DOE/ER/25446-1

DOE Grant #DE-FG02-01ER25446

# FINAL TECHNICAL REPORT

The SIAM Conference on Geometric Design and Computing was held in Sacramento, CA, from November 5-8, 2001, and was preceded on November 4 by a Short Course on "Unstructured Mesh Generation," organized by Professor David Marcum of Mississippi State University.

The conference enjoyed strong participation from both domestic and international researchers, and encompassed a broad spectrum of topics ranging from basic theory and mathematics to education, algorithms, and applications. Although the total number of persons attending the conference, 164, was less than on previous occasions, it should be noted that this was the first SIAM conference to be held after the tragic events of September 11, 2001. The attendance, though lower, can be considered heartening in the face of the prevailing fears and restrictions on both domestic and international travel. There was particularly strong representation from some foreign countries (notably, Norway and Austria).

The conference themes included the traditional topics of curve and surface design, geometric modeling, computational geometry, computer graphics, solid modeling, visualization, and reverse engineering, and also new and rapidly-developing areas such as manufacturing geometry, haptic interfaces, and processing of very large data sets.

The conference provided a stimulating forum for researchers and practitioners from academia, industry, and government, to discuss recent developments in the mathematical and computational problems of representing and processing geometrical data in computer-aided design, manufacturing, scientific computing, animation, visualization, and related fields.

The eight invited speakers (listed in the appendix below) were chosen to reflect the themes of the conference, while also providing broad coverage of some of the most exciting new developments in the field. These speakers were carefully chosen by the Organizing Committee to offer a balance between theory and applications, industry and academia, and domestic and international researchers, and to accurately convey the rich diversity of theoretical paradigms, computational methods, application contexts, and open problems in the field.

Minisymposia were solicited to complement the invited presentations, in subject areas where important new developments have transpired in the two years since the previous conference. These eight minisymposia dealt with Subdivision Methods, Computational Methods for Algebraic Spline Surfaces, Scattered Data Modelling, Geometric Computations and Lie Groups, Computational Differential Geometry, Open Source Software for Geometric Modelling, Computational Topology, and Computational Techniques for Sculptured Surface Machining. Besides these invited minisymposia, the

## DISCLAIMER

conference program included an additional six contributed mini-symposia, twelve contributed-paper sessions, and one poster session.

A Business Meeting of the SIAM Activity Group on Geometric Design, held in the evening of November 6, was attended by approximately 30 persons. Topics on the agenda included the choice of venue for the next conference, the group's Web site, and the current status of and future directions for the field. These topics generated lively debate and a healthy exchange of ideas.

Conference Summary:

The SIAM Conference on Geometric Design and Computing attracted 164 domestic and international researchers, from academia, industry, and government. It provided a stimulating forum in which to learn about the latest developments, to discuss exciting new research directions, and to forge stronger ties between theory and applications.

Submitted by:

Rida T. Farouki
Miriam L. Lucian
Conference Co-chairs

Society for Industrial and Applied Mathematics 3600 University City Science Center
Philadelphia, PA 19104-2688

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LIST OF INVITED SPEAKERS

CAGD: THE EVOLUTION OF A DISCIPLINE
Gerald E. Farin, Arizona State University

THE DIGITAL MICHELANGELO PROJECT
Marc Levoy, Stanford University

MULTIVARIATE SPLINES FOR SCATTERED DATA MODELING Mike Neamtu, Vanderbilt University

GEOMETRICAL PROBLEMS IN ROBOTICS AND VISION Takeo Kanade, Carnegie Mellon University

MEDIAL AXES OF CURVES AND SURFACES
Peter J. Giblin, University of Liverpool

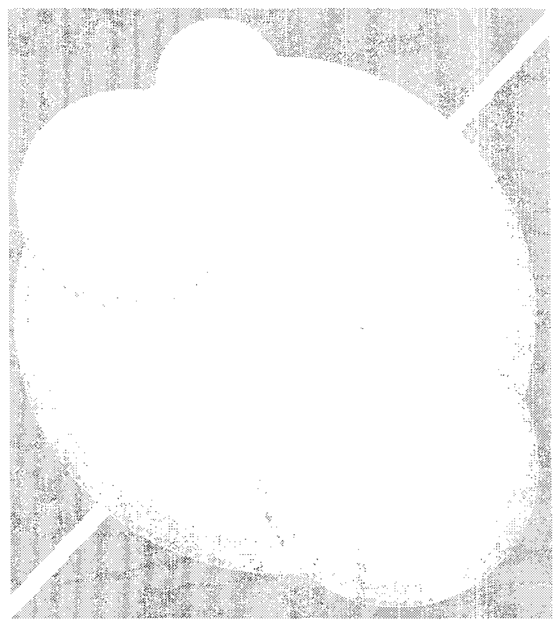
APPLICATIONS OF HAPTIC TECHNOLOGY
Paul J. Stewart, Ford Motor Company

RECONSTRUCTING GEOMETRIC OBJECTS FROM PARTIAL INFORMATION
Marshall Bern, Xerox PARC

COMPUTATIONAL GEOMETRIC TECHNIQUES FOR SCULPTURED SURFACE MACHINING Yuan Shin Lee, North Carolina State University

# Final Program and Abstracts

SIAM Conference on geometric design



November 5-8, 2001
Holiday Inn Capitol Plaza Hotel
Sacramento, California

### Sponsored by the SIAM Activity Group on Geometric Design

The SIAM Activity Group on Geometric Design is concerned with the mathematical and computational issues that arise in generating and processing geometric information for various engineering applications, such as mechanical design, process planning, and manufacturing. The scope of the group's activities encompasses a wide spectrum of scientific, technological, and other skills, ranging from rigorous mathematics to the subjective aesthetics of shape.

The purpose of this conference is to bring together researchers from academia, industry, and government to discuss the mathematical and computational problems associated with the application of geometry to current problems of design, manufacturing, and the representation and analysis of physical phenomena.


SIAM Society for Industrial and Applied Mathematics
3600 University City Science Center
Philadelphia, PA 19104-2688
Telephone: 215-382-9800 Fax: 215-386-7999
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## Table of Contents



## Organizing Committee

**Rida Farouki (Co-chair),**
University of California, Davis

**Miriam Lucian (Co-chair),**
The Boeing Company

**Thomas Banchoff,**
Brown University

**Michel Bercovier,**
Hebrew University of Jerusalem, Israel

**Hyeong In Choi,**
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Duke University

**David Field,**
General Motors Research Labs

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University of California, Davis

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**Tom Sederberg,**
Brigham Young University

**Alessandra Sestini,**
University of Florence, Italy

**Tim Strotman,**
Structural Dynamics Research Corporation

**Wenping Wang,**
University of Hong Kong, China

**Hans Wolters,**
Hewlett Packard Company

## SIAM Registration Desk

The SIAM registration desk is located in the convention foyer of the lobby area of the Holiday Inn Capitol Plaza Hotel. It is open during the following times:

Saturday, Nov. 3 ........... 5:00 PM - 7:00 PM
Sunday, Nov. 4 ............ 8:00 AM - 8:00 PM
Monday, Nov. 5 ........... 8:00 AM - 3:00 PM
Tuesday, Nov. 6 ........... 8:00 AM - 3:00 PM
Wednesday, Nov. 7 ........ 8:00 AM - 3:00 PM
Thursday, Nov. 8 ........ 8:00 AM - 11:00 AM

## Hotel Address

Holiday Inn Capitol Plaza Hotel
300 "J" Street
Sacramento, California 95814
916-446-0117 Fax

## Hotel Telephone Number

The telephone number of The Holiday Inn Capitol Plaza Hotel is 916-446-0100. The hotel operator can either connect a caller with the SIAM registration desk for a message to be taken and posted to the SIAM message board or forward a caller to an attendee's room to leave a message.

## Get-togethers

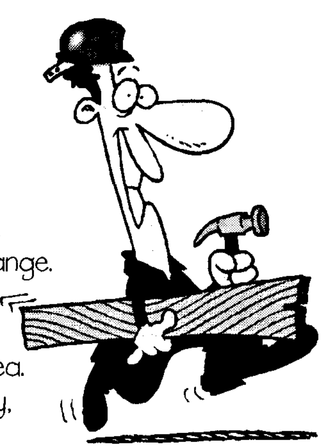
### Sunday, November 4

6:00 PM - 8:00 PM
Welcome Reception
Room: John Q Ballroom

### Wednesday, November 7

4:00 PM - 5:00 PM
Poster Session
Room: Foyer

5:30 PM - 8:00 PM
River Cruise & Dinner
Event Fee: $35.00



UNDER CONSTRUCTION
This program is subject to change. Check the "Program Updates" posted on the bulletin board located in the registration area. Changes are posted once daily, prior to the opening session.

# GD01

## Program-At-A-Glance

SIAM Conference on geometric design and computing

November 5-8, 2001
Holiday Inn Capitol Plaza Hotel
Sacramento, California

# OPEN HERE

# General Information

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## Funding Agency

SIAM and the Conference Organizing Committee wish to extend their thanks and appreciation to the Army Research Office, the Department of Energy, and the National Science Foundation for their support of this conference.

## Non-SIAM Members Join SIAM Now and SAVE!

Enjoy the year 2002 as a SIAM member! If you registered for this conference as a non-member, you may apply $90, the difference between a member and non-member registration fee, toward your membership dues! You can get 12 months of membership benefits for just $15. SIAM members receive subscriptions to *SIAM Review* and *SIAM News*. SIAM members also enjoy substantial discounts on SIAM books, conference registrations and journal subscriptions, and have an opportunity to join SIAM Activity Groups. For more information, see a SIAM staff member at the registration desk.

## SIAM Audio-Visual Policy

All conference speakers were contacted in advance regarding audio-visual equipment required for presentation.

The following policy applies: Invited speakers for plenary sessions may order equipment subject to availability. Minisymposium speakers may order equipment if more than one speaker in a session will use it. Other speakers may use equipment that has already been ordered by an invited or minisymposium speaker if it is already available in the assigned meeting room on the day and time of presentation. Computers cannot be ordered for any speaker. If a computer-generated presentation is planned, it is the responsibility of the speaker to bring his or her own computer.

If you have any questions about audio-visual equipment for your presentation, please see a SIAM staff member at the registration desk.

## Hotel Check-in and Check-out Times

Check in time is 3:00 PM
Checkout time is 12:00 PM

## E-mail Access

SIAM cannot offer e-mail access. If you have not brought your own computer to use in your room, the hotel business center has a computer available to attendees for a fee.

## Registration Fee Includes

- Welcome Reception
- Two coffee breaks daily
- Admission to all technical sessions
- Room set-ups and audiovisual equipment

## Job Postings

There is a dedicated bulletin board located in the registration area for job postings. Academic and corporate employers who wish to solicit applications or interview during the conference should post information here. Attendees who wish to review job opportunities should check this board.

# SIAM Short Course: Unstructured Mesh Generation

## Sunday, November 4, 2001

*9:00 AM - 5:00 PM*

Location: Fresno

Lecturer and Organizer:
**David L. Marcum**
Professor, Mechanical Engineering
Computational Simulation and Design Center
Engineering Research Center
Mississippi State University

### Course Description:

Introduction to unstructured mesh generation based on Delaunay, Advancing-Front, Iterative Point Placement, and Local-Reconnection techniques with an emphasis on engineering applications. Overview of selected state-of-the-art procedures and computational field simulation applications.

### Objective:

Provide a basic understanding of current unstructured mesh generation techniques from an engineering and application viewpoint.

Level of Material:

| | |
|---|---|
| Introductory | 30% |
| Intermediate | 50% |
| Advanced | 20% |

Who Should Attend:

Research and design engineers or scientists, students, and researchers from academia, industry and government who are directly involved in mesh generation or a mesh application area, such as computational fluid dynamics, mechanical design, or visualization.

### Recommended Background:

Working knowledge of numerical methods (equivalent to an upper level undergraduate course or introductory graduate level course), modest proficiency in some form of computer programing, such as FORTRAN, C, or C++, and experience in a mesh application area, such as computational fluid dynamics, mechanical design, or visualization.

| Time | Schedule | Meeting Room |
|---|---|---|
| 9:00 - 10:30 AM | Short Course | Fresno |
| 10:30 - 11:00 AM | Coffee Break | Foyer |
| 11:00 - 12:00 PM | Short Course | Fresno |
| 12:00 - 1:30 PM | Lunch | Calavaras/Granada |
| 1:30 - 3:00 PM | Short Course | Fresno |
| 3:00 - 3:30 PM | Coffee Break | Foyer |
| 3:30 - 5:00 PM | Short Course | Fresno |

# Invited Plenary Presentations

## Monday, November 5

8:30 AM - 9:15 AM

### IP1 CAGD: The Evolution of a Discipline

Gerald E. Farin, Arizona State University

9:15 AM - 10:00 AM

### IP2 The Digital Michelangelo Project: 3D Scanning and Display of Billion-Polygon Models

Marc Levoy, Stanford University

## Tuesday, November 6

8:30 AM - 9:15 AM

### IP3 Multivariate Splines for Scattered Data

Mike Neamtu, Vanderbilt University

9:15 AM - 10:00 AM

### IP4 Geometrical Problems in Robotics and Vision

Takeo Kanade, Carnegie Mellon University

## Wednesday, November 7

8:30 AM - 9:15 AM

### IP5 Medial Axes of Curves and Surfaces

Peter J. Giblin, University of Liverpool, United Kingdom

9:15 AM - 10:00 AM

### IP6 Applications of Haptic Technology

Paul J. Stewart, Ford Research Laboratory

## Thursday, November 8

8:30 AM - 9:15 AM

### IP7 Reconstructing Geometric Objects from Partial Information

Marshall W. Bern, Xerox Corporation

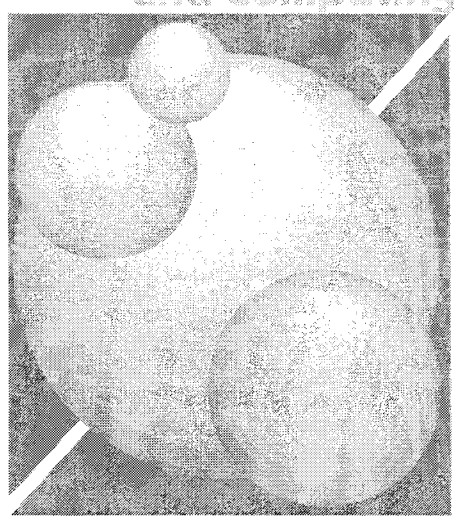
9:15 AM - 10:00 AM

### IP8 Computational Geometric Techniques for Sculptured Surface Machining

Yuan Shin Lee, North Carolina State University

# GD01 Program

SIAM Conference on geometric design and computing



November 5-8, 2001
Holiday Inn Capitol Plaza Hotel
Sacramento, California

## Saturday, November 3

### Registration
*5:00 PM-7:00 PM*
*Room: Foyer*

## Sunday, November 4

### Registration
*8:00 AM-8:00 PM*
*Room: Foyer*

### Short Course: Unstructured Mesh Generation

**David Marcum**
Mississippi State University
*9:00 AM-5:00 PM* *(see page 4)*
*Room: Fresno*

### Welcome Reception
*6:00 PM-8:00 PM*
*Room: John Q Ballroom*

## Monday, November 5

### Registration
*8:00 AM-3:00 PM*
*Room: Foyer*

### Welcoming Remarks
*8:15 AM-8:30 AM*
*Room: Fresno/El Dorado/Diablo*

**Rida Farouki,**
University of California, Davis

Monday, November 5

# IP1

## CAGD: The Evolution of a Discipline

*8:30 AM-9:15 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Miriam Lucian, The Boeing Company*

The origins of CAGD go back to the middle of the last century and can be traced to automotive and aerospace industries. What was then a set of unrelated methodologies has now evolved into a discipline in its own right. The talk gives a historical overview together with an assessment of various theories and approaches. Some of these are essentially forgotten, others show great promise for the future.

**Gerald E. Farin**
*Arizona State University*

Monday, November 5

# IP2

## The Digital Michelangelo Project: 3D Scanning and Display of Billion-Polygon Models

*9:15 AM-10:00 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Hans J. Wolters, BEA Systems, Inc.*

Recent improvements in laser rangefinder technology and related geometric processing algorithms allow us to accurately digitize the external shape and appearance of many physical objects. As an application of this technology, I and a team of 30 researchers spent the 1998-99 academic year in Italy digitizing the sculptures of Michelangelo. Our primary acquisition device was a laser triangulation rangefinder mounted on a 25-foot motorized gantry. Our largest single dataset is of the David - 2 billion polygons and 7,000 color images. In this talk, I will outline the challenges we faced building our unique hardware and software system, the lessons we learned, and the algorithms we developed for aligning, merging, storing, and displaying large polygon meshes. Finally, I will briefly describe our project to digitize and fit together the 1,163 fragments of the Forma Urbis Romae, a giant marble map of ancient Rome. Piecing this map together is one of the key unsolved problems in classical archeology.

**Marc Levoy**
*Stanford University*

## Coffee Break

*10:00 AM-10:30 AM*

*Foyer*

Monday, November 5

# MS1

## Subdivision Methods

*10:30 AM-12:30 PM*

*Room: Fresno*

Subdivision surfaces are a powerful and flexible surface representation used in a number of popular computer animation and modeling systems (Alias|wavefront Maya, Lightscape 3D, Mirai). During the last few years considerable advances were made in the theory and applications of subdivision. This minisymposium includes talks presenting recent developments in subdivision methods with applications in geometric modeling and simulation.

