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**Author**
O'Brien, James F

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# Modern Techniques for Implicit Modeling

**(A course proposal for SIGGRAPH 2005)**


Course Organizers:

James F. O'Brien
University of California Berkeley

Terry S. Yoo
National Library of Medicine, NIH

Lecturers:

Marc Alexa
DGM, TU Darmstadt

Haixia Du
National Library of Medicine, NIH

John Hart
University of Illinois Urbana-Champaign



Summary:

This course presents recent developments in modern implicit surfaces, particularly the use of radial-basis functions, MPUs, and digital Morse theory, plus examples of real-world applications from shape transformation to medical modeling. Lectures include the mathematics of implicit modeling and some formal treatment of smoothness issues and sampling constrained implicit surfaces.

# Modern Techniques for Implicit Modeling

(A Course Proposal for SIGGRAPH 2005)

**Category:** Modeling – implicit surfaces

**Organizers:**

**James F. O'Brien**
EECS, Computer Science Division
633 Soda Hall, Mail Code 1776
University of California at Berkeley
Berkeley, California 94720-1776

(510) 642-0865
fax: (510) 642-5775
job@eecs.berkeley.edu

**Terry S. Yoo**
National Library of Medicine
National Institutes of Health
8600 Rockville Pike
Bethesda, MD 20894

(301) 435-3268
fax: (301) 402-4080
yoo@nlm.nih.gov

**Proposed length:** Full-day

**Proposed venue:** Regular session room

**Summary Statement:**

This course presents recent developments in modern implicit surfaces, particularly the use of radial-basis functions, MPUs, and digital Morse theory, plus examples of real-world applications from shape transformation to medical modeling. Lectures include the mathematics of implicit modeling and some formal treatment of smoothness issues and sampling constrained implicit surfaces.

**Lecturers:**

Marc Alexa
DGM, TU Darmstadt
alexa@informatik.tu-darmstadt.de

Haixia Du
National Library of Medicine, NIH
hdu@mail.nih.gov

John C. Hart
University of Illinois Urbana Champaign
jch@cs.uiuc.edu

James F. O'Brien
University of California at Berkeley
job@eecs.berkeley.edu

Terry S. Yoo
National Library of Medicine, NIH
yoo@nlm.nih.gov

## Course Abstract:

Several recent advances allow implicit surfaces to move beyond the simple modeling of blobby objects and simple sculpting with constructive geometry. Advanced techniques and emerging methods can now be used for modeling and controlling implicit surfaces generated by approximating and/or interpolating known data points. To demonstrate this, we show how radial basis functions can model various body parts, partial differential equations can be used to mold and shape surfaces, curvature can tie-dye bunnies, and how objects can be extruded from polygon soup. These forms of "constraint-based" or "data-driven" implicit surfaces have begun to supersede previous implicit techniques for modeling objects with biological or natural appearances. Formal approaches to computation, sampling, control, shape transformation, and user-applications will be discussed. In particular, the course will contain new material on the use of nonlinear, partial differential equations in modeling as well as sampling analysis for constrained, interpolating, implicit surfaces. Some people think that implicit surfaces are rubbery, but we will show that they are a solid foundation upon which to build modeling, animation and visualization tools.

This course presents these techniques in a full day of valuable detailed talks, including mathematical foundations of linear algebra, PDEs, sampling, and smoothness, application demonstrations, implementation details and well-documented source code for implementing these techniques. Topics include generating implicit surfaces that interpolate point data, implicit surfaces for shape transformation, surface reconstruction from computer vision data, medical applications, modern level sets, implicit methods to compute medial structures, digital Morse theory, concluding with the presentation of a library of software tools for interactive modeling with implicit surfaces.

## Intended Audience:

Our target audience is those who want to use implicit surfaces to model something other than goo. Attendees will depart with an overview of the techniques, a survey of the mathematics, an introduction to real-world applications, and a primer on open-source software freely-available for modeling with implicit surfaces.

## Prerequisites:

Attendees should have a good working knowledge of basic graphics techniques and be not easily frightened by terms such as "Partial Differential Equations," "Radial Basis Functions," or "Line Integral." Familiarity with basic implicit surface techniques would be useful, but not necessary.

## Modern Techniques for Implicit Modeling

by James F. O'Brien and Terry S. Yoo

Course Syllabus proposed for 2005 – Full Day.

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**Session 1: Mathematical Foundations of Implicit Surfaces that Interpolate**

Welcome and Intro [Yoo] (25 min.)

