland,

In this talk I presented a framework for multiresolution compression and reconstruction of arbitrarily dimensioned data sets, which is designed for distributed applications. Although being restricted to uniform sample data, our versatile approach enables the handling of a large variety of real world settings including nonparametric, parametric and implicit lines, surfaces and volumes.
Compression is done by a remote server and consists of a newly designed pipeline stemming from an initial B-spline wavelet representation. It supports progressiv transmission and geometric reconstruction using thoroughly selected oracles to predict the importance of individual wavelets. In addition, geometric contstraints such as boundary lines can be compressed in a lossless scheme and combined with the resulting bitstream.
Reconstruction on a local client computes an adaptive piecewise linear approximation using a fast point removal strategy which works with any subsequent triangulation scheme also rendering lines, triangles and tetrahedra the underlying higher order approximation can be exploited to reconstruct implicit functions such as isolines or isosurfaces more smoothly and accurately than common plane methods. Some results illustrate the performance of our set of methods.

Wavelet-based Multiresolution Representation of Computational Field Simulation Data Sets

Robert Moorhead, Raghu Machiraju, and Zhifan Zhu
Mississippi State University, NSF Engineering Research Center, USA

This talk addresses multiresolutional representation of datasets arising from a computational field simulation. The approach determines the regions of interest, breaks the volume into variable size blocks to localize the information, and then codes each block using a wavelet transform. The blocks are then ranked by visual information content so that the most informative wavelet coefficients can be embedded in a bitstream for progressive transmission or access. The technique is demonstrated on a widely-used computational field simulation dataset.

Data Dependent Triangulation Schemes for Hierarchical Rendering

Kenneth I. Joy
University of California at Davis, Department of Computer Science, USA

We describe a construction of a hierarchy of triangulations which approximate the given data at various levels of detail. Intermediate triangulations can be associated with a particular level of the hierarchy by considering their approximation errors. This paper presents a new data-dependent triangulation scheme for multivalued data in the plane. We perform piecewise linear approximation based on data dependent triangulations. We subdivide triangles until the error in the piecewise linear approximation is smaller than some tolerance.

Enhanced Line Integral Convolution with Flow Feature Detection

Arthur Okada
Parametric Technology Corporation
David Kao
NASA Maes Research Center, USA

The Line Integral Convolution (LIC) method, which blurs white noise textures along a vector field, is an effective way to visualize overall flow patterns in a 2D domain. The method produces a flow texture image based on the input velocity field defined in the domain. Because of the nature of the algorithm, the texture image tends to be blurry. This sometimes makes it difficult to identify boundaries where flow separations and reattachments occur. We present techniques to enhance LIC texture images and use colored texture images to high light flow separation and reattachment boundaries. Our techniques have been applied to several flow fields defined in 3D curvilinear multi-block grids and scientists have found the results to be very useful.

Hierarchical Methods for Data Analysis and Visualization

Thomas Ertl
Universität Erlangen-Nürnberg, Germany

Multilevel representations are the basis for efficient feature extraction and visualization techniques. We report on our progress in the field of wavelet-based multiresolution analysis and adaptive multilevel finite elements. Compression domain volume rendering serves as a good example how high quality

images can be generated from massively compressed 3D datasets, however, at the expense of the much more costly reconstruction of the function value (as compared to the trilinear interpolation). Finite element methods, in contrast, provide a framework, where the well-known and efficient full grid algorithms can be applied to adaptively refined meshes, which give us a compact representation of the data properties. In this approach we consider the mesh optimization as an approximation problem interpreting the input data as a function in a finite element space of piecewise linear functions. Starting with a very coarse triangulation of the domain we construct an corresponding FE space and compute the best approximation. Based on the local contributions of the error, we construct a hierarchy of better triangulations by local mesh refinement following the red/green rule. The approximation properties of various norm (h_2, Sobolev) have been studied. Application examples (MRI, CT datasets) show that visualization algorithms like marching tetrahedra or a tetrahedrical volume raycaster can exploit the hierarchical data structures, and significantly speed up the mapping and the rendering (by orders of magnitudes). For the future we force a combination of techniques: wavelet-based scale space methods for extracting prominent features and adaptive mesh optimization for data and geometry compression.

Design of Vector Fields with Geometric Algebra

Alyn Rockwood
Arizona State University, Department of Computer Science and Engineering, USA

Geometric Algebra is a Clifford Algebra derivative that has been applied to many problems in science and engineering. We introduced the algebra and then indicated potential uses of it for visualizing vectorfields. A demonstration program was shown in 2D that was based in Geometric Algebra It allows insertion, deletion and modification of singularities of any index by using a polynomial derived by G. Algebraic concepts. It is interactive in displaying vectorglyphs and separatrices.

