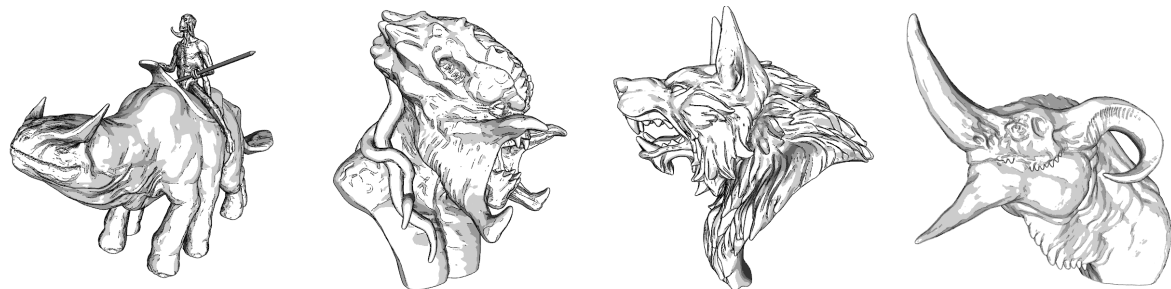


Photic Extremum Lines

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Abstract

In the field of illustrative visualization, feature lines are essential for conveying the shape of a given object. Photic extremum lines (PELs) are a type of feature lines in object space, which are, besides surface geometry and view position, dependent on the illumination. In this way, illustrations generated by PELs strongly coincide with line drawings created by hand due to human perception. Furthermore, PELs are easily adjustable by switching between lighting models and allow various post-processing techniques for line stylization and shading. The algorithm to extract PELs from scenes mainly has to compute up to third-order derivatives for each vertex and may be parallelized. Implementations allowing real-time performance exist for the CPU and GPU. By comparison to other feature line types, it can be seen that PELs are an effective and flexible tool for scientific illustration.

Keywords: Illustrative Visualization, Non-Photorealistic Rendering, Feature Lines, Object-Space Algorithm, Contours, Silhouettes, Suggestive Contours, Photic Extremum Lines, Illumination

1 Introduction

Illustrative visualization is the science and art of effectively communicating known aspects of scientific data in an accurate and intuitive way. Especially for the rendering of volumetric data sets in medicine, it is a valuable tool to reduce a vast amount of complex information to its essence. In this respect, photorealistic rendering techniques are suboptimal because they are not able to efficiently depict features of interest. Our knowledge of human cognition shows that, artistic drawings or paintings, in comparison to a photograph of the same scene, seem to be more suitable for communication and more pleasing in visual experience (Xie et al. 2007). Therefore non-photorealistic rendering techniques, typically inspired by artistic styles, are used

to create such illustrations. (Viola et al. 2005)¹

Feature lines represent a given data set as a line drawing to mimic hand-drawn illustrations. In such a way, a large amount of information can be communicated in a succinct manner by taking advantage of human visual acuity. Used as an abstraction tool in illustrative visualization, feature lines convey the shape of objects much more efficiently compared to a photograph. (Isenberg et al. 2003; Viola et al. 2005; Xie et al. 2007)

There are many different types of commonly-used feature lines, such as contours (Isenberg et al. 2003), suggestive contours (DeCarlo et al. 2003), ridge-valley lines (Ohtake, Belyaev, and Seidel 2004), apparent ridges (Judd, Durand, and Adelson 2007), and demar-

¹In this report, citations concerning more than one sentence are given at the end of the respective paragraph.

cating curves (Kolomenkin, Shimshoni, and Tal 2008). Typically, these only depend on the surface geometry, such as normal and curvature, and possibly the view position. However, human perception is highly sensitive to high variations in illumination. As a consequence, for conveying the shape of objects according to human perception, feature lines should also depend on the lighting of an object. (Xie et al. 2007; Zhang et al. 2011)

In this report, we present the concept and implementation of photic extremum lines (PELs), one of the first types of feature lines exhibiting a dependency on illumination. PELs have been first introduced in Xie et al. (2007) and further developed in Zhang, He, and Seah (2010). Strongly inspired by the edge detection techniques for 2D images, they are characterized by a sudden change of illumination on the surface of a 3D object. Since their computation is taken out in object space, PELs are flexible and enable further post-processing such as line stylization and shading (Isenberg et al. 2003). Furthermore, by manipulating the illumination of an object, the user can take full control to adjust the rendering output and achieve desired illustration results. Implementations for PELs can be done for the CPU and GPU, nowadays, achieving real-time performance. (Xie et al. 2007; Zhang, He, and Seah 2010)

