

Line Direction Matters: An Argument For The Use Of Principal Directions In 3D Line Drawings

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ABSTRACT

While many factors contribute to shape perception, psychological research indicates that the direction of lines on the surface may have an important influence. This is especially the case when other techniques (shading, silhouetting) do not present sufficient shape information. The psychology literature suggests that lines in the principal directions of curvature may communicate surface shape better than lines in other directions. Moreover, principal directions have the quality of geometric invariance so line directions are based on the surface geometry and are viewpoint and light source independent, and the lines do not move above over the surface during animation unless desired. In this work we describe principal direction line drawings which show the flow of curvature over the surface. The technique is presented for arbitrary surfaces represented by either 3D volume data or a polygonal surface mesh. The latter format is common in the field of computer graphics yet thus far has not been widely used for principal direction estimation. The methods offered in this paper can be used alone or in conjunction with other NPR techniques to improve artistic 3D renderings of arbitrary surfaces.

Keywords: non-photorealistic rendering, principal direction line drawings, line direction, line drawings, geometrically invariant line drawings.

1 INTRODUCTION

Amongst the varied goals of artistic Non-Photorealistic Rendering (NPR) is the pursuit of *perceptually efficient* images. A perceptually efficient visual representation emphasizes important features and minimizes extraneous detail and is essential for making comprehensible artistic images. Computer-generated line

drawings are a particularly effective form of NPR since lines' features (length, width, intensity, density, quality, direction, etc.) can be combined to create shaded, textured, and expressive images which capture the essence of the form of an object. In the field of computer-generated line drawing, 3D representations of curved surfaces generally focus on the silhouette edges, disregarding large amounts of interior curvature information. These depictions often rely on either previous knowledge of the surface or the use of motion (movement of the surface, viewpoint, or light source). In this work we explore a 3D line drawing technique which is independent of the surface's orientation, the viewpoint, or the light source. In particular, we examine line direction and use this paper to raise the question: Does line direction matter?

We argue that line direction does matter, and suggest the use of the principal directions of curvature for directing lines to improve the depiction of surface shape in artistic line drawings. The advantages of principal directions (see Appendix A for a mathematical definition) are that they are geometrically-invariant, highlight the most direct path on a surface between two points, indicate the directions of the curvature extrema at any point, and have been suggested by psychologists as the preferred interpretation for making surface shape judgments.

The importance of geometric invariance should not be underestimated. Geometrically-invariant cues are based on properties of the surface geometry and are by definition viewpoint and light source independent. While shading and silhouetting provide substantial shape information, valuable curvature information can be lost in shadows or the interior of the surface. Furthermore, viewpoint dependent lines may move around in a distracting manner during motion or animation. Geometric invariance does not imply that lines must be rigidly "pasted" onto the surface during animation. If line movement is desired, the geometrically-invariant vector field can help guide more fluid movement over the surface. Combining geometrically-invariant cues with shading or silhouetting can be especially powerful. Geometrically-invariant line attributes such as color and density can be manipulated with respect to viewpoint or light source [7].

Despite the promise for principal directions, their full potential in NPR has yet to be realized. The reasons perhaps may be related to the difficulties in estimating an accurate, smoothly continuous vector field of principal directions. The problem is most challenging for polygonal surface meshes, a particularly common data format for arbitrary 3D surfaces. Additionally, principal direction line drawings must address the complex issues of creating uniformly distributed, non-intersecting, long smooth lines which gracefully traverse umbilics, planar regions, and transitions of directional dominance. Here we examine both 3D

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volume datasets and polygonal surface meshes, and suggest some techniques for line tracing.

The main contribution of this work is to show that for a 3D line drawing, line direction can matter and principal direction line drawings can be used to better convey surface shape. In the next section we motivate the importance of line direction with psychological evidence. We follow with related work in computer-generated 3D line drawing. In section four, we provide a brief overview of principal direction estimation techniques. Section five shows the effects of line direction and section six presents techniques for principal direction line drawings. In the final section we draw some conclusions and discuss areas of future work.

2 PSYCHOLOGICAL EVIDENCE FOR THE IMPORTANCE OF LINE DIRECTION

The psychology literature gives us a sense of how the human visual system perceives images and is an essential reference for making perceptually efficient renderings. Early research asserted that humans can use surface markings, or texture, to perceive surface orientation. Gibson [8] was amongst the first to emphasize the significance of texture cues for shape and depth perception. He was able to show convincingly that observers could reliably interpret the slant of the planar surface by the cues provided by the projection distortion of the texture patterns.