Visualizing critical points of arbitrary Poincaré-Index

Gerik Scheuermann, Hans Hagen
Universität Kaiserlautern, Germany

One major discipline of Scientific Visualization is the display of vector field data. We address the problem of visualizing vector fields containing critical points of higher order Poincaré-Index. We use polynomial pieces so that the degree is high enough to get the right Poincaré-Index at the location of the critical points. This is an essential improvement because nearly all visualization of vector fields up to now used piecewise linear interpolation and therefore cannot show this kind of critical points. A description of vector fields in Clifford Algebra opens the way to a better understanding on some plane polynomial vector fields. This is used to choose the polynomial approximations needed for the visualization.

Multiresolution Analysis on Irregular Triangular Meshes

Georges-Pierre Bonneau, Stefanie Hahmann, Alexandre Gerussi
LMC-IMAG, University of Grenoble, France

Triangular multiresolution analysis schemes enable to compute successive lower resolution approximations of large data sets defined on triangular meshes. Unfortunately, these schemes can only be applied to regular meshes. In this talk we present a generalization of these schemes that is applicable to piecewise constant data defined on irregular triangular meshes. Our method consists in computing successive simplifications of the original mesh, and to compute the corresponding successive lower resolution approximations of the

original data on the new simplified meshes. Moreover, we are able to exactly reconstruct the original data from the current approximation and from a set of so-called detail coefficients.

Deformable surfaces for Field Visualization

I. Ari Sadarjoen, Frits H. Post
Delft University of Technology, The Netherlands

Surface extraction and feature extraction are two different types of techniques in scientific visualization. In this talk, elements from both types are combined to a general method for localized surface extraction from scalar and vector fields. With feature extraction techniques, a region containing a feature is found within a data set, using a region selection criterion. In this region an initial polygonal surface is placed, using geometric and morphological attributes calculated for the region. The shape of this initial surface is then deformed to adapt to local field characteristics. The deformation is done by displacing the surface nodes according to a displacement criterion. The polygon resolution of the surface can be refined during displacement to achieve a good approximation of a smooth surface. Different types of surfaces can be extracted depending on the criteria for region selection and surface deformation. The versatility of the technique is illustrated by 2 applications: extraction of recirculation zones and vortex tubes from flow fields.

Basic Problems in Visualizing Vector Fields

David. C. Banks
Mississippi State University, USA

This talk presents examples of elementary problems that arise when vector-valued datasets are displayed. Even a small collection of reasonable goals for a visualization are demonstrated to be inconsistent. These conflicts suggest two basic problems: (1) Feature Placement Problem (what to draw and where to draw it), and (2) Feature Advection Problem (how to honor both the vector field and the feature's integrity).
Examples are given in 2D and 3D, with both steady and unsteady vector fields.

Shape Spaces from Deformation

Herbert Edelsbrunner
University of Illinois, Urbana , USA

Given two shapes X_0 and X_1 in R^3, a continuous deformation creates a 1-dimensional segment of shapes which we write as

$$X_t = (1 - t)X_0 + tX_1 \tag{1}$$

for $t \in [0, 1]$. If we admit t outside the unit interval we get a 1-dimensional line of shapes, and if we have $k+1$ base shapes $X_0, X_1, \ldots, X_k$ we can define a k-flat of shapes:

$$X = \sum_{i=0}^{k} t_i X_i, \tag{2}$$

where $\sum_{i=0}^{k} t_i = 1$. Imagine this flat to sit inside the infinite-dimensional shape space symbolized by a cube:

While the computational representation of the infinite-dimensional shape space seems hopelessly out of reach, we believe the construction of low-dimensional shape subspaces is feasible.
The bulk of the talk is spent on demonstrating that the out lined approach to shapes can be made concrete. The main steps are:

I a concrete and general representation of shape,

II a concrete and canonical deformation used to define the shapes X in (1) and (2),

III a concrete metric that defines for a shape Y the nearest shape Y in the k-flat of shapes X and the distance between Y and Y'.

Algorithms are needed for I, II, III, and for identifying an appropriate and hopefully small collection of base shapes.

Stabile Elements of Delaunay Triangulations

Heinrich Müller, Stefan Jokisch, Frank Weller
Informatik VII, University of Dortmund, Germany

How do errors of measurement affect a Delaunay triangulation of the measured points?

We are given an "exact" and a "measured" set of points P and P', respectively, in the plane. The error of measurement is bounded above by ϵ. Obviously, two Delaunay triangulations T of P and T' of P' may differ in their topologies. However, for certain triangles and edges of T we can guarantee that any "measured" triangulation will contain the corresponding triangle or edges. These edges are called ϵ-stable. This report shows necessary and sufficient conditions for ϵ-stability of triangles and edges. Algorithms are proposed for deciding stability with regard to a given ϵ.

