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Transfer Function Optimization Based on a Combined Model of Visibility and Saliency

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Abstract

We present an automated technique to optimize the clarity of features in visualizations of 3D volume datasets. By adjusting the opacity transfer function, we achieve user-specified target distributions of feature conspicuity. Unlike previous techniques our approach accounts for both the issues of view-dependent occlusion and visual saliency of features in volume data. We demonstrate how the automated approach is useful in particular for optimizing the visualization of time-varying volume datasets.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

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1. Introduction

In volume visualization, "visibility" is a term commonly used to describe the opacity of a feature combined with the degree to which it is occluded by other features. However a significant element of visibility is also the degree to which it stands out from its neighborhood. For disambiguation we refer to these properties collectively as the conspicuity of a feature and argue that it is this property that needs to be enhanced in order to support most visualization tasks.

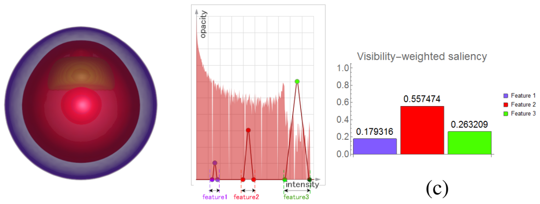
Users typically have a general idea of how conspicuous certain features should be for a given task and, accordingly, adjust visualization parameters such as opacity values in the transfer function. However, as the relationship between the opacity of voxels and the conspicuity of features in the final image is not linear, this typically necessitates a trial-and-error process with users having only indirect control through a set of parameters that have an unintuitive effect on the final rendering. To address this issue, we propose an approach for automatically refining the opacity transfer function to achieve any conspicuity distributions specified by users. Unlike previous approaches, we employ a model of visibility that takes into account issues of saliency as well as occlusion and transparency.

2. Background: Visibility weighted saliency metric

In [LD15] a metric called visibility-weighted saliency (VWS) is proposed, which simultaneously indicates the perceptual saliency and visibility of features in volume rendered images. VWS is defined based on two components: the *saliency* field, based on [KV06], is essentially a difference of Gaussian in 3D indicating the center-surround effect in a local neighborhood of voxels with respect to appearance attributes such as brightness and saturation, the *visibility* field is computed from the opacity contribution of voxels to the final rendered image, and indicates viewpoint-dependent occlusions of the voxels [Ems08] [CM11] [WZC*11]. Figure 1 shows, respectively, the rendered image of a nucleon data set [Pra13], the transfer function and visibility-weighted saliency. In this context, a *feature* is defined as a range in the histogram of scalar intensity values (three sample features are annotated in Figure 1(b)) and the VWS of a feature is the sum of the VWS values of all the voxels comprising that feature (for details see [LD15]).

3. VWS-based Optimization of Transfer Functions

Our transfer function optimization approach exploits the visibility-weighted saliency metric to automatically adjust the relative con-



(a) (b) (c)

Figure 1: (a) Nucleon data set; (b) Transfer function with 3 features with peak control points set to opacities in ratio 0.1 : 0.3 : 0.6; (c) VWS indicates feature 2 is most prominent despite lower opacity.

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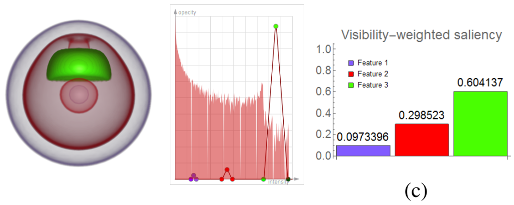


(a) (b) (c)

Figure 2: (a) After optimization towards relative visibility distribution of $\{0.1, 0.3, 0.6\}$, the green feature is particularly emphasized. (b) The optimized transfer function; (c) VWS

spicuity of features based on a user's specification of their relative importance (see Figure 2). We denote a target conspicuity distribution as $\{v_1, v_2, \dots v_n\}$ where each v_i is a relative VWS value for a feature, and $\sum v_i = 1$. We show examples with $n = 3$ as a small number of discrete features is typical in practice, however there are no specific constraints on the value of n in our framework.

