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Over the last decades, the use of the Space-Time Cube (STC) has seen an increase. The STC is considered as one of the most suitable representations for the visual analysis of movement data since it allows a view from spatial and temporal perspectives simultaneously. However, at the same time, an increase in size and complexity of the movement data can be witnessed. Is the STC still suitable under such circumstances, and what role does the cartographic design play? STC usability studies done before do not take into account the aspects of cartographic design. Therefore, this paper reports on the outcomes of an empirical evaluation of the use of visual variables (color hue, saturation, value, size and orientation) and depth cues (shading, transparency) as well as their perceptual properties to define their effectiveness and efficiency in depicting the STC content.

In case of the STC, depth cues can strengthen the visualization in the 3D visual environment when used rationally in combination with visual variables, especially in situations where the data are likely to be cluttered. Design combinations were applied to two different use case studies varying in thematic and data complexity. In all situations a logical organization of displayed information based on a visualization strategy for different data complexities is required. Accordingly, the hypothesis was that the design is not only linked to the qualitative and quantitative nature of the data, its complexity or volume, but also to particular steps in the execution of the visualization strategies.

Fifteen volunteered participants joined task-based experiments to judge the effectiveness and efficiency of design alternatives for a simple and complex dataset. Ten different design combinations were presented to get an understanding of the cognitive aspects of the design alternatives for the STC content. The user tests were executed based on real world problems with particular attention to the visualization strategy regarding data complexity. Each

use case was evaluated in two sessions for the representation of both qualitative and quantitative data. With the user research techniques thinking aloud, video/audio/screen/eye recordings, task execution and user interviews usability metrics were derived.

The outcomes of the empirical evaluation lead to better understand the cognitive aspects of the use of visual variables in the STC. In particular, the experiment uncovered interesting results for different levels of complexity in the evaluated datasets, which did not always coincide with the hypothesis that each step of the visualization strategy might require a different design, depending on the data complexity. In particular, at overview level, a small dataset would already allow a more advanced (complex) design related to the space-time paths, while complex data representation requires simple graphics to avoid exaggeration of visual clutter. On the other hand, at the level of exploring details, complex design might work for both simple and complex data. The outcomes of this experiment provide new criteria for the use of design alternatives in regard to small and complex datasets. In most cases, the results did not show a strong relation between the design alternatives and the visualization strategy as hypothesized initially. When a design option proved to be useful at the overview step, it was also useful at the zoom step and vice versa.

The findings of the experiment also indicate that the perceptual properties of color are effective and efficient to guide the user's attention in the 3D visual environment of the STC. Color hue allows to distinguish elements of a particular category, while color value and saturation allow to perceive a ranking and distinguish similar elements. However, increased data complexity potentially blurs these results due to the visual clutter. Here color hue had a clear advantage over color value and color saturation. Size is known as the only visual variable with three perceptual properties, but this experiment could only confirm its selective perceptual characteristics. In this particular experiment it worked for ordered (non-quantitative) data, but not for absolute numbers. The reason could be that in some situations too many classes were used to allow a proper distinction between the paths, and in other situations non-classified paths were applied. The visual variable orientation is associative and emphasizes similarity. Our results do not support this idea. It could be because it was only applied to line symbols (paths). The experiment also revealed that the transparency option only contributed positively with specific color combinations. Contrary to transparency, the users had a high preference for shading as depth perception in the 3D visual environment of the STC.