Methods of Constrained Navigation

Andrew J. Hanson
Indiana University, Computer Science Department, USA

Navigation through complex environments in computer graphics and virtual reality applications presents nontrivial problems. Frequently, there is a poor match between the goal of such a navigation activity, the control device, and the skills of the average user. A system designer can in principle identify significant goals and viewpoints for the user. We study a unified framework for incorporating context dependent constraints into the generalized viewpoint generation problem. These approaches bridge the gap between classic animation and unconstrained G degree of freedom controls. The method allows great flexibility, and can incorporate very complex geometries or even multiple-valued Riemann-sheet-like objects as navigation domains. Examples include goal-appropriate traversal of terrain, complex molecules, and architectural spaces.

Collaborative Visualization

Kenneth Brodlie
University of Leeds, Great Britain

Visualization is fundamentally a collaborative activity - members of a research team (possibly geographically spread) need to get together to collectively analyse their results. Yet existing tools are typically designed around a single-user model. In this talk, we show how the existing modular visualization environments (and IRIS Explorer in particular) can be extended to allow multi-user working. Each person in a collaboration runs their own instance of the visualization system, but can connect into their dataflow pipeline special modules that share data, or module control parameters, with other persons.

The Web is increasingly important as a delivery vehicle for data visualization. We show how existing visualization systems can provide the basis of a Web visualization service - the user points their browser at a Web page completes a form specifying data location and required technique, and then a visualization process runs on the Web server to create a VRML file that is returned to the user. Finally, we explore how collaboration might be supported in such a service, by recording an annotated public audit trail on the server.

Credit to: Jason Wood, Helen Wright.

Vis-à-Web, a Visualization Service

Hans-Georg Pagendarm
DLR, Deutsche Forschungsanstalt für Umwelt und Raumfahrt, Germany

A visualization service may be accessed via the WWW. The user interface is loaded within an html-page. The user interface as well as the server are both implemented in Java. A user can send his data to the service by two access mechanisms, clipboard cut/past or URL. Using the controls in the user interface he can fine up a visualization tool at the server-side. The resulting visualization is VRML-coded and will be displayed at the users side.
The Vis-à-Web service allows to make a wide range of applications available on the WWW. It may be used to make sophisticated visualization algorithms available to the research community. Presently two implementations of Vis-à-Web are operational. One runs at DLR in Göttingen, Germany and offers a slicer for curvilinear grids and a streamline code. The second Vis-à-Web service runs at TU Delft in the Netherlands offering access to the spot noise texture mapping algorithm.
A WWW-Page at DLR serves as a Vis-à-Web depository. From there links point to the various services offered by using this software. The software itself is distributed from this page as well as the documentation. The address is: “http://www.ts.go.dlr.de/Vis-a-Web/”.
The software was demonstrated during the presentation. Jens Trapp (DLR), Ton van der Wonden, Ari Sadarjoen, Frits Post (all TU Delft) co-operated with the author to create this distributed Visualization Service.

Time-critical Visualization of Scalably Large Data

M. William Ribarsky
GVU Center, Georgia Tech, USA

I discussed visualization and analysis issues as datasets grow towards terabyte and beyond. Datasets of this size become exploration-dominant. The scientists who create or collect them do not know, in detail, what’s inside. They must explore them to find key attributes. Yet the exploration process is difficult or impossible to carry out. A contend that it is best to display global views quickly and then let the user explore and refine her view until she collects the necessary attributes. This implies a time budget on collection and display of the global view, which affects the amount of details it can contain and the methods that can be applied. I set up a framework for exploring very large scale data that starts with fast global views, steps to particular overview, and ends with detailed subviews. This process is meant to cover the whole gamut of detail down to highest resolution and except for the global overview, is controlled by user interaction. It is important at each step of this time-critical process to have definite control of the time complexity of the calculation and to have an adjustable threshold directly related to scene complexity. I then presented a more detailed structure for the visualization process. It should start with setting the scale for the dataset that makes possible further processing within the allotted time budget. Thus the original number of data elements N would be replaced by an (interactively adjustalbe) number n which are determined as fast as possible. Then clustering to determine patterns followed by 3D feature extraction is applied. This is an important step in determining information-rich attributes. I ended with some ongoing implementation based on this approach.