- Basic Implicit Surfaces
- What will be covered.
- What will not be covered.
- Overview of the day.

Implicit Surfaces that Interpolate: Introduction [O'Brien] (35 min.)

- Implicit surfaces using radial splines
- Matrix method for making an implicit surface that passes through points.
- Shape transformation

Radial spline theory [Hart] (45 min.)

- The connectedness of implicit surfaces
- Maintaining dynamic meshes on RBF surfaces and level sets
- Modeling with thin-plate splines.
- Curvature minimization

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**Session 2: Numerical Analysis and Nonlinear Control of Constrained Implicit Surfaces**

Compactly Supported RBFs in Implicit Surface Management [Yoo] (55 min.)

- Families of basis functions
- Computation, memory loads, numerical concerns
- Implicit Snakes: Active surfaces and contours using implicit derivations

Implicit Modeling with PDE-based techniques [Du] (50 min.)

- Advantages of PDE-based techniques
- PDE formulation: from parametric to implicit
- Numerical methods to solve PDEs
- Data and derivative constraints for implicit modeling
- Implicit shape design, reconstruction and control

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**Session 3:** **Techniques: Multi-level Partitions of Unity and Moving Least Squares**

Multi-level Partition of Unity Implicits (MPUs) [Marc Alexa] (55 min.)

- basics of functional interpolation / approximation
- blending of local interpolants / approximants -- resulting properties
- implicit approach, constraints
- special local approximation sets for fitting sharp features
- spatial data structures
  - octree
  - kd tree
  - bsp + heuristics for split planes
  - effect of DS on the results
- compression
- quick rendering

Implicit Moving Least Squares Surfaces (IMLS) [O'Brien] (50 min.)

- Basics and tie-in to MPUs
- Improved normal constraints
- Constraints over surfaces
- Basis, point, and weight function choices
- Limited guarantees of correctness

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**Session 4:** **Applications and Software**

Medical Applications of Implicit Surfaces [Yoo] (45 min.)

- Issues of computational complexity
- Managing spatial locality: sparse matrices and k-d trees
- Anatomic implicit models using variational methods.
- Examples and results: compact model representations, shape analysis, geometry.

Wickbert: An Open-source Interactive Implicit Surface Modeler [Hart] (60 mins)

- Structure and design of implicit function implementation
- Demonstration of RBF concepts from earlier in course
- Issues of interactive modeling of implicit surfaces.

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## Course History

This is a redesign of a SIGGRAPH 2003 course in which we presented an advanced, in-depth look at techniques that offer advantages over earlier work on implicit surfaces, a mainstay of computer graphics since the days of metaballs and blobby models. The course was well received in both San Antonio and San Diego (survey scores averaged 4.5 out of 5), with approximately between 175 and 200 attendees filled each session of the program in both 2002 and 2003. Our new course covers impressive innovations from the intervening years, presented by some new faces making this our best course yet.

## Suggestions for Shorter Presentations:

We believe that we have created a strong course outline, covering some of the most important emerging research areas in modeling with implicit surfaces. Our intention is to create the most complete treatment of this material possible, acknowledging the need for modularity while providing a coherent approach. We would not recommend curtailing sections of the proposed course.

## Course notes and presentation details: Source Code

The details of these emerging techniques have been recorded in the literature; unfortunately, a comprehensive treatment of these methods has never been collected into a single volume. Beyond a simple recording of the presentation slides, our course notes will serve as a reference document through the inclusion of the seminal papers that describe the underlying foundations of the proposed talks. The combination of papers, slide reproductions, and multimedia elements (animations on the CD-ROM/DVD) will be a valuable resource for attendees wishing to pursue extended research in this field.

Beyond the documentation and explanations of the techniques, we propose to provide implementations. Even though we are not planning to conduct interactive hands-on demonstrations, we are committed to providing source code for some of the tools and methods that we will present. We intend to make these files available on the CD-ROM proceedings as part of the course notes. We hope this core software will accelerate research in implicit surfaces.

We have collected all of these methods into a single, exciting course for SIGGRAPH 2005. We have a strong team of presenters with interests and expertise in many techniques and across many disciplines. All five of the course presenters have given numerous talks at conferences in computer graphics and computer vision. In particular, these speakers have collectively given more than 20 paper or course presentations at SIGGRAPH. We intend to inform the audience about these tools and techniques and show that they are applicable to many of the problems faced in graphics research today.

