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Comparative Evaluation of Feature Line Techniques for Shape Depiction

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Abstract

This paper presents a qualitative evaluation of feature line techniques on various surfaces. We introduce the most commonly used feature lines and compare them. The techniques were analyzed with respect to the degree of realism in comparison with a shaded image with respect to the aesthetic impression they create. First, a pilot study with 20 participants was conducted to make an inquiry about their behavior and the duration. Based on the result of the pilot study, the final evaluation was carried out with 129 participants. We evaluate and interpret the trial results by using the Schulze method and give recommendations for which kind of surface, which feature line technique is most appropriate.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Curve, surface, solid, and object representations

1. Introduction

Illustrative visualization techniques are used to present a meaningful, expressive, and simplified representation of an object or a complex scene. Mostly, these concepts can be applied to focus-and-context visualization where a few local regions are depicted in detail. Surrounding contextual objects are illustrated with less detail for avoiding distraction from important structures. Illustrative visualization concepts can be divided into several categories. According to Rautek et al. [RBGV08] illustrative visualization techniques can be divided into low-level and high-level visual abstractions. Low-level visual abstractions may change the layout of the surface or alter the features to convey the communicative intent of the author. High-level visual abstractions are techniques which convey relevant information for the examination, e.g., interactive cutaways [BGKG06], close-ups [BG05], exploded views [BG06], or peel-aways [CSC06] for volume data. The development of new illustrative visualization techniques might be inspired by limitations of previous work. Such limitations may be discovered by analyzing different scenes or objects, or might be identified by the results of a comprehensive user study. Thus, the evaluation can help to analyze established techniques and for indicating further refinements.

This paper deals with the evaluation of a special kind of low-level visual abstractions: *feature lines*. Feature line methods attempt to convey the most salient regions of a surface with single lines. The most commonly used feature lines comprehend six methods. As different evaluations compared some feature line methods, no study exists, which compared these feature line methods together. Such a comparison would be difficult to provide since the methods exhibit strengths and weaknesses depending on different surface types. Therefore, this paper investigates the six major feature line methods and compares them in an extensive evaluation with 149 participants. The techniques are qualitatively evaluated in the context of realistic and aesthetic depiction and for choosing a favorite techniques. We use the results of the evaluation to provide guidelines for which kind of surface which feature line method is best-suited. In summary, this paper makes the following contribution:

- A survey of the six major feature line methods.
- A pilot study comprising 20 participants and a final evaluation with 129 participants.
- An analysis of the results and recommendations for which kind of surface, which feature line method is best suited.

2. Related Work

Perceptual studies are an important element in the quality assessment of illustrative visualization techniques. The studies are an important tool for further analysis and refinement.

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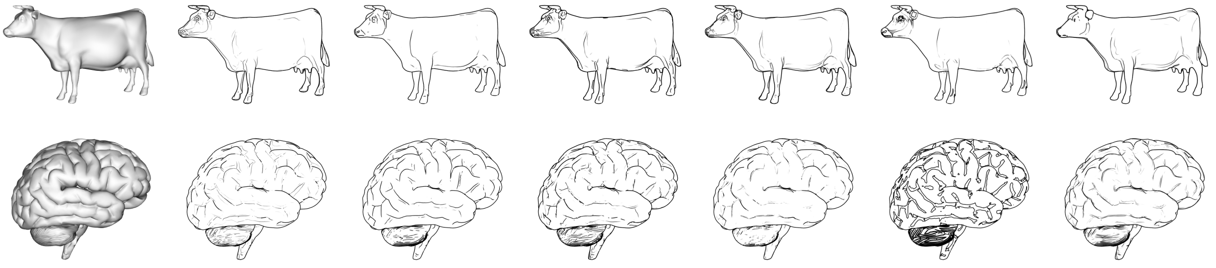


Figure 1: Two examples of a shaded model (SH,left) with the 6 feature line methods.

