Mathematics and Visualization

Series Editors

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Editors

Mathematical Foundations of Scientific Visualization, Computer Graphics, and Massive Data Exploration

With 183 Figures, 134 in Color and 15 Tables

Springer

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Preface

The goal of visualization is the accurate, interactive, and intuitive presentation of data. Complex numerical simulations, high-resolution imaging devices and increasingly common environment-embedded sensors are the primary generators of massive data sets. Being able to derive scientific insight from data increasingly depends on having mathematical and perceptual models to provide the necessary foundation for effective data analysis and comprehension. The peer-reviewed state-of-the-art research papers included in this book focus on continuous data models, such as is common in medical imaging or computational modeling.

From the viewpoint of a visualization scientist, we typically collaborate with an application scientist or engineer who needs to visually explore or study an object which is given by a set of sample points, which originally may or may not have been connected by a mesh. At some point, one generally employs low-order piecewise polynomial approximations of an object, using one or several dependent functions.

In order to have an understanding of a higher-dimensional geometrical "object" or function, efficient algorithms supporting real-time analysis and manipulation (rotation, zooming) are needed. Often, the data represents 3D or even time-varying 3D phenomena (such as medical data), and the access to different layers (slices) and structures (the underlying topology) comprising such data is needed. It has become evident over recent years that, due to the ever-increasing complexity inherent in today's data sets, it is necessary to develop feature extraction algorithms that facilitate sensible mappings of physical data values to visual attributes, enhancing the understanding of structures and structure relationships. It is crucially important that visualization algorithms support precise, error-controlled quantitative visual analysis, especially in applications like medical data analysis for diagnosis and surgical planning.

Over the last 20 years the profound impact of scientific computing on nearly every area of science and engineering has become more and more evident. Visualization, being a very young scientific field which has evolved as a branch of computer graphics, has in turn become an important driver for the development of exciting new directions in mathematics and computer science. Many common approaches used in contemporary visualization algorithms and software are still quite "ad-hoc," and

considerable work remains to be done to establish the much-needed mathematical foundation for the growing field of scientific visualization.

Most current visualization algorithms break down for very large data sets. While standard approaches use multiresolution data structures, approximations, and visualization paradigms, peta-size data sets cannot be handled with the presently used approaches and software. New algorithms based on sophisticated mathematical modeling techniques must be devised that permit the extraction of high-level topological structures that can be visualized and understood.

We organized a workshop at the Banff International Research Station (BIRS), at the Banff Centre, Canada, from May 22 to May 27, 2004. The workshop focused specifically on *mathematical issues* as they relate to the challenges posed by the need to more effectively perform data processing and analysis on very large and highly complex data sets for visual exploration. The primary objective of the workshop was to bring together the leading researchers focusing on mathematical and foundational research in visualization. Scientists presented their recent research results and also shared their views concerning the most pressing research challenges facing this field in the near future. The workshop was organized in the following five topical areas:

- Topology and discrete methods
- Signal and geometry processing
- Partial differential equations
- Data approximation techniques
- Massive data applications

While a large portion of the workshop consisted of presentations by participants from of state-of-the-art research in the various fields, a significant amount of time was reserved for open-ended brainstorming sessions. In three such sessions, the participants were split into four groups which discussed these focus areas in detail. The group leaders were asked to obtain answers to a number of questions that were distributed among the participants beforehand. The group leaders summarized these sessions and the results. The questions distributed before the workshop were:

- What are the scientifically challenging problems to be tackled in your topic area?
- What are the driving applications in this field?
- Which journals and conferences exist today that are appropriate venues for publishing mathematically oriented methods in this field?
- Which good on-line resources exist today supporting research in this subfield, e.g., data sets, commercial and free software libraries, publication databases, benchmarking sites, etc.?
- Which scientific domains and subfields are needed to solve successfully and elegantly the identified problems?

The brainstorming sessions were welcomed by the participants. As far as we know, this format of discussing specialized topics in a question-driven fashion has not previously been used in visualization workshops. Participants commented positively on the format, and it seems to us that sharing ideas and perspectives in this way is a highly effective means for defining relevant new directions in visualization.

This book contains papers authored by participants at the workshop. We hope that they are inspiring and convey some of the excitement we all experienced during the sunny days at the Banff workshop. We would like to thank the following colleagues for helping with the organization of the workshop or serving as group discussion leaders: Herbert Edelsbrunner, Hans Hagen, Chris Johnson, Ken Joy, Raghu Machiraju, Tamara Munzner, Greg Nielsen, Jack Snoeyink, Gabriel Taubin, and Ross Whitaker.

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