Of relevance to this work is the open question of whether anisotropic (directed) textures are as suitable for conveying shape information as isotropic (undirected) textures. Interrante [12] was unable to show an effect of texture type in shape perception under conditions of stereo and motion for various plausible isotropic and anisotropic textures for transparent surfaces, including grids and principal direction textures. Yet Cumming et al. [3] found an indicative effect of texture type for stereoscopic shape perception between a plausible and unlikely texture. While shape-from-texture research often makes assumptions of isotropy or homogeneity, Knill [16] hypothesized that there are different modes to visually perceive isotropic and anisotropic textures.

While the question of effects of isotropic versus anisotropic texture still remains open, it is evident that when anisotropic surface markings are dependent on surface geometry, surface depth and orientation perception is improved. Knill [16] found that in an anisotropic texture processing mode, the curvature of geodesic surface markings determines perception of local surface orientation. The experiments of Johnston et al. [14] showed that stereoscopic depth perception of curved surfaces with texture which provided a good indication of surface geometry was superior to random dot textures. Stevens [24] was among the first to suggest that humans can make surface shape judgments by assuming that surface contours (lines on the surface) are aligned with the principal directions of curvature. In later work Stevens and Brookes [23] demonstrated that principal direction surface contours are also good indications of relative surface slant. More recently, Mamassian and Landy [17] found that surface shape judgments are biased by the assumption that surface contours are aligned with the principal directions. From the above literature, it is reasonable to believe that surface shape and depth perception may be generally aided by textures, and also by anisotropic textures based on surface geometry, particularly lines aligned with the principal directions

3 RELATED WORK

Computer-generated 3D line drawings borrow from centuries of artists' techniques and have recently received significant attention in the NPR community. Winkenbach and Salesin used stroke textures to create depth and shape in line drawings of parametric surfaces [26]. Markosian et al. emphasized the silhouette edges for viewpoint-dependent images of arbitrary 3D surfaces [18]. Curtis used 3D models to generate loose and artistic sketches and animations [4]. Elber rendered geometrically-invariant line drawings and textures of parametric and implicit surfaces [6].

Principal directions have been suggested [11,26] and approached [2,6] in line drawings. In [26,6], lines were traced along the parametric lines of parametric surfaces, which sometimes coincided with the principal directions. Saito and Takahashi [20] rendered line drawings lines of parametric surfaces along geodesic lines. Interrante et al. [11] used 3D principal direction textures to illustrate surface shape in volume data. However, none of these works addressed the challenge of estimating the principal directions from arbitrary surfaces (particularly polygonal surface mesh formats) nor that of tracing long strokes in one direction (rather than cross-hatching) through umbilics, planar regions, and areas of changing directional dominance. This work is based upon a preliminary sketch by Girshick and Interrante [9].

4 PRINCIPAL DIRECTION ESTIMATION

For data of any format, the first step towards a principal direction line drawing is to estimate the principal direction vector field, comprised of the principal directions at a set of points on the surface. There are a variety of methods for estimating principal directions, each with its various strengths and weaknesses, however a full discussion of the computational details is not in the scope of this paper. Do Carmo outlines analytic calculations of principal directions for parametric surfaces in [5]. For iso-intensity surfaces in 3D volume data, Monga et al. used the Hessian of the 3D data to compute the principal directions [19]. Interrante et al. used a similar technique based on Gaussian-

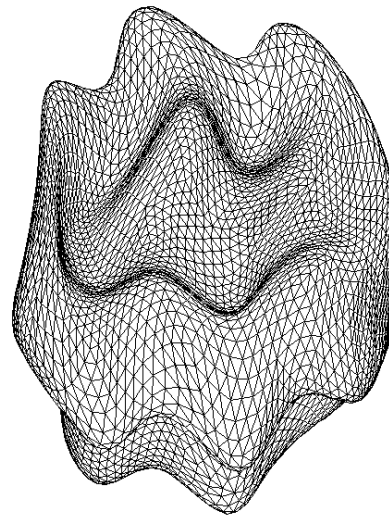


Figure 1 Polygonal surface mesh of arbitrary 3D "blob".

Figure 2 Random vector field of object in figure 1.

Figure 3 Uniform (vertical) vector field of object in figure 1.

Figure 4 First principal direction vector field of object in figure 1.

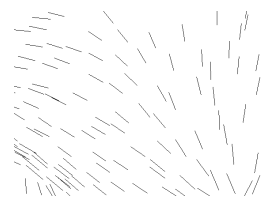
Figure 5 Second principal direction vector field of object in figure 1.

6a Shaded surface mesh

6b Random vector field

6c Uniform vector field

6d First principal direction
vector field



6e Second principle direction
vector field

Figure 6 Close-ups of the same region of the object in figure 1.