Furthermore, it serves as a quality demand for subsequent techniques. In the following, we give an overview of prior work in the area of feature lines and perceptual studies.

Feature lines: As mentioned, feature lines can be divided into image-based and object-based methods. Image-based methods are performed on the rendered image. Therefore, mostly a convolution kernel is applied to the image to detect features. These method allow only a limited control over the resulting line attributes. Especially for interactive exploration of 3D models, an object-based method is more appropriate as frame-coherence can be guaranteed.

The most important object-based lines are contours, which depict the strongest shape cues of the model [IFH*03]. These lines can, however, not illustrate all important features to convey the surface. Interrante et al. [IFP97] employed *ridges and valleys* a curvature-based method for the depiction of salient regions. From an artists' point of view, these lines are not suitable because they are view-independent and artists tend to draw lines depending on the viewing direction. Therefore, DeCarlo et al. [DFRS03] introduced *suggestive contours*, which extend the definition of the contour to produce view-dependent feature lines. Unfortunately, these lines cannot depict convex structures. Thus, Judd et al. [JDA07] developed *apparent ridges* a feature line method, which combines the advantages of suggestive contours and ridges and valleys. Kolomenkin et al. [KST08] introduced *demarcating curves* a curvature-based method. These lines are evaluated on antiquary models to emphasize slight features, e.g., old scripts. Xi et al. [XHT*07] suggested *photic extremum lines*. This feature line method is view- and light-dependent and has been optimized by Zhang et al. [ZHS10] to reach real-time performance. Furthermore, Zhang et al. [ZHX*11] developed *Laplacian lines*. They adopt the Laplacian of Gaussian edge detector to 3D surfaces.

Perceptual Studies: The importance of perceptual aspects in computer graphics is described in [BCF*08] and used to improve the effectiveness of 3D and 2D visualizations. Several attempts have been made to evaluate feature lines. Cole et al. [CGL*08] conducted an evaluation about line drawings. The aim was to assess where artists draw lines to convey the shape of a surface. The artists were asked to draw various surfaces. The painted images were scanned and used to analyze the positions of the lines. Later, Cole et al. [CSD*09] examined how well line drawings can depict the shape of the surface. For this, different gauges were placed on the painting and the participants were asked to orient them according to an imaginary normal. The deviation of the oriented gauge in comparison to the computed normal serves as a measure of how well the shape was perceived. Lawonn et al. [LGP13] compared different feature lines in a qualitative evaluation on anatomical surfaces. They compared ridges and valleys, suggestive contours, apparent ridges, and photic extrumum lines on three medical surfaces derived medical image data. The participants were medical experts who assessed the quality of the feature line methods. The evaluation stated a slightly tendency for suggestive contours.

In the context of non-photorealistic rendering (NPR), Isenberg et al. [INC*06] conducted an observational study for different NPR styles. The participants were given images of different NPR techniques and had to fulfill several tasks, for example to sort them in an arbitrary number of piles. As a result, different recommendations for NPR techniques were pointed out. Baer et al. [BGCP11] conducted a quantitative and qualitative evaluation for shape and depth perception of different vessel visualization techniques. They also used gauges to measure the deviation in comparison to the computed normal. Shape depiction was also improved by using different textures, see [BH07] and [KHSI04]. Borkin et al. [BGP*11] evaluated visualization techniques for the diagnosis of coronary artery disease. Based on the result, an interactive visualization application was developed. An evaluation of depth of field was conducted by Grosset et al. [GSBC13]. They used accuracy and response time as a measure of the usefulness of depth of field. Tietjen et al. [TIP05] used different visualization technique on medical datasets and evaluated them. Ritter et al. [RHP*06] adapted hatching techniques to improve the depth perception of vascular trees and evaluated the perceptual effects.

3. Method

In this section, we briefly recap the evaluated feature line methods.

