Towards Interactive Multisensory Data Representations

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Abstract: Despite the availability of a broad range of newly developed multisensory displays and interaction techniques, multisensory interactive data representations are still not widely used. We argue that for complex information analysis multisensory data representations and multimodal interactivity are essential. By leveraging the benefits of the individual sensory modalities multisensory representations and interaction techniques can make the representation and handling of complex data more intuitive and transparent. This can make complex data analysis accessible to a wider audience, also including non-experts. However, there is currently a lack of agreed guidelines for their integrated design, as well as little empirical research in this area. We argue that there is an urgent need for further systematic research into human multisensory information processing to provide rules that enable the design and construction of representations and interfaces that achieve optimal synergistic cooperation across sensory modalities.

1 INTRODUCTION

Visualizations are powerful tools that can provide users with rapid insight into complex data by mapping data attributes to visual properties such as position, size, shape, texture, color and animation. Appropriate visualizations enable users to discern and interpret data patterns that may otherwise be hard to distinguish or would even remain unnoticed. However, visualizations are inherently limited by the spatiotemporal bandwidth of the visual system, i.e. by the amount of visual characteristics that can simultaneously be represented without obscuring or cluttering the representation.

In this paper, we argue that the representations of complex data need to be complemented with multisensory information and/or interactivity. Though these two solutions are not novel, there is a lack of guidelines and empirical evidence how such representations should be designed and constructed (Sarter, 2006).

The use of multiple sensory modalities in the representation of complex data can significantly increase the number of data characteristics that can be represented and analyzed simultaneously. Over the last two decades there has been a growing interest in multisensory data representation or *data sensification*. A wide range of auditory, tactile, olfactory and even gustatory and vestibular display devices haven been developed (Basdogan and Loftin, 2008); (Kortum, 2008), which can be used to present information in situations where the visual capability is either overloaded or impractical (Loftin, 2003). Sensification can be used to effectively convey both qualitative and quantitative information. The results of rigorous sensory perception studies can be used to develop guidelines that may serve to design multisensory representations that optimize information transfer while avoiding issues with sensory bias and sensory conflict (Nesbitt, 2005). However, despite their many potential benefits, multisensory interfaces and displays are still not widely used for the representation and exploration of complex data.

2 MULTISENSORY REPRESENTATION

In this section, we examine the limits of the visual channel and the potential of non-visual (auditory, haptic, olfactory, gustatory, vestibular) display techniques. We argue that multisensory display techniques can be used to increase the bandwidth of information transfer.

Multisensory data representations or *sensifications* can be achieved by mapping data parameters not only to visual but also to tactile

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(roughness, viscosity, temperature, wetness, air flow pressure), auditory (pitch, tempo, rhythm, loudness, timbre), olfactory (valence, intensity), gustatory and vestibular parameters (Loftin, 2003); for examples see e.g. Harding et al., 2002; Harding and Souleyrette, 2010; Newcomb and Harding, 2006; Ogi and Hirose, 1997). Multisensory displays may enable the operator to *a)* acquire a wider range of details and subtle cues from the display (bandwidth expansion); *b)* fill in missing information from one sensory channel with cues from another sensory channel (data completion); and *c)* integrate all these informative cues from the different senses in an active and creative manner into a unified coherent percept (Gestalt forming).

Temporal integration of multisensory signals can create salient emergent features that automatically draw attention in cluttered dynamic displays (Van der Burg et al., 2008, 2009). More specifically, tactile (Van der Burg et al., 2009) and auditory (Van der Burg et al., 2008) cues can boost the saliency of visual features, even when the cues themselves provide no information about the location or nature of the visual feature. Multisensory representations can therefore yield a richer and more coherent experience, thus enabling users to perceive spatio-temporal patterns in complex dynamic multidimensional data that may otherwise be hard to perceive or even go unnoticed.

2.1 The Limits of Visualization

Visual representations map data parameters to visual features like color, saturation, intensity, density, and animation frequency. However, the human visual system is inherently band limited and suffers from occlusion, crowding and clutter (Van den Berg et al., 2009), inattentional blindness and change blindness (Mancero et al., 2007). Enriching visualizations with additional sensory modalities may considerably expand the human information processing capability.

2.2 Sonification

Sonification is "the use of non-speech audio to convey information" (Kramer,1993). Sonification represents data as sound by mapping data parameters to audio parameters such as pitch, volume, rhythm, loudness, timbre. Auditory representations can be used to perform trend analysis, point estimation, pattern detection, and point comparison (Walker and Nees, 2005). Encoding uncertainty as an extra layer of sound enables the interactive exploration of visualizations with inherent uncertainty (Brown and Bearman, 2012). Auditory displays can highlight subtle changes in values, illuminate gradual changes, present several data-streams concurrently, and emphasize anomalies and outliers, thereby complementing visualization methods (Ferguson et al., 2012). Sonification has successfully been deployed to represent uncertainty in climate change predictions (Bearman, 2011), positional uncertainty (Bearman and Lovett, 2010) and cell normality (Edwards et al., 2010).

