SIGGRAPH 97
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AND INTERACTIVE TECHNIQUES

COURSE NOTES

8

# Texture Synthesis with Line Integral Convolution

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Course Notes for SIGGRAPH '97

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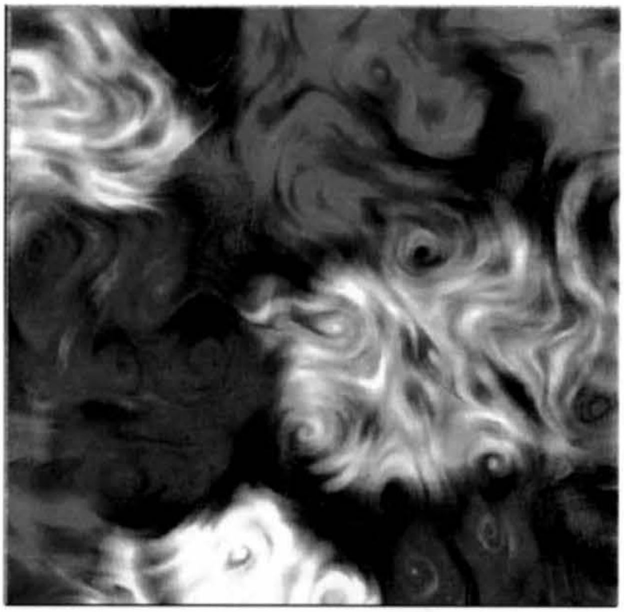
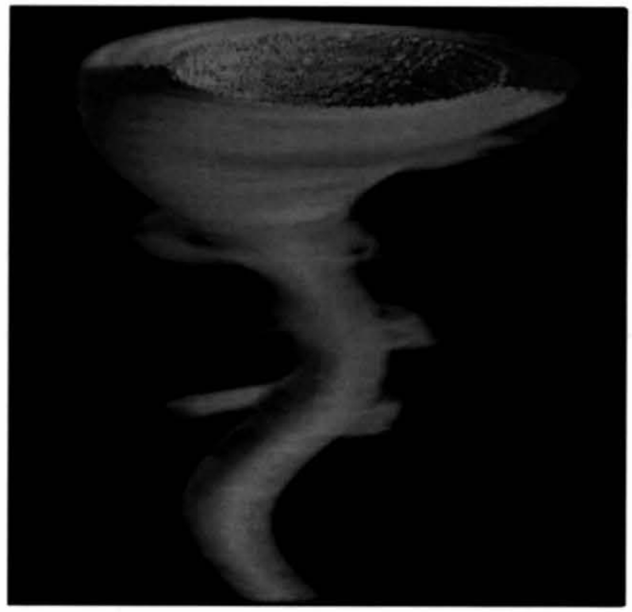
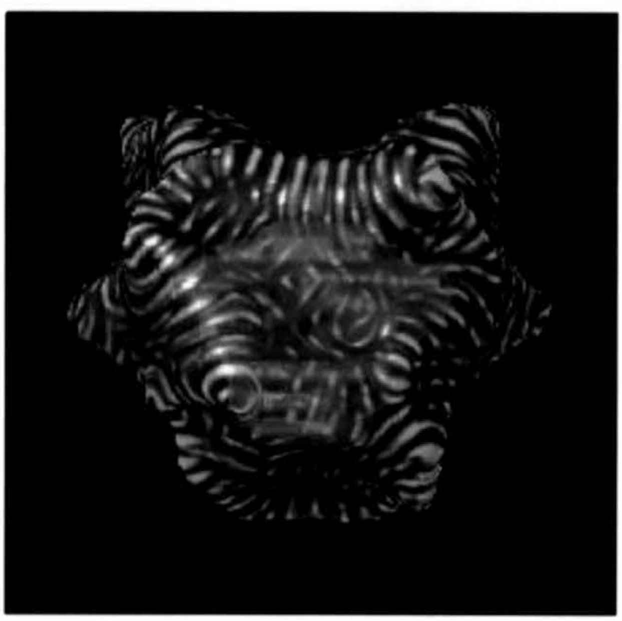
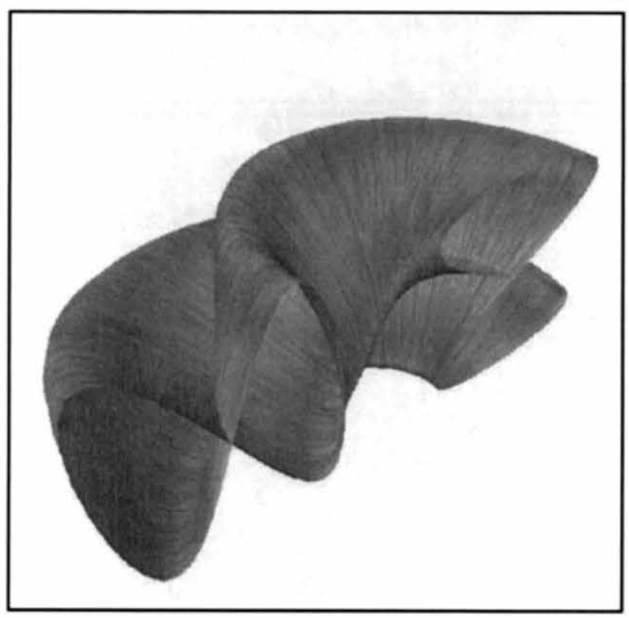