Ridges and Valleys (RV) [IFP97] are defined as the loci of points at which the principle curvatures assume an extremum in the principle direction:

$$D_{\mathbf{k}_1} \kappa_1 = 0, \tag{1}$$

where κ_1 is the principle curvature (PC) with $|\kappa_1| \geq |\kappa_2|$ and $\mathbf{k}_1$ is the associated principle curvature direction (PCD). The points, which fulfill Eq.1, can be divided into ridges and valleys, if:

$$D_{\mathbf{k}_1} D_{\mathbf{k}_1} \kappa_1 \begin{cases} < 0, & \text{and } \kappa_1 > 0\text{: ridges} \\ > 0, & \text{and } \kappa_1 < 0\text{: valleys.} \end{cases} \tag{2}$$

Suggestive Contours (SC) [DFRS03] are view-dependent and defined as the set of minima of $\langle \mathbf{n}, \mathbf{v} \rangle$ in the direction of $\mathbf{w}$, where $\mathbf{n}$ is the surface normal, $\mathbf{v}$ is the view vector which points towards the camera, and $\mathbf{w} = (\mathrm{Id} - \mathbf{n}\mathbf{n}^T)\mathbf{v}$ is the projection of the view vector on the tangent plane:

$$D_{\mathbf{w}} \langle \mathbf{n}, \mathbf{v} \rangle = 0 \text{ and } D_{\mathbf{w}} D_{\mathbf{w}} \langle \mathbf{n}, \mathbf{v} \rangle > 0. \tag{3}$$

Apparent Ridges (AR) [JDA07] are defined as the loci of points where the view-dependent PC κ_1 assumes an extremum in the view-dependent PCD $\mathbf{t}$:

$$D_{\mathbf{t}'} \kappa_1' = 0 \text{ and } D_{\mathbf{t}'} D_{\mathbf{t}'} \kappa_1' < 0. \tag{4}$$

This definition is similar to the ridges and valleys instead of using view-dependent PCs and PCDs. Informally, a projection operator is defined, which projects the measures of the surface on the screen plane.

Photic Extremum Lines (PEL) [XHT*07] illustrate the surface where the variation of illumination reaches a maximum. With $f = \langle \mathbf{n}, \mathbf{v} \rangle$ and $\mathbf{w} = \frac{\nabla f}{\|\nabla f\|}$ these lines are defined as:

$$D_{\mathbf{w}} \|\nabla f\| = 0 \text{ and } D_{\mathbf{w}} D_{\mathbf{w}} \|\nabla f\| < 0. \tag{5}$$

Demarcating Curves (DEM) [KST08] are defined as the transition of a ridge to a valley line. These lines are defined as the loci of points where the curvature derivative is maximal:

$$\langle \mathbf{w}, S\mathbf{w} \rangle = 0 \text{ with } \mathbf{w} = \arg \max_{\|\mathbf{v}\|=1} D_{\mathbf{v}} \kappa, \tag{6}$$

where S is the shape operator (see [Rus04]). The vector $\mathbf{w}$ can be analytically determined.

Laplacian Lines (LL) [ZHX*11] inspired by the Laplacian-of-Gaussian (LoG) edge detector in image processing. The Laplacian of the illumination function is determined, mostly f is defined as a headlight $f = \langle \mathbf{n}, \mathbf{v} \rangle$. Formally, Laplacian Lines are defined as the set of points which fulfill:

$$\Delta f = 0 \text{ and } \|\nabla f\| \geq \tau, \tag{7}$$

where τ is a user-defined parameter.

