# Using Saliency to Support the Design of Visualizations of Spatial Data in 3D Terrain

Steve Dübel*      Christine Ripken†      Heidrun Schumann‡

Institute for Visual & Analytic Computing
University of Rostock

## ABSTRACT

Designing visualizations of spatial data and 3D terrain is challenging. Usually the designer has to focus on selected relevant aspects of the data, emphasize them, and attenuate less relevant information. Yet, it is not clear upfront if design decisions with respect to emphasis lead to the desired result. Conducting user studies is often infeasible due to their high costs. We propose to utilize saliency maps early in the design phase to help designers assess their visualizations. Saliency maps provide information about the uniqueness of visual features in an images and hence can predict which part of a visualization is likely to attract the user's attention. Our approach is to compute saliency maps in real-time and show them alongside the actual visualization. This provides designers with immediate feedback on the effectiveness of their design decisions.

**Index Terms:** Human-centered computing—Visualization—Visualization design and evaluation methods

## 1 INTRODUCTION

For the visual analysis of spatial information, we need to visualize both the spatial data and their spatial frame of reference. This is challenging because spatial data can be quite complex. The depiction of the spatial frame of reference is typically done as a 2D map, but many application (e.g., geology or avionics) require a 3D terrain surface. When visualizing large data in 3D terrain, visual clutter can easily occur. To reduce the complexity in visual representations, a distinction has to be made between relevant data and contextual data. Which data are relevant can be determined, for example, based on data characteristics or analysis task.

In order to properly communicate the relevant data, they must be presented prominently. Various strategies exist to emphasize relevant data. Typically, they are represented with unique visual marks (e.g., an eye-catching color, a contour, or a higher saturation) that differ from the rest of the visualization. The objective is to draw the attention of the user to the relevant data.

While there are many established methods to emphasize relevant data in a visualization, only few approaches exist to evaluate the effectiveness of these methods. This is, for one thing, because the effectiveness of emphasis techniques heavily depends on the particular application case. For example, emphasis for a simple visualization with few graphical elements requires different techniques than complex visualizations that shows much data with many graphical elements. Moreover, the effectiveness of emphasis is somewhat subjective and difficult to measure.

One way to evaluate whether a certain feature in a visualization attracts the user's attention are user studies, often in combination with eye-tracking. However, a visualization designer who is working on emphasizing a particular data aspect usually cannot afford the extremely time-consuming and expensive iterative process of visual design followed by a user study followed by a reconfiguration of the design followed by a repetition of the study.

Our idea is to employ saliency maps to tackle this problem. The models that underlys the saliency maps take into account the characteristics of human perception to predict which part of an image is likely to attract the attention of the user. Our approach is to compute and show saliency maps in parallel to the actual visualization. The saliency maps provide the visualization designer with early feedback on whether the measures taken to emphasize relevant data are effective or not. This shortens the design cycle significantly and enables experimenting with different designs in a timely manner.

Next in Section 2, we will describe the computation of saliency maps. In Section 3, we apply our approach to support the design process of visualizations of spatial data in 3D terrain.

## 2 COMPUTING SALIENCY MAPS

A saliency map depicts which pixels of an image have a high probability of attracting attention. Many factors may contribute to the saliency, and there are various models of saliency considering these factors to different degrees [1]. Here, we need a model that properly predicts the user's attention and is also quick to compute to allow for immediate results. We looked at different comparative evaluations of existing models, in particular at the work of Borji et al. [2] who tested and compared 35 visual saliency models. Based on this research, we decided to use the model by Itti et al. [4]. It is characterized by a good prediction quality and allows for a GPU-friendly implementation [3].

The saliency model of Itti et al. first extracts feature maps, then derives conspicuity maps and finally fuses them into the saliency map. The feature extraction is based on the lightness $L$ and the color $C$ of pixels (in CIELAB space) and the orientation $O$ of edges. These features are computed for multiple resolutions of the image to account for the fact that the human visual system is responsive to local discontinuities. We obtain the feature maps $M$ using across-scale addition of the extracted features.

