3D Flow Visualization Using Volume Line Integral Convolution

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Introduction

Line integral convolution (LIC) is a flow-driven texture generation method that has become one of the best-known and most commonly used techniques in computer graphics for visualizing 2D flow, or flow over a surface in 3D. The popularity of LIC as a tool for 3D flow visualization, or the depiction of flow through a volume, has been relatively limited in contrast, however, primarily due to the difficulties inherent in clearly and effectively portraying a dense volume texture in a static, 2D image. Over the past months, we have been investigating strategies for more effectively using 3D LIC for the visualization of 3D flow. Much of this work is described in our ICASE Report No. 97-35. In this article we highlight new results from our continuing work in this area.

Background and Motivation

Given a vector field and an input texture, line integral convolution produces an output texture in which the data values are highly correlated in the direction of the flow. Our work focuses on methods for effectively representing the flow information contained in the dense volumetric textures produced by 3D LIC. Our strategies include selectively emphasizing flow information in critical regions of interest in the volume and clarifying the 3D structure of the flow by facilitating the perceptual differentiation of the densely clustered streamlines.

Region of Interest Definition

By concentrating the 3D texture in the most significant areas of the flow, we can clarify the visual representation of the data and facilitate the appreciation of the most relevant information.

When LIC is used in conjunction with a region of interest (ROI) definition based on the value of a scalar quantity across the volume, we have found that best results are achieved when the ROI mask is applied to the *input* texture rather than to the output. Figure 1 compares the two effects.

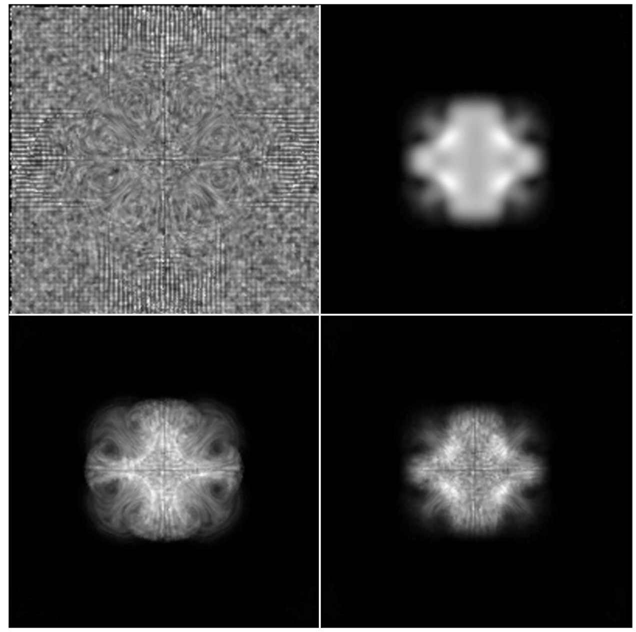

Figure 1: Clockwise from upper left: a 2D slice from a 3D LIC texture; a region of interest mask, defined by velocity magnitude; results when the ROI mask is applied to the texture generated by LIC; results when the ROI mask is applied, as a preprocess, to the input texture whose values are then convolved by LIC.

When the ROI mask is applied as a post process, the visibility of the flow information is directly defined by the values in the ROI, whose edges are not, in general, guaranteed to be everywhere tangent to the direction of the flow. When the ROI mask is applied as a preprocess, the same basic segmenta-

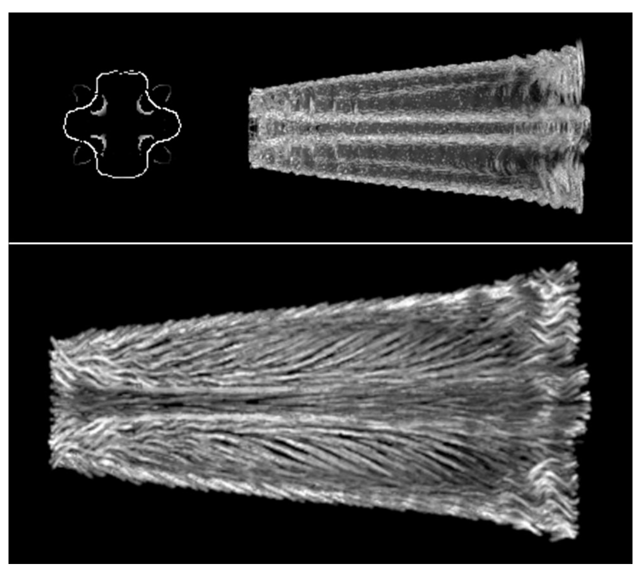

Figure 2: Upper: ridges of velocity magnitude can be used to define a surface of interest in the flow; Lower: 3D LIC applied to a texture of points evenly distributed over this velocity ridge surface.