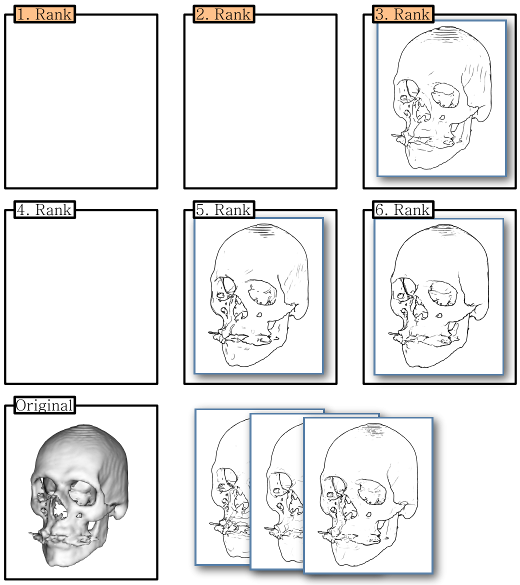


Figure 2: The evaluation tool. The participants were asked to place the various feature line results to their favorite rank. First, all model-specific pre-generated images are placed at the bottom in a random order for each participant.

4. Qualitative Evaluation

Investigating the realistic and the aesthetic depiction of feature lines is important for further refinements and guidelines. Thus, this evaluation is divided into three parts:

- realistic assessment,
- aesthetic depiction, and
- selection of preferred technique.

In this study, we wanted to figure out what is the most realistic feature line method and which method can depict the surface well in an aesthetic way. We developed an evaluation tool to analyze the most realistic, the most aesthetic, and the favored techniques of our participants. In our evaluation, we only used screenshots of the surface models. Therefore, zooming and rotation were not supported. The screenshots were generated in cooperation with two artists who are familiar with computer-generated line drawings. Furthermore, we used different surface models to provide a broad spectrum of surfaces. For all models, we used a headlight to generate the feature lines. During the evaluation, we want to analyze, which feature line method is more appropriate regarding the specific task. Thus, we decided that the user can rank the methods. He could place the different methods from rank 1 to rank 6 where rank 1 is the best place. This allows us to analyze and determine the winner and a technique rank order for the specific tasks.

Table 1: Results of the tasks with the corresponding model.

Rank	Aesthetic						Realistic					
	Buddha	Brain	Cow	Femur	Max	Skull	Buddha	Brain	Cow	Femur	Max	Skull
1	AR	LL	PEL	LL	AR	PEL	SC	AR	AR	LL	AR	SC
2	RV	SC	AR	AR	LL	RV	AR	SC	PEL	DEM	LL	LL
3	SC	AR	RV	PEL	RV	SC	RV	LL	RV	AR	SC	PEL
4	LL	RV	DEM	DEM	PEL	AR	LL	RV	DEM	PEL	RV	AR
5	PEL	PEL	SC	SC	SC	LL	PEL	PEL	SC	SC	PEL	DEM
6	DEM	DEM	LL	RV	DEM	DEM	DEM	DEM	LL	RV	DEM	RV

4.1. Evaluation Tool

For every participant, an ID was generated and the results of the evaluation with specific personal details were saved. The structure of the evaluation was:

- Personal data acquisition,
- Instruction and training, and
- the evaluation.

First, we asked about the gender and the age. Then, a test scenario started to make the participants familiar with the evaluation program and to learn the drag-and-drop feature. The participants saw a final image which consists of a sentence with six words. Next to the final image, six pictures were randomly ordered where each picture contains one word. The participants were asked to sort the words such that the final sentence occurs. After this training, the study began. In the bottom left corner a surface model in a gray shading were shown. Next, six images with the different feature line methods were shown, see Figure 1.

The first question was about *realistic appearance*. The participants should order the six feature line result from rank 1 to rank 6 according to realistic appearance where rank 1 means the most realistic image. Afterwards, the same model was shown and the participants were asked to order the feature line results according to *aesthetic appearance*. Finally, the last task was to choose a *favorite*.

The evaluation was organized in two parts. In the first part, we conducted a pilot study to make an inquiry about the participants' behavior. From this insight, we slightly altered the final evaluation, see 4.2.

4.2. Pilot Study

In the pilot study, every participant saw six models, see Figure 1, 2, and 5. For every model they had to rank the feature line methods according to realistic appearance and to aesthetic appearance. Furthermore, they should chose a favorite. In the end, they could write a comment. During the pilot study, we also noted the spoken comments by the participants. The pilot study lasted about 15-20 minutes. We asked 20 participants, 15 male, 5 female, an average age of 28.9, the youngest person was 16, the oldest 55. The participants most frequently comment on the duration time. They said that it lasts too long and that this leads to reduced concentration. Therefore, we decided to split the final evaluation. Instead of using six models, we used three computers where each computer was used to present two models.