2 Related Work

For the comprehension and implementation of PELs, we also need to rely on several basic techniques and definitions. In Isenberg et al. (2003), we get a thorough classification of feature line types together with recommendations according to the requirements of an application. It also describes the general routine for feature line extraction by using subpolygon interpolation which is also used in Zhang, He, and Seah (2010) to render PELs. Furthermore, a basic but general approach for the hidden line removal for object-space algorithms by using a two-pass rendering with depth buffer testing is provided. And additionally, using the above techniques the algorithm for extracting the contours of an object is explained. (Isenberg et al. 2003)

The definition of PELs involves up to third-order derivatives of scalar illumination functions given on a triangle mesh. Algorithms to correctly estimate curvatures and such derivatives are given in Rusinkiewicz (2004). The main content of this report is based on Xie

et al. (2007) which defines PELs and provides a first algorithm and a whole framework to properly generate them. Supposable, the algorithm was implemented using the CPU. In Zhang, He, and Seah (2010), an improved real-time implementation for PELs on the GPU using the standard graphics pipeline for gradient computations is described. Hereby, the authors have used a simpler threshold test and a transformed equation to estimate derivatives for vertices.

3 Mathematical Preliminaries

DEFINITION 3.1: Mesh Function

$$f: S \rightarrow \mathbb{R}$$

DEFINITION 3.2: (First Fundamental Form Triangle)

$$I_{uv} := \begin{pmatrix} \|u\|^2 & \langle u | v \rangle \\ \langle u | v \rangle & \|v\|^2 \end{pmatrix}$$

$$I_{uv}^{-1} = \frac{\text{adj } I_{uv}}{\det I_{uv}} = \frac{1}{\|u\|^2 \|v\|^2 - |\langle u | v \rangle|^2} \begin{pmatrix} \|v\|^2 & -\langle u | v \rangle \\ -\langle u | v \rangle & \|u\|^2 \end{pmatrix}$$

DEFINITION 3.3: (Gradient Triangle)

$$[\nabla f]_{uv} = I_{uv}^{-1} \begin{pmatrix} \Delta_u f \\ \Delta_v f \end{pmatrix}$$

$$\nabla f = \begin{pmatrix} u & v \end{pmatrix} [\nabla f]_{uv}$$

DEFINITION 3.4:

$$\partial_w f(x) := \langle \nabla f(x) | w \rangle$$

$$\mathcal{D}_f g(x) := \left\langle \nabla g(x) \left| \frac{\nabla f(x)}{\|\nabla f(x)\|} \right. \right\rangle$$

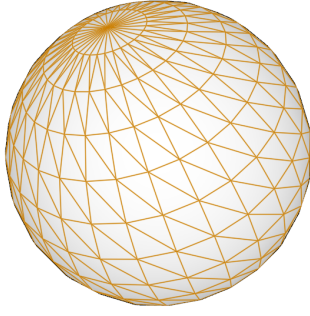


Figure 1: Triangulated Meshes

4 Photic Extremum Lines

For this section, let S be a smooth surface patch and $\varphi: S \rightarrow \mathbb{R}$ three-times continuously differentiable scalar illumination function.

In other words, photic extrema are points where the variation of illumination in the direction of its gradient reaches a local maximum.

DEFINITION 4.1: (Photic Extremum Lines)

The set $PEL(S, \varphi)$ of photic extremum lines consists of all points $x \in S$ such that the following holds.

$$\mathcal{D}_\varphi \|\nabla \varphi\| (x) = 0 \quad \mathcal{D}_\varphi^2 \|\nabla \varphi\| (x) < 0$$

Let $\tau \in \mathbb{R}_0^+$ be an arbitrary threshold.

$$PEL_\tau(S, \varphi) := \{x \in PEL(S, \varphi) \mid \|\nabla \varphi\| (x) > \tau\}$$

5 Algorithm

5.1 Overview

Algorithm

1. Compute illumination
2. Compute variation
3. Compute directional derivative
4. Compute second-order derivative
5. Detect line vertices on edges by testing for photic extremum
6. Trace and filter out lines by using threshold

7. Render only visible lines by using hidden line removal

5.2 Preprocessing

Besides loading the triangle mesh to be rendered with PELs, generating interpolated normals for every vertex have to be computed if they are not already present. Here, we refer to standard procedures given by Max (1999) and Jin, Lewis, and West (2005). Further preprocessing would involve reducing the noise of such normals by using bilateral normal filter.

