

# Technical Report

Department of Computer Science  
and Engineering  
University of Minnesota  
4-192 EECS Building  
200 Union Street SE  
Minneapolis, MN 55455-0159 USA

TR 99-011

Real-time Principal Direction Line Drawings of Arbitrary 3D Surfaces

Ahna Girshick and Viictoria Interrante

April 07, 1999



# Real-time Principal Direction Line Drawings of Arbitrary 3D Surfaces

*Ahna Girshick*

*Victoria Interrante*

Department of Computer Science  
University of Minnesota  
Minneapolis, MN 55455  
{girshick, interran}@cs.umn.edu

## Introduction and Related Work

Computer-generated line drawings [4,7] are becoming an increasingly popular method of non-photorealistic rendering (NPR). While many factors contribute to an effective line drawing-- quality of line, line placement and density-- line direction is among the most critical for conveying surface shape. The principal directions hold particular promise in this respect [2]. In a human perceptual study, subjects displayed consistent biases toward perceiving surface contours (lines drawn on the surface) as being aligned with the principal directions [5]. Despite the potential for principal directions and their suggestion by previous authors [1,2,7], there are currently no available techniques for using them to render viewpoint-independent line drawings of arbitrary 3D surfaces.

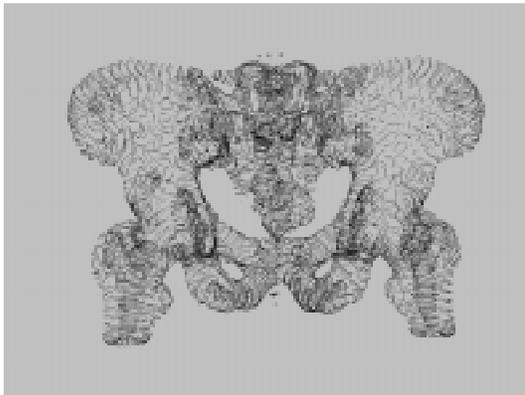


Figure 1: Principal direction line drawing (without hidden surface removal) of a bone/soft tissue boundary surface in a CT volume dataset.

The line drawing algorithm of Markosian et al. [4] handled arbitrary 3D surfaces, but line direction was chosen in a viewpoint-dependent manner and lines tended to cluster on silhouette edges with little interior curvature information.

Interrante [2] used a 3D principal direction texture to show the shapes of transparent isosurfaces in volume data. Stalling [8] suggested line drawing based on 3D streamlines following the principal directions. Figure 1, derived by these methods, was a motivating factor for this research. However, because of the desire to handle not only volume data but also surface data, this work focuses on the application to polygonal meshes.

The major contribution of this work is to motivate the use of principal directions in line drawings and show how to apply them to arbitrary polygonally defined 3D surfaces. The result is a viewpoint-independent set of shaded strokes which can be rendered in real time.

### **Estimating the Principal Directions on a Polygonal Mesh**

Much of the difficulty of this problem lies in accurately computing smoothly continuous estimates of the principal directions at arbitrary points on a potentially coarse polygonal mesh. The method we use is one proposed by Taubin [6]. First, adjacency information and vertex normals are computed. Then for each vertex  $v_i$ , we construct a symmetric matrix  $M_{v_i}$  based on the weighted sum of the projected directional curvatures of the edges in the neighborhood of  $v_i$ . The eigenvectors of  $M_{v_i}$  form an orthonormal basis at  $v_i$ . To determine the principal directions we must restrict  $M_{v_i}$  to the tangent plane and then rotate the vectors. The angle of rotation can be computed by diagonalizing the 2x2 submatrix of the transformed  $M_{v_i}$  and used to transform the eigenvectors of  $M_{v_i}$  into the principal directions. The principal curvatures can be calculated with a simple linear transformation on the corresponding eigenvalues. The first principal direction is chosen as the principal direction with the largest corresponding curvature. The algorithm is linear in time and space as a function of the number of vertices and faces of the polygonal surface.