The first talk will survey the current state of the subdivision theory and applications. The other three talks will represent three directions in development of subdivision methods: nonstationary generalization of a classic subdivision scheme, generalization of subdivision to volumes, and applications of subdivision to simulation.

**Organizer: Denis Zorin**
*New York University and IBM T.J. Watson Research*

**10:30-10:55 Advances in Subdivision Methods**
Denis Zorin, New York University and IBM T.J. Watson Research

**11:00-11:25 A Subdivision Scheme for Surfaces of Revolution**
Joe Warren, Rice University

**11:30-11:55 Subdivision Surface Interference Detection**
Eitan Grinspun, Caltech

**12:00-12:25 Tetrahedral Subdivision of Solids**
Guenther Greiner, Universität Erlangen, Germany

Monday, November 5

# MS2

## Computational Methods for Algebraic Spline Surfaces

*10:30 AM-12:30 PM*

*Room: El Dorado*

The implicit representation of curves and surfaces offers various computational advantages. For instance, the problem of surface fitting can be solved without generating an auxiliary (artificial) parameterization of the data. On the other hand, efficient techniques for conversion to and from parametric form are needed. The talks are devoted to recent advances in computational methods for algebraic spline surfaces. Based on techniques for surface fitting, the speakers report on applications in reverse engineering. They also discuss methods for conversion between surfaces in parametric and implicit form, by discussing both methods for exact or numerical implicitization, and for parameterization of algebraic surfaces.

**Organizer: Bert Juettler**
*University of Linz, Austria*

**10:30-10:55 Least-Squares Fitting of Algebraic Spline Surfaces**
Alf Felis, ProSREP, Germany; Pavel Chalmoviansky, Johannes Kepler University, Austria; and Bert Juettler, University of Linz, Austria

**11:00-11:25 Approximate Implicitization**
Tor Dokken, SINTEF Applied Mathematics, Norway

**11:30-11:55 Three Implicitization Methods for Rational Surfaces**
Ron Goldman, Rice University

**12:00-12:25 Parameterization Methods for Algebraic Surfaces**
Josef Schicho, RISC, Austria

## Lunch Break

*12:30 PM-2:00 PM*

*Attendees on their own.*

Monday, November 5

# CP1

## Deformations of Surfaces and Volumes

*2:00 PM-4:00 PM*

*Room: El Dorado*

*Chair: Wenping Wang, University of Hong Kong, Hong Kong*

**2:00-2:15 Reconstructing Moving Volumes**
Leonardo Traversoni, Universidad Autonoma Metropolitana-Azcapotzalco, Mexico

**2:20-2:35 Reconstruction and Animation of Surfaces**
Catalina Ibanez, Universidad Autonoma Metropolitana (Iztapalapa), Mexico

**2:40-2:55 Curve and Surface Deformation by Scaling Derivatives**
*Kenjiro T. Miura*, Shizuoka University, Japan; Lazhu Wang, Raindrop Geomagic, Inc.; and Fuhua Cheng, University of Kentucky

**3:00-3:15 Dynamic Highlight Line Generation for Locally Deforming Nurbs Surfaces**
Kenjiro T. Miura, Shizuoka University, Japan; and Fuhua Cheng and *Junhai Yong*, University of Kentucky

**3:20-3:35 Dynamic Nurbs with Time-Varying Knot Vectors**
Hong Qin and *Hui Xie*, State University of New York, Stony Brook

**3:40-3:55 A Novel Subdivision-Based Deformable Model for Surface Reconstruction of Arbitrary Topology**
Hong Qin and *Ye Duan*, State University of New York, Stony Brook

Monday, November 5

# CP2

## Geometric Computing

*2:00 PM-4:00 PM*

*Room: Diablo*

*Chair: Jens Gravesen, Technical University of Denmark, Denmark*

**2:00-2:15 Robust Voronoi Diagrams of Polygonal Contours**
Carlo H. Sequin and *Jordan P. Smith*, University of California, Berkeley

**2:20-2:35 Adaptive Sign Detection Method 4 X 4 Determinants Using a Floating Point Processing**
Jun Doi, IBM Japan, Ltd, Japan; Norimasa Yoshida, Tokyo University of Agriculture and Technology, Japan; and Fujio Yamaguchi and *Toshiya Yamauchi*, Waseda University, Japan

**2:40-2:55 Geometric Complications in Numerical Algorithms: A Case Study**
William A. Denker, Spatial Technology Inc

**3:00-3:15 Mesh Parametrization**
C. Bezawada and *Gerald E. Farin*, Arizona State University

**3:20-3:35 Piecewise Convex Contouring of Implicit Functions**
Joe Warren and Tao Ju, Rice University

**3:40-3:55 Curves, Surfaces and Digital Topology**
Mohammed Khachan, CERCA, Canada; and *Patrick Chenin*, Universite Joseph Fourier, France

Monday, November 5

# MS3

## Surface Parameterization in Computer Graphics, CAD and CAE

*2:00 PM-4:00 PM*

*Room: Fresno*

Parameterization of three-dimensional surfaces is a common requirement for many applications in computer graphics, CAD, and CAE. Those applications include texture mapping, surface reconstruction, processing of medical imaging, multiresolutional analysis, finite-element surface meshing, formation of ship hulls, generation of clothing patterns, and metal forming.

Such parameterization is not available directly for composite surfaces or surface tessellations which are a common representation of CAD and graphics models. Multiple recent publications had addressed the problem of constructing a parameterization from a tessellated surface. The presented approaches differ significantly based on the type of the application for which the parameterization is developed. The approaches also seem to reflect the research background of the authors and the tools used within different research communities. The suggested tools include multiresolutional analysis, harmonic maps, finite element simulations, constrained numerical optimization, and physical simulations.

The purpose of the minisymposium is to bring the different research communities together to discuss the challenges involved and to exchange ideas.

**Organizer: Eric De Sturler**
*University of Illinois, Urbana-Champaign*

**Organizer: Alla Sheffer**
*Technion IIT, Haifa, Israel*

**2:00-2:25 Angle Based Flattening of Tesselated Surfaces**
*Eric De Sturler,* University of Illinois, Urbana-Champaign; and Alla Sheffer, Technion IIT, Haifa, Israel

**2:30-2:55 Parameterization with Constraints**
Craig Gottsman, Technion IIT, Haifa, Israel

**3:00-3:25 Parameterization of Tessellated Surfaces for Surface FE Mesh Generation**
David L. Marcum, Mississippi State University

**3:30-3:55 Quasi-Conformal Flattening of Tessellated Surfaces with Applications to MRI Data of the Human Brain**
Monica K. Hurdal, Florida State University

Monday, November 5

## Coffee Break

*4:00 PM-4:30 PM*

*Foyer*

Monday, November 5

# CP3

## Subdivision Curves and Surfaces

*4:30 PM-6:30 PM*

*Room: El Dorado*

*Chair: John E. Lavery, Army Research Office*

**4:30-4:45 Interpolation Constraints in Recursive Subdivision Curves and Surfaces**
*Ahmad Nasri,* American University of Beirut; and Malcolm Sabin, Numerical Geometry Ltd, United Kingdom

**4:50-5:05 An Algorithm for Tessellating Trimmed Patches Based on Recursive Subdivisions**
Dominique Michel and *Ahmed Zidna,* Université de METZ, France

**5:10-5:25 Subdivision Surface Reconstruction from a Dense Triangle Mesh**
*Xiaohu Ma,* Shiu-Kit Tso, and Weiyin Ma, City University of Hong Kong, Hong Kong

**5:30-5:45 Interpolating Subdivision Surface Revisited**
*Thomas Yu,* Rensselaer Polytechnic Institute

**5:50-6:05 Interpolatory Subdivision for Surfaces of Revolution**
Joe Warren and *Scott D. Schaefer,* Rice University

**6:10-6:25 Cut-and-Paste Editing of Multiresolution Surfaces**
Henning Biermann, New York University; Ioana M. Martin, IBM T.J. Watson Research Center; Denis Zorin, New York University; Fausto Bernardini, IBM T.J. Watson Research Center

Monday, November 5

# CP4

## Mathematical Methods

*4:30 PM-6:10 PM*

*Room: Diablo*

*Chair: Stephen Mann, University of Waterloo, Canada*

**4:30-4:45 Minkowski Geometric Algebra of Quaternion Sets**
Weiqing Gu, Harvey Mudd College

**4:50-5:05 Some Geometric Aspects of the Orlicz Spaces**
Pedro Espinoza Haro, Universidad de Lima, Peru

**5:10-5:25 Natural Geometry Weighted-Point and Vector Space**
Achan Lin, York University, Canada

**5:30-5:45 Stability of B-Spline Wavelets**
Peeter Oja, Tartu University, Estonia; and Ewald Quak and *Jon A. Mikkelsen*, SINTEF Applied Mathematics, Norway

**5:50-6:05 An Extended Domain for the Analytic Blossom**
Ronald Goldman and Géraldine Morin, Rice University

Monday, November 5

# MS4

## Shape Matching: Approaches and Methods

*4:30 PM-6:30 PM*

*Room: Fresno*

Aim of this workshop is to investigate the relationships between current geometric models and issues related to measuring the similarity among shapes of solid objects. First, the main limitations of traditional geometric models in supporting shape-based reasoning and shape similarity measures will be discussed (1st speaker). Approches based on geometry (2nd speaker) and deformation of shapes (3rd speaker) will be presented for the definition of similarity measures. Finally, the importance of topological and morphological structures (4th speaker) will be discussed for assessing the similarity at a higher-level of abstraction.

**Organizer: Michela Spagnuolo**
*Consiglio Nazionale delle Ricerche, Italy*

**Organizer: Bianca Falcidieno**
*CNR, Genova, Italy*

**4:30-4:55 The Role of Models in Shape-Based Reasoning**
Bianca Falcidieno, CNR, Genova, Italy

**5:00-5:25 Topological and Morphological Structures for Shape Description**
Michela Spagnuolo, Consiglio Nazionale delle Ricerche, Italy

**5:30-5:55 Matching and Retrieval of Polyhedral Shapes**
Remco Veltkamp and *Johan W.H. Tangelder*, Utrecht University, The Netherlands

**6:00-6:25 Quantifying Shape Deformation Based on Gradients of the Mapping**
Marc Alexa, Technische Universitaet Darmstadt, Germany

# Tuesday, November 6

## Registration

*8:00 AM-3:00 PM*

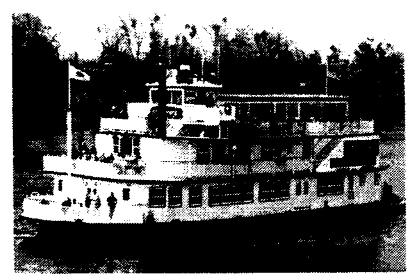
*Room: Foyer*

## Announcements

*8:15 AM-8:30 AM*

*Room: Fresno/El Dorado/Diablo*

**Miriam Lucian**
The Boeing Company



**Did you sign up?**

Last Chance to buy tickets, 12:00 noon today!

See us at the registration desk-- $35.00 per person

Tuesday, November 6

# IP3

## Multivariate Splines for Scattered Data Modeling

*8:30 AM-9:15 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Rida Farouki, University of California, Davis*

The classical univariate splines (or piecewise polynomials) are a standard tool in many applications, including the design of curves and data fitting. Yet, when it comes to bivariate or multivariate settings (such as in FEM methods or in Computer-Aided Geometric Design), the analogs of univariate splines in these settings come in many flavors and different kinds. We will discuss one particular generalization of splines, based on multivariate B-splines, also called simplex splines. Recently, the speaker introduced a novel approach to constructing such splines. In this talk, we discuss the new spline spaces and describe some recent developments in this area.

**Mike Neamtu**
*Vanderbilt University*

Tuesday, November 6

# IP4

## Geometrical Problems in Robotics and Vision

*9:15 AM-10:00 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Thomas W. Sederberg, Brigham Young University*

Talk summary not available at press time.

**Takeo Kanade**
*Carnegie Mellon University*

## Coffee Break

*10:00 AM-10:30 AM*

*Foyer*

Tuesday, November 6

# MS5

## Scattered Data Modelling

*10:30 AM-12:30 PM*

*Room: Fresno*

In many modelling situations we are given (huge ammounts of ) data which are spaced in some irregular fashion. In such cases we need methods for scattered data modelling. The minisymposium offers some examples of the widespread research in scattered data modelling illustrating both theory and applications.

**Organizer: Tom Lyche**
*University of Oslo, Norway*

**10:30-10:55 Multi-Level Triangulations of Scattered Data and Real-Time Rendering of Terrain Surfaces**
Thomas Sevaldrud and *Morten Daehlen*, Simula Research Laboratory, Norway

**11:00-11:25 One-to-One Piecewise Linear Mappings over Triangulations**
Michael S. Floater, SINTEF Applied Mathematics, Norway

**11:30-11:55 Parametric Surfaces Over Arbitrary Meshes**
*Stefanie Hahmann*, LMC-IMAG, Grenoble, France; and Georges-Pierre Bonneau, GRAVIR-IMAG, Grenoble, France

**12:00-12:25 Fast Evaluation of Radial Basis Functions**
Holger Wendland, Universitaet Goettingen, Germany

Tuesday, November 6

# MS6

## Geometric Computations and Lie Groups

*10:30 AM-12:30 PM*

*Room: El Dorado*

This mini-symposium merges concepts from the field Mathematics and CAGD (Computer Aided geometric Design) to solve practical problems in computer graphics, animation, robotics, and geometric modeling and design. It is shown that Lie Groups and the associated Lie Algebra's provide a computational framework to deal with many problems of nonlinear geometry of curved spaces. Many problems in engineering and computer science when formulated geometrically involve a nonlinear or curved structure and therefore well-established techniques of geometric computations cannot be used since they are in general for finite dimensional vector spaces and not curved geometries. Developing techniques for such geometries require a different level of mathematics based on the theory of Lie Groups, which is the subject of this mini-symposia. Specific topics covered in the mini-symposia include motion simulation and animation, use of symmetry groups in modeling, non-commutative harmonic analysis and geometry of robot manipulators and DNA molecules, motion approximation and interpolation.

**Organizer: Bahram Ravani**
*University of California, Davis*

**10:30-10:55 Geometric Motion Design and Lie Groups**
Bahram Ravani, University of California, Davis

**11:00-11:25 Applications of Computational Harmonic Analysis on Lie Groups to Geometric Problems**
Greg Chirikjian, Johns Hopkins University

**11:30-11:55 Taylor Series Methods for Rigid Body Simulation and Extensions to Lie Groups**
Samuel Buss, University of California, San Diego

**12:00-12:25 Lie and Symmetry Subgroups of Rigid Motion: Classification and Applications**
Vijay Srinivasan, IBM Corporation and Columbia University

Tuesday, November 6

## Lunch Break

*12:30 PM-2:00 PM*

*Attendees on their own.*

# CP5

## Variational Methods

*2:00 PM-4:00 PM*

*Room: El Dorado*

*Chair: Alessandra Sestini, University of Florence, Italy*

**2:00-2:15 Approximation of the Energy Integral for a Piecewise Polynomial Surface**
Om Prakash Sha and *Rajiv Sharma*, Indian Institute of Technology, Kanpur

**2:20-2:35 Circle Splines on the Sphere and in 3-Space**
Jane Yen and *Carlo H. Sequin*, University of California, Berkeley

**2:40-2:55 Triangular Patch Modeling Using Combination Method**
Caiming Zhang, Shandong University, China; and *Fuhua Cheng*, University of Kentucky

**3:00-3:15 Variational Spline Interpolation**
*Johannes Wallner*, Technische Universitat Vienna, Austria; and Helmut Pottmann, Technische Universitaet Wien, Germany

**3:20-3:35 Variational Surface Design with Multiresolution Constraints**
*Ioana M. Martin*, Remi Ronfard, and Fausto Bernardini, IBM T.J. Watson Research Center

**3:40-3:55 Minimal Degree Determining Sets for C1 Functional Surfaces over Non Structured Tensor Product Patches**
Tanya Matskewich and *Michel Bercovier*, Hebrew University, Israel

Tuesday, November 6

# CP6

## Geometry Processing

*2:00 PM-4:00 PM*

*Room: Diablo*

*Chair: Takashi Maekawa, Massachusetts Institute of Technology*

**2:00-2:15 Interference Analysis of Ellipsoids**
Myung-Soo Kim, Seoul National University, Korea; Jiaye Wang, Shandong University, China; and *Wenping Wang*, University of Hong Kong, Hong Kong

**2:20-2:35 A Quasi-Monte Carlo Method for Computing Surface Areas of CSG Models**
Ralph Martin, University of Cardiff, United Kingdom; Xueqing Li, Shandong University, China; Adrian Bowyer, University of Bath, United Kingdom; and *Wenping Wang*, University of Hong Kong, Hong Kong

**2:40-2:55 Feasibility of Shape Design Method Based on the Velocity Parameter**
Yuichiro Kume, Norihiko Mori, and *Junji Sone*, Tokyo Institute of Polytechnics, Japan; Hiroshi Toriya, Lattice technology, Inc, Japan; and Hiroaki Chiyokura, Keio University, Japan

**3:00-3:15 Solving Geometry Re-Use - Experience and Tools**
Michael Forster, FEGS Ltd, Germany

**3:20-3:35 Shadow Generation Based on Re Loops and Their Angular Representations**
Kenjiro T. Miura, Shizuoka University, Japan; and Fuhua Cheng and *Khageshwar Thakur*, University of Kentucky

**3:40-3:55 Physics-Based Pde Solids with Global and Local Constraints for Geometric Design**
Hong Qin and *Haixia Du*, State University of New York, Stony Brook

Tuesday, November 6

# MS7

## Multi-Resolution Modelling

*2:00 PM-4:00 PM*

*Room: Fresno*

Challenging research problems are posed by the hierarchical, multiresolution representation, visualization and interpretation of very large, high-resolution discrete data sets. These data sets commonly result from numerical computer simulations of complicated physical phenomena or high-resolution imaging. The technology currently in use to represent massive discrete data sets is largely inappropriate for interactive, efficient data analysis and visualization tasks. This minisymposium brings together leading researchers in the maturing area of multiresolution data modeling and approximation with applications in scientific data exploration. Multiresolution technology has become a key enabling technology for making effective visualization of very large data sets possible.