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# BIOGRAPHIES

**Brian Cabral** is a manager of visualization toolkit Core Rendering software within the Advanced Graphics Division at Silicon Graphics Computer Systems. His current technical focus is on Cosmo3D based toolkits for visualizing large geometric databases and scientific and engineering data. Previously, Brian, developed algorithms and techniques in the areas of Medical visualization and image processing, scientific visualization, and physical based shading and lighting. Prior to working at SGI, Brian, was a lead engineer and researcher at Lawerence Livermore National Laboratory where he worked a variety of visualization algorithms, tools and systems. He received a BS in computer science from California State University Stanislaus and a MS in computer science from University of California, Davis. His interests include differential geometry, image processing, shading techniques, computational geometry and signal processing. When he's not toiling over a large equation or chunk of code Brian enjoys the good life of California.

**Hans-Christian Hege** is head of the Scientific Visualization Department at Konrad-Zuse-Zentrum Berlin (ZIB) – a research institute of the State of Berlin operating in the field of algorithmic mathematics. He studied physics at Free University Berlin. From 1984-1989 he has been research assistant at the physics department there, working in the areas quantum field theory, statistical physics and numerical physics. He is a co-founder of mental images and Gesellschaft für Digital Simulation (GDS) that started 1986 to produce computer animations and rendering software. From 1986 to 1989 he worked as researcher at mental images and managing director at GDS. Since 1989 he is with ZIB, first as scientific consultant and then as director of the Visualization and Parallel Computing department. His research interests are in computer graphics, scientific visualization, biomedical computing, and physics. He is member of ACM, IEEE, and the steering committee 'Computer Graphics' of GI.

**Victoria Interrante** is a staff scientist at the Institute for Computer Applications in Science and Engineering (ICASE), a center of research in applied mathematics, numerical analysis, fluid dynamics and computer science operated by the Universities Space Research Association at the NASA Langley Research Center. She received a PhD in computer science from the University of North Carolina at Chapel Hill in 1996, where she completed a dissertation under the direction of Drs. Henry Fuchs and Stephen Pizer on the design of perceptually-inspired artistic techniques for improving the comprehensibility of layered transparent surfaces. Her current research focuses on the application of insights from perceptual psychophysics, art and illustration to the design of more effective techniques for visualizing data, the study of shape and depth perception, the use of texture to convey 3D shape and flow information.

**Kwan-Liu Ma** received his PhD degree in computer science from the University of Utah. He is a staff scientist at the Institute of Computer Applications in Science and Engineering and an adjunct assistant professor of computer science at Old Dominion University, where he teaches scientific visualization. He is a co-chair of the 1997 Symposium on Parallel Rendering. and also in the program committee of Visualization and Mathematics '97. His research interests include computer graphics, scientific visualization and high performance computing. In particular, he has developed several parallel volume rendering algorithms, feature extraction algorithms, and interactive visualization techniques. Dr. Ma is a member of the IEEE, ACM, SIGGRAPH and Phi Kappa Phi.

**Detlev Stalling** studied physics at the University of Osnabrück and the Free University of Berlin, where he received his MS degree in 1993. In 1992 he spent some months at the European Center for Particle Physics (CERN). After study he joined the Konrad-Zuse-Zentrum Berlin (ZIB) as a research scientist in the scientific visualization department. His research interests include accurate visualization methods, geometric modeling, and image processing. Currently he is working on his PhD thesis about visual methods for analyzing vector fields.

