A meta-framework of methodological approaches exemplified by 3D geovisualization research

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Most data has a geospatial component (MacEachren and Kraak 2001). Such data may consequently be represented graphically using maps – external visual artefacts that act as additional resources to aid (spatial) cognitive processing - or it can be analysed through geovisualization techniques that support spatial sensemaking. The geospatial component of data is often reduced to two-dimensional location as part of this process. There are some advantages in this simplification in terms of data processing, perception and cognitive load (MacEachren 1995). Elevation may also be important in geographic data analysis, however, especially for data sets collected in mountainous environments and in analytical tasks where altitude needs to be considered to make sense of data. Computing resources increasingly enable us to interact with 3D models of landscape and 'geobrowser' has become a de facto standard for visualising spatial information on the desktop (Wood et al. 2007).

Consequently, we are researching the visual combination of abstract numeric data with the surrounding landscape in 3D desktop-based virtual environments and its appropriateness in supporting a variety of geovisualization tasks. We are doing so by displaying numeric data as bars or bar charts within 3D scenes of varying elevation (Bleisch et al. 2008). Such a combination may facilitate the analysis of a data set in relation to altitude and landform - but how do we effectively evaluate such a technique? We propose a meta-framework that relates studies using research methods that vary along a continuum from perceptual experiments to studies in applied settings (Table 1).

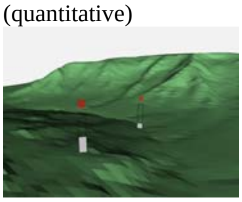
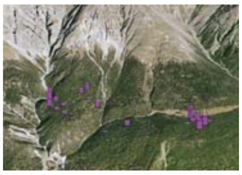
	setting I	**setting II**	**setting III**	**setting IV**
data	two single values (random)	# of deer visits per location	# of deer visits per time and location	multi-dimensional
symbol	single bars	single bars	bar charts	bar charts
task complexity	low	medium	medium/high	high
main method	questionnaire (quantitative)	questionnaire (qualitative)	insight reports	observation, interview
example visualization				

Table 1. Some characteristics of each research setting along the continuum

Much cartographic research uses quantitative techniques, such as controlled experiments, to establish knowledge about cognitive responses to maps (Montello 2002). Experiments usually involve large numbers of users, with little contextual information and thus no (or few controllable) influencing factors. In applied research settings very few users are typically involved and qualitative approaches are employed. Much contextual and tacit knowledge influences and enriches these studies and many influencing factors exist that we cannot or do not want to control (Yin 2003). Research in geovisualization is done mostly by employing controlled experiments (e.g. Bair and House 2007; Fabrikant, Montello et al. 2006). Case studies or applied settings are often used when assessing implementation or usability issues (e.g. Brooks and Whalley 2008; Koua, MacEachren et al. 2006) and rarely evaluate the effectiveness of visualization techniques. Research that lies between these poles, for example, using experimental settings for evaluating the appropriateness of different visualization types to ease understanding of and to gain insight into a dataset (Rester, Pohl et al. 2007) is rare. We argue that the approach of using different research methodologies from along the continuum to evaluate a visualization technique 'in vitro' and 'in vivo' can benefit from each to build an appropriate and valuable 'bridge' of knowledge.

There are a number of difficulties associated with this approach. Using different methods and techniques opens a wide area of possibilities and research issues and it is more difficult to keep the research focussed. Otherwise, by focussing on a single representation type (numeric values through bar heights) while using different research methods, we might miss other appropriate displays. It is vital that the results of all the employed research methods can be related and compared, which is the foundation for building the 'bridge' of knowledge between the research settings. Additionally, employing different methodological approaches requires functional knowledge of all of them. To address this, the collaboration of scientists from different disciplines or having a methodology 'broker' would be valuable.

Thinking about the above mentioned difficulties may reinforce the advantages of the proposed approach. To overcome the problem of researching too broadly we need to keep focused. This is possible at different levels. For example, we evaluate with typical users and changes in the characteristics of each research setting are driven by increasing context, data and task complexity but kept as minimal as possible to ensure comparability of the results along the 'bridge'. The interaction with display and data needs special attention. While most interaction taxonomies (Yin et al. 2007) combine navigation, data display manipulation and task, we try to separate. The navigational part of interaction is kept as standard as possible. For example, by using the functionality offered by an established virtual environment display technology such as Google Earth with which typical users are already familiar. Data manipulation is not possible. Tasks are designed using Andrienko et al.'s (2006) functional data and task view, which allows a structured evaluation of the results. Focusing on a single data display technique (bar heights in our case) in all research methods gives a broad impression of the responses to this technique from experimental to applied settings that allows triangulation between experiments. We argue that this knowledge is applicable to other designs for visualization while, for example, researching different display techniques experimentally only would require research in more applied settings as the results of controlled experiments are rarely directly usable in applications. For instance, in the setting of a controlled experiment, we found that using a reference frame with the bar charts helps the efficiency of the tasks in the 3D environment (Bleisch et al. 2008). Evidence from the more complex and more applied research settings II and III shows that while the references frames are still useful, they are also distracting. Another strength of the approach is the possibility to benefit from the advantages and overcome the limitations associated with each research method. For example, we typically have a small number of geovisualization experts who work with large data sets in an applied setting. Their use of complex visual tasks to better understand the data may be best researched using a case study method taking into account and valueing the many influencing factors of such a complex setting. But on the other hand, the complex setting and the influencing factors may hinder the research of more generic aspects like the influence of perspective on the data displays. This is better investigated through more controlled experiments with a larger number of informed participants and thus underpins the evaluations in the applied settings.

We argue that it is appropriate to use different research methods ranging from controlled experiments to applied case studies to research a single visualization technique, with respect to increasingly complex data, tasks and context. Our research provides a number of examples, which we have developed into a methodological meta-framework. Research that relies upon related evidence is perhaps less profound regarding any single aspect of study than an in-depth study of such an aspect but it is more holistic and leads to applicable results quickly given that it stays focussed and avoids or addresses the challenges described above. With the ever-increasing amount of data to be analysed and the rapid development and adaptation of visualization techniques it is appropriate to focus on holistic approaches in their evaluation. Thus, we propose that our meta-framework which relates evidence from controlled experiments and applied settings is also applicable to other visualization designs.

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