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The role of Depth and Gestalt cues in information-rich virtual environments

Nicholas F. Polys*, Doug A. Bowman, Chris North

Department of Computer Science, Center for Human–Computer Interaction, Virginia Polytechnic Institute and State University, Mail code 0219, Blacksburg 24061, USA

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Abstract

Managing the layout of multi-dimensional visualizations is a crucial concern for the development of effective visual analytic interfaces. In these environments, heterogeneous and multi-dimensional information must be structured and combined into data representations that demand low cognitive resources but yield accurate mental models and insights. In this paper, we use Information-Rich Virtual Environments (IRVE) to articulate crucial tradeoffs in the use of Depth and Gestalt cues in text label layouts. We present a design space and evaluation methodology to explore the usability effects of these tradeoffs and collect results from a series of user studies. These lessons are posed as a set of design guidelines to aid developers of new, advantageous interfaces and specifications.

Keywords: Information visualization; Virtual environments; Information theory; Psychology of perception; Augmented cognition

1. Introduction

Across domains, researchers, engineers, and designers are faced with large volumes of data that are heterogeneous in nature—including spatial, abstract, and temporal information. There are numerous design and technical challenges when considering the unification, management, and presentation of these information types. While computers can provide excellent memory and computational prostheses for solving complex problems, they are unable to match the human's abilities for pattern-recognition, creative reasoning, and insight. It is imperative that next-generation interfaces leverage the strengths of the human operator to create useful and economical tools for analysis and decision-making. In this paper we present an experimental method and set of user studies aimed at describing the value of visual perceptual cues in label layouts in 3D virtual environments. Specifically, our studies seek to understand the role of Depth and Gestalt cues in communicating the relationship between spatial objects and their text labels.

In the pursuit of efficient and effective Human–Computer Interaction, we are seeking to reduce the cognitive distance between the user and the system and increase the information throughput between the user and the system. The essence of these visual design challenges are being variously addressed in the fields of Virtual Environments (VEs) i.e. (Bowman et al., 2006; Munro et al., 2002; Salzman et al., 1999), Scientific Visualization i.e. (Ware, 2000), Information Visualization (InfoVis) i.e. (Card et al., 1999; Keller, 1993), and the various Psychologies of Perception (Mayer, 2002; Saiki, 2003; Tardieu and Gyselink, 2003; Vogel et al., 2001). Engineering approaches that design displays by human perceptual organization and chunking have demonstrated significant performance benefits (Wickens and Hollands, 2000). When assessing human information processing such as the use of attentional resources and managing cognitive load, the 'Augmented Cognition' research initiative has provided some guidance on the configuration and tempo of visual presentations (McBride and Schmorrow, 2005; Schmorrow

*Corresponding author. Tel./fax: + 1 540 2310968.
E-mail address: npolys@vt.edu (N.F. Polys).

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and Kruse, 2002). 'Visual Analytics' is a newer term that refers to the convergent challenges of facilitating analytical reasoning through interactive visual interfaces (Johnson et al., 2006; Thomas and Cook, 2006). In this vein, we propose '*Information-Rich Virtual Environments*' (IRVEs) as a class of visual analysis tools for integrated information spaces.

In many systems, dynamic properties are best modeled with their spatial and structural aspects—spatial relationships are important when structure, location, and function are related. Indeed, this is the case in many domains where physical systems are designed, simulated, or analyzed (i.e. Eubank et al., 2004; Polys et al., 2004d; Subramaniam, 2003). Information-Rich Virtual Environments (IRVEs) start with realistic perceptual and spatial information and enhance it with abstract and temporal information. The goal of IRVE interfaces then, is to provide a set of organized, multi-dimensional representations (e.g. Bolter et al., 1995) that aid users to quickly form accurate concepts about (e.g. Bowman et al., 1999; Bowman et al., 2003a) and mental models of (e.g. Polys et al., 2004) the system they are examining.