Visualization of Very Large Datasets

Chuck Hansen
University of Utah, Computer Science Department, USA

This talk presents the design, implementation and application of SCIRun, a scientific programming environment that allows the interactive construction, debugging and steering of large scale scientific computations. Using this computational workbench, a scientist can design and modify simulations interactively via a dataflow programming model. SCIRun enables scientists to design and modify models and automatically change parameters and boundary conditions as well as the mesh discretization level needed for an accurate numerical solution. As opposed to the typical off-line/batch simulation mode - in which the scientist manually sets imput parameters, computes results, visualizes the results via a separate visualization package, then starts over again at the beginning - SCIRun closes the loop and allows interactive steering of the design and computation phases of the simulation. To make the dataflow programming paradigm applicable to large scientific problems, we have identified ways to avoid the excessive memory use inherent in standard dataflow implementations, and we have implemented fine-grained dataflow in order to further promote computational efficiency. SCIRun provides visualization at all levels: algorithmic, performance as well as data visualization. This provides a rich environment which is necessary for meeting the requirements of computational steering.

Credits to: Steve Parker who designed and implemented SCIRun

Visual Database Exploration

Daniel Keim
Institut für Informatik, Universität München, Germany

Visual database exploration aims at integrating the human in the exploration process, applying its perceptual abilities to the large data sets available in today's computer systems. Visual data exploration techniques have proven to be of high value in exploratory data analysis and they also have a high potential for exploring large databases. Visual database exploration is especially powerful for the first steps of the data mining process, namely understanding the data and generating hypotheses about the data, but it may also significantly contribute to the actual knowledge discovery by guiding the search using visual feedback. The goal of the talk is to provide a brief overview of techniques for visualizing large amounts of multidimensional data as they occur, for example, in relational databases. The data usually does not have any two- or three-dimensional semantics and therefore does not lend itself to an easy display. After classifying the current multidimensional data visualization techniques, the talk focuses on techniques which allow a visualization of very large amounts of data.

Perceptual Benchmarking for Multivariate Data Visualization

Matthew O. Ward and Kevin J. Theroux
Worcester Polytechnic Institute, Computer Science Department, USA

Benchmarking is a method for quantitatively assessing and comparing the performance of systems. We define "perceptual benchmarking" as a method for assessing the performance of humans in solving perceptual tasks, and in this paper we describe our research to develop benchmarks for evaluating different multivariate visualization methods under different data and task characteristics.

Key Words: visual perception, multivariate data visualization, performance evaluation

A Java Class Library for Scientific Data and Visualization

William Hibbard
Space Science and Engineering Center, University of Wisconsin, USA

The VISAD system intergrates metadata into the computational and display semantics of data so that users can conceive of data operations in terms of the mathematical objects that data represents. This includes metadata driven display generation by rewriting VISAD in JAVA, it will also enable users to work with distributed data and computations without needing to know details of the network. The combination of JAVA and VISAD will enable data sharing and user collaboration between different data sources, data types, physical computers and even scientific disciplines.

Analytic anti-aliased volume rendering

Nelson Max
University of California, Lawrence Livermore National Lab., USA

Anti-aliasing is important in volume rendering of data sets with small but important volume cells that may fall between rays sampling at pixel centers. If an analytic representation of the volume rendered image is available, it can be convolved with an anti-aliasing filter kernel before it is sampled at the pixel centers, so that all data contributes appropriately. My method for doing this, for an arbitrary irregular or curvilinear mesh, is to project the volume cells in front to back order. The edges of the cells incrementally slice the image plane into regions where an analytic representation of the accumulated opacity is available, because all rays through a region intersect the same set of cell faces. After the edges of each new cell refine the image plane subdivision, the cell's color is multiplied by the accumulated opacity and the filter kernel, and integrated over each region, to get the contribution of the cell to each affected pixel. Then the accumulated opacities are updated by adding the opacity of the new cell.

Real-time Volumetric Modeling and Visualization

Sarah F. F. Gibson
MERL - Mitsubishi Electric Research Laboratory, USA

Representing objects as volumes of sampled data points rather than by surface elements can allow us to model and visualize objects with complex interior structure. This is important in applications like surgical simulation where the goal is to produce physically realistic models of human anatomy for surgical training and patient-specific surgical planning. A second important goal for surgical simulation systems is interactivity. Surgeons need to be able to see and feel the results of a simulated surgical intervention in real-time. In this talk, several methods for modeling physically realistic interactions between volumetric objects – including collision detection, calculation of impact forces, and calculation of tissue deformation – were presented. The challenge of providing real-time visual and haptic feedback of these deformed volumes was also discussed.