4.3. Study

In the final study, every participant saw two models. The study was conducted on three computers all equipped with the same monitor. This study lasted about 7-10 minutes. Mostly, the participants did not write any comments at the end. See Figure 2 for a draft of the evaluation tool.

5. Analysis & Result

We considered the realistic impression, the aesthetic depiction, and the favorite feature line method as an indicator for preference. Therefore, we evaluated the results of every category for each model. Afterwards, we analyzed the results for all models together for the categories. As the participants had to order the diverse methods from rank 1 to rank 6, we have to use a method to evaluate the different results. Determining the winner of ranked results is widely used in elections and such methods are called *Condorcet* methods. They are used in elections where the voters order the candidates. It selects the winner of an election by majority in comparison to all pairings against the other candidate. Therefore, each candidate will be compared pairwise and it will take into account if one candidate is more often preferred against another candidate. There exists different *Condorcet* methods. We used the most widespread method, the *Schulze* method [Sch11]. This method gives the resulting rank for the evaluation. Furthermore, the *Schulze* method fulfill several criteria, which are important for the election. For example the *Condorcet* criterion, which means whenever a candidate is more often preferred in comparison to the other candidates, this candidate should win. Another example would be the *reversal symmetry*, which means that if an election chooses a candidate as the winner the same candidate should not be the winner if the rankings would be inverted.

5.1. Schulze Method

Having a list of ranked candidates, the Schulze method determines the winner and the final rank order of the candi-

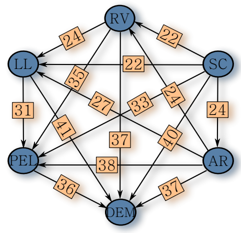
Rank

1	2	3	4	5	6
AR	SC	PEL	LL	RV	DEM
SC	PEL	LL	AR	DEM	RV
LL	SC	AR	DEM	PEL	RV
SC	LL	RV	AR	DEM	PEL
⋮	⋮	⋮	⋮	⋮	⋮

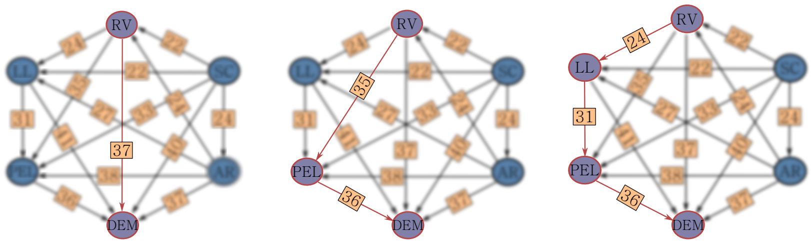
(a) Rankings

	RV	SC	AR	DEM	PEL	LL
RV	0	21	19	37	35	24
SC	22	0	24	40	33	22
AR	24	19	0	37	38	27
DEM	6	3	6	0	7	2
PEL	8	10	5	36	0	12
LL	19	21	16	41	31	0

(b) Rank matrix



(c) Graph



(d) Path 1 (e) Path 2 (f) Path 3

	RV	SC	AR	DEM	PEL	LL
RV	0	0	0	37	37	24
SC	24	0	24	40	33	24
AR	24	0	0	37	38	27
DEM	0	0	0	0	0	0
PEL	0	0	0	36	0	0
LL	0	0	0	41	31	0