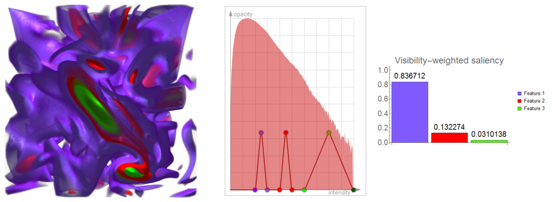
VWS provides the means to score the relative conspicuity of features in any given visualization, however as there is no direct relationship between the visualization parameters (e.g. voxel opacities) and output scores, an iterative approach must be applied to achieve a targeted visibility distribution. A gradient descent algorithm with an inexact line search [CZ13] is employed to adjust the transfer function to match the VWS with the targeted distribution. The objective function is defined as the root mean square of the differences of the visibility-weighted saliency and target importance of each feature. In our approach, only the opacity of features are changed in the transfer function domain whilst the classification of features (e.g. intensity ranges on 1D transfer functions) represented by the color map remains invariant. This is based on the assumption that there exists some pre-defined classification of features ranges and our approach aims to adjust the saliency distribution and reduce occlusion while preserving the classification of the data set.

4. Results

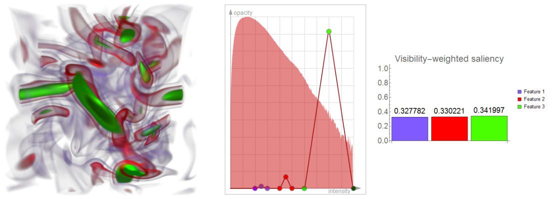
Figure 2 shows the result of VWS optimization applied to Figure 1 with a target distribution of $\{0.1, 0.3, 0.6\}$ intended to visualize the features at increasing conspicuity to show the interior structures more clearly. Figure 2 (b) and (c) are the optimized transfer function and visibility-weighted saliency histogram respectively.

We also demonstrate the applicability of our technique to optimizing a time-varying vortex data set [Ma03]. As a test case we used a target distribution with equal weights i.e. $\{1/3, 1/3, 1/3\}$ for 3 arbitrary chosen features. The naive example, Figure 3(a), demonstrates that merely setting equal opacities for features does not lead to equal visibility; due to the variance in distribution, the red and green features are overwhelmed and occluded by the purple feature. Whereas after optimization, Figure 3(b), the purple feature is noticeably less opaque but the spatial properties of the three features is simultaneously more apparent from an overall perspective.

Furthermore, our automated framework allows optimization of the time-variant visualization dynamically. As the simulation progresses, the distribution of voxels in each feature changes thus a single transfer function will not preserve a specific target conspicuity distribution as can be seen in Figure 4(a), which shows the VWS values for a transfer function optimized for Frame 1 of the simulation only. In Figure 4(b), the simulation is optimized for each frame leading to an adaptive visualization that maintains the desired conspicuity distribution throughout. Sample frames from each respective optimization can be compared in Figure 4(c) and (d). For a more detailed comparison please see the supplemental video.

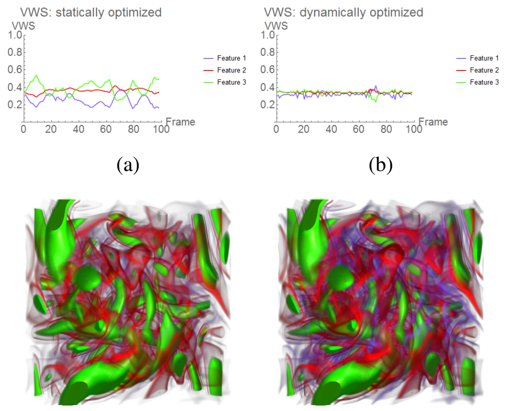


(a) Opacities set to $\{1/3, 1/3, 1/3\}$



(b) Optimized to VWS $\{1/3, 1/3, 1/3\}$

Figure 3: Visualization, transfer function and VWS of Vortex: (a) feature 1 dominates even though opacities are set to equal; (b) details in internal green and red features are more recognizable.



(a) (b)

(c) (d)

Figure 4: (a) VWS plot of the vortex simulation after a single optimization based on the first timestep; (b) Dynamically optimized for each time step; (c) Rendering of timestep 80 with the single optimization; (d) Timestep 80 with dynamic optimization

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