Data Level Comparison of Direct Volume Rendering Algorithms

Alex Pang, Kavansik Kim
University of California at Santa Cruz, Baskin Center for Computer Engineering, USA

We describe an approach for data level comparison (DLC) of direct volume rendering (DVR) algorithms. The primary motivation is a need for a more in-depth comparison of DVR algorithms beyond side-by-side comparisons. Our focus is not on speedups or efficiency of various algorithms but the "quality" of the images produced by them. It is also not our goal to determine if one algorithm is better than another, nor try to compare how well one algorithm compares against a canonical DVR solution. Instead, we provide an approach for relative comparison among two or more DVR algorithms.
The most obvious approach is to do image level comparison (ILC) such as side-by-side or difference imaging. However, the starting points are 2D images. We can do better if we use intermediate 3D information available during the rendering process. We call this ILC. The advantage of DLC is that in addition to identifying location and extent of differences, it can also identify the sources of these difference, and hence ability to explain why images are different.
DLC of a DVR algorithm requires selecting a common basis for comparing other DVR algorithms. In this paper, we use raycasting. We then simulate other DVR algorithms, e.g. projection-based, in terms of raycasting. A set of metrics using the base algorithm is then derived e.g. number of samples along the ray. Observations of how well these metrics work in isolation and in conjunction with each other are presented. We believe that a variant of this approach can be used for DLC of different volumetric data sets such as those found in experimental wind tunnels and CFD.

Comparative Visualization of Computational and Experimental Data in an Aeronautics Application

Samuel P. Uselton
MRJ Technology Solution at NASA Ames Research Center, USA

Visualization of Computational Fluid Dynamics (CFD) data is difficult for several reasons including the volume of data, the circle variety of data types and the wide range of resolutions in a single data set. A particular difficulty less often mentioned is the wide variety of users and the things they wish to learn from the data. Visualizing experimental data collected in wind tunnels is difficult for some of the same reasons, but also for different ones. In

particular, researchers working in the wind tunnels have less confidence in computer-mediated analysis. Trying to compare data from these two sources inherits all the same difficulties and creates additional problems. This presentation discusses some of these challenges and reports on preliminary work in the area.

Application of Volume Rendering to Flow Visualization

Thomas Frühauf
Fraunhofer Institut, Darmstadt, Germany

Direct Volume Rendering is an attractive approach for the visualization of CFD data for several reasons: First, DVR has proven to be efficient for visualizing very large data sets, e.g. from medical imaging, where modelling and rendering of polygonal visualization objects is tedious. Second, DVR provides a holistic view onto the data in the whole definition domain in one simple image. Third, non-sharp visualizations as they are generated when applying the homogenous material model seems to be the intuitively right mapping for fluids.
However, we identify those critical aspects to be considered when applying DVR to flow data: First, how to handle the non-regular grid structure of the data in our volume rendering algorithms. Second, how can we display local features which have a well-defined non-fuzzy geometrical structure, such as isosurfaces faces or vortex cones. Third, how can we apply the DVR approach successfully not only to scalar but to vector fields, too.
The talk proposes solutions for these three identified critical aspects in direct rendering of flow data.

Fast Iso-Contouring and the Image Spectrum

Chandrajit Bajaj
Computer Science, Purdue University, USA

The search for intersected cells in isocontouring can be accelerated using suitable range query data structures, such as the interval tree or segment tree. The storage overhead of the search structure can be significantly reduced by searching over a subset of the cells S, called seed set, which contains at least one cell per connected component of every isocontour. I shall present two new algorithms for seed set generation and compare this computational complexity and performance in terms of the number of seed cells generated for a variety of structured and unstructured meshes. The first algorithm (sweep filtering) has the advantage of being fast and computing a seed set which is amenable to contour computation of out-of-core data (very large data sets). The second method produces a much smaller seed set but has a greater computational cost and lacks the out-of-core feature. I compare the use of three range query data structures, examining the tradeoffs in terms of both theoretical and empirical observations of space requirements.

I also introduce the contour spectrum, a user interface component for improving user interaction and quantifications in visualization of isocontours. The contour spectrum is a signature consisting of a variety of scalar data and contour attributes, computed over the range of function values. Computed properties are presented to the user as 1D/2D plots giving the user a quantitative measure of the function to assist in selecting relevant isovalues for informations visualizations.

Computing Segmented Volumes

Richard Franke
Naval Postgraduate School
Gregory M. Nielson
Arizona State University, USA

Given a set of scattered data ($x - y - z$ points) that has a class associated with each point, it is desired to construct volumes, each containing only data points of a given class. The initial step is to tetrahedize the input data. The algorithm then determines the volumes as unions of tetrahedra. The algorithm is very simple, easy to implement, and applies without limit to the number of classes. Examples are given.