To derive the conspicuity maps and the final saliency map, we need to consider the feature maps' degrees of uniqueness $H$ as a measure to weight them. The notion of uniqueness models the fact that elements are salient only if they are different from their surroundings. Accordingly, a feature map with higher uniqueness contributes more than a feature map with lower uniqueness. The uniqueness for each feature map $M$ can be calculated using the Shannon entropy $H(M) = -\log_2(p(M))$.

Finally, the uniqueness and the amplitude (given by the global maximum) are utilized to weight each feature map using the function $\overline{w}(M) = H(M) \max |v(i,j)|$, with $v(i,j) \in M$. Using $\overline{w}$ the individual conspicuity maps are generated with $L = \sum_\sigma \overline{w}(M_{L_\sigma})|M_{L_\sigma}|$, $C = \sum_\tau \sum_\sigma \overline{w}(M_{\tau_\sigma})|M_{\tau_\sigma}|$, and $O = \sum_\upsilon \overline{w}(M_{O_\upsilon}) \times |M_{O_\upsilon}|$, where $\sigma \in \{+,-\}$, $\tau \in \{A,B\}$, and $\upsilon \in \{0°,45°,90°,135°\}$. To obtain the weights of the final saliency map, we take into account the uniqueness of each conspicuity map using again the Shannon entropy.

*e-mail: steve.duebel@uni-rostock.de
†e-mail:christine.ripken@uni-rostock.de
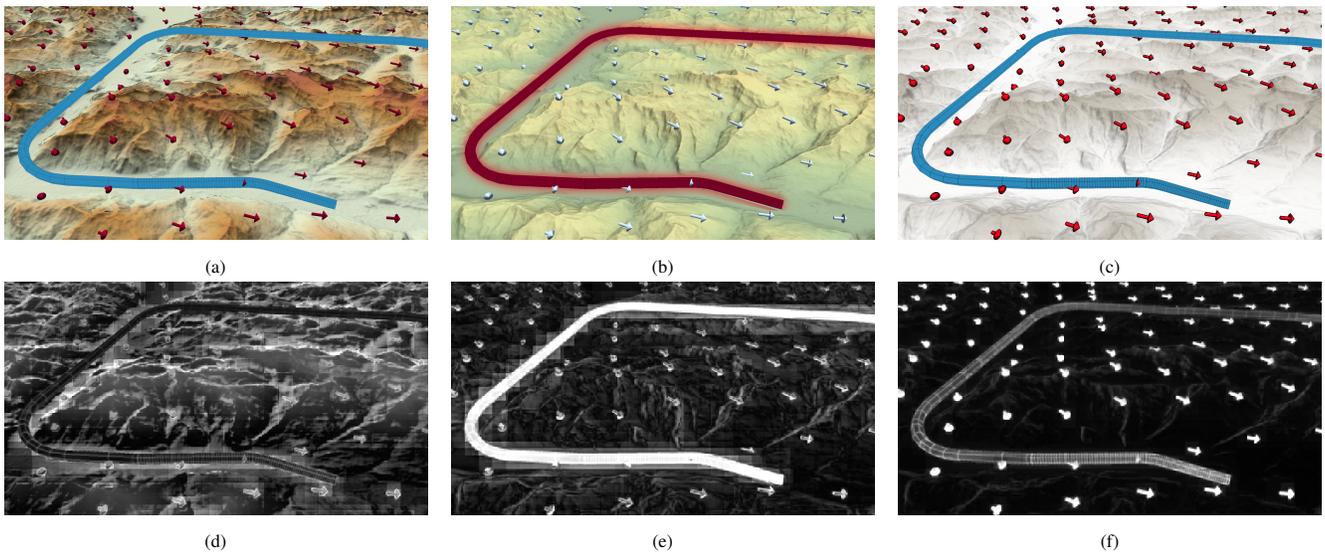‡e-mail:heidrun.schumann@uni-rostock.de

Figure 1: Visualization of spatial data in 3D terrain with emphasis on the terrain (a), a trajectory (b), and wind arrows (c). The respective saliency maps (d), (e), and (f) show which parts of the visualization are likely to attract the user's attention.