2.3 Haptification

A wide range of haptic data visualization or haptification techniques and devices have been developed to let users feel and interact with data (for recent reviews see Kaber and Zhang, 2011; Paneels and Roberts, 2010). Haptification of volumetric data has successfully been applied in virtual reality to represent molecular models to let users feel the bonds between molecules and interact with them, and in virtual surgery to interact in real-time with virtual organs and feel their deformations. Haptic models are rendered in terms of forces and vibrations. Variables that can be used to convey information are for instance actuator position, vibration frequency, and surface texture.

Artificial force fields appear intuitively suitable to represent information uncertainty. For instance, when a person using a tactile device touches a surface or volume element the system may signal its positional certainty through forced feedback (a more solid or stiffer feel or higher resistance signals high certainty, a weaker feel or lower resistance corresponds to a lower certainty: Schmidt et al., 2004).

2.4 Other Senses

The information transmission capability of the olfactory sense is still largely unknown (Washburn and Jones, 2004). This is also true for gustatory and vestibular parameters (Basdogan and Loftin, 2008).

2.5 Using Multisensory Information for Data Representation

For a simple 2D threat avoidance task it has been found that users showed comparable performance when uncertainty was represented either visually (color), auditory (tone pitch) vibro-tactile (vibration amplitude) (Basapur et al., 2003). Previous research has also shown that users like the ability to receive information about 'invisible' data via friction or sound while exploring surfaces (Harding et al., 2002). Finally, multisensory display systems have successfully been used to represent and investigate GIS data (Faeth et al., 2008); (Harding and Souleyrette, 2010) and medical data (Diepenbrock et al., 2011). However, there is still little empirical evidence for the added value of multisensory representations. Also, it is not yet clear how information from different senses can best complement one another, or what happens when two senses give conflicting information.

The use of multisensory information appears promising from a theoretical point of view, by alleviating visualization problems such as occlusion, crowding and clutter. However, more research is needed to examine how different data aspects can best be represented sonically, haptically, or even olfactory.

3 TOWARD MULTISENSORY INTERACTION

Tools for visual analysis can be enriched with interactive elements. Heer and Shneiderman (2012) introduced a taxonomy of interactive dynamics for visual analysis. Here, we examine how *interactive* multisensory representation can be used to help users understand and engage with complex data.

Speech and gestures can be used for data and view specification as well as view manipulation. Speech interaction is suited for descriptive techniques, while gestural interaction is ideal for direct manipulation of objects (Oviatt, 1999). Speech allows interaction with objects regardless of their degree of visual exposure (occlusion). It appears that users prefer using combined speech and gestural interaction over either modality alone when handling graphics manipulation (Hauptmann and McAvinney,1993). While some tasks are inherently graphical, others are verbal, and yet others require both vocal and gestural input. Allowing both interaction types broadens the range of tasks that can be done intuitively and simultaneously. However, it has been observed that different contexts pose different representation requirements, particularly for data sonifications (Ferguson et al., 2012). Thus, more research is needed to derive consistent rules for integrating multiple sensory modalities in a common interaction framework.

Voice input appears a natural mode for process and provenance, to allow users to vocally annotate their observations and replay sequences to other users. Also, previous work has generated promising results regarding the use of sonification for representing uncertainty information.

Olfactory cues can be deployed to provide subtle feedback while the user is exploring the data. In contrast, haptic feedback is possibly more suitable for notification and alerting purposes.

4 CONCLUSIONS

Over the last decades there have been significant developments in the design and development of user interfaces deploying individual sensory channels. The integration of computer vision based techniques like gaze, gesture and facial expression recognition, with speech recognition and tactile input devices will enable the construction of multisensory interfaces that allow natural and dynamic interaction with complex data. The availability of intuitive multisensory interfaces in combination with appropriate data sensifications will democratize the analysis of complex data by making it accessible to a wide audience.

Although preliminary studies on interaction (e.g. gestural, voice, tactile) and data representation (e.g. 3D, sonification, haptification) techniques for different individual sensory channels have shown promising results, these methods have not been widely integrated and adopted for the representation and analysis of complex multidimensional data. This is mainly due to a lack of consistent rules and guidelines for the integrated design of multisensory displays (data sensifications) and their user interfaces. We argue that rigorous user studies are required to derive guidelines that ensure the consistency between different information channels.

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