Interval Volume: Field Interval Analysis for Effective Volume Exploration

Issei Fujishiro, Yuriko Takeshima
Department of Information Sciences, Ochanomizu University, Japan

In this talk, a new type of geometric model called *interval volume* for volumetric data exploration is presented. An interval volume represents a three-dimensional subvolume for which the associate scalar values lie within a user-specified interval, and provides one of the promising approaches to *solid fitting*, which is an extended concept of traditional surface fitting. A well-known isosurfacing algorithm called Marching Cubes is extended to obtain a solid fitting algorithm, which extracts from a given volumetric dataset a high-resolution, polyhedral solid data structure of an interval volume. Branch-on-Need octree is used as an auxiliary data structure to accelerate the extraction process. Existing disambiguation schemes for the Marching Cubes isosurfacing algorithm are extended to alleviate the topological ambiguities arising in the connection of polyhedral blocks of interval volume. A variety of interval volume rendering methods and principal related operations, including focusing and measurements, are also presented. The effectiveness of measurement-coupled visualization capabilities of the present approach is demonstrated by application to visualizing a four-dimensional simulated data from atomic collision research. As for user interface issues, an initial attempt to construct a goal-oriented application design guidance system termed *GADGET* for modular visualization environments is briefly described. Finally, the concept of a hybrid volume exploration environment is discussed.

Efficient Surface and Volume Shading Using the Tangent Space Transform

Brian Cabral
Silicon Graphics Inc., USA

It is well known that surface shading is coordinate system independent. However, great efficience can be found when shading polygons by transforming the light and viewer location into "flat" target transfer space. By transferring these two vectors at each polygon vertex we simplify the per-pixel calculation of Bump Map Shading. The technique generalizes to higher dimensions, most interesting by the volume rendering case. In this case we treat the scalar volume field as we treated "bumps" (scalar values) in the plane. In both cases shading of the "bumps" is done with explicit calculation of a gradient.

Advances in Fast Isosurface Extraction Algorithms

Dietmar Saupe
Universität Freiburg, Germany

We consider the problem of fast isosurface extraction from scalar data sampled on a regular or irregular grid. The known methods used for this task can be grouped in two classes: (I) hierarchical geometrical space decomposition, and (II) the stabbing approach for a set of range intervals. The first category applies to volume data on structured grids where octrees have proven useful. We propose a solution based on the new concept of optimal, generalized binary space partitions, which provides a speed-up relative to the octree-based approach at the cost of increased preprocessing. The second category of algorithms applies also to unstructured volume data, because only the set of intervals of the scalar function values in the cells are needed. The best previous method, based on the "span-space" (Livnat et al, IEEE TVCG '96) offers a time complexity of $O(k + \sqrt{n})$, where n is the size of the data and k is the number of cells intersecting the isosurface. We propose an algorithm based on interval trees with a search complexity of only $O(k)$ and less preprocessing ($O(n)$ in place of $O(n \log n)$) without significant extra cost in space.

Engineering Visualization in Virtual Environments

Martin Göbel
GMD Gesellschaft für Mathematik und Datenverarbeitung mbH, Germany

Postprocessing of numerical simulations generally uses specific “postprocessors” usually provided with the numerical solver. In addition to this general purpose visualization packages like AVS allow also visualization tailored to the application field. At this time, all of those very powerful visualization systems are desktop oriented, applying mouse, keyboard, spacemice and possible active stereo mode.
We presented a system for scientific and engineering visualization that uses the Responsive Workbench Virtual Environment. The visualization techniques implemented so far include interactive, realtime cutting planes, particle tracing etc. Visualization is controlled by easy to use intuitive interaction techniques on the workbench environment. As an outlook, the visual and audible potential of cave-like installations, such as GMD's Cyberstage for scientific visualization was given.

Visualizing the Curvature of Vector Fields

Holger Theisel
Universität Rostock, Fachbereich Informatik, Germany

The treatment of tangent curves is a powerful tool for analyzing and visualizing the behavior of vector fields. Unfortunately, for sufficiently complicated vector fields, the tangent curves can only be implicitly described as the solution of a system of differential equations.
In this paper we show how to compute the curvature of tangent curves and mention fundamental properties of these curvatures. We discuss how to use the curvature of tangent curves as a vector field visualization technique and show examples.

Spot Noise for a Large DNS Simulation

Willem de Leeuw, C. W. I., Amsterdam, The Netherlands

In this talk we present the visualization of large vector data set produced by direct numerical simulation of a turbulent flow using a visualization technique called “spot noise”. Spot noise is a texture synthesis technique introduced by J. J. van Wijk, which can be used for the visualization of 2D vector fields. Typical uses for spot noise are the presentation of an overview of the flow field, the presentation of correlations of the flow field and scalar fields such as pressure or vorticity magnitude using colour, and the visualization of separation lines on surfaces. In order to be able to visualize the time dependent DNS-simulation spot noise was extended to produce time dependent texture animation. This was achieved by assuming particles at the spot positions.