**Organizer: Bernd Hamann**
*University of California, Davis*

**Organizer: Ken Joy**
*University of California, Davis*

**2:00-2:25 Efficient Simplification of Massive Polygonal Models**
Michael Garland, University of Illinois, Urbana-Champaign

**2:30-2:55 Feature Preserving Multiscale Transforms**
Raghu K. Machiraju, The Ohio State University

**3:00-3:25 Number Crunching for Large-Scale Earthquake Simulation**
Jeorg Meyer, Mississippi State University

**3:30-3:55 Terascale Visualization: Multi-Resolution Aspirin for Big-Data Headaches**
Mark A. Duchaineau, Lawrence Livermore National Laboratory

## Coffee Break

*4:00 PM-4:30 PM*

*Foyer*

Tuesday, November 6

# CP7

## Surface Fitting

*4:30 PM-6:30 PM*

*Room: El Dorado*

*Chair: Tom Lyche, University of Oslo, Norway*

**4:30-4:45 Smooth Connection of Trimmed Nurbs Surfaces**
Pifu Zhang and *Fuhua Cheng*, University of Kentucky

**4:50-5:05 Nurbs Fitting Through Large Sets of Scattered Data**
Iain Ainsworth, Mihailo Ristic, and Djordje S. Brujic, Imperial College of Science Technology & Medicine, UK; and *Vesna Brujic*, University of Surrey, United Kingdom

**5:10-5:25 Data Reduction for Scattered Data**
Rossana Morandi and *Alessandra Sestini*, University of Florence, Italy

**5:30-5:45 Surface Reconstruction by Fitting Unorganized Curves**
Kwang Hee Ko and *Takashi Maekawa*, Massachusetts Institute of Technology

**5:50-6:05 Incremental Algorithms for The Design Of Triangular-Based Spline Surfaces**
Dianna Xu and *Jean H. Gallier*, University of Pennsylvania

**6:10-6:25 Gamma Shapes**
*Kenneth R. Sloan*, University of Alabama; Marietta Cameron, Birmingham-Southern College; and John K. Johnstone, University of Alabama, Birmingham

Tuesday, November 6

# CP8

## Curves, Surfaces and Volumes

*4:30 PM-5:50 PM*

*Room: Diablo*

*Chair: Ahmad Nasri, American University of Beirut, Lebanon*

**4:30-4:45 Interactive Design of Interpolating Splines.**
Giovanni Figueroa, Francisco Tovar, and *Marco Paluszny*, Universidad Central de Venezuela, Venezuela

**4:50-5:05 Curve Shape Comparison**
Georgios Stylianou, Arizona State University

**5:10-5:25 Approximate Implicit Surfaces and Intersections**
Jan Thomassen, Tor Dokken, and *Atgeirr F. Rasmussen*, SINTEF Applied Mathematics, Norway

**5:30-5:45 Shape-Preserving Interpolation Based on Dmbvp**
Boris I. Kvasov, Suranaree University of Technology, Thailand

Tuesday, November 6

# MS8

## $L_1$ Splines: New Results on Performance and Algorithms

*4:30 PM-6:30 PM*

*Room: Fresno*

$L_1$ splines have recently arisen as an method for shape-preserving interpolation and approximation of irregular, multiscale data, a method that requires no constraints, penalties, a posteriori filtering, fairing or human interaction. This minisymposium presents new theoretical and computational results on performance of $L_1$ splines and on algorithms by which the coefficients of $L_1$ splines are calculated. First, bivariate $L_1$ splines of various degrees and smoothness for interpolation of scattered data on arbitrary triangulations and for filling polygonal holes are investigated. Then, domain decomposition procedures for bivariate $L_1$ splines on tensor-product grids are examined. A new geometric programming approach for calculating the coefficients of $L_1$ splines is presented. Finally, a new class of univariate curvature-based cubic $L_1$ splines in Cartesian and polar coordinates is explored.

**Organizer: John E. Lavery**
*Army Research Office*

**4:30-4:49 $L_1$ Splines for Scattered Data Interpolation**
Ming-Jun Lai and *Paul Wenston*, University of Georgia

**4:54-5:13 Polygonal Hole Filling by the $L_1$ Spline Method**
Ming-Jun Lai, University of Georgia

**5:18-5:37 Domain Decomposition for Bivariate Cubic $L_1$ Splines**
David Gilsinn, National Institute of Standards and Technology

**5:42-6:01 A Geometric Programming Approach for $L_1$ Splines**
Hao Cheng, North Carolina State University

**6:06-6:25 Univariate Curvature-Based Cubic $L_1$ Splines**
John E. Lavery, Army Research Office

Tuesday, November 6

## SIAG GD Business Meeting

*7:00 PM-7:30 PM*

*Room: Fresno*

# Wednesday, November 7

## Registration

*8:00 AM-3:00 PM*

*Room: Foyer*

## Announcements

*8:15 AM-8:30 AM*

*Room: Fresno/El Dorado/Diablo*

**Rida Farouki,**
University of California, Davis

Wednesday, November 7

# IP5

## Medial Axes of Curves and Surfaces

*8:30 AM-9:15 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Thomas Banchoff, Brown University*

The medial axis of a simple closed plane curve is a 1-dimensional `skeleton' of e region bounded by the curve, formed by placing circles of maximal radius entirel within the region and tracing their centres. For a surface in 3-space one takes spheres instead of circles. A larger set is the symmetry set, formed (for a curve) from e centres of all circles tangent to the curve in two or more places, without the requirement of being maximal and contained inside the region. The symmetry set is easier to study from the point of view of singularity theory, since it makes up a `full bi rcation set' which is a standard object in the theory. On the other hand the medial axis is m e useful in practice, since it is much less complicated and contains in a sense th same information. In fact the medial axis, augmented with data on the radii of the circles or spheres which created it, gives enough information to reconstruct the curve or surface completely. The full structure of medial axes and symmetry sets is known for curves and for 1-parameter families of curves; in particular it is known how the extra complication of the symmetry set goes a long way towards explaining the change is structure of the medial axis as the underlying curve changes shape. The situation for surfaces is less complete in that the generic evolutions of the medial axis ave not been classified in detail. Approximately the same can be said of the differe ial geometry of the medial axis: a great deal is known in the curve situation but not so much in the case of surfaces. In the talk I shall describe the background to the medial axis and symmetry set and say something about recent developments in this area.

**Peter J. Giblin**
*University of Liverpool, United Kingdom*

Wednesday, November 7

# IP6

## Applications of Haptic Interfaces to Automotive Design

*9:15 AM-10:00 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Timothy L. Strotman, Structural Dynamics Research Corporation*

Designing the components of a vehicle's human-machine interface is a particularly challenging task for an automotive designer. Beyond the functionality and aesthetics of the geometric shape, the designer must also consider the accessibility, convenience, and perceived quality of parts such as doors, lift-gates, and instrument panel controls.

Yet the complexity of mechanical design and lack of flexible conceptual prototypes make consistently achieving superior designs a holy grail of the industry. Ford is currently developing a haptic modeling solution that allows a designer to sit inside a CAD model of a vehicle, reach out and grasp the various mechanisms (for instance a door handle or knob) and, with the aid of the force-feedback provided by a haptic device, experience and experiment with both the geometric shape and dynamic feel of a mechanism.

**Paul J. Stewart**
*Ford Research Laboratory*

## Coffee Break

*10:00 AM-10:30 AM*

*Foyer*

Wednesday, November 7

# MS9

## Computational Differential Geometry

*10:30 AM-12:30 PM*

*Room: Fresno*

Over the past decade, mathematicians have started to explore the geometry and topology of discrete (triangulated) surfaces, thinking of them not as approximations to smooth surfaces, but as analogs of smooth surfaces. For instance, one can define the Gaussian and mean curvatures of discrete surfaces, find discrete minimal surfaces and their (discrete) conjugates, and solve other optimization problems in the discrete category. This minisymposium will explore issues related to this work, including how the discrete notions of curvatures, for instance, can be viewed as the most natural discretizations of the smooth quantities.

**Organizer: John M. Sullivan**
*University of Illinois*

**10:30-10:55 Curvature Measures for Discrete Surfaces**
John M. Sullivan, University of Illinois

**11:00-11:25 Unfolding Planar Polygons Using Energies**
Jason Cantarella, University of Georgia

**11:30-11:55 Differential Operators on Discrete Surfaces**
Konrad Polthier, Technische Universitaet Berlin, Germany

**12:00-12:25 Computing Conformal Shapes with Applications to Grothendieck Dessins Andanatomical Mappings**
Phil Bowers, Florida State University

Wednesday, November 7

# MS10

## Open Source Software for Geometric Modeling

*10:30 AM-12:30 PM*

*Room: El Dorado*

This minisymposium covers work performed in the open source community on software for geometric modeling. The speakers cover the Open Cascade modeling kernel and applications built on top of it as well as the Jupiter toolkit that has been developed to address the challenges of large models displays.

**Organizer: Hans J. Wolters**
*BEA Systems, Inc.*

**Organizer: Michel Bercovier**
*Hebrew University, Israel*

**10:30-10:55 Jupiter: A Toolkit for Interactive Large Model Visualization**
Dirk Bartz, University of Tuebingen, Germany

**11:00-11:25 An Open Source 3D Modeling Kernel**
Gilles Debarbouille, Open CASCADE SA

**11:30-11:55 From Measured Data to a Model in Open CASCADE**
Tor Dokken, SINTEF Applied Mathematics, Norway

**12:00-12:25 The Power Crust Software**
Nina Amenta, University of Texas

## Lunch Break

*12:30 PM-2:00 PM*

*Attendees on their own.*

Wednesday, November 7
# CP9
## Classical Geometry
*2:00 PM-4:00 PM*

*Room: El Dorado*

*Chair: Stefan Leopoldseder, Technische Universitaet Wien, Germany*

**2:00-2:15 Surface Envelopes**
Jorg Peters, University of Florida

**2:20-2:35 Dual Curves**
Richard R. Patterson, Indiana University

**2:40-2:55 Third Order Invariants on Surfaces**
Jens Gravesen, Technical University of Denmark, Denmark

**3:00-3:15 Developable Surfaces with Creases**
Stefan Leopoldseder, Technische Universitaet Wien, Germany

**3:20-3:35 Morphological Functionals of Spatial Patterns**
*Jean F. Poiraudeau* and Isabelle Blasquez, Limoges University, France

**3:40-3:55 CAGD Techniques for Manifolds**
Marshall D. Walker, York University

Wednesday, November 7
# CP10
## CAD Applications
*2:00 PM-4:00 PM*

*Room: Diablo*

*Chair: Michael Forster, Fluxus Technology Ltd.*

**2:00-2:15 Hierarchical B-Splines for Image Registration**
Gerald E. Farin and Zhiyong Xie, Arizona State University

**2:20-2:35 Designing Smooth Motions in the Presence of Obstacles**
Helmut Pottmann, Technische Universitaet Wien, Germany; and Michael Hofer, Vienna University of Technology, Austria

**2:40-2:55 Haptic Feedback in Cagd**
Tor Dokken, SINTEF Applied Mathematics, Norway

**3:00-3:15 Geometry Reconstruction and Mesh Generation For Biological Systems From Image Data**
John Fowler and Robert Hotchkiss, Los Alamos National Laboratory; and Harold E. Trease, Pacific Northwest National Laboratory

**3:20-3:35 Real-time Volume Sculpting System Using Implicit Functions**
Hong Qin and Jing Hua, State University of New York, Stony Brook

**3:40-3:55 Strategies for Rendering Large-Scale Tetrahedral Meshes for Earthquake Simulation**
Joerg Meyer, Michael L. Stokes, and Prashant Chopra, Mississippi State University

Wednesday, November 7
# MS11
## Design and Optimization of Aerospace Configurations
*2:00 PM-4:00 PM*

*Room: Fresno*

Geometric design of aerospace vehicles is a sophisticated process due to its multi-disciplinary nature. In this session, scientists from government labs, industry, and academia will discuss different aspects of this process. In particular, the interaction between the geometry of the body and the geometry of the flow plays an important role in the construction of efficient numerical algorithms for both the analysis and design of aerospace vehicles. Applications to airfoils, wings, and propellers at low speeds will be also considered.

**Organizer: M. Hafez**
*University of California, Davis*

**2:00-2:25 The Role of Geometry in the Multi-disciplinary Design of Aerospace Vehicles**
*T.A. Zang* and J. A. Samarch, NASA Langley Research Center

**2:30-2:55 Nonlinear Elimination in Aerodynamic Analysis and Design Optimization**
D. Young, Boeing Corporation

**3:00-3:25 Some Aspects of Flow Geometry in the Analysis of Aerodynamic Configurations**
M. Hafez, University of California, Davis

**3:30-3:55 Optimization of Profiles, Wings, and Propellers at Low Speeds**
J.J. Chattot, University of California, Davis

## Coffee Break
*4:00 PM-4:30 PM*

*Foyer*

Wednesday, November 7

# PP1

## Poster Session

*4:00 PM-5:00 PM*

*Room: Foyer*

**Load-Balancing for a Parallel Quadtree Algorithm**
David E. Stewart, Suely B. Oliveira, and *Christopher K. Cartwright*, University of Iowa

**Remarkable Bézier Curves in Polar Coordinates**
Javier Sanchez-Reyes, University of Castilla-La Mancha, Spain

**About Bonnet Theorem in Octonion Space**
Grushko P. Pavel, Irkutsk University, Russia

**Computer Aided Violin Design**
Stephen Mann, University of Waterloo, Canada and Quentin Playfair

**Robust Analysis of Discrete Systems Represented by An Interval Matrix**
Eduardo Hernandez-Morales, Rodolfo Gonzalez-Garza, and *Juan J. Delgado-Romero*, Instituto Tecnologico de Morelia, Mexico

# Thursday, November 8

## Registration

*8:00 AM-11:00 AM*

*Room: Foyer*

## Announcements

*8:15 AM-8:30 AM*

*Room: Fresno/El Dorado/Diablo*

**Miriam Lucian,**
The Boeing Company

Thursday, November 8

# IP7

## Reconstructing Geometric Objects from Partial Information

*8:30 AM-9:15 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Joel Hass, University of California, Davis*

I will talk about the algorithms used to reconstruct geometric objects from partial information. This problem arises in computer vision, graphics, electron microscopy, and so forth. I will focus on mathematical analysis of the algorithms, more than on empirical results.

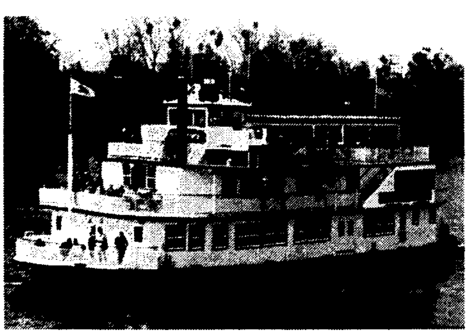
**Marshall W. Bern**
*Xerox Corporation*

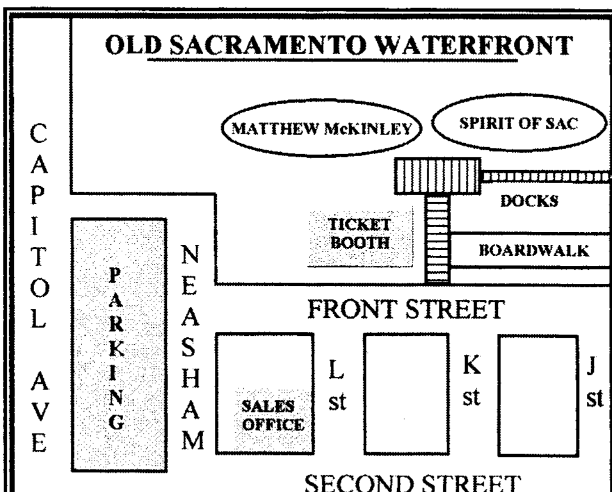
## Riverboat Dinner Cruise (Optional Event)

*5:30 PM*

*Off-site*

This is an optional ticketed event.
Bring your ticket to board the boat.