### **Tracing Lines Over the Surface**

The collection of estimated principal directions results in a vector field over the surface. We trace long curved strokes whose directions are determined by the flow of the vector field.

To maintain an approximately even line density and avoid line crossings, the choice of each line's starting point and length is crucial. We extend the placement strategy of Jobard et al. [3] from 2D images to the 3D surface. Each line's starting point is selected randomly on the surface with the constraint that it is no closer than a distance  $d$  from all existing lines. All possible starting points within  $d$  from a given line are considered in a random order before considering neighbors of the next line.

In regions where the surface shape is locally planar or spherical (called *umbilics*), the principal directions are undefined because there is either zero or equal curvature in all directions respectively. During line tracing, if a vertex with an undefined principal direction is encountered, surrounded by vertices with well-defined principal directions, the line's direction is linearly interpolated from points in the neighborhood. If there are no neighboring well-defined principal directions, the line is terminated. If there is a sudden change in surface curvature the lines are ended.

After the coordinates of all the lines are determined, there are several visual enhancements we used to improve the overall image. Line shading and hidden line removal were added using the normals of the underlying mesh. To give the image a hand-drawn appearance, the principal directions were jittered in a random fashion to cause waviness in the lines. We found that a very

slight waviness of no more than 1% is enough to provide the desired effect while allowing the lines to still flow in the principal directions.



Figure 2: Principal direction line drawing of a vase.  
Mesh consists of 400 triangles

### **Implementation and Results**

We implemented this work in OpenGL. Our implementation used triangular meshes but is generalizable to other polygonal meshes. There are several rendering parameters which may be varied for different visual effects, such as line density, maximum number of lines, maximum line length, and line waviness. Figure 2 shows the technique applied to a coarse triangular model of a vase.

### **Conclusions and Future Work**

We are engaged in ongoing efforts to refine and improve the techniques used to estimate the principal directions, and want to immediately begin to apply this technique to more complex models. Future work will incorporate additional methods for maintaining continuity through umbilic regions and aesthetically merging opposing lines of force.

The perceptual efficiency of principal direction lines for the understanding of surface shape will hopefully be a continuing area of research.

### **Acknowledgments**

This work was supported by a Grant-in-Aid of Research, Artistry, and Scholarship from the Office of the Vice President for Research and Dean of the Graduate School of University of Minnesota. Thanks to Detlev Stalling and Todd LeMoine.

### **References**

- [1] R. Coutts and D. Greenberg. "Rendering with Streamlines", *Visual Proc. (SIGGRAPH 97)*, p.188.
- [2] V. Interrante. "Illustrating Surface Shape in Volume Data via Principal Direction-Driven 3D Line Integral Convolution", *Computer Graphics (Proc. SIGGRAPH 97)*, pp.109-116.

- [3] B. Jobard and W. Lefer. "Creating Evenly-Spaced Streamlines of Arbitrary Density", Visualization in Scientific Computing '97, W.Lefer and M. Grave (Editors) (*Proc. of 8th Eurographics Workshop on Visualization in Scientific Computing*, Boulogn sur Mer, France, 1997, pp.45-55.
- [4] L. Markosian, M. Kowalski, S. Trychin, L. Bourdev, D. Goldstein, and J. Hughes. "Real-Time Nonphotorealistic Rendering", *Computer Graphics* (Proc. SIGGRAPH 97), pp.415-420.
- [5] P. Mamassian and M. Landy. "Observer Biases in the 3D Interpretation of Line Drawings", *Vision Research*, 38 (1998), pp. 2817-2832.
- [6] G. Taubin. "Estimating the Tensor of Curvature of a Surface from a Polyhedral Approximation", *Proc. 5th International Conference on Computer Vision (ICCV)*, 1995, pp.902-907.
- [7] G. Winkenbach and D. Salesin. "Rendering Parametric Surfaces in Pen and Ink," *Computer Graphics* (Proc.SIGGRAPH 96), pp.496-476.
- [8] D. Stalling. *Personal communication*.