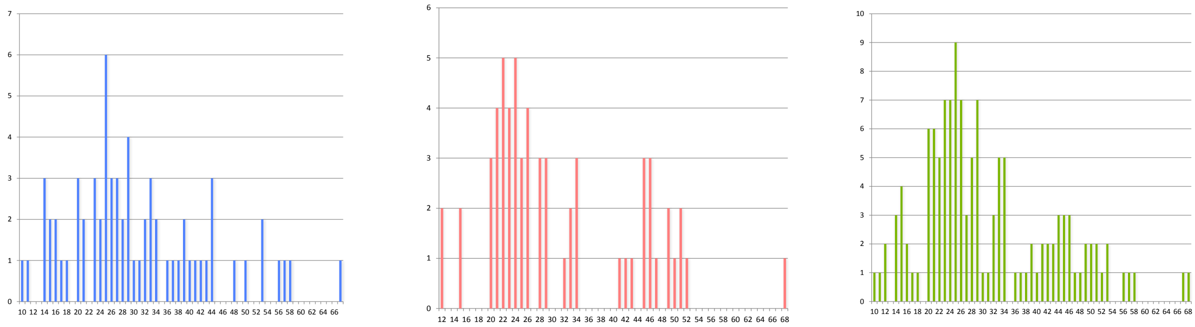
(g) Minimal weight

Figure 3: First, all rankings, which occur, are listed (a). Afterwards, a ranked matrix R is created in (b) where r_{ij} denotes how often i has a better rank than j. The orange box represents that $r_{ij} \geq r_{ji}$. These values are used to create a weighted direct graph, (c). Afterwards, a new matrix M is determined. The entry $m_{1,5}$ is obtained by all possible paths from SC to PEL, here depicted in (d)-(f). The minimal weights are denoted (37,35,24) and the biggest determines the entry $m_{1,5} = 37$, see (g). Finally, SC is the winner as it beats all the other methods. The other rankings from 2 to 6 are: AR, RV, LL, PEL, and DEM.

dates. Hence, it is well suited for the comparison of feature line methods in our evaluation. First, all the possibilities of the feature line methods will be written down and the number of occurrences will be denoted. Therefore, having six feature line methods $6! = 720$ possible rankings may occur, see Figure 3a. We explain the Schulze method with an example of the evaluation: the test for realistic of the Buddha model, see Figure 3. A rank matrix R is created such that r_{ij} denotes how often method i has a better rank than method j. For example in Figure 3b the suggestive contour is 40 times more often preferred against demarcating curves, so $r_{2,4} = 40$. The next step is about creating a direct weighted graph. If $r_{ij} > r_{ji}$ then, a direct edge (i, j) with weight r_{ij} is created. In our example, we have $r_{2,4} = 40$ and $r_{4,2} = 3$, therefore a direct edge with weight 40 is created, see Figure 3c. Afterwards, a new matrix M is determined. Therefore, all paths from i to j are considered and m_{ij} is set to the overall strongest edge of the weakest element in a path, i.e., having two paths p_1, p_2 from i to j and let w_1 be the lowest weight of p_1 and w_2 of p_2 if $w_1 \geq w_2$ then $m_{ij} = w_1$. For example, we consider all paths from RV to DEM, see Figures 3d-3f. The lowest weights of the three paths are 37,35,24 and from these (lowest) values the highest value is 37, thus, we set $m_{1,5} = 37$. Finding the matrix M, the Floyd-Warshall algorithm [Flo62] can be applied. Finally, the matrix M is analyzed according to the highest value entries. The winner is suggestive contours as it beats the other candidates (the row is completely orange), see Figure 3g. Erasing the row and the column consisting of suggestive contours, the second place goes to apparent ridges. The further places are RV, LL, PEL, and DEM. Table 1 depicts the rankings of all feature line methods divided into tasks (realistic, aesthetic) and model (Buddha, Brain, Cow, Femur, Max Planck, Skull). Furthermore, we list how often which method was selected as the participants favorite technique.