All cruises depart from the "L" Street Landing in Old Sacramento. From Interstate 5 take the "J" Street/Downtown off-ramp, follow the signs to Old Sacramento. Hourly parking available in Lot "R"

Thursday, November 8

# IP8

## Geometric Computing for Sculptured Surface Machining

*9:15 AM-10:00 AM*

*Room: Fresno/El Dorado/Diablo*

*Chair: Helmut Pottmann, Technische Universitat Vienna, Austria*

I will talk about the computational geometric techniques for sculptured surface manufacturing. Sculptured surface manufacturing plays a vital role in the process of bringing new products from design to the market place. A great variety of modern products, from cellular phones to automotive body panels, all rely on this technology for the design and manufacturing of sculptured surface shapes used in the product development. Sculptured surface machining is a mathematically challenging area, full of tough computer science problems and hard geometrical puzzles that are yet to be solved. There are plenty of unsolved problems to go around. The problems are certainly interdisciplinary, and good solutions will required the efforts of engineers, mathematicians and computer scientists. It is our hope that this talk will help to stimulate the existence of a larger research community in this area.

**Yuan Shin Lee**
*North Carolina State University*

## Coffee Break

*10:00 AM-10:30 AM*

*Room: Foyer*

Thursday, November 8

# MS12

## Computational Topology

*10:30 AM-12:30 PM*

*Room: Fresno*

Computational topology is an emerging field that is concerned both with algorithmic questions in topology (such as recognizing and efficiently computing topological or geometric properties of knots and manifolds) and topological questions in algorithms (such as whether a discrete reconstruction of a continuous object correctly captures its shape). Some of the main applications in this area are in the areas of shape acquisition, shape representation and configuration spaces. As the field evolves, techniques of topology and combinatorial geometry are finding new uses. This minisymposium will present a sample of some current research in these areas.

**Organizer: Joel Hass**
*University of California, Davis*

**10:30-10:55 Morse Complexes and Topological Persistence**
Herbert Edelsbrunner, Duke University

**11:00-11:25 Mayer Vietoris Methods in Linear Algebra**
Gunnar E. Carlsson, Stanford University

**11:30-11:55 Shape Decomposition with the Medial Axis**
Nina Amenta, University of Texas

**12:00-12:25 Contour Trees for Exploring Static and Time-Varying Volume Data**
Jack S. Snoeyink, University of North Carolina

Thursday, November 8

# MS13

## Computational Techniques for Sculptured Surface Machining

*10:30 AM-12:30 PM*

*Room: El Dorado*

Sculptured surfaces, or so-called free-form surfaces, are commonly used in the aerospace, automotive, die/mold manufacturing and consumer products industry. These surfaces usually have free-formed geometry of complex shapes and are difficult to be machined. Sculptured surface objects are usually produced by using 2.5D roughing, and 3-axis or 5-axis finishing by using numerical controlled (NC) machine tools or rapid prototyping (RP). One of the main obstacles, which prevents the implementation of entirely automatic manufacturing of free-form objects, is the lack of robustness of the geometric computation techniques and the interrogation tools to support the planning and programming for the manufacturing processes. In this minisymposium, important issues of geometric computation and robust geometric interrogation analysis for sculptured surface manufacturing will be addressed.

**Organizer: Yuan-Shin Lee**
*North Carolina State University*

**Organizer: Helmut Pottmann**
*Technische Universitaet Wien, Germany*

**10:30-10:55 Modeling and Interference Checking for Multi-Axis Sculptured Surface Machining**
Sanjay Sarma, Massachusetts Institute of Technology

**11:00-11:25 Optimal Contour Orientations for Machining of Free-Form Surfaces**
Helmut Pottmann, Technische Universitaet Wien, Germany; and Rida Farouki, Mohammad al-Kandari, and *Tait S. Smith*, University of California, Davis

**11:30-11:55 A Boundary Search Method for Optimal Tool Orientations**
Kyungduck Cha, Georgia Institute of Technology; and Yuan-Shin Lee and *Cha-Soo Jun*, North Carolina State University

**12:00-12:25 Reconstruction and Machining of Triangulated Sculptured Surfaces from Unorganized Laser Scan Data**
Chuan-Chu Kuo and *Hong-Tzong Yau*, National Chung-Cheng University, Chia-Yi, Taiwan

Thursday, November 8

## Lunch Break

12:30 PM-2:00 PM

*Attendees on their own.*

Thursday, November 8

# CP11

## Manufacturing Geometry

2:00 PM-4:00 PM

*Room: El Dorado*

*Chair: Javier Sanchez-Reyes, University of Castilla-La Mancha, Spain*

**2:00-2:15 Traversing a Machining Graph of a Pocket**
Kai Tang, Unigraphics Solutions

**2:20-2:35 Tool-Path Linking Algorithm for Contour Parallel Machining**
Yun C. Chung and *Sangc. Park*, Cubic Technology Research Center

**2:40-2:55 Optimal Design of Self-Aligning Robot Gripper Jaws**
Ken Goldberg and *Tao Zhang*, University of California, Berkeley

**3:00-3:15 Computational Issues in Layered Manufacturing**
Carlo Séquin and *Sara McMains*, University of California, Berkeley

**3:20-3:35 Performance Analysis of Cnc Interpolators for Time-Dependent Feedrates Along Ph Curves**
*Yi-Feng Tsai*, SDRC; and Rida Farouki and Bryan Feldman, University of California, Davis

**3:40-3:55 The Geometry of Buckled Developable Surfaces for Binder Design**
William H. Frey, General Motors R&D Center

Thursday, November 8

# CP12

## Mesh Generation

2:00 PM-4:00 PM

*Room: Diablo*

*Chair: Bill Denker, PlanetCAD*

**2:00-2:15 Dynamic Unstructured Grid Generation Using Spline Fitting over Data Dependent Triangulation**
*Rajiv Sharma*, Indian Institute of Technology, Kanpur

**2:20-2:35 Adaptive Mesh Generation for Analysis and Optimisation**
Michael J. Wilson, Malcolm Bloor, and *Hassan Ugail*, Leeds University, United Kingdom

**2:40-2:55 Automated Gear Teeth Grid Generation Via Solution of Elliptic Pdes**
Edward Huff and *Upender K. Kaul*, NASA Ames Research Center

**3:00-3:15 Sample Shuffling for Quality Hierarchic Surface Meshing**
*Tamal K. Dey*, Joachim Giesen, and James Hudson, Ohio State University

**3:20-3:35 High Quality Triangulation of Point Clouds by Simulated Annealing**
Marc Wagner, Guenther Greiner, and *Ulf Labsik*, Universität Erlangen, Germany

**3:40-3:55 Efficient Approach to Adaptive 4-8 Mesh Generation**
*Laurent Balmelli*, IBM Corporation; and Martin Vetterli and Thomas Liebling, Ecole Polytechnique Federale de Lausanne, Switzerland

Thursday, November 8

# MS14

## Robust Geometric Computation

2:00 PM-4:00 PM

*Room: Fresno*

Numerical nonrobustness is a well-known and widespread problem. It is particularly insidious for geometric computation. It is almost an axiom among researchers in this field that current geometric software (almost without exception) can be made to break, crash or produce wrong results. Nonrobustness has a large economic impact, from preventing full automation of important industrial processes, to consuming a large fraction of programmers' and researchers' effort. Some have declared this an unsolvable problem. After all, if the geometric primitive to intersect two line segments robustly has been posed as a challenge, the robust construction of complex algorithms and large geometric software must be a hopeless cause. In the last 15 years, the computational geometry and geometric modeling communities have proposed various solutions. How much of this work is practical? What insights we have gained? Are there success stories? What are the pressing research issues ahead? These are some of the questions our speakers will address.

**Organizer: Chee K. Yap**
*New York University*

**2:00-2:19 On the Role of Exact Arithmetic in Geometric Computation**
Christoph M. Hoffmann, Purdue University

**2:24-2:43 Fast and Accurate Computations with Algebraic Primitives and Predicates**
Dinesh Manocha, University of North Carolina, Chapel Hill

**2:48-3:07 Solutions to Robustness Problems in CGAL**
Sylvain Pion, INRIA

**3:12-3:31 Making Roundoff Error Less Unbearable**
Jonathan Shewchuk, University of California, Berkeley

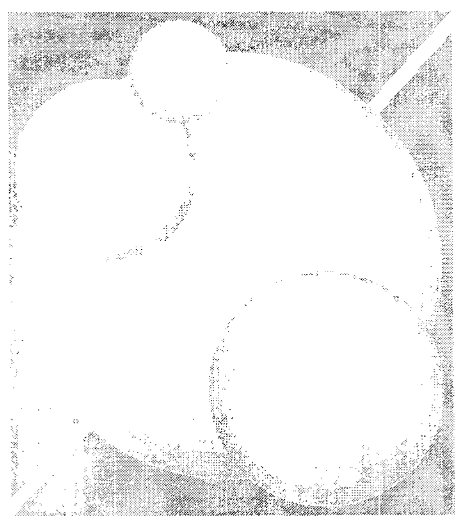
**3:36-3:55 Robustness for Everyone**
Chee K. Yap, New York University

## Conference Adjourns

4:00 PM

# Abstracts

SIAM Conference on geometric design



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## CP1

### A Novel Subdivision-Based Deformable Model for Surface Reconstruction of Arbitrary Topology

We propose a novel subdivision-based deformable model that is capable of recovering arbitrary, complicated shape geometry and its unknown topology simultaneously. Starting from a simple seed inside the dataset, the model will grow according to the principle of energy-based minimization. Our algorithm can adaptively subdivide the model geometry, automatically detect self-collision of the model, properly modify its topology, continuously evolve the model towards the object boundary, and reduce fitting error and improve fitting quality via global subdivision. Commonly-used mesh optimization techniques are employed to ensure the model both locally smooth and globally well-conditioned. Our model overcomes the topological limitation of traditional deformable models and provides a unified approach to handle both volumetric image dataset and range dataset.

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## CP1

### Reconstruction and Animation of Surfaces

The purpose is to reconstruct and animate a flexible surface given some constraints. We use repeatedly a De Casteljau algorithm applied to quaternionic functions, our control points for the definition of the surface are really control quaternions that applied to for example a line, make it describe the surface Then we apply the movements (also represented by quaternions) to the control quaternions so we obtain a moving surface. This is very useful for industrial applications.

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## CP1

### Curve and Surface Deformation by Scaling Derivatives

A deformation-based fine tuning technique for parametric curves and surfaces is presented. A curve or surface is deformed by scaling its derivative, instead of manipulating its control points. Since only the norm of the derivative is adjusted, the resulting curve or surface keeps the basic shape of the original profile and curvature distribution. Therefore, the new technique is especially suitable for last minute fine tuning of the design process.

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## CP1

### Reconstructing Moving Volumes

We present two approaches, the first one is animating an object given the independent movements of a set of some of its parts and reconstructing the movement of all the other parts via quaternionic interpolation. The second approach is starting only with the knowledge of the set of moving parts and reconstructing both the movement and the shape of the rest. We suppose known the physical properties of the object. Rigid motions may also be considered.

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## CP1

### Dynamic Nurbs with Time-Varying Knot Vectors

This paper enhances the previously-formulated D-NURBS by incorporating NURBS knot vectors into the generalized coordinates (which are controlled by physical laws) and develops a large variety of physics-based sculpting tools for a wide range of geometric applications in a unified manner. Our novel D-NURBS formulation can automatically evolve not only the control points and the non-unity weights but also the non-uniform knots through efficient time integration of non-linear Lagrangian dynamics, subject to geometric constraints, functional requirements, and externally applied forces. D-NURBS with time-varying knots afford designers to exploit the full modeling potential of industry-standard NURBS.

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## CP1

### Dynamic Highlight Line Generation for Locally Deforming Nurbs Surfaces

Dynamic highlight line generation NURBS surface is achieved by directly modifying the highlight lines using a Taylor expansion approach, instead of going through a tracing process. The highlight lines computation process adopted here enables a unified distance surface to generate all highlight lines in the highlight-line family. The computation process is also facilitated by the usage of a look up table of pre-calculated information of the tessellation mesh and an indexing technique for the distance surface.

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CP2

**Curves, Surfaces and Digital Topology**

Voxels and n-trees can be used to localize curves and surfaces. By defining a good topology on these sets, it is possible to get topological information on curves and surfaces. For example, Jordan-Brower theorems in n-dimensional discrete spaces are obtained. For that purpose, new definitions and results of combinatorial topology are shown. These results give us some algorithms for applied problems: implicit curves and surfaces, offsets, re-engineering, analysis of singularity.

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CP2

**Geometric Complications in Numerical Algorithms: A Case Study**

Implementing numerical geometric algorithms in commercial software systems can be greatly complicated by geometric uncertainty in the geometry representation and the finite precision of computers. Geometric and parametric conditions such as poles, seams, and convergence to incorrect solutions must be handled. Unfortunately, numerical fuzziness can make it difficult to handle such cases, or even to detect them reliably. Tolerance mismatches between software systems can also cause problems. This paper describes some specific examples of some of the interesting problems encountered in a real-world application, and how they were handled. The context was a rewrite of an algorithm to approximate the parameter-space curve corresponding to a three-dimensional curve lying on a parametric surface, in a commercial solid modeler.

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CP2

**Mesh Parametrization**

We address the problem of assigning 2D parameter values for a 3D genus 0 triangular mesh. The method is based on a recent one by Floater. That method forces the boundary of the 2D domain mesh to be convex, whereas our method does not have that restriction. If the 3D mesh is actually planar, our method produces an affine map of that mesh.

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CP2

**Piecewise Convex Contouring of Implicit Functions**

In this paper we represent a 3D environment generated using piecewise convex contouring of scalar fields. The modeling technique is based on CSG operations and fractal subdivision. Using the scalar grid, we adopt per-grid-point texture representation and generate per-vertex texture information using linear interpolation. With the flexibility of implicit representation of both geometry and texture, we were able to do real-time rendering of special effects such as destructive geometry and alpha blending.

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**Robust Voronoi Diagrams of Polygonal Contours**

The Voronoi diagram (VD) of a set of 2D polygonal contours is a useful topological data structure for many applications in manufacturing, eg. offsetting in rapid prototyping. We present a numerically robust algorithm that constructs the VD where the input sites are 2D line segments and vertices, such as those created by a planar slice through a 3D polyhedral model. Our algorithm is structured around three new numerically-adaptive predicates: oriented-inscribed-circle-center, site-in-circle, and site-proximity-test.

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CP2

**Adaptive Sign Detection Method $4 \times 4$ Determinants Using a Floating Point Processing**

The stability of Boolean set operation algorithms is an important issue. This is achieved by using homogeneous processing and the exact integer arithmetic. However, the increase of the data length of integers involves the increase of the computation time. Boolean set operation algorithms modify the topological data structure according to the sign of $4 \times 4$ determinants. An adaptive sign detection method using an FPU is proposed for detecting the sign of $4 \times 4$ determinants efficiently.

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**CP3**

**Cut-and-Paste Editing of Multiresolution Surfaces**

We propose a novel cut-and-paste approach to interactive surface design. In a cut-and-paste step, a geometric feature is cut from one surface and pasted onto another. This technique is especially useful in early design stages when many different options need to be explored. A feature is transferred between surfaces by separating the source surface into a base surface and a 3D offset feature. The offset is added to the target surface after reparameterization and resampling. We exploit the multiresolution structure of the surfaces for efficient fitting and multigrid algorithms. Our prototype allows interactive copy-and-paste editing.

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**CP3**

**Subdivision Surface Reconstruction from a Dense Triangle Mesh**

The speaker will present some algorithms on Loop subdivision surface reconstruction from a known dense triangle mesh with arbitrary topology. The initial mesh model is first simplified with a topology- and feature-preserving mesh simplification algorithm. The simplified mesh is further optimized and used as the topological model for defining a piecewise smooth subdivision surface. The subdivision surface is finally fitted from a subset of vertices of the original dense mesh in the least squares sense.

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**CP3**

**Interpolation Constraints in Recursive Subdivision Curves and Surfaces**

We describe and classify various situations which any complete study of interpolation constraints for a recursive subdivision surface needs to consider. This is done in the form of a systematic taxonomy of situation, first of curve interpolation conditions, and then of surfaces. The focus is on conditions in the Doo-Sabin and the Catmull-Clark contexts, but most of the principles applied are equally applicable to other schemes. We classify known results and identify open questions in this domain.

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**CP3**

**Interpolatory Subdivision for Surfaces of Revolution**

We present a non-stationary, four-point subdivision scheme that unifies cubic, mixed trigonometric, and exponential schemes for interpolatory splines. The method is then generalized to closed, quadrilateral meshes. Since the scheme is capable of representing trigonometric functions exactly, the space of surfaces that can be represented by this interpolatory scheme includes surfaces of revolution and helical surfaces.

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**CP3**

**Interpolating Subdivision Surface Revisited**

It is well-known to users of subdivision surfaces that spline-based non-interpolating schemes (e.g. Loop and Catmull-Clark) produce surfaces of unmatched fairness when compared to those from interpolating subdivision schemes (e.g. Butterfly scheme.) We construct a new interpolating subdivision scheme with a small support which we expect can remedy this situation. Like the Butterfly scheme, this new scheme is almost $C^2$ , is interpolating and reproduces all polynomials of bidegree $\leq 3$. Unlike the Butterfly scheme, the new scheme has a support more local than the butterfly; and is based not only on vertex positions but also on auxiliary gradient data. Examples on various triangle meshes of arbitrary topology will be presented. Implementational details, smoothness optimization and also open questions will be discussed.

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**CP3**

**An Algorithm for Tessellating Trimmed Patches Based on Recursive Subdivisions**

Trimmed patches occur inevitably when boolean operations between solids are processed. Tessellating consists in transforming a trimmed patch into a polyhedral approximation. We propose an algorithm for tessellating trimmed patches based on recursive subdivisions. It retains surface definition until the end of the tessellating process and it also ovoids cracks. In order to check the algorithm robustness we implemented it with the X.Scheng algorithm (based on delaunay triangulation) and we compared their

performances.