Saliency maps generated with the described approach are depicted in Fig. 1d–1f. The maps are displayed as intensity images, where bright regions mark salient areas. The computation of the saliency map is done entirely on the GPU in parallel to rendering the actual visualization. This allows to use saliency maps to assess visualization designs in real-time.

## 3 APPLYING SALIENCY MAPS

We integrated the saliency maps into an existing design tool for visualizing spatial data embedded into sophisticated 3D terrain renderings. To test our approach, we consider the visualization of an approaching flight trajectory in mountainous terrain and wind data, as illustrated in Fig. 1. Depending on the given application scenario, different aspects can be of relevance. (a) When considering mountains as obstacles and thus hazardous for the flight, the topography of the surface is important. (b) When analyzing the path of a flight, the trajectory itself is of interest. (c) In a landing scenario, current wind directions and speeds are the relevant information.

In order to design appropriate presentations for each scenario, our tool provides a wealth of settings and parameters for the designer to adjust, including color, form, size, and type of the visualization. For the purpose of illustration, we will concentrate on the use of color.

In Fig. 1a, the designer's objective is to emphasize the terrain by using different hypsometric tints and sophisticated shading. In Fig. 1b, the flight path is emphasized by showing the trajectory in an intense color in combination with an additional glow effect. In Fig. 1c, the wind arrows are shown in an intense color, whereas pale colors are used for the terrain. Are these design decisions effective with regard to the sketched scenarios?

By examining the respective saliency maps, designers can immediately assess the designs and determine whether they achieve the desired attraction of attention to the relevant data. Comparing the visualization in Fig. 1a and the corresponding saliency map in Fig. 1d makes clear that particularly the mountains are salient (dark, brown areas in the visualization and bright tones in the saliency map). This can indeed be desirable when higher elevations are particularly relevant. For the second scenario, Fig. 1e shows some visual saliency for the wind arrows but primarily a high saliency for the trajectory. This suggests to the designer that the chosen intense color for the trajectory indeed stands out from the green-to-yellow-colored terrain. Finally, Fig. 1f shows a high saliency for the wind arrows, whereas the trajectory and the terrain are less salient. But still, the designer

has some room to attenuate the trajectory to make the wind arrows even more prominent. Maybe the light blue color could be toned down to better blend with the terrain. Our tool gives the designer the opportunity to try this idea and get immediate feedback of the effect.

In this examples, we can see how different design decisions lead to the emphasis of different data aspects (the terrain, the trajectory, and the wind data). Using our saliency-supported approach, designers are enabled to quickly test and evaluate different design alternatives.

## 4 CONCLUSION

In this work, we proposed a novel approach to facilitate the design and evaluation of visualizations. The approach is based on perception-based saliency maps capable of predicting which parts of a visualization will draw the user's attention. Our GPU-based implementation generates saliency maps on the fly, which makes it possible to show visualization and saliency map simultaneously. Embedded in the design process, the saliency maps can assist the designer in encoding the relevant data in a way that particularly attracts attention. We demonstrated the feasibility of our approach in the context of spatial data visualization in 3D terrain. The poster presentation will include a live demo of the developed system.

In future work, we plan to conduct formal user studies. We intend to test both the predicted saliency as well as the visual designs created with the help of the saliency maps. It would also be interesting to study whether saliency maps can actually speed up the design process or have an impact on the quality of the visualization. Another interesting avenue for future work is to investigate the possibility of automating the visualization design. Using the saliency information, one could automatically search the design space and identify adequate combinations of parameter settings.

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