5.2. Participants

Overall 149 persons participated in the evaluation, 20 in the pilot study and 129 in the final evaluation. The participants had a broad spectrum of educational backgrounds. We gathered them at the *long night of the sciences*, therefore openness and interest in science is above average. Of the 129 participants, we had 68 men and 61 women, see Figure 4. The age of the men comprised from 10 to 67 years with an average of 30.53 years and a standard deviation of 12.3 years, the median is 28 years. On the other hand, the age of the women ranged from 12 to 68 years with an average of 30.92 years and a standard deviation of 12.0 years, the median is 26 years. The final evaluation took about 7 to 10 minutes. The participants could write a comment at the end of the evaluation. Only eight comments were noted. Mostly, the participants mentioned that "some methods were hard to distinguish". Furthermore, some mentioned that the realistic and



(a) Male (b) Female (c) All

Figure 4: Age frequency distribution of the participants.

(a) Femur (b) Max Planck (c) Buddha

Figure 5: Models also used in the evaluation.

Table 2: Frequency of how often the method reach a rank from 1-3 and from rank 4-6.

Method	Rank 1-3	Rank 4-6
RV	6	6
SC	7	5
AR	11	1
PEL	5	7
DEM	1	11
LL	8	5

the aesthetic task were hard to distinguish. One participant wrote that some parts of the brain seemed a bit more realistic for some methods and other methods delivered a more realistic impression on other regions of the brain. In summary, the participants had no problems to answer the questions. The duration time seemed to be appropriate and we did not notice that the later tasks were finished faster than the first tasks. This may be an indication for equal concentration time during the evaluation.

5.3. Results

The result of the Schulze method can be found in Table 1. First, it is noticeable that AR is mostly on a rank 1 to 3. Only for the skull model (realistic task), it is placed on rank 4. In Table 2, we list how often a method is placed on rank 1-3 and rank 4-6. As a first tendency, AR, SC, and LL are more often in places 1-3 as on the bottom places.

For the final result, we used all the rankings of the aesthetic task and the realistic task. Therefore, we merged the rankings such that we have two tables for both tasks independent of the underlying surface. Afterwards, we apply the Schulze method and obtain the final ranking. The result of the realistic task in the order of the final rank from 1 to 6 is: AR, LL, SC, RV, PEL, DEM. The result of the aesthetic task is very similar: AR, SC, LL, RV, PEL, DEM. Thus, the result of the evaluation asserts the favorite techniques are apparent ridges, suggestive contours, and Laplacian lines. Analyzing the results of the evaluation, mostly the participants had similar favorites for the realistic and the aesthetic task. The results are always similar, but for the skull model the ridge and valley method differs strongly. For the aesthetic task, it reached a second rank, whereas it is on the last rank with the realistic task. Also the result strongly differs from this model. The explanation may be found in the complexity of the skull model. As it has too many features, it is hard to distinguish the different feature line methods. Moreover, several participants stated that they do not like this model and based on that, they found it hard to rank according to aesthetic aspects. Thus, the result strongly varies.

In comparison to the selection of the favorite feature line method, Table 3, the result is similar to the result of the aesthetic and realistic task. Apparent ridges had the most votes for the cow and Max Planck model, this coincides with the result from Table 1. Although, suggestive contours were chosen as the favorite method for the Buddha and the skull model. Laplacian lines were the favorite for the brain and the femur model. Interestingly, the demarcating curves were also chosen as the favorite method for the femur model. Here, this method was rated as the second rank for the realistic task for the femur model. Nevertheless, mostly it does not reach a rank better than four. In summary, the Schulze method placed the first three rankings as AR, SC, LL for realistic as well as for the aesthetic task. The analysis of the participants favored techniques confirmed this trend. Here, the three techniques were also mostly chosen.

6. Discussion

The evaluation was conducted using six models, see Figure 1, 2, and 5. Three models are used in the publications on feature lines. Furthermore, we additionally used three models, which are derived from medical image data. Thus, we used established and non-established surface models.

As a limitation in our evaluation, we used pre-generated images. Thus, the user was not able to interact with the surface model and could not set own thresholds to fine tune the illustration techniques. The image generation was agreed by two artists. We decided to use screenshots only as we think that the participants would otherwise lose their concentration after observing a few models.