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CP4

**Some Geometric Aspects of the Orlicz Spaces**

We study the geometry, from analytical and computational point of view, of the interseccion of spheres of the Orlicz space with planes spanned by two simple and linearly independent functions.

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CP4

**Minkowski Geometric Algebra of Quaternion Sets**

The Minkowski product of quaternion sets is defined and investigated, extending the recent work of Farouki, et al. on the Minkowski product of complex sets. Some interesting products are calculated. A theorem is proven that relates the quaternion Minkowski product of bodies of revolution with a radial symmetry axis to the complex Minkowski product of their 2 dimensional slices along their axis of symmetry. A generalization of the quaternion Minkowski product is proposed which reduces in special cases to Laguerre geometry and to the standard Minkowski product. It is demonstrated that this generalization can generate a wide range of surfaces, including all canal surfaces and all ruled surfaces.

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CP4

**Natural Geometry Weighted-Point and Vector Space**

In this paper, we give a new definition of point : weighted point. (This term was used before but we give a totally different meaning to that. ) Under the new definition we can unify points and vectors, give quite a number of geometry theorems new meanings and make a lot of calculation simple , more importantly, possible! And amazingly , Euclidean geometry, affine geometry and projective geometry come up naturally under this simple concept.

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CP4

**Stability of B-Spline Wavelets**

We will here present some stability results of a basis for the $L_2$ complement space to a coarse spline space $S_{d,\tau}$ in a refined spline space $S_{d,t}$. Only linear splines where the knot vector $t$ includes all knots in $\tau$ plus one knot inside each knot interval will be considered.

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CP4

**An Extended Domain for the Analytic Blossom**

In a previous work, we defined the blossom of an analytic function over an infinite number of arguments almost all of which are zero. Here, we generalize this notion of blossom to a more general domain, so that infinitely many arguments can now be non zero. We show that this new definition of the blossom is more statisfying; as an example, this new blossom is affine invariant.

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CP5

**Minimal Degree Determining Sets for C1 Functional Surfaces over Non Structured Tensor Product Patches**

This work generalizes the Bivariate Spline Finite Element approach to arbitrary convex quadrangulation of a given planar domain $T\Omega$ and subparametric Beziér tensor product FE for every mesh element. Choice of in plane parameterization a priory provides a way of linearization of $C^1$-continuity conditions and allows to define the notion of the minimal determining set (MDS) of the control points. The MDS are explicitly built for the space of $C^1(T\Omega)$-smooth, piecewise parametric polynomials of degree $n \geq 4$. No restrictive assumptions regarding the underlying mesh structure are required. The approach works for quadrilateral meshes; no macro-elements are used. The MDS are constructed for both polygonal meshes and meshes with $G^1$-smooth global boundary. Different MDS which are suitable for different interpolation/boundary conditions are analyzed.

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CP5

**Triangular Patch Modeling Using Combination Method**

A triangular patch that interpolates given boundary curves and cross-boundary slopes is formed by blending three traditional side-vertex interpolation operators with a new, *interior interpolation operator*. The new operator is the solution of an interpolation process which interpolates both the interior and the boundary of the triangle. The new operator has better approximation precision on the interior of the triangle than the side-vertex operators. The constructed triangular patch reproduces polynomial surfaces of degree four.

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**CP5**

**Variational Surface Design with Multiresolution Constraints**

We present a framework for interactive modeling of Catmull-Clark subdivision surfaces using point, normal, and curve constraints. Our method extends the work of Halstead et al (1993) by combining the isometric parameterization of Kobbelt (2000) with a novel multigrid approach for thin-plate energy minimization. We start with a set of constraints defined on the limit surface and propagate them to coarser levels using the subdivision masks. The level down to which a constraint is restricted is a parameter of the algorithm and is used to control the extent of the editing operation. During relaxation the constraints are solved in the least-squares sense at each level and energy minimization is performed using a modified version of the Uzawa algorithm. We apply the standard subdivision rules for prolongation.

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**CP5**

**Circle Splines on the Sphere and in 3-Space**

We present a fair and robust curve interpolation scheme inspired by the globally optimal minimum variation curve (MVC). This scheme has local support and relies on a carefully designed blending between circular arcs so that our curves approach zero variation in curvature wherever possible. These so-called C-splines robustly produce fair-looking G2-continuous curves even through rather challenging sets of interpolation points. This general scheme is applicable in the plane, on the sphere, and in 3D.

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**CP5**

**Approximation of the Energy Integral for a Piecewise Polynomial Surface**

In surface reconstruction driven by principles of physics, e.g. incorporation of mass distributions, internal deformation energies, forces, minimization of some kind of energy functional, and other physical quantities into the surface's geometric substrate, the dynamic behavior resulting from the set of non-linear differential equations is solved using numerical techniques. Here we consider only the natural energy in bending where the numerical solution to the bending is computationally expensive. This paper explores the approximation of the computation for the bending energy function associated with the surfaces that are represented in Bernstein-Bzier form. The formulas are derived recursively and are suitable for various interpolation and smoothing methods. The role of present approximation in the computational efficiency has also been discussed. In this work the specific application to 3-D cubic and quartic surfaces has been considered. The solution developed here can be used in other methods, i.e. data dependent triangulation, minimal energy surfaces using spline fitting, etc.

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**CP5**

**Variational Spline Interpolation**

We consider the problem of interpolating subsets (such as points, lines, surfaces, and tolerance zones) in certain spaces (such as Euclidean space, or a surface in Euclidean space), by $C^2$ curves which minimize the linearized bending energy $\int \|c''\|^2$. We consider existence, uniqueness, and computation of solutions for several important cases. The simplest of these cases, interpolation of points in Euclidean space with a $C^2$ curve, is the well known case of interpolation with a cubic B-spline curve.

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**CP6**

**Physics-Based Pde Solids with Global and Local Constraints for Geometric Design**

We present a unified dynamic approach to model solid objects using second-order or fourth-order elliptic PDEs with flexible and general boundary conditions. It permits designers to directly deform PDE solids naturally and intuitively through the use of generalized global and local constraints subject to physical behaviors. Users can easily model solids of complicated geometry and/or arbitrary topology with locally-defined PDE primitives through trimming operations. The PDEs are solved numerically using the finite-difference discretization and the multi-grid subdivision. Our PDE technique offers various sculpting toolkits for geometric design, including interactive modification of the physical and geometric properties on boundary surfaces, and direct manipulation of any interior regions of modeled solids.

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## CP6

### Solving Geometry Re-Use - Experience and Tools

Re-use of geometric models in a different system is not trivial, and experience gathered across European and US industries will be presented alongside with tools which improve the re-use processes. Translators between different systems are improving, but fully automatic exchange of reusable models is generally thwarted by the human factor during geometry creation. Solutions focus on intermediate stages of quality control (e.g. "six sigma" process improvement) combined with automatic data repair and interactive rework using specialised tools.

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## CP6

### Feasibility of Shape Design Method Based on the Velocity Parameter

We usually have analogical inference with physical phenomenon "H. Hagen, Simulation-based surface and solid modeling techniques, The Mathmatics of Surfaces VIII, 1998." designing 3D shape to realize our image. For example, high speed car and airplane are designed by sharp shape, because we consider fluid dynamics. From this result, we assert shape image is characterized by velocity parameter and study the feasibility of characteristic curve designed method based on the velocity parameter.

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## CP6

### Shadow Generation Based on Re Loops and Their Angular Representations

A new shadow generation technique without the need of performing expensive tests is presented. By storing the angular representations of the ridge edge (RE) loops in a look up table, one can avoid the need of decomposing RE loops into non-overlapping loops and, consequently, the need of performing extensive edge-edge intersection tests. Actually, one can use the table in the scan conversion process to mark the pixels that are in shadow directly, without the need of performing any ray-polygon intersection tests as required in the shadow-volume based shadow generation algorithm.

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## CP6

### A Quasi-Monte Carlo Method for Computing Surface Areas of CSG Models

A quasi-Monte Carlo method is presented for computing the surface areas of CSG models using low discrepancy sequences. This method is based on the Cauchy-Crofton and Maurer-Cartan formula in integral geometry, which relates the surface area of a 3D object to the number of intersection points between the bounding surface of the object with a set of lines in $E^3$. Low discrepancy sequences are used to generate the set of lines to reduce the estimation errors that would be caused by using statistically uniformly distributed lines. Experiments show that this new method is more efficient than the conventional approach based on surface tessellation.

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## CP6

### Interference Analysis of Ellipsoids

Interference analysis of two ellipsoids refers to classifying the interference pattern of two ellipsoids into one of the following cases: separation, intersection, and containment. It is shown that all possible interference patterns of two ellipsoids can be classified by isolating the roots of their quartic characteristic equation; for instance, two ellipsoids are separated by a plane if and only if their characteristic equation has two distinct real positive roots. These results enable interference classification to be carried out more exactly and efficiently than other existing methods based on numerical techniques or polyhedral approximation of ellipsoids.

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**CP7**

**Nurbs Fitting Through Large Sets of Scattered Data**

The paper presents significant improvements in the computational efficiency of least squares fitting of NURBS based on the newly observed and proved sparse structures of relevant matrices. The memory requirements are linear with the number of control points and independent on the number of measured points. The computational time for setting normal equations is linear with the number of measured points while the solving time is linear with the number of control points.

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**CP7**

**Smooth Connection of Trimmed Nurbs Surfaces**

An automatic smooth surface connection method with tension control capability is presented. The connection satisfies pseudo-$G^1$ or pseudo-$C^1$ smoothness requirement. The construction process consists of four steps: *connection curves construction and alignment*, *initial blends construction*, *setting up continuity constraints*, and *internal and external boundary smoothing*. The new method includes the classical blending as a special case but with more flexibility on the setting of the rail curves. Smoothness of the connection surface is achieved through energy optimization.

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**CP7**

**Incremental Algorithms for The Design Of Triangular-Based Spline Surfaces**

We present a new de Boor-like algorithm to design triangular $C^1$-splines based on general triangulations. Through careful analysis of the continuity constraints, we discovered a way of choosing strategic control points, so that the remaining control points are computed using a simple propagation scheme. Due to its local nature, the algorithm can be easily made incremental. It operates in linear time. Holes and sharp corners are easily handled. The algorithm can be extended to $C^2$-splines.

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**CP7**

**Surface Reconstruction by Fitting Unorganized Curves**

We present a novel technique to reconstruct a B-spline surface from unorganized curves in 3D space. Unlike the lofting or skinning methods, where the family of curves to be lofted form isoparametric lines of the resulting surface, our method relaxes this restriction and allows a set of curves to take arbitrary orientation and possibly intersect each other. We employ the concept of a curve on a surface which is used in obtaining the arc element of a curve on the surface in differential geometry.

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**CP7**

**Data Reduction for Scattered Data**

Data reduction is particularly useful in surface approximation because of the large amount of data usually given. In this work scattered data are considered, extending an approach previously introduced by the authors in case of gridded data. First the given set of data is replaced with a new one of smaller size by means of the iterative nonlinear Jacobi method and a suitable data distribution is obtained thanks to the use of a "shape" function based on the discrete Gaussian curvature. Then, an approximating surface is defined through radial basis functions whose knots are positioned taking care of the information given by the discrete Gaussian curvature distribution.

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**CP7**

**Gamma Shapes**

Gamma Shapes are a variation on Alpha Shapes (Edelsbrunner and Mucke). The motivation is similar to that for "weighted Alpha Shapes", but the mechanism and the results are different. The key idea is that the radius (alpha) of the cutting ball is locally modulated by a scalar field. Our driving application is the reconstruction of surfaces from scattered data. We show how to use intermediate results from (Amenta, et al.) to derive the scalar field.

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CP8

**Shape-Preserving Interpolation Based on Dmbvp**

The spline theory is mainly grounded on two approaches: the algebraic one (where splines are understood as smooth piecewise functions, see, e.g. [5]) and the variational one (where splines are obtained via minimization of quadratic functionals with equality and/or inequality constraints, see, e.g. [4]). Although less common, a third approach, where splines are defined as the solutions of differential multipoint boundary value problems (DMBVP for short), has been considered [1,2]. Even though some of the impotrant classes of splines can be obtained from all three schemes, specific features sometimes make the last one an important tool in practical settings. We want to illustrate this fact by the examples of hyperbolic tension splines and generalized thin plate splines. For the numerical treatment of DMBVP we replace the differential operator by its difference approximation. This permits us to avoid calculating hyperbolic functions and to easily find mesh solution whose extension will, however, be a discrete tension spline with continuous differences instead of derivatives. Recently discrete generalized splines and GB-splines have been studied in [3]. We consider the basic computational aspects of this approach and illustrate its main advantages.

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CP8

**Interactive Design of Interpolating Splines.**

We present an interactive procedure to construct a smooth 2D convex curve that interpolates a given sequence of points. Having constructed a convex curve that interpolates $k$ points the program restricts the area in which an additional $(k+1)$ point could be placed by the user, so that the convex spline can be extended to interpolate the latter point. Given a more general, not necessarily convex, sequence of points the above idea is used to subdivide it, into "monotonically convex" subsequences to each of which it is fitted a "Catmull - Rom like" spline.

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CP8

**Approximate Implicit Surfaces and Intersections**

We present some results from our experiments with approximate implicit surfaces. Such surfaces can often be found with high enough accuracy to be useful even with low degree. The technique is used in a CAD setting to improve performance and quality of intersection and self-intersection algorithms. Both detection and classification algorithms are discussed. Some numerical properties of the methods used are also covered.

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CP8

**Curve Shape Comparison**

We present a rotationally and translationally invariant comparison technique for planar and space quadratic B-spline curves. We first convert the input curves to piecewise quadratic Bézier curves. Every segment of the curve is defined by three points. We compare them using the theorem of equal triangles. We use for every segment the length of an edge and two signed angles. We have also implemented curve morphing to demonstrate that this technique works fine.

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CP9

**Third Order Invariants on Surfaces**

We use the classical *invariant theory* from the end of the 19th century to determine a complete system of 3rd order invariants on a surface. We get 18 polynomials in the components of the first and the second fundamental form and the covariant derivative of the latter. We will describe the algebraic structure of the invariant ring and demonstrate how the invariants allow us to determine 3rd order structures like *ridges* on a surface.

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CP9

**Developable Surfaces with Creases**

The existence of crumpled paper suggests that there are developable surfaces which are not smooth. A new geometric approach will be presented for studying *developable surfaces with creases*, which in this context will mean developable surfaces which are smooth everywhere except in a finite number of smooth curve segments.

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CP9

**Dual Curves**

A planar algebraic curve $C$ has an implicit equation and a tangential equation. The tangential equation defines a dual curve to $C$. Starting with a parametrization of $C$, we find a parametrization of the dual curve, the tangential equation and the implicit equation of $C$ in a novel way. We find equations whose roots are the parameter values of the cusps and inflection points of $C$. Methods include polar reciprocation and the theory of envelopes.

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## CP9

### Surface Envelopes

Surface envelopes are tight, two-sided enclosures of composite surfaces. They are approximate implicitizations with a known error bound. This helps with intersection and positional queries. The talk gives an efficient construction.

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## CP9

### Morphological Functionals of Spatial Patterns

The Minkowski sum of two sets of $R^d$ is a classical concept in geometry. When one set is a compact convex and the other a ball of radius $r$ centered on the origin, the Steiner formula gives the volume of the new set. This formula supplies $d+1$ coefficients, known as Minkowski functionals or measures. In the framework of integral geometry, Hadwiger has shown that those functionals form a complete system of additive functionals on the set of objects which are the union of a finite number of convex bodies. Even for non-smooth sets, the Minkowski measures are related to familiar measures ; in the case $d = 3$ : covered volume, surface area, integrable mean curvature and Euler characteristic. We show that these functionals can be easily processed on a lattice of voxels and can give geometrical and topological measures of spatial patterns. In particular, they are useful to describe a coverage of point sets with balls of varying radius.

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## CP9

### CAGD Techniques for Manifolds

Given a sequence of points which lie in a differentiable 2-manifold embedded in $R^3$, we propose a method for construction of approximating or interpolating curves that respect intrinsic geometry. The curves reproduce geodesic arcs. They are analogs of Bézier, B-spline, and Lagrange interpolatory curves, and are constructed by substituting geodesic arcs for line segments in the de Casteljau, de Boor and Atiken algorithms. An efficient algorithm for the calculation of geodesics is presented.

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## CP10

### Strategies for Rendering Large-Scale Tetrahedral Meshes for Earthquake Simulation

In this lecture we present strategies for computational analysis of large-scale seismic activity and structural response. The data is based on ground motion and single-degree-of-freedom (SDOF) building simulation. The basic geometry consists of 11,800,639 nodes with tetrahedral connectivity, and a velocity vector in 120 time steps associated with each node. Building locations are associated with selected nodes on the top surface of the layered, block-shaped soil model. The total amount of data generated approximates 40GB. For the simulation, we used the entire topology of the tetrahedal mesh, which represents an area of 20km x 20km. The rupture is 20km deep under the surface. By restricting the visualization to the surface grid, and the actual building response to a selected region of interest, we were able to create interactive simulations for stand-alone desktop visualization of the ground motion, and an interactive computational web-portal that generates the structural response data for selected parameters and visualizes them as an animated GIF or MPEG movie.