These particles are advected along particle paths in the flow. This way the coherence between subsequent frames is guaranteed.

Computational Steering

Jarke J. van Wijk, Robert van Liere
Netherland Energy Reserach Foundation ECN
Jurriaan D. Mulder
CWI, The Netherlands

Computational steering enables researchers to get insight in their simulations by changing parameters and watching the effects. We have developed an environment that enables researchers to define such computational steering interfaces easily and effectively. The architecture consists of a central data manager, surrounded by satellites. These satellites produce and consume data. User interfaces and visualizations can be defined with a general purpose satellite based on Parametrized Graphics Objects. Both a 2D and 3D version have been developed. The latter has an elegant way to define multiple views on the data: a camera that can be parametrized in the same way as the other objects. Several applications were presented: nuclear model (parameter estimation), wind turbine simulation, 2D Euler flow, and planetary light scattering. These examples showed that computational steering indeed is effective and that the environment developed can be used for a wide range of applications.

Multiresolution Iso-Surface Rendering

R. Daniel Bergeron
University of New Hampshire, USA

Orthogonal wavelets can be used to create a multiresolution data representation for volume data. A critical aspect of any multiresolution representation is the ability to determine the authenticity of each level of the hierarchy and the effectiveness of any rendering of the data. This research explores the error that results from a wavelet decomposition of volume data using three efficient wavelet transforms. We also investigate the additional loss of information resulting from the deletion of wavelet coefficients near zero. We present both numerical error calculations to characterize the data representation and visual results using the Marching Cubes isosurface rendering.

Methods for 3D Data Compression

Pavel Slavik, Petr Chlumsky, Pavel Diblik
Czech Technical University, Prague, Czech Republic

Traditional scientific visualization methods are being extended into network environment. One of the key problems is the time effective data transmission by means of networks. The solution to this problem is data compression. As the volume of data used in the field of scientific visualization is very large the lossy compression methods could be a solution.

Two methods for 3D data compression have been developed and implemented. The first one is based on DCT extended into 3D space. The compressed data (with an information loss) is transmitted via network followed by additional data chunks that contain the missing information. In such a way it is possible to gradually reconstruct the original volume information without information loss. The reconstructed volume during the first steps (with an information loss) could be used as a sort of preview. The second method is based on the dithering process extended into 3D space. This method is suitable for voxel data where each voxel is assigned to a scalar value. By means of an undithering process it is possible to reconstruct the original 3D information with a small information loss. This reconstruction process uses image processing algorithms extended into 3D space.

Fluoroscopy Simulation for Endovascular Surgery

Theo van Walsum
Image Sciences Institute, Utrecht, The Netherlands

New minimally invasive surgery techniques require special skills of the surgeons. Endovascular repair of abdominal aorta aneurysms is an example of such a minimally invasive surgery. Endovascular management of these aneurysms is an important area of research for the Vascular Surgery Department of the Utrecht University Hospital. Techniques for a training system for this type of operation are also investigated. As part of the development of such a training system for endovascular abdominal aorta aneurysm surgery, we developed a method for fluoroscopy simulation.

Fluoroscopic and DSA images are generated by simulating the X-ray process using CT data. In order to achieve interactive frame rates, the visualization process is divided into two stages: a preprocessing stage, and an interactive rendering stage. In the preprocessing stage, the CT-data is segmented, a separate dataset is generated for bone, soft tissue, and vessels, and a simulated X-ray image is generated for each of these datasets. In the rendering stage, these intermediate images are warped, filtered, and blended to obtain a simulated fluoroscopic or DSA image. Since the operations in the rendering stage map well onto texture mapping hardware, interactive frame rates can be obtained. The resulting images are of sufficient quality to be used in the training system.

Volume Visualization for 3D Interactive Anatomical Atlases of the Visible Human

Ulf Tiede
Universität Hamburg, Institut für Mathematik und Datenverarbeitung in der Medizin (IMDM), Germany

A variety of 3D visualization techniques for tomographic data have been developed during the last years. The main application areas for these techniques are diagnostics and surgery support. However, computation time is critical and the rendered images often lack quality. Another application that has been widely overseen is teaching and learning, where the material can be explored and prepared in fine detail. A concept is described that connects "static" anatomical knowledge and volume visualization techniques yielding 3D anatomical atlases . With the advent of the Visible-Human dataset a new quality of 3D reconstructions became possible. We developed a method for the segmentation of the data using ellipsoids in RGB-space and a strategy to reconstruct the continous surface locations from discrete object labels using the same classification scheme as in the segmentation step. These new techniques allow the generation of nearly photorealistic reconstructions. Different body models derived from the VH dataset are shown in a video.