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tion is in effect, however the flow itself is allowed to define the explicit boundaries of the visible information.

Figure 2 illustrates a second method for ROI definition. Here, a ridge-finding algorithm is used to define a precise *surface* of interest in the volume, and the LIC texture is derived from a set of Gaussian spots uniformly distributed over this surface. However, the directional information is not projected onto the 2D surface. All calculations are done in 3D, so that the tufts in the output texture will accurately reflect the local 3D orientation of the flow in the immediate vicinity of the specified surface of interest.

Clarifying the Dense Texture Data

When the LIC output densely occupies a 3D region of space, individual streamlines can be difficult to discriminate due to their similar shading. The three-dimensional spatial relationships among the overlapping streamlines represented in the LIC texture volume will be clarified if the depth discontinuities in the scene are emphasized through the use of 'visibility-impeding halos', as demonstrated in Figure 3.

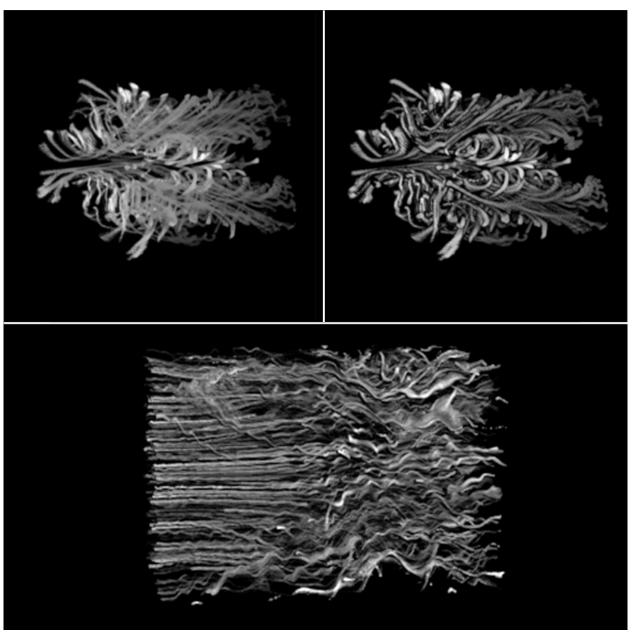

Figure 3: Upper left: volume rendered streamlines in a flow through a circular jet with tabs; Upper right: visibility-impeding halos emphasize depth discontinuities; Bottom: haloed streamlines in a flow through a rectangular aperture.

Information about the forward/backward direction of the flow can be incorporated into a static 2D image through the use of tapered streamlines.

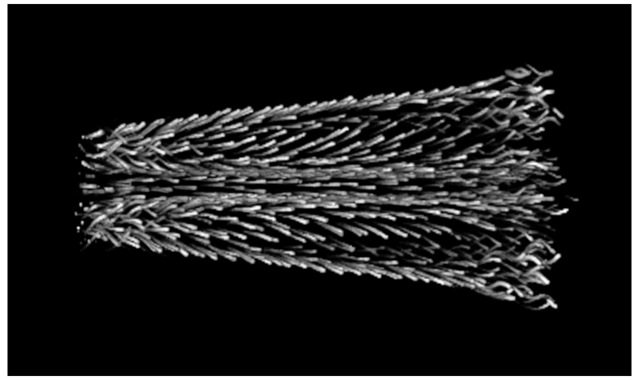

Figure 4: Tapered streamlines convey the forward/backward direction of the flow.

A simple modification to the fast-LIC algorithm allows the efficient computation of oriented streamlines, as shown in Figure 4. This modification is based on the use of an asymmetric filter of the form:

$$I'_0 = \sum_{i=0}^{flength} v_i c^i, \quad c < 1$$

in place of a simple box filter. Texture values at subsequent voxels along a streamline may still be computed incrementally based on previous values:

$$I'_1 = (I'_0 - v_0)/c + v_{flength+1} c^{flength}$$

$$I'_{-1} = (I'_0 - v_{flength} c^{flength})c + v_{-1}.$$

Future Work

We are continuing to investigate methods for more efficiently generating smooth, cyclic animations of 3D LIC textures along streamlines in steady flow data, and are actively working on extending our 3D LIC algorithm to the visualization of streaklines in 3D unsteady flow data.

References

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