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## CP10

### Haptic Feedback in Cagd

Interpretation of computer described geometry has until now been either through computer generated images or though solid copies made by e.g. rapid prototyping. The introduction by www.computouch.no of a small haptic motor integrated into a standard mouse opens up the possibility to feel geometry. The first tests of this prototype mouse has been a small application enabling the user to feel the knot multiplicity as the mouse moves along a B-spline curve. Other examples of haptic interaction is currently planned for implementation.

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## CP10

### Designing Smooth Motions in the Presence of Obstacles

We discuss the following problem which arises in robot motion planning and computer animation: Given $N$ positions $\Sigma(t_i)$ of a moving body $\Sigma \subset R^3$ at time instances $t_i$ and $M$ obstacles $O_j$, compute a smooth motion $\Sigma(t)$ which interpolates (or approximates) the given positions $\Sigma(t_i)$, such that the moving system does not collide with the given obstacles. This work is an extension of known results on the design of motions using methods from CAGD. It involves geometric optimization procedures which are similar to active contour models in Computer Vision.

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## CP10

### Real-time Volume Sculpting System Using Implicit

**Functions**

Our system integrates implicit functions with parametric representation such as piecewise scalar B-splines, which permits interactive and direct manipulation of implicit solids in real-time. All the solids sculpted in our environment are semi-algebraic sets of volumetric implicit functions. By further enhancing our system with physics-based modeling capability, we unify both geometric and physical aspects for implicit solid modeling. We have developed a large variety of sculpting toolkits equipped with a haptic interface to facilitate the direct and intuitive manipulation.

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## CP10
### Geometry Reconstruction and Mesh Generation For Biological Systems From Image Data

One of the most important steps toward the simulation and modeling of biological systems, using anatomy and physiology based computational models, is the process of extracting geometry from image data. The source of image data can be from several different sources like TEM, confocal microscopy, NMR, CT, etc. When using image data, usually in the form of a 3-D stack of 2-D images, the process of feature extraction is highly dependent on the signal/noise ratio, threshold value(s), and filters that are used in the process of segmenting an image. In this talk we will describe how we extract 3-D geometry from stacks of 2-D image data. This process will be demonstrated using NMR images of the upper and lower respiratory tract of rats and for confocal microscopy images for cells. The result of the geometry reconstruction process are surfaces which are then used to define closed geometric objects which are meshed using a hybrid mesh generator.

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## CP10
### Hierarchical B-Splines for Image Registration

Deformation addresses the problem of mapping one shape onto another one. We present a deformation method which is based on the concepts of free form deformation, hierarchical B-splines, and scattered data approximation. It is adaptive in that it puts more effort in complex regions which need more attention. It has a variety of applications in animation, target recognition, and image registration.

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## CP11
### The Geometry of Buckled Developable Surfaces for Binder Design

In the binder-forming stage of a sheet-metal stamping process, the binder ring closes on a flat blank, bending it to a shape called the binder wrap. Since the blank is bent isometrically, the binder wrap surface will be developable, but not necessarily smooth. The author will review the basic geometry of folded and buckled developable surfaces and describe a method for designing approximations of buckled binder wrap surfaces by triangulation.

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## CP11
### Computational Issues in Layered Manufacturing

Geometric models suitable for computer graphics display are often inadequate as input for layered manufacturing. Problems can arise due to round-off errors during modeling or process planning, during data translation, etc. Operations to close cracks in B-reps may even introduce self-intersections. We will discuss techniques for reducing the incidence of such errors, but also argue that data exchange standards must include well-defined semantics for consistent interpretations of ambiguous input to replace current manufacturer-specific ad-hoc solutions.

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## CP11
### Tool-Path Linking Algorithm for Contour Parallel Machining

Contour-parallel offset (CPO) machining uses successive offsets of the boundary curves of the machining region as the tool-path-elements. For the efficiency of the CPO machining, it is very important to minimize the number of tool-retractions causing additional tool movements, which don't contribute to the actual cutting. Presented in the paper is a CPO tool-path linking algorithm, which guarantees 'zero' number of tool-retractions. The algorithm employs the concept of a 'TPE-net' providing the information on the parent/child relationships among the tool-path-elements. By find a tour through the TPE-net, a CPO tool-path without tool-retractions can be generated.

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## CP11

### Traversing a Machining Graph of a Pocket

We present simple and linear-time algorithms for solving the problem of traversing a machining graph with minimum retractions encountered in zigzag pocket machining. The major result is a linear-time algorithm that finds a traversal of the machining graph of a general pocket P with Nh holes, such that the number of retractions in this traversal is no greater than OPT+Nh+Nir, where OPT is the (unknown) minimum number of retractions required by any algorithm and Nir is the number of irregular blocks in P (to be defined in the paper). When the step-over distance is small enough relative to the size of P, Nir becomes zero, and our result deviates from the true minimum by at most the number of holes in P, a significant improvement over the 5*OPT + 6*Nh + 1 upper bound achieved in references [1,3]. In particular, if Nh is zero as well, i.e. when P has no holes, our linear-time algorithm outputs an optimal result.

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## CP11

### Performance Analysis of Cnc Interpolators for Time-Dependent Feedrates Along Ph Curves

Previous studies have shown that the PH curve CNC interpolators entail exact computations of tool locations in real time, and is thus very suitable for high-speed machining of complex shapes. This paper discusses time-dependent feedrate functions for PH curve interpolators, which offer powerful capability of specifying variable feedrates along curved paths. Experiments on an open-architecture CNC machine verifies that the performance is greatly enhanced, both in the accuracy and smoothness of the machine tool motion.

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## CP11

### Optimal Design of Self-Aligning Robot Gripper Jaws

Assembly lines often require grippers. It is possible in many cases to compensate for the difference in part orientation using a parallel-jaw gripper with appropriate jaw design. The idea is to arrange contacts on each gripper jaw so that the part is aligned as it is grasped and yet cannot jam. We consider jaws based on a set of trapezoidal jaw modules that maximize contact between the gripper and the part at its desired final orientation. Furthermore, jaws are constrained to capture and rotate the part to its desired orientation and achieve a form-closure grasp. Given the $n$-sided 2D convex projection of an extruded polygonal part, we present an implemented $O(n^3 \log n)$ algorithm to efficiently construct optimal jaw design. The algorithm combines toppling, jamming, non-liftoff, accessibility, and form-closure analysis. We also develop an $O(n \log n)$ algorithm to find a tolerance class for jaws (specified as maximum and minimum material conditions) given the optimal jaw design. We introduce new geometric functions and a new data structure, the toppling graph, to represent the mechanical and geometric properties of jaw design. We implement the algorithm in Java and verify the resulting jaw design by physical experiments.

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## CP12

### Efficient Approach to Adaptive 4-8 Mesh Generation

Triangular meshes with subdivision connectivity are popular in applications such as visualization and finite element analysis. We consider a particular class of such meshes known as *4-8 meshes.* These meshes are used to triangulate matrices of amplitudes (e.g. terrains). More recently, Velho and Zorin have shown how to obtain approximations of subdivision surfaces using 4-8 subdivision rules. We present an efficient approach to generate adaptive representations of 4-8 meshes. In adaptive representations, triangles are concentrated in regions with "high activity", whereas smooth areas are approximated with large triangles. Our algorithm is inspired from an algorithm used to compute adaptive quantizers for compression presented by Chou et al. A similar algorithm has also been used by Ramchandran and Vetterli to compute optimal wavelet bases for image coding. Our mesh approximation problem poses further constraints and we explain how to address them in this talk. Our algorithm to generate adaptive representations has a fine to coarse approach. More precisely, an approximation of an initial fine mesh is obtained by successive decimations of vertices. Coarse to fine approaches have previously been proposed by Lindstrom et al. and Pajarola et al. However, these solutions use local error metrics and a greedy strategy to optimize the mesh. In contrast, we use a global error metric based on an optimal approach used in compression. We define a rate-distortion framework to obtain a metric for simplifying the mesh. A rate and a distortion functional is evaluated at each vertex. We show how to maintain global error estimates for the vertices when computing approximations. We explain that a direct algorithm using the global estimate has cost $\Theta(n^2)$. Our solution uses several properties of the 4-8 construction to obtain an efficient $Theta(n \log n)$ algorithm using the same error metric. In conclusion, our approach, optimal with respect to a global error metric, has the same computational cost as previously proposed greedy strategies using local error.

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**CP12**

**Sample Shuffling for Quality Hierarchic Surface Meshing**

A variety of applications need to compute a surface mesh from a set of discrete sample points obtained by some scanning device, or generated by some scientific simulations. A mesh hierarchy for mutiresolution modeling can be created from such samples by first generating a sample hierarchy and then computing surface meshes from them. This approach preserves geometric and topological features automatically and avoids self-intersection, a major concern in the edge collapsing methods used for mesh decimation. In order to create the sample hierarchy, we introduce the sample shuffling technique which deletes and repositions the sample points so that the triangles have bounded aspect ratio in a resulting mesh out of them.

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**CP12**

**Automated Gear Teeth Grid Generation Via Solution of Elliptic Pdes**

This paper discusses the source term treatment in the numerical solution of elliptic partial differential equations for an interior grid generation problem in generalized curvilinear coordinates. New constraints on the parameters in the source terms are derived. The new formulation thus affords a fully automated elliptic grid generation capability without having to input any parameters, which is absolutely essential for unsteady problems of structural dynamics where grids need to be re-generated continuously in time.

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**CP12**

**High Quality Triangulation of Point Clouds by Simulated Annealing**

We present a new algorithm for the triangulation of a set of unorganized points. In contrast to many other approaches, we can guarantee the reconstruction of topolgically correct manifold triangle meshes without holes even for sparsely sampled surfaces. These results are achieved by combining an algorithm for local Delaunay triangulations with the technique of simulated annealing. In addition we improve the quality of the surface by an edge flipping algorithm based on discrete curvature analysis.

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**CP12**

**Dynamic Unstructured Grid Generation Using Spline Fitting over Data Dependent Triangulation**

Grid generation is an essential part of any analytical tool for effective discretization. Since there is no underlying structure (enforced) in unstructured grids so this technology is computationally efficient especially for higher order computations. In general the problem of grid generation to a scattered data (3D) is done by applying the construction of piecewise polynomial parametric surfaces which interpolate prescribed 3D scattered data using spaces of parametric splines defined on 2D triangulation. In these methods projection is involved so this may restrict the quality of the grid in the geometry sensitive cases. In order to get dynamically meaningful grids, it has been proposed by various authors in modern times to incorporate the principles of physics in surface modeling, e.g. minimization of some kind of energy functional over the surface. This paper explores the possibility of unstructured grid generation using piecewise polynomial parametric surfaces which interpolate prescribed 3D scattered data using spaces of parametric splines defined on 3D triangulations in the case of surfaces consisting of complex curves. The method is based upon minimizing a certain natural energy expression over the parametric surface. The geometry is defined as a set of stitched triangles prior to the grid generation. As for topological continuities between the two triangular patches a combination of zero, first or second order directional continuities, as per the requirements, has been imposed. This method also allows for refinement (i.e. global or local) based upon global (dynamic property) or local (weights user's defined).

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**CP12**

**Adaptive Mesh Generation for Analysis and Optimisation**

We describe the interactive design and functional optimisation of thin-walled, plastic structures. When designing these objects it is important to minimise the amount of plastic used, to reduce production costs and to conserve raw materials. An important aspect we consider is the generation of a valid mesh from the surface geometry. We show how the necessary surface mesh can be generated and adapted for complex practical objects subjected to functional analysis and optimisation.

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**MS1**

**Tetrahedral Subdivision of Solids**

Besides for the modeling of surfaces, subdivision is of interest for data compression and for numerical simulation. The latter two issues are even more important for 3D-space than just for 2D. Therefore, subdivision for volumes is of some importance. We will derive several subdivision rules for tetrahedral subdivision of 3D-space, discuss the smoothness and convergence properties of the different schemes. We also present some applications for compression of volume data.

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### MS1
### Subdivision Surface Interference Detection

Subdivision surfaces show great promise for applications in engineering design and computer animation. Algorithms that detect interference are key to these applications. We introduce a framework for interference and self-interference detection of subdivision surfaces undergoing arbitrary deformations, with optimizations specifically for self-interference detection. In particular we introduce techniques to bound the direction of surface normals of irregular surface patches, which cannot be treated with the approaches previously reported for splines. Such bounds have been previously used to optimize applications in constructive solid geometry, machining and milling, simulation, animation, trimming, surface area approximations, silhouette curve computations, and rendering. Our results make such bounds available for subdivision surfaces.

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### MS1
### A Subdivision Scheme for Surfaces of Revolution

This paper describes a simple and efficient non-stationary subdivision scheme of order 4. This curve scheme unifies known subdivision rules for cubic B-splines, splines in tension and a certain class of trigonometric splines capable of reproducing circles. The curves generated by this unified subdivision scheme are a $C^2$ splines whose segments are either polynomial, hyperbolic or trigonometric functions, depending on a single tension parameter. This curve scheme easily generalizes to a surface scheme over quadrilateral meshes. For a particular choice of tension parameters, the scheme reproduces a variant of the Catmull-Clark subdivision scheme. As an application, this scheme is used to generate surfaces of revolution from a given profile curve.

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### MS1
### Advances in Subdivision Methods

I will provide a survey of the recent advances in subdivision techniques, including new subdivision schemes for surfaces, algorithms for computing intersections of subdivision surfaces, subdivision surface trimming and boolean operations on solids bounded by surfaces. I will also briefly describe the current state of the theory of subdivision surfaces and some important open problems.

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### MS2
### Least-Squares Fitting of Algebraic Spline Surfaces

We present an algorithm for fitting algebraic spline surfaces to scattered data. In order to obtain a method which is both computationally simple and geometrically invariant, we approximate simultaneously point data and associated normal vectors. The method can be applied both to tensor-product representations and to other domain splits, in order to generate lower degree algebraic spline surfaces. For instance, using trivariate Powell Sabin elements, we may fit a quadric spline surface to given data. The talk will also discuss the potential applications of algebraic spline surfaces in reverse engineering.

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### MS2
### Approximate Implicitization

Within CAGD parametric and algebraic descriptions are combined to achieve good computational efficiency for conic sections and quadric surfaces. For more complex smooth shapes piecewise rational parametric descriptions (NURBS) dominate. The reason is that the process of finding an algebraic description is computational expensive, results in algebraic surfaces of high degree and requires exact arithmetic. A method for the approximation of piecewise rational parametric manifolds of a chosen degree with an algebraic hypersurface is presented. This method has good convergence rate, uses singular value decomposition to find a set of alternative approximations and enables the selection of an approximation to be based on required behavior of the gradient of the resulting approximating algebraic surface. The EU - FET assessment project GAIA IST-1999-29010 "Application of approximate algebraic geometry in industrial computer aided geometry" (October 1st 2000 - September 30th 2001) addresses the use of approximate implicitization within CAD. The potential of this approach for improving intersection and self-intersection of CAD-type surfaces is analyzed.

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### MS2
### Three Implicitization Methods for Rational Surfaces

This talk surveys three current techniques for implicitizing rational surfaces: classical resultants, moving surfaces (syzygies), and A-resultants. Classical resultants for bivariate polynomials, such as the resultants of Sylvester, Cayley, and Macauley are effective tools when the rational surface is free of base points. But when base points are present, classical resultant methods require expensive perturbation techniques. Moving surfaces work well even in the presence of base points, and base points may even help to simplify the accompanying computations. Nevertheless, at present, the general method of moving surfaces still requires solving a large system of linear equations. A-resultants are specialized resultants, adapted to work in the presence of base points. These A-resultants are especially effective for implicitizing certain multi-sided Bezier patches generated by toric varieties. This talk will examine each of these three implicitization techniques, highlighting the advantages and disadvantages of each approach.

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**MS2**
**Parameterization Methods for Algebraic Surfaces**

An algebraic curve or surface is called unirational iff it may be given by a parametrization (x,y)=(X(t),Y(t)) or (x,y,z)=(X(s,t),Y(s,t),Z(s,t)), respectively, where X,Y(,Z) are rational functions in (s,)t. The unirational curves are precisely those with genus zero. A similar characterisation for surfaces is given by Castelnuovo's theorem: a surface is unirational over the complex numbers iff its arithmetic genus and its second plurigenus vanish. The parametrization problem is the problem of finding a parametrization for a given unirational curve/surface. Usually, one wants to construct parametrizations with real coefficients. This talk gives a survey over the main aspects of the parametrization problem for surfaces.

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**MS3**
**Angle Based Flattening of Tesselated Surfaces**

his work proposes a new method to compute planar triangulations of faceted surfaces for surface parameterization. In contrast to previous approaches that define the flattening problem as a mapping of the three-dimensional node locations to the plane, our method defines the flattening problem as a constrained optimization problem in terms of angles (only). We minimize the relative deformation of the angles in the plane with respect to their counterparts in the three-dimensional surface while maintaining a set of constraint which ensure the validity of the two-dimensional mesh. This approach makes the method more stable and robust than previous approaches, which used node locations in their formulations. The new method can handle any manifold surface for which a connected, valid, two-dimensional parameterization exists, including surfaces with large curvature gradients. It does not require the boundary of the flat two-dimensional domain to be predefined or convex. We use only the necessary and sufficient constraints for a valid two-dimensional triangulation. As a result, the existence of a theoretical solution to the minimization procedure is guaranteed.

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**MS3**
**Parameterization with Constraints**

Abstract not available at press time.