For the computation of gradients and directional derivatives on the mesh, local coordinate system and Voronoi weights should be precomputed. Additionally, neighboring vertices should be stored for parallelization.

5.3 Gradient Computation

For each face, compute the constant gradient by using formula in background. Transform and rotate this gradient into the local vertex system and accumulate multiplied with Voronoi weight. Afterwards iterate over all vertices for normalization.

5.4 Line Tracing

5.5 Hidden Line Removal

6 Implementation

7 Results and Comparison

8 Conclusions

PELs are view- and light-dependent feature lines in object space. They are characterized by points where the variation of illumination is larger than a given threshold and reaches a local maximum in the direction of its gradient. To compute PELs, we therefore have to evaluate up to third-order derivatives of a given illumination function every animation frame. This makes PELs computationally much more expensive than other feature line types. However, real-time capability can be achieved by GPU implementations. And with the provided CPU implementation, we are still able to achieve interactive frame rates. Using different lighting techniques, PEL generation can be adjusted and shows similarities to hand-drawn illustrations. PEL in conjunction

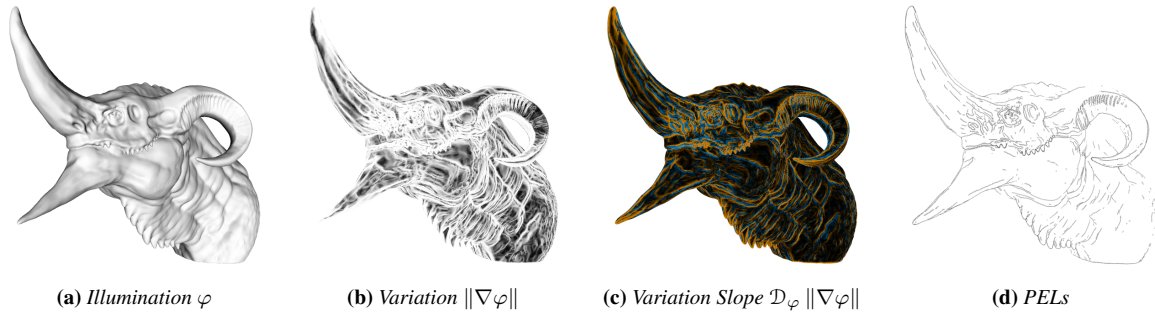


Figure 2: Variation

These images show the same shaded object (dragon head) to visually explain the definition of PELs.