## Speakers committed to other course proposals:

Terry Yoo is also a presenter in a proposed course, “Advanced 3D Medical Visualization: An Open Source Approach,” (Terry S. Yoo, organizer). John Hart is proposed as a presenter in a course on Real-Time Shading (Marc Olano, organizer). The audiences for each of the proposed courses differ in their focus and interests. We see these topics as either unrelated or as complementary to the material we are presenting, and we have made accommodations in our scheduling.

## Speaker Information

**Marc Alexa**
Darmstadt University of Technology
Discrete Geometric Modeling Group
Fraunhoferstr. 5
D-64283 Darmstadt

Phone: +49 6151 155 679
Fax: +49 6151 155 669
alexa@informatik.tu-darmstadt.de

**Haixia Du**
Visiting Scientist
National Library of Medicine
National Institutes of Health
8600 Rockville Pike
Bethesda, MD 20894

(301) 435-3268
fax: (301) 402-4080
hdu@mail.nih.gov

**John C. Hart**
Associate Professor
Department of Computer Science
University of Illinois Urbana-Champaign
3212 DCL, MC 258
1304 W Springfield
Urbana, IL 61801

(217) 333-8740
fax: (217) 244-6869
jch@cs.uiuc.edu

**James F. O'Brien**
Assistant Professor
EECS, Computer Science Division
633 Soda Hall, Mail Code 1776
University of California at Berkeley
Berkeley, California 94720-1776

(510) 642-0865
fax: (510) 642-5775
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Head, 3D Informatics Program
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fax: (301) 402-4080
yoo@nlm.nih.gov

**Speaker Biosketches**

**Marc Alexa** is an Assistant Professor of Computer Science at Darmstadt University of Technology and heads the Discrete Geometric Modeling group. He is interested in representing shapes and their deformation, using point sampled geometry, implicit surfaces, explicit representations, and linear spaces of base shapes. He has lectured on topics related to shape representations at SIGGRAPH and other conferences, has been a co-chair and has served as a memeber of several committees of major graphics conferences, and will be papers co-chair of Eurographics 2005 and general co-chair of the ACM/Eurographics Symposium on Point Based Rendering 2005.

**Haixia Du** is a Postdoctoral Fellow in the Office of High Performance Computing and Communications at the National Library of Medicine in the 3D Informatics Group. Her research interests are in geometric and physics-based modeling, visualization, and medical imaging, with emphasis on PDE-based shape modeling, including shape design, reconstruction, metamorphosis, and simplification. She has co-authored several papers on implicit surface reconstruction and manipulation from curve sketches, scattered data points, and volumetric data using PDE techniques. Haixia received her Ph.D. in Computer Science from Stony Brook University in 2004.

**John C. Hart** is Associate Professor of Computer Science at the University of Illinois Urbana-Champaign. In 1993 he received an NSF award to explore implicit surfaces, and got hooked. He co-chaired the 1996 Eurographics/SIGGRAPH Workshop on Implicit Surfaces, and has organized/lectured in previous SIGGRAPH courses, including several on implicit surfaces. Hart is co-author of *Real-Time Shading* and a contributing author of *Modeling and Texturing: A Procedural Approach*, 3rd edition. Hart is the Editor-in-Chief of ACM Transactions on Graphics. He served five years on the SIGGRAPH Executive Committee and was an executive producer of the documentary "The Story of Computer Graphics."

**James O'Brien** is an Assistant Professor of Computer Science at the University of California, Berkeley. His interests focus on generating realistic motion using physically based simulation and motion-capture techniques. He has authored several papers on these topics, including ten presented at SIGGRAPH and his work has been featured multiple times in SIGGRAPH's Electronic Theater. He received his doctorate from the Georgia Institute of Technology in 2000, the same year he joined Berkeley's Faculty. O'Brien is a Sloan Fellow, Technology Review selected him one of their TR-100 for 2004, and he was recently awarded grants from the Okawa and Hellman Foundations.

**Terry S. Yoo** is a Computer Scientist in the Office of High Performance Computing and Communications, National Library of Medicine, NIH, where he explores the processing and visualizing of 3D medical data, interactive 3D graphics, and computational geometry. Previously as a professor of Radiology, he managed a research program in Interventional MRI with the University of Mississippi. Terry holds an A.B. in Biology from Harvard, and a M.S. and Ph.D. in Computer Science from UNC Chapel Hill.