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**MS3**
**Quasi-Conformal Flattening of Tessellated Surfaces with Applications to MRI Data of the Human Brain**

It is impossible to flatten a surface embedded in 3-space without introducing linear and areal distortion. However, the Riemann Mapping Theorem states that conformal (angle-preserving) maps exist. I will present a novel computer realization of the Riemann Mapping Theorem that uses circle packings to compute an initial approximation of the conformal (flat) map of a tessellated surface. I will also present results obtained by applying this method to data from the human brain. A tessellated surface representing the grey matter of the human brain can be constructed from magnetic resonance (MR) images. Because of its complexities, there is great interest by the neuroscience community to "unfold" and flatten this surface to create a flat map of the brain. These flattened surfaces from different subjects can then be compared to elucidate information about individual differences in the functional organization of the brain.

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**MS3**
**Parameterization of Tessellated Surfaces for Surface Mesh Generation**

Parameterized surfaces can be used to efficiently generate high-quality unstructured surface meshes suitable for finite-element analysis. A mapping procedure is presented to parameterize tessellated surfaces for use in cases where a parameterization does not exist or where a single parameterization for multiple surfaces is required. The mapping procedure is derived from the topological connectivity of a given tessellated surface. Parameterized coordinates are obtained by solving a set of Laplacian equations coupled through adaptive boundary conditions. The overall surface mesh generation procedure is based on the well-proven Advancing-Front/Local-Reconnection (AFLR) method. Results are presented which demonstrate that near orthogonal parameterizations can be automatically obtained in an efficient manner for a variety of tessellated surfaces. Also, results are presented which show that high-quality unstructured surface meshes can be efficiently generated on surfaces defined by multiple patches using these procedures.

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**MS4**

**Quantifying Shape Deformation Based on Gradients of the Mapping**

This paper introduces a method to quantify the similarity between two objects. The objects should be represented by simple polygons, i.e. as linear approximations of their boundaries. Assuming a correspondence of the boundaries is given we construct compatible triangulations of the given polygons. We introduce a notion of similarity on these triangulations: The similarity of two triangulations is defined as the median similarity of their corresponding triangles. The similarity of two triangles can be expressed by the gradient of their mapping. This is done by cost functions of the Jacobi matrix. We propose a cost function which considers the eigenvectors. The in influence of the triangulations can be reduced by optimizing the vertex coordinates, so that similar figures are triangulated similarly. Further optimization can be done by splitting and collapsing edges. The definition of the cost function can be extended to continuous space to become independent of triangulations.

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**MS4**

**The Role of Models in Shape-Based Reasoning**

Formally representing objects through models is fundamental in any application field. The term model usually means a mathematical construct which describes real or virtual objects, with the addition of some verbal interpretations. Despite the evolution in Geometric Modelling, however, much of the information our senses collect is visual and shape-oriented, and much of our knowledge about the physical world comes to us in the form of shape information. Reasoning about shape is a common way of describing and representing real objects in engineering, architecture, medicine, biology, physics and in daily life. Modelling shapes is part of both cognitive and creative processes, and from the outset models of physical shapes have satisfied the desire to see the result of a project in advance (the very origins of the architects profession). So far, all development has focused on geometry, which provides a complete description of the (geometric) shape of a solid. The aim of this paper is to investigate new modelling approaches able to represent both geometry and semantics. In seeking to associate shape and meaning, the physical universe, related to the real or virtual world, should be integrated with a "semantic universe" should be considered for representing human knowledge of a particular domain. The mathematical abstraction of this knowledge is based on the notions of class and class structures. Since classification depends on human experience and individuals may form different sets of concepts depending on context and culture, more than one class structure should be defined for a domain, thus allowing the coexistence of multiple classification. In particular, when we want to abstract geometry and semantics, there may be different but equally valid class structures for the same geometric model. In other words, the shape of an object is unique and can be modelled fixing one mathematical abstraction of its geometric characteristics, while its semantics are multiple and can be modelled differently according to the choices made by the user. Therefore, the key issue is to clarify the notion of shape through the comprehension and formalization of the basic activities beyond shape understanding and reasoning processes. In particular, the use of similarity and equivalence relations among shapes are considered basic constructors of shapes and shape classes and their possible use will be exemplified by practical applications to CAD/CAM and terrain modelling.

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**MS4**

**Topological and Morphological Structures for Shape Description**

Techniques of computational topology will be described, which can be used to define and extract morphological structures from geometric models. In particular, approaches of differential geometry and topology (curvature, critical points and Morse theory) will be addressed and a method to extract a topological graph from a surface mesh will be presented. By adding geometric information to the topological graph, the morphology (or structure) of a given surface can be efficiently described and represented. The resulting morphological skeleton can be used to provide a minimal rendering of objects as well as a topologically correct compression of the original model. Issues related to the use of such structures in relation to shape similarity assessment will also be discussed.

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**MS4**

**Matching and Retrieval of Polyhedral Shapes**

Shape matching is an important ingredient in shape retrieval, recognition and classification, alignment and registration, and approximation and simplification. In this presentation we will give an overview of geometric approaches to matching 3D shapes represented by polyhedral models. We will discuss properties of similarity measures in relation with retrieval, present a retrieval framework, and show some experimental results.

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**MS5**

**Multi-Level Triangulations of Scattered Data and**

**Real-Time Rendering of Terrain Surfaces**

We present a multi-level representation of triangle-based surfaces constructed from huge sets of scattered data. The multi-level triangulation is based on a combination of domain decomposition and hierarchical methods. In particular, we show how the multi-level representation can be used to obtain resolution and view dependent real-time terrain rendering for flight simulation purposes.

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**MS5**

**One-to-One Piecewise Linear Mappings over Triangulations**

I call a piecewise linear mapping from a triangulation in $R^2$ or $R^3$ to the plane a *convex combination mapping* if the image of every interior vertex is a convex combination of the images of its neighbouring vertices. Such mappings have been used both for parameterization of surfaces and for image morphing. I will discuss various aspects of such mappings, including sufficient conditions for them to be one-to-one.

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**MS5**

**Parametric Surfaces Over Arbitrary Meshes**

Triangular Bézier patches are an important tool for defining smooth surfaces over arbitrary triangular meshes. The previously introduced 4-split method interpolates the vertices of a 2-manifold triangle mesh by a set of tangent plane continuous triangular Bézier patches of degree five. The resulting surface has an explicit closed form representation and is defined locally. In this talk, we introduce a new method for visually smooth interpolation of arbitrary triangle meshes based on a regular 4-split of the domain triangles. Ensuring $G^1$ continuity of the surface is not enough for producing an overall fair shape. Interpolation of irregular control-polygons, be that in 1D or in 2D, often yields unwanted undulations. Note that this undulation problem is not particular to parametric interpolation, but also occur with interpolatory subdivision surfaces. Our new method avoids unwanted undulations by relaxing the constraint of the first derivatives at the input mesh vertices: the tangent directions of the boundary curves at the mesh vertices are now completely free. Irregular triangulations can be handled much better in the sense that unwanted undulations due to flat triangles in the mesh are now avoided. This work was supported by the Europeen Community with the Research Training Network MINGLE (HPRN-1999-00117).

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**MS5**

**Fast Evaluation of Radial Basis Functions**

Interpolation by radial basis functions is a popular choice for reconstructing a function from scattered data. The approach is in general simple and easy to implement, but problems arise if the number $N$ of data points becomes large. Direct methods lead to a complexity of $O(N^3)$ for solving the interpolation equations and $O(N)$ for each additional evaluation. In this talk we review existing methods and present new techniques for overcoming this problem. It is possible to reduce the cost of evaluation to $O(\log N)$ or even $O(1)$ and the cost for solving the equations to $O(N \log N)$ if an intelligent data structure is used.

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**MS6**

**Taylor Series Methods for Rigid Body Simulation and Extensions to Lie Groups**

We present higher-order accurate Taylor series methods for rigid body simulations which perform single-step updates by calculating the average rotation vector during a time step. The higher-order Taylor series terms serve to correct for the non-linearity of rigid body motion. Our algorithms exactly preserve angular momentum, and approximately preserve energy. We further present a method based on the Poinsot ellipsoid to readjust orientation as to exactly preserve energy. The formulas for the Taylor series methods are established in the setting of general Lie groups so similar higher-order accurate methods apply to simulations in Lie groups. The proofs are based on the exponential function and its derivative. Experiments on the simulation of a freely moving, wobbling, rigid body to compare our Taylor series methods and energy preservation with a variety of other methods, including symplectic methods.

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**MS6**

**Applications of Computational Harmonic Analysis on Lie Groups to Geometric Problems**

Abstract not available at press time. Noncommutative harmonic analysis (harmonic analysis on Lie groups) is an area of mathematics which is a generalization of classical Fourier analysis . In this talk, computational techniques of noncommutative harmonic analysis applied to the group of rigid-body motions are used in the context of the geometry of robotic manipulators and polymer chains. It is shown how probability density functions describing the relative position and orientation of one end of a robotic manipulator (or polymer chain) can be generated using these techniques. Issues such as self-avoidance and applications of FFTs developed for Lie Groups will be discussed. These techniques will also be demonstrated in the context of computational molecular biology, and particularly as applied to the conformational analysis of stiff macromolecules such as DNA.

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### MS6
### Geometric Motion Design and Lie Groups

Modeling, planning, and programming many mechanical tasks require generation and animation of movement of rigid bodies. Such tasks include computer animation, key framing, robot path planning, reconstructing dynamic scenes in computer vision, and numerical control machining. Although well-established techniques exist for interpolation and approximation in finite dimensional vector spaces, the same is not true for the underlying nonlinear geometry of the space of rigid body motion. Using Lie Groups, coordinate invariant methods of Reimanian geometry can be used to represent rigid body motions in a way that the curved geometry of the underlying space is taken into account. The computational structure of the Lie Algebra associated with Lie Groups then provides for a computational framework for motion interpolation and approximation. Techniques are developed for motion approximation and interpolation using the Lie Group structure of Euclidean displacements. The results presented not only advance the state of art in CAGD but also enhances the theory of Lie Groups in mathematics by providing several useful computational results.

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### MS6
### Lie and Symmetry Subgroups of Rigid Motion: Classification and Applications

This talk will trace the evolution of a theory of dimensioning to a theory of parameterization of geometric objects for computer-aided design. After providing a motivation from early works in engineering drafting, it will first show that there are 12 connected Lie subgroups of rigid motion. This will be followed by a classification of continuous symmetry into 7 subgroups. Using this classification, a formalism will be provided for relative positioning of geometric objects. The talk will conclude with an application of this formalism to intrinsic and relational parameterization of geometric models.

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### MS7
### Terascale Visualization: Multi-Resolution Aspirin for Big-Data Headaches

Recent experience on the Accelerated Strategic Computing Initiative (ASCI) computers shows that computational physicists are successfully producing a prodigious collection of numbers on several thousand processors. But with this wealth of numbers comes an unprecedented difficulty in processing and moving them to provide useful insight and analysis. In this talk, a few simulations are highlighted where recent advancements in multiple-resolution mathematical representations and algorithms have provided some hope of seeing most of the physics of interest while keeping within the practical limits of the post-simulation storage and interactive data-exploration resources. A whole host of visualization research activities was spawned by the 1999 Gordon Bell Prize-winning computation of a shock-tube experiment showing Richtmyer-Meshkov turbulent instabilities. This includes efforts for the entire data pipeline from running simulation to interactive display: wavelet compression of field data, multi-resolution volume rendering and slice planes, out-of-core extraction and simplification of mixing-interface surfaces, shrink-wrapping to semi-regularize the surfaces, semi-structured surface wavelet compression, and view-dependent display-mesh optimization. More recently on the 12 TeraOps ASCI platform, initial results from a 5120-processor, billion-atom molecular dynamics simulation showed that 30-to-1 reductions in storage size can be achieved with no human-observable errors for the analysis required in simulations of supersonic crack propagation. This made it possible to store the 25 trillion bytes worth of simulation numbers in the available storage, which was under 1 trillion bytes. While multi-resolution methods and related systems are still in their infancy, for the largest-scale simulations there is often no other choice should the science require detailed exploration of the results.

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### MS7
### Efficient Simplification of Massive Polygonal Models

Over the last decade, the growing availability of polygonal surface models far too expensive to render at interactive rates has led to a significant amount of work in the area of surface simplification. The general goal has been to automatically produce approximate surfaces with far fewer triangles, which nevertheless are as similar as possible to the original. Several effective simplification techniques have been developed, and have achieved fairly widespread use. However, advances in scanning and acquisition technology have started to produce models 1000 times more complex than the largest datasets that prior simplification methods are capable of handling. This has led several researchers to re-think the general strategies adopted by simplification methods, and to formulate much more memory-efficient algorithms, many of which operate on out-of-core datasets. This talk will examine the current approaches to simplifying extremely large polygonal surface models – datasets on the order of 100 million triangles or more. In particular, I will focus on a new algorithm that we have developed for producing adaptive approximations of massive polygonal models. In an initial pass over the model, a volumetric grid is used to quantize the underlying model into some fixed-resolution representation. The resulting fixed-resolution data is then used to construct a BSP-tree which adaptively partitions space around the surface. A final pass uses this BSP-tree to generate an approximate model from the original data. The importance of this algorithmic structure is that it provides output sensitive memory requirements and accesses the original model only in simple linear scans of the data on disk.

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MS7

**Feature Preserving Multiscale Transforms**

Multiresolution methods have been deployed towards analysis of datasets. Although, the focus has been mostly on coding and compression the emphasis on their ability to preserve features has not received ample attention. In this talk, work is presented on the design of linear wavelet transforms that enable the preservation of features. A family of functions that possess the total variation diminishing (TVD) property will be the focus of this talk. We describe how these functions are generated and then demonstrate their effectiveness.

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MS7

**Number Crunching for Large-Scale Earthquake Simulation**

Earthquakes and other natural hazards are highly unpredictable. Complex data models of soil layers and simulation of structural response to earthquakes can help emergency planners to calculate the risk of structural failure, and to develop better emergency plans. Large-scale simulations generate enormous amounts of data, which must be interpreted and correlated in order to get an overview of the situation and a detailed analysis. Zooming and scaling is necessary to understand both local constraints and the global context of the simulation. We present hierarchical methods for web-based rendering and an immersive rendering system for earthquake simulations, which has been tested on an ImmersaDesk, and in a stereoscopic, room-sized projection environment (CAVE).

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MS8

**A Geometric Programming Approach for $L_1$ Splines**

Calculating the coefficients of a cubic $L_1$ spline is equivalent to solving a nonsmooth convex optimization problem with special structure. Properties of the primal and dual problems are described. The structure of these problems makes geometric programming a good choice for carrying out the optimization. We implement geometric programming in a way that utilizes the structure of the primal and dual problems to reduce operation count.

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MS8

**Domain Decomposition for Bivariate Cubic $L_1$ Splines**

Domain-decomposition techniques for parallel computation of the coefficients of cubic $L_1$ splines on tensor-product grids are investigated. No conditions enforcing matching across interior boundaries are used. The results of computational experiments indicate that surfaces patched together from cubic $L_1$ splines calculated on slightly overlapping subdomains coincide with the $L_1$ splines calculated globally on the whole domain. In contrast, cubic $L_2$ splines cannot in general be calculated by domain decomposition without interior matching conditions.

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MS8

**Polygonal Hole Filling by the $L_1$ Spline Method**

We use the $L_1$ method to fill polygonal holes by bivariate triangular spline patches. Dependent on the smoothness of the original surface patches which form a hole, the spline filling patches will match the desirable smoothness. The existence of such spline filling will be shown and several examples will be demonstrated.

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MS8

**Univariate Curvature-Based Cubic $L_1$ Splines**

$C^1$-smooth univariate curvature-based cubic $L_1$ interpolating splines are investigated. In Cartesian and polar coordinates, these $L_1$ splines preserve the shape of multiscale data much better than both curvature-based and second-derivative-based cubic $L_2$ splines. In polar coordinates, curvature-based $L_1$ splines preserve shape better than second-derivative-based $L_1$ splines. Extensions of curvature-based $L_1$ splines to general curvilinear coordinate systems, to bivariate data in spherical coordinate systems and to nonpolynomial splines are outlined.

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MS8

**$L_1$ Splines for Scattered Data Interpolation**

We consider bivariate splines of any degree and any smoothness over arbitrary triangulations. These spline functions are used to construct an interpolation which minimizes the $L_1$ norm of the second order derivatives of all spline interpolants. That is, the interpolation surface possesses the least absolute deviation in the second order derivatives. Thus, the interpolation surface has the least variations. We show the existence of such surfaces and then convert this minimization problem into a linear programming problem and solve it using a variation of Karmarkar's algorithm. Finally, we present some computer demos.

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**MS9**

**Computing Conformal Shapes with Applications to Grothendieck Dessins Andanatomical Mappings**

We present a method of computing the conformally correct shapes of triangulations of curved surfaces using the geometry of circle packings on constant curvature surfaces. The circle packing approximations are more than a path to computing the conformal structures; they provide faithful discrete analogues of the continuous conformal structures and offer great flexibility in adjusting approximations. We show example applications in two areas where curved surfaces arise naturally—first, in computing the conformally correct shapes of the faces of piecewise equilateral surfaces that arise, for example, in Grothendieck's theory of dessins d'enfants, and second, in computing flat conformal mappings of highly curved surfaces in 3-space such as the surface of the human brain. We will end with a tantalizing "science fiction" application of conformal approximation dubbed "conformal compression".