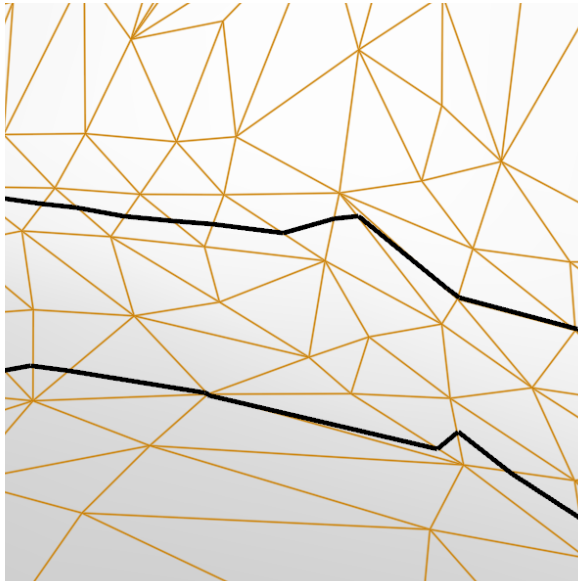


Figure 3: Sub-Polygon Feature Lines

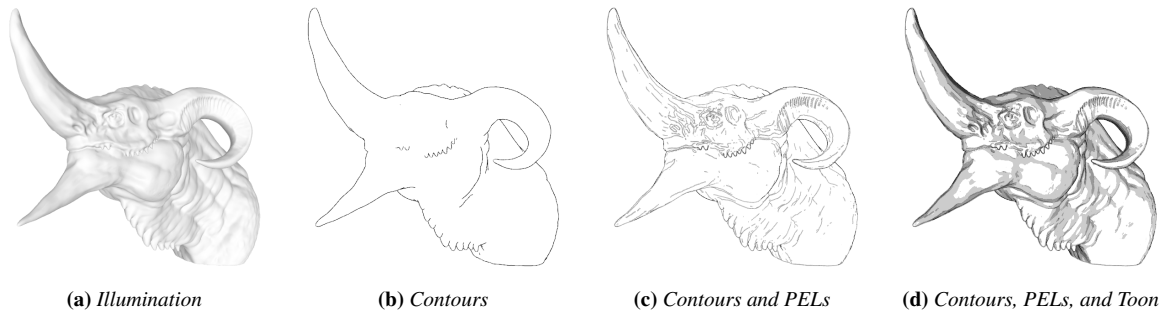
with additional shading techniques, such as contours and toon shading, even more improves the rendered output.

Comparison to other algorithms.

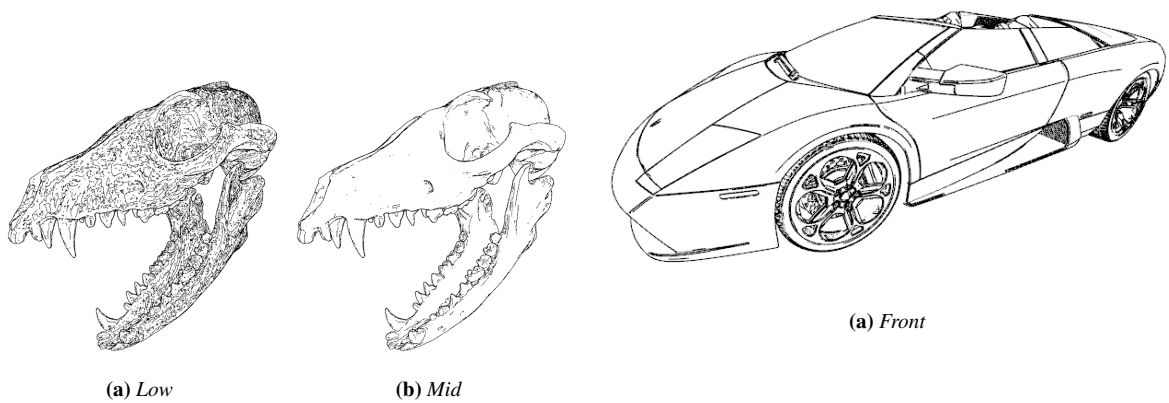
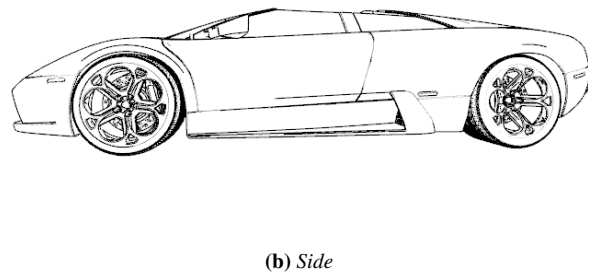
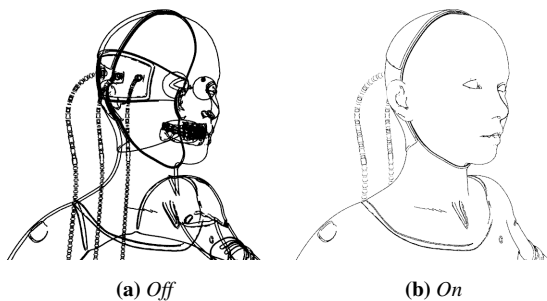
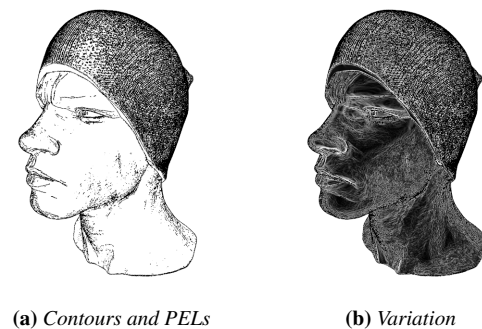
For the future, exaggerated shading and automatic thresholding and normal filtering should be used.

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**Figure 4: Short Summary Part**

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**Figure 5: Effect of thresholding****Figure 7: Nearly Perfect Line Extraction for Smooth Objects****Figure 6: Two-Pass Rendering for Hidden Line Removal****Figure 8: Erroneous Line Extraction for Noisy Objects**

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