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# Prolegomenon

We have seen striking, realistic images made with synthetic textures for 3d graphics, visualization and special effects. The use of synthesized textures has recently gained increasing popularity because more elaborated, powerful techniques are being developed and may be applied to application problems in an economical manner. The Line Integral Convolution (LIC) method introduced by Brian Cabral and Casey Leedom [2] is a particularly powerful and elegant texture synthesis algorithm for visualizing *motion* and *shape.* LIC transforms vector data into lively visualization by distorting an input texture image according to the local vector field.

Cabral and Leedom's creation has inspired many visualization researchers. Forssell [3, 4] extends LIC to vector fields on the curvilinear grids used in computational fluid dynamics simulations. Stalling and Hege develop a fast and resolution independent LIC algorithm that is an order of magnitude faster than the original implementation [13]. Both Cabral/Leedom [1] and Stalling/Zockler/Hege [14] also investigate how to parallelize the LIC calculations to achieve real-time visualization. Kiu and Banks show how the use of multi-frequency noise texture images may enhance a user's perception of the features in the vector flow [8]. Wegenkittl, Gröller and Purgathofer add orientation information to still LIC images [16].

Shen, Johnson and Ma show how to integrate the LIC algorithm into direct volume rendering to construct multiple semi-transparent surfaces and to simulate the use of dye advection in experimental flow visualization [12]. Okada and Kao develop an enhancement technique especially for highlighting flow separation and reattachment boundaries in flow fields defined in 3D curvilinear multi-block grids [10]. To apply LIC to arbitrary 3D polygonal surfaces, Battke, Stalling and Hege come out with an efficient local texture algorithm [5], while Mao, et al. use a view-dependent approach to generate more accurate results [9].

More recently, Interrante experiments with the idea of using the LIC method to illustrate the shape of arbitrary surfaces [6]. She also investigates perceptual issues in visualizing three-dimensional flow data [7]. Wegenkittl and Gröller design an approximated version of their oriented LIC algorithm to allow very fast visualization [15]. Shen and Kao are currently developing a new algorithm for handling time-varying data in a more physically correct manner [11].

The continuous, intensive effort by various researchers has made LIC now practical for many applications. Therefore, we believe a course on the LIC method is appropriate and will greatly benefit the users of 3d graphics and visualization technology. This course provides a comprehensive presentation of the LIC techniques. You will learn about the core algorithm and why it works. You will also learn how to implement the algorithms efficiently and how certain key parameters control the intended visual effects. You will be exposed to various application problems through many visual examples including videos and live demonstrations. At the end of the course, you should be able to apply LIC to your application problems by modifying the computer source programs provided by the lecturers.

The lectures contain three parts: the basic algorithm, the optimized algorithms and the extended algorithms. Brian Cabral will talk about the history and motivation of LIC and give an overview of the basic algorithm. This lecture will provide you with the needed background to follow the material covered in the rest of the course.

Next, Hans-Christian Hege and Detlev Stalling will talk about their optimized LIC algorithms and how the LIC calculations may be parallelized to achieve interactive vector field visualization. They will also describe how to perform LIC on arbitrary surfaces by converting the surfaces into triangular meshes.

Then, Victoria Interrante will describe how LIC can be applied to visualization of surface shape to generate non-photorealistic scientific illustrations. She will also address some perception issues with using the LIC method.

Finally, Kwan-Liu Ma will talk about combining LIC and direct volume rendering to visualize vector and scalar volume data in a single visualization, and how to enhance local features in flow-field data by using colors. He will also describe some useful entensions of LIC including the idea of using multi-resolution texture input introduced by Kiu and Banks, the oriented LIC techniques invented by Wegenkittl, Gröller and Goldsteiner, as well as the techniques developed by Shen and Kao for visualizing time-varying data.

We have prepared an implementation of the LIC algorithm and installed in the Creative Applications Laboratory set up by the conference. In this way you can try out some of the ideas introduced in the lectures to grasp the key concepts more clearly. As the results of applying LIC can vary significantly when the input parameters and texture change, we believe this hand-on experience will be highly rewarding to you. The source code is also made available on-line.

Besides the authors/lecturers, David Banks, E. Gröller, Ming-Hoe Kiu, Casey Leedom, and Han-Wei Shen have helped put these notes together. We would especially like to thank Viki Dennis, Barb Helfer, Scott Senften and Stephen Spencer of SIGGRAPH for working closely with us to make possible our course and notes.

Kwan-Liu Ma
*April 26, 1997*

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