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**MS9**

**Unfolding Planar Polygons Using Energies**

The "Carpenter's Rule" problem asks the following question: Can any planar polygon without self-intersections be convexified by a series of motions which preserve the number of edges and the length of each edge, and which don't introduce any self-intersections during the motion? Connelly, Demaine and Rote recently answered this question in the affirmative, and provided a method to generate unfolding motions numerically. In this talk, which represents joint work with James O'Brien and Erik Demaine, we'll discuss a new, natural method of constructing unfoldings using energy functionals. This approach offers significant numerical and computational improvements in the construction of unfoldings.

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**MS9**

**Differential Operators on Discrete Surfaces**

We consider simplicial complexes equipped with a discrete metric as geometric objects in their own right. Based on this point of view we derive higher order differential operators of polyhedral surfaces, give new results on discrete minimal surfaces and on the index of constant mean curvature surfaces, and provide applications to the Hodge decomposition of discrete vector fields. In several examples we show that these discrete operators provide a good language for studying meshes used in computer graphics. Online experiments may be found at http://www.javaview.de/.

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**MS9**

**Curvature Measures for Discrete Surfaces**

The shape of a smooth surface in space is (usually) determined by its mean and Gauss curvatures. There are various ways to discretize these curvatures and compute them for discrete (triangulated) surfaces which approximate a smooth surface. We consider particular discretizations that have direct interpretations on the triangulated surfaces, independent of how close these are to a smooth surface.

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**MS10**

**The Power Crust Software**

We describe the Power Crust software for surface reconstruction from an input point cloud. This software uses a robust freeware Delaunay triangulation program to reconstruct a solid with the point cloud on its boundary.

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**MS10**

**Jupiter: A Toolkit for Interactive Large Model Visualization**

The fast increasing size of datasets in scientific computing, mechanical engineering, or virtual medicine is quickly exceeding the graphics capabilities of modern computers. Toolkits for the large model visualization address this problem by combining efficient geometric techniques, such as occlusion and visibility culling, mesh reduction, and efficient rendering. In this presentation, we introduce Jupiter, a toolkit for the interactive visualization of large models which exploits the above mentioned techniques. Jupiter was originally developed by Hewlett-Packard and EAI, and it was recently equipped with new functionality by the University of Tübingen, as being part of the Kelvin project. Earlier this year, an initial version of Jupiter was also released as open source.

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**MS10**

**An Open Source 3D Modeling Kernel**

Open CASCADE provides either all the facilities useful to develop CAD/CAM/CAE applications and also an easy to use environment to develop. Users can also enrich geometrical definitions which are automatically understood by all the modeling functions of the system.

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**MS10**

**From Measured Data to a Model in Open CASCADE**

CAD kernels such as Open CASCADE open the possibility to introduce none standard geometry representations and algorithms into a CAD environment. The talk will address the process of going from a 3D measured point cloud to a surface representation that can be interrogated by standard functionality in Open CASCADE. The process has the following steps: 1. Mapping the 3D points into 2D parameter domain 2. Triangulation based on the mapped points 3. Interrogating the surface as a Open CASCADE procedural surface The talk will give examples from the EU sponsored project "Object Oriented Methods Environment for Geoscience Applications" ESPRIT project, No. 23245, and examples from modelling of parametric surfaces from point clouds.

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**MS11**

**Optimization of Profiles, Wings, and Propellers at Low Speeds**

Optimization of aerodynamic objects, such as profiles, wings and propellers, is a multidisciplinary activity that requires input from aerodynamics, structures, controls and possibly manufacturing. To approach such a sophisticated problem with the most elaborate tools from each discipline, such as full Navier-Stokes solver, finite element structure code is impractical at best, will exceed the computer resources available today and the cost would be prohibitively high. We present simpler models that are well established, based on linear theories of incompressible flows past profiles, wings and propellers. They can perform rapid, yet realistic high Reynolds number flow simulations , provided the flows remain attached. The key feature in this approach is the minimization of a functional that is well-behaved and leads to a solution in which the designer has some basic control on the geometry to insure that the result is of practical value.

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**MS11**

**Some Aspects of Flow Geometry in the Analysis and Design of Aerodynamic Configurations**

Two examples of flow geometry are discussed.The first is related to flow kinematics, involving the continuity equation and the definition of vorticity.For two dimensions this formulation gives rise to Cauchy/Riemann equations.A generalization to three dimensions is presented with some preliminary results.The second example is based on Helmholtz velocity decomposition and is completely equivalent to Navier Stokes equations in primitive variables. Simulations of incompressible and compressible viscous flows are studied and the advantages of the decomposition are outlined.

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**MS11**

**Nonlinear Elimination in Aerodynamic Analysis and Design Optimization**

A common element in the compressible CFD analysis problem and the design optimization problem is that the nonlinear aspects of the problem can be among the most challenging. A commonly used solution method for both problems is Newton's method. Often in discussions of these methods, the emphasis has been on methods for computing the required derivatives rather than on the perhaps equally important issue of the globalization strategy. In fact, the globalization strategy can be more important in cases where there are bifurcations or complex interactions with grid refinement. In this talk, we will discuss some globalization strategies based on nonlinear elimination and their application to incease the reliability of CFD computations. In this algorithmic context, we will describe some applications of optimization in aerodynamic design and consider the algorithmic implications of the engineering requirements.

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**MS11**

**The Role of Geometry in the Multidisciplinary Design of Aerospace Vehicles**

Geometry models are essential at all phases of aerospace vehicle design. At the detailed design phase the geometry models focus on the structural components of the vehicle, must have all the detail needed for manufacturing, and model development times on the order of months are acceptable. At the conceptual design phase the models must permit consistent, broad multidisciplinary analysis and design, must be able to be constructed in a matter of days for a given vehicle concept, must permit parametric variations in a matter of seconds, but need have relatively little detail. This presentation will focus on the geometry modeling challenges for conceptual design (and systems analysis) and for early preliminary design. The gaps between the geometry modeling requirements and the current capabilities will be highlighted.

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**MS12**

**Shape Decomposition with the Medial Axis**

The medial axis is a geometric shape representation which reveals topological features. While recent progress on computing the medial axis has been promising, practical applications such as using the medial axis to decompose a shape or its boundary into simple pieces are still elusive. We describe some recent progress and outline some challenges.

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### MS12

### Mayer Vietoris Methods in Linear Algebra

Th Mayer Vietoris exact sequence and spectral sequence are important tools for computing homology of topological spaces. It turns out that they are also useful in Gaussian elimination of sparse matrices (of which the boundary operators in chain complexes attached to topological spaces are prime examples). The algorithms they provide are readily parallelizable, and provide significant speedup over general purpose algorithms. We will discuss these ideas in this talk.

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### MS12

### Morse Complexes and Topological Persistence

We consider Morse complexes decomposing a manifold with a smooth height function into regions that have the same gradient flow pattern. We use a combinatorial algorithm with numerical components to construct such a complex via handle slides. A hierarchy of progressively simpler Morse complexes is then constructed by cancelling critical points in pairs. These cancellations are performed in the order of increasing importance, or persistence of critical points.

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### MS12

### Contour Trees for Exploring Static and Time-Varying Volume Data

A common way to explore volume data is via level sets—surfaces that consist of all points of a given threshold value. We describe the efficient computation of a contour tree, which records changes in connected components as a function of the threshold value (capturing a subset of the Morse singularities.) This aids flexible contouring and navigation in time-varying volume data. Collaborators in this work include Hamish Carr, Lutz Kettner, Ajith Mascarenhas, and Jarek Rossignac.

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### MS13

### A Boundary Search Method for Optimal Tool Orientations

Since 5-axis machines have two more degrees of freedom than 3-axis machines, it is very important to find desirable tool orientations in order to make an efficient use of expensive 5-axis NC machines. Developed in this research is an algorithm to determine "optimal" tool orientations for 5-axis machining of sculptured surfaces. For a given CC (Cutter Contact) point, this algorithm determines the cutter axis vector which minimizes cusp height and satisfies constraints. To use the cusp height as the objective function of the optimization problem, a method calculating an approximate cusp height independent of the orientations at the adjacent cutter positions is suggested. Through investigating the characteristics of 5-axis surface machining, some properties of the optimization problem are identified. Based on the properties, the original 2D-optimization problem is converted as a 1D- boundary search problem, which is efficiently implemented using an edge detection algorithm.

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### MS13

### Modeling and Interference Checking for Multi-Axis Sculptured Surface Machining

Interference is a fundamental issue path generation: much of path generation dealswith avoiding interference "in the small" and "in the large." In the small, collisions are usually referred to as gouging, and the opposite problem, one of the co ormance of the swept volume to the required surface, is referred to as scalloping.Most commercial softwares have concentrated on this problem for several reasons, the most important of which is the fact that gouging can be estimated with local fferential geometric properties. Over the last few years, we have studied the pr lem of collisions in the large. Using very rapid collision detection algorithms at we have developed, and using fast methods of approximating the C-Space of mac nes, we have developed methods for generating gouge-free, collision free tool pa s for rough and finish machining. I will describe these methods and explain thei applications.

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### MS13

### Optimal Contour Orientations for Machining of Free-Form Surfaces

The Gauss map and medial axis transform are used in the context of contour machining of free–form surfaces to minimize the *scallop height* between successive tool paths. The medial axis transform of the plane stereographic projection of the complement of the Gauss map identifies the sectioning plane orientation that is "most distant" from the Gauss map boundary. The method is implemented in the context of bicubic Bézier surfaces, with tool paths on the offset surface approximated by PH space curves.

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## MS13

### Reconstruction and Machining of Triangulated Sculptured Surfaces from Unorganized Laser Scan Data

Sculptured surface modeling and machining is an important subject in CAD/CAM as modern design adopts more and more free-form geometric shapes. Recently, due to the rapid development of scanning technology, the use of laser scanner for the digitization of free-form surfaces has been widely accepted. The scan data is usually fitted to a parametric sculptured surface such as B-Spline, then the surface can be machined using a commercial CAM package. However, the surface reconstruction procedure is usually a painful process if the data points are random or unorganized. In addition, surface edge detection and surface patch determination need to be carefully carried out, which are not always easy and intuitive. This paper presents a new approach for reconstruction and machining of triangulated sculptured surfaces from unorganized scan data. Assuming the scanning density is sufficient, we propose to reconstruct triangulated surfaces automatically from the scan data and then machine the resulting triangulated surfaces. Robust triangulation and surface reconstruction from 3-D discrete points is not a trivial problem. It is becoming increasingly important in geometric modeling. In this paper, a new approach based on computational geometry methods such as 3-D Delaunay triangulation is proposed to solve the problem. Extreme Voronoi vertices defined as inner or outer poles are determined to help detect concave surface regions. The result is a robust and efficient method for building triangulated surfaces of complex geometry from unorganized discrete data. In addition, this method lends itself to a natural and systematic way of creating 3-D offsets, which is useful to generate NC tool-path for surface machining using ball-end mills. Examples including surface reconstruction and tool-path generation will be shown to validate the proposed approach.

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## MS14

### On the Role of Exact Arithmetic in Geometric Computation

Exact arithmetic is emerging as final arbiter of uncertainty in geometric computations such as segment intersection, Delaunay triangulation, Voronoi diagrams, and many others. This creates a false sense of security in a world where even the input is in doubt. We discuss this trend and possible alternatives.

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## MS14

### Fast and Accurate Computations with Algebraic Primitives and Predicates

Most of the work in accurate and robust geometric computations has been restricted to linear primitives. It is based on "exact computation paradigm" that uses rational arithmetic for the underlying computations. There is a general perception that extending "exact computation paradigm" to non-linear problems is impractical and very hard to implement. I describe some approaches for accurate evaluation of algebraic predicates, root isolation of polynomial systems, and exact manipulation of algebraic points and curves for geometric applications. The set of applications include boundary evaluation of low degree algebraic solids, medial axis computations, computing curve arrangements etc. Based on these algorithms, I will describe two libraries, MAPC and PRECISE, which can be used for different geometric applications. The next major challenge is to develop robust approaches to handle degeneracies.

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## MS14

### Solutions to Robustness Problems in CGAL

The CGAL library is a collection of geometric algorithms implemented in C++ in a generic way. This talk will describe how the well known non-robustness problems have influenced the design of the library, what are the actual solutions that we propose in order to solve these problems and what are their trade-offs in terms of efficiency, generality and ease of use. The CGAL library is a collection of geometric algorithms implemented in C++ in a generic way. This talk will describe how the well known non-robustness problems have influenced the design of the library, what are the actual solutions that we propose in order to solve these problems and what are their trade-offs in terms of efficiency, generality and ease of use.

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## MS14

### Making Roundoff Error Less Unbearable

Sometimes you don't have time – running time or programming time – to use exact arithmetic or other methods of achieving numerical robustness. Sometimes, luckily, the worst effects of floating-point roundouff can be alleviated by chooseing expressions wisely. I offer some advice on how to write less dangerous mathematical expressions for floating-point computation.

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## MS14

### Robustness for Everyone

We have now reached the point where a large class of basic but important geometric computations can be achieved robustly and quite efficiently. Such computational problems include mesh-generation and low-degree algebraic problems. There are basically two current libraries that offer this capability: LEDA_Real and our own Core Library. Both are C++-libraries, and any C++ programmer can write robust programs by calling these libraries. The underlying approach of these libraries is the Exact Geometric Computation (EGC) approach. We outline the major challenges ahead as we continue to develop the theory and technology of EGC.

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**PP1**

**Load-Balancing for a Parallel Quadtree Algorithm**

For a collection of sets in $R^d$ we consider the task of finding all sets in the collection that contain a given point. The parallel algorithm introduced in this paper is based on quadtrees and their generalizations to $R^d$. We discuss some load-balancing techniques for dealing with problems that have unbalanced quadtrees. The performance of the algorithm will be demonstrated numerically by comparing results obtained with and without load-balancing. Our algorithm solves a difficult problem faced by meshfree discretizations, and was parallelized from a sequential algorithm of Han, Oliveira, and Stewart.

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**PP1**

**Robust Analysis of Discrete Systems Represented by An Interval Matrix**

In this paper we describe a new bound to assure robust stability of a discrete linear time invariant system represented by an interval matrix. The bound is based in Juang's theorem and Perron's theorem. We include some examples to show the application of the bound. In this paper we use parametric uncartainty and the system is represented by an interval matrix. The principal motivation of this work is given by the existance of dynamical systems with parametric uncertainty in its models. We know the stability of a discrete linear time invariant system is given by A matrix, now when the system contains parametric uncertainty, the A matrix can be represented by an interval matrix A=(L, U).

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**PP1**

**Computer Aided Violin Design**

This poster investigates the hypothesis that the cross-archings used in most golden-period Cremonese instruments (which include those of the Amati, Guarneri, and Stradivari) were cycloid curves, in particular the curtate cycloid. A curtate cycloid is obtained by rolling a circle along a line, and tracing the path of a point on the interior of the circle, a construction well known in the 16th and 17th centuries, which can generate a wide range of curves.

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**PP1**

**About Bonnet Theorem in Octonion Space**

Given an homogeneous G-structure on M where dim(M)=7, G=$G_2$ is exceptional Lie group, dim(G)=14. The presence of vector product [x,y] on tangent spaces and 3-form $\Omega$ make extremely profound the geometric properties of submanifolds M with such G-strucure. Let S be an oriented submanifold such that dim S=6. Let $U \subset R^6$ be a domain and $f : U \to V$ an immersion such that $f(U) = S$. Then $df$ induces differential 2-form $\psi$ and 3-form $h$ on U in naturar way. **Proposision** . Given $\{h_{ijk}, \psi_{ij}\}$, we can calculate all components of derivation formulas $\{\Gamma^k_{ij}, b_{ij}, c_{ij}\}$ from a linear system. This system is linear regarding 183 unknowns $\Gamma^\alpha_{jk}$, $b_{ij}$, $c_{ij}$. There are 210 equations in the system, but its rank is equal to 183. Computer program written in Delphi gives explicit expression for variables $\Gamma^k_{ij}$, $b_{ij}$, $c_{ij}$. **Theorem.** Given differential forms $h, \psi$ on U satisfying the structure equations there exists unique up to isomorphism immersion $f : U \to V$ such that $h, \psi$ coinside with given one.

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**PP1**

**Remarkable Bzier Curves in Polar Coordinates**

p-Bézier curves are the analogue in polar coordinates of nonparametric Bézier curves. These curves form a subset of rational Bézier curves characterized by control points on radial directions regularly spaced with respect to the polar angle and weights equal to the inverse of the distance to the origin. We show that, in addition to conics with focus at the origin, this subset encompasses other remarkable curves, such as Tschirnhausen's cubic or the Trisectrix of Maclaurin.

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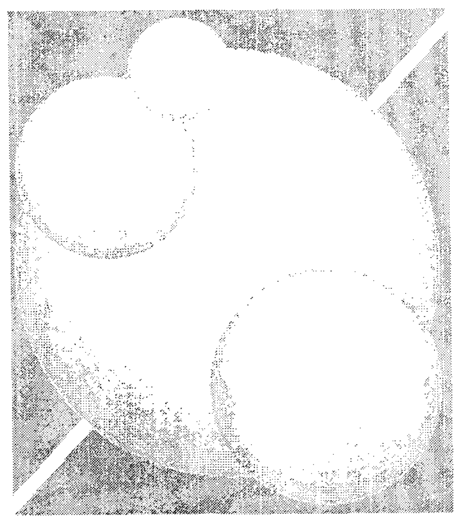
SIAM Conference on geometric design



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