As stated by one participant, some parts of the brain model seemed more realistic with one feature line method, but are less significant at another part. This is also observed by the cow model. For instance, regarding the eyes of the cow, some feature line methods strongly depict them, although they are hardly perceivable from the shaded image. Thus, one can raise the question, whether it is realistic to emphasize the eyes or not. Artists would illustrate the eyes as they are an important characteristic for such a model. Unfortunately, this decision making process is assessed by knowing the surface, which cannot be performed by modern feature line methods as they only use surface measurements.

7. Recommendations

To choose the right feature line method, it is first a matter of taste and second a question of the underlying surface. According to the results of the evaluation, we will mainly give recommendations for AR, SC, and LL.

First, on surfaces which exhibit noise, it is recommendable to use a method of low order derivatives. Thus, suggestive contours are recommended, as this method is of second order, whereas the other uses third-order derivatives. One advantage of suggestive contours is that it has two equivalent representations. This feature line method may be determined by radial curvature directions as well as with headlight. Therefore, no preprocessing is necessary if suggestive contours are determined by the light representation. One disadvantage is that the suggestive contours can not depict convex features. Furthermore, the contour must be activated as suggestive contours cannot illustrate the contour.

The apparent ridges on the other hand, are able to convey the contour. Moreover, this feature line method is able

Table 3: Results of the favorite feature line selection.

	Buddha	Brain	Cow	Femur	Max	Skull
RV	8	7	3	2	6	1
SC	13	7	4	6	5	14
AR	11	12	14	6	16	6
PEL	2	1	10	9	3	8
DEM	1	3	8	10	1	3
LL	8	13	4	10	12	11

to illustrate sharp edges and can depict a cube well. A disadvantage is that this method is the slowest of the presented methods. As the computational effort is very high, it reaches only 8 FPS on a mid-class PC of a model with 64k triangles. In comparison, SC reaches 45 FPS and LL 15 FPS.

The Laplacian lines can also depict sharp edges and the contour. One disadvantage is that this method needs substantial computational effort for preprocessing. First, the Laplacian of the surface needs to be calculated. As it is recommended in [ZHX*11] to use the Belkin weights [BSW08], first a parameter is used to determine the Laplacian. Unfortunately, the user has to wait until the computation is finished and afterwards, if he is not satisfied with the result, a different parameter is tried. Therefore, a trial-and-error loop is performed until the satisfied result is reached.

In summary, we recommend to use suggestive contours or apparent ridges in general. Suggestive contours are very fast and deliver satisfying results on most meshes. Unfortunately, not on convex surfaces where we recommend to use apparent ridges. Especially, for organic surfaces which are derived from medical image data, we recommend to use SC as these surfaces may exhibit surface noise. For representing industrial models, which exhibit sharp edges, AR is strongly recommended.

8. Conclusion

This paper presented an evaluation investigating the capability of illustrating surfaces according to the aesthetic and realistic depiction by feature line methods. We presented the feature line methods and compared them on six surfaces. For this, 149 participants take part in the evaluation. 20 people participated in a pilot study and the remaining persons took part in the final study. The result of the evaluation revealed a tendency in the preference to the feature line methods: apparent ridges, suggestive contours, and Laplacian lines. For the analysis of the result, we used the Schulze method, which is originally used in elections. Additionally, we give recommendations for which kind of surface, which feature line technique is more appropriate. However, the results of the study just give a tendency and should not be seen as a definite statement.

However, regarding our evaluation, we provided recommendations for feature line methods on various surfaces, which are concluded by the results of evaluation.

9. Future Work

For future work, we are planning to extend the evaluation to a more analytic approach. Instead of presenting the final image, we could support the candidate in the decision making process. For instance, the user could brush on the surface with different size and could therefore define regions on which a feature line should be or should not be occur. Thus the final image could be analyzed and interpreted. For this, we need specific participants, e.g., artist or artist students.

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