In IRVEs, the virtual space serves as a context for the methods of VEs and InfoVis to be combined and so enables a unified interface for exploring the relationships between objects, space, and information. Each spatial item, which we call a 'referent' (an object, a location, a group, people, and place) may have a variety of time-varying attributes or properties; that is, abstract and temporal information corresponding to it. The challenge is to support users in analyzing such heterogeneous environments and understanding the relationships and patterns both *within* information types and *between* information types. IRVEs aim to render clear views of such complex systems and this research seeks to understand how best to accomplish that in terms of user performance.

In order to support insight both within information type (spatial, abstract, and temporal), and between information types, the design space of Information-Rich Virtual Environments is large. There are numerous design combinations when it comes to building an IRVE visualization since any given referent in the environment may have task-relevant properties. In addition to the significant challenges of 3D User Interfaces (such and navigation, selection and manipulation), consider that one can represent and display augmenting information: in a variety of **Locations** (the coordinate system in which the information is presented), with a number of **Associations** (the graphical and interactive representation of relationships), and by different means of **Aggregation** (the visualization technique applied to the variables, overview, detail) (Bowman et al., 2003a).

For example, the PathSim engine (Thorley-Lawson et al., 2007; Shapiro et al., 2008) is an agent-based simulation that models the dynamics of the immune system. In PathSim, the various agents (T-cells and B-cells of various flavors plus pathogens) populate, move and interact on in a 3D anatomical mesh measured in hundreds of micrometers. In the case of Epstein-Barr infections, the relevant human anatomies are the various tissues of the tonsils, the blood and the lymph. Population values change over time and different user tasks require access to raw numbers, proportions at a given time or a view the course of agents over the complete timeline. Such spatially registered time-series data is a prime target to leverage the techniques of IRVEs.

Fig. 1 is a screen capture of the PathSim visualization environment with user-driven aggregations and encodings of result variables. The population visualizations are located and associated to their respective anatomy in a variety of ways depending on the user's task. Because the virtual environment serves as the spatial–perceptual context of the IRVE (the basis of the information space), we use the term 'annotation' to describe any portrayal of abstract and/or temporal data (however aggregated and encoded) that refers to a spatial item, group or location (to a referent, a noun). Thus, our broad notion of IRVE annotation includes both text labels and any variety or combination of interactive, augmenting visualizations (adjectives, verbs). In the general IRVE sense, 'annotation' content presents a rich set of design choices for linked representations. In this way, IRVEs are able to build on the guidance and best-practices of the InfoVis community especially where visual encodings, multiple views and interaction are concerned.

While the nature of an annotation's contents (i.e. the encoding/aggregation of spatially registered information) are certain to have a significant impact on performance (e.g. Yost and North, 2006), in this research we focus on the Location and Association portion of the IRVE design space. There are significant visual design tradeoffs concerning the layout of annotations in relation to their referent objects in a virtual environment since the annotations may be drawn with any number of Depth cues and Gestalt cues consistent with the Depth cues and Gestalt

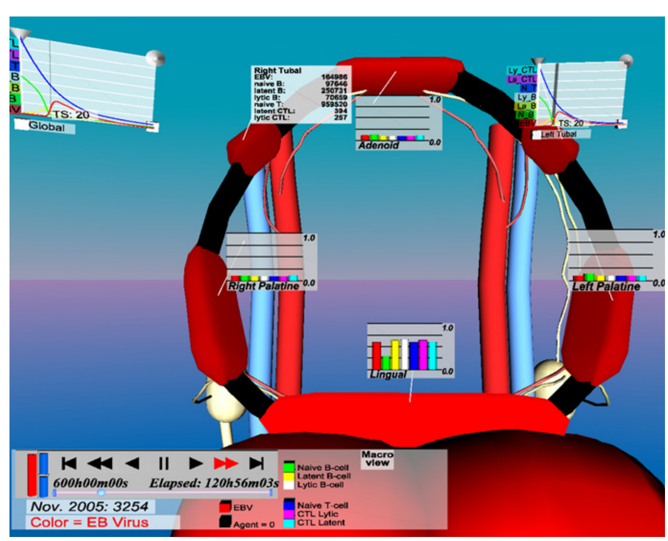

Fig. 1. The PathSim IRVE combining spatial referents with information visualizations. Global and localized agent populations are rendered as interactive visualizations embedded and overlaid in the VE.