InVIS - Interactive Visualization of Medical Data Sets

Jörg Meyer
Universität Kaiserslautern, Germany

Interactive rendering of large data sets requires fast algorithms and effective hardware acceleration. Both can be improved, but this does not ensure interactive response times yet. If a scene is too complex, performance decreases rapidly, and neither faster algorithms nor improved hardware can guarantee interactive behavior. Certain timing characteristics should therefore be incorporated into the rendering system in order to support such properties.
In our new approach we propose an interactive rendering pipeline and a special timing predicate. In medical applications large data sets derived from CT or MRI scans as well as CAD designs must be rendered in real-time with immediate feedback for the user.
Interactive behavior enables the user to manipulate and adjust the visualization straight on demand.

Various Techniques for the Visualization of Dynamical Systems

Eduard Gröller
Vienna University of Technology, Austria

Visualization of analytically defined dynamical systems increases insight into their complex behavior. Visualization techniques illustrate either local or global flow properties. Topological structures, e.g., critical sets and separatrices, and depiction of entire classes of dynamical systems simultaneously facilitate interpretation. Several ongoing research projects are presented. One project deals with an extension of Line Integral Convolution, which is a texture based approach to show global flow patterns. Orientation information is introduced by using sparse textures and asymmetric convolution kernels. Variations of the method, e.g., accelerated calculation, virtual ink droplets, and internet based implementation, are discussed as well. Another project investigates various methods to visualize higher dimensional trajectories of dynamical systems. These methods include: extruded parallel coordinates, base trajectories with wings, and three-dimensional parallel coordinates. Poincaré maps are (n-1)-dimensional discrete dynamical systems of a continous n-dimensional flow. Many properties of the flow carry over to the Poincaré map, which might be easier to investigate. Visualization techniques for Poincaré maps comprise: spot noise, texture warping, and embedding the map within the actual flow. Other visualization projects, e.g., (hierarchical) streamarrows, collaborative augmented reality, case studies on econometric models, will be shortly discussed.

Visualization of Complex Physics Phenomena

Stanislav Klimenko, Igor Nikitin,
Institute for High Energy Physics, Protvino, Russia

This talk presents our research under grant of Ministry of Science of Russian Federation and our cooperative work at GMD/IMK.VMSD from October 1996.

1. Visualization in relativistic string theory
Theory of strings, pretending to be the physical "Theory of Everything", studies the properties of minimal surfaces, analogous to soap films, but placed in Minkowsky space-time. The string itself is a curve, obtained in sequential slicing of the minimal surface by moving plane of constant time in Minkowsky space. The main physical destination of string theory is the description of elementary particles, which are treated as strings with typical size 10^{-13} cm and tension 10 tons.
Our purpose was to develop the software for visualization of minimal surfaces and animation of string dynamics. As a result, a set of programs was created, which generate the static images of minimal surfaces and represent string dynamics as interactive computer film. Using this utility a complete classification of **stable singular points** on strings was performed. Singular points are the points of infinite concentration of the energy on the string. Their stability has topological nature, similar to the stability of knots.
Many new interesting phenomena were found, particularly, it was shown, that singular points behave like point particles (solitons) on strings. They move at light velocity, born by pairs, scatter or annihilate in collisions, form coupled states. Such behavior allows to identify them with the elements of non-quark structure of particles and explain the nature of so called exotic particles in the frame of string theory. Singular properties of classical string theory lead also to deep consequences in quantum string theory.

2. Visualization of projective plane assembling
The Möbius band has one side and *one edge*. The disc has also one edge, so we can patch them together along the edges. The obtained closed surface is called the projective plane, it is one of top objects in mathematical and physical research. Its assembling from Möbius band and the disc is the famous topological problem, which being said by words of George Francis, "was a gate to topology for a number of generations of the students".
We've produced a video, where new, more evident solution of this problem was shown. Various properties of the projective plane are demonstrated in the video.

3. Visualization of rotation group topological structure
Group of rotations has a structure of projective space RP^3. Closed loops

in rotation group are separated into two classes: (1) the loops, which can be contracted to a point (unity in rotation group) and (2) the loops, which can be deformed to a contour, representing the rotation by 2π around some axis. In particle physics this topological property of rotation group (existence of **non-trivial homotopic class**) leads to great consequences, particularly explains, why in our 3D world the particles have only integer or half-integer inner orbital moment (spin), and cannot have, for instance, the spin 1/3. We've shown this property in clearly visible way, using the animation of fast rotating object with slowly changing parameters of rotation.