

# Using All Our Senses: the need for a Unified Theoretical Approach to Multi-sensory Information Visualization

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**Abstract**— There is an opportunity to consider the theory of visualization for each of our senses together. We should have a united theory of visualization that covers all senses and allows users to integrate modalities. We believe there are several important facets to the theory that need to be addressed at all stages of the multi-sensory visualization *process*. (1) Data enhancement for multi-sensory visualization; (2) perceptual variables for each sense; (3) Transference of the visualization methods and designs from one domain to another. (4) Cross-modal device integration. How multi-sensory devices are built and are used together; (5) Sensory integration and cross-modal interference: how different sensations interfere or reinforce each other. We need a body of research that will help researchers tackle questions such as ‘what are the perceptual variables that are available?’, ‘what are their limitations?’, ‘Do ideas and concepts that work in one modality transfer to another?’ and ‘what are the best design strategies for depicting information in another modality?’.

**Index Terms**—Information Visualization, non-visual visualization, multi-modal, multi-sense

## 1 INTRODUCTION

Every day we perceive information through many different senses: we hear, see, touch and smell. We use senses to observe, interact or move effectively in our environment. In some situations we may rely on one sense instead of another. For example, we may hear someone approaching down a corridor long before we see them. In other situations we may perceive the same information through multiple senses, where each sense reinforces the overall perception and provides a comprehensive understanding of the environment. Importantly we perceive information through multiple modalities.

The aim of a developer of an information visualization tool is to provide techniques that will enable the user to understand the data through interactive graphical depictions. That is, researchers consider how to best represent the given data such that a user will be able to perceive it. In the same way it is possible and beneficial to represent information in *non-visual* forms and information can be perceived (potentially) through any sensory input.

There is burgeoning interest in non-visual forms of visualization. These methods use touch and tactile devices (haptics), sound (sonification) or maybe smell (olfaction) to represent information [2]. Consider haptics; blind or partially sighted users may be unable to use traditional visualization to perceive their data, but they may be able to feel the information through a haptic device. On the other hand, there may be situations when the user’s visual attention is already in use and another modality (such as sound) could be used to grab the attention of the user.

In this article we call for a more integrated approach to the theory of visualization. If we are to move towards an interactive multi-sensory visualization environment, or even at least utilize different devices for input, then we should understand each domain and how information can be best presented in several domains at the same time.

## 2 MOTIVATION

The challenges of non-visual representations are relevant today. The use of multiple modalities is certainly growing. Technologies such as powerwalls, table-top displays and the ubiquitous mobile phone are all starting to utilize several senses. Mobile phones include vibrotactile devices that can give feedback to the user that a text message

has arrived. Gaming joysticks provide force-feedback when the player fires a gun. The certain growth of the Internet and especially the 3D-Internet will act as a conduit for new visions to become reality.

The use and integration of multiple senses will be more pertinent in the future. One vision is that new technology will allow users to communicate and interact in a high-fidelity immersive world. In these tele-immersive virtual worlds the user can see, touch, hear, smell and even taste their environment. Perhaps the technologies will be head-mounted displays, personal spaces such as cocoons or pods, or rooms filled with sensors and displays. In this vision, information may be depicted to the user through any number of sensations and users could interact with their multi-sensory depictions. Another, complementary vision places the user in the real-world with a ubiquitous device which augments their life. Researchers are already using hand-held devices in this fashion, overlaying the real world with information. But in the future users could feel forces and listen to any real-world information augmented by the virtual.

Each ‘vision of the future’ utilizes several human senses and novel interaction devices. These visions make ‘visualization’ a multimodal experience. But whatever the future holds it is clear is that *information visualization* and multi-sensory visualizations (or more generally, information depiction) will be important, whether these are information representations within the virtual world, or information visualizations augmenting the real-world.

To be able to create these multi-sensory visualizations we need to understand how to design effective representations. We need to understand the capabilities and affordances of each technology. Currently, there are several good examples of visualization through different senses. But researchers have focused on the ‘visualization’ of one modality alone. There are also many inexpensive multi-sensory devices capable of being used for multi-sensory perception. There are, however, few guidelines for visualization, and fewer theories of multi-sensory visualization. Consequently, we do not understand the limitations of these technologies, or how best to use them to depict data.

## 3 MULTI-SENSORY VISUALIZATION PROCESS

In recent work we proposed that a dataflow model could be readily adapted [3] for Haptic Data Perception (haptic visualization). Whether this is an appropriate approach, in all instances and other senses, remains open to discussion. However, the processes of Multi-sensory presentation and Data Visualization are similar. The user should prepare the data, process the information (including data wrangling, select what they wish to demonstrate, maybe enhanced or summarized in some way). It then needs to be *mapped* to the appropriate sensory variables (this is equivalent to mapping the data to *retinal variables* in the

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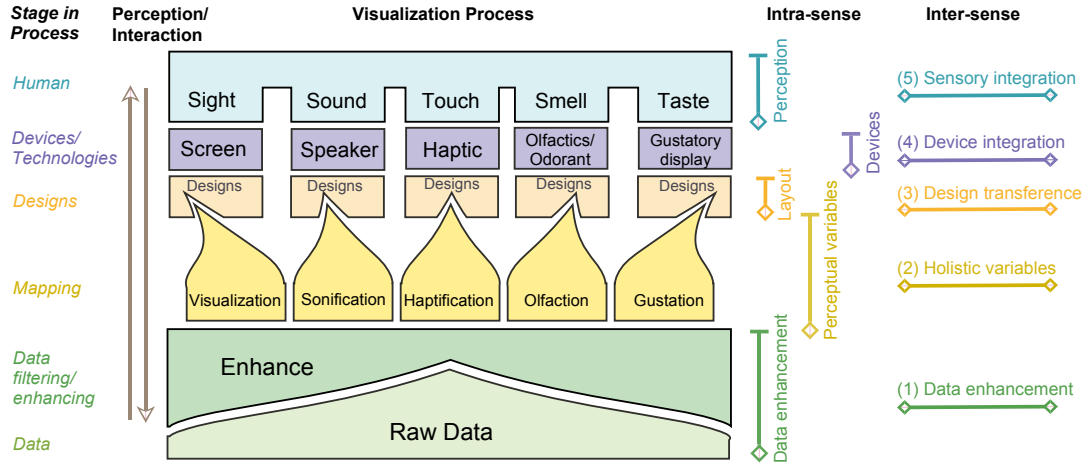


Fig. 1. There are several facets to generating a holistic approach for multi-sensory information visualization. Theories can be formulated for a specific sensory channel (intra-sense) while other theories should focus on methods that go between modalities (inter-sense).

visual domain) that form the Visualization Design. The information is then displayed (by whatever sense) to the user.

We use this general visualization process to help discuss what theories are required, with reference to Figure 1, basing the work on five human senses<sup>1</sup>. We believe that it is prudent to look at both issues that are within a sense (intra-sense) and between senses (inter-sense).

#### 4 DATA ENHANCEMENT

Our experience with visualization, haptic data perception and sonification encourage us to think that the data-enhancement stage is similar for any sensory display, and thus the intra-sense theories are probably interchangeable between senses. Whatever the domain, it is a time-consuming stage. But each sense does offer a different breadth and capabilities of the variables. Hence the differences are more evident with the following theories.

#### 5 HOLISTIC (PERCEPTUAL) VARIABLES: BERTIN++

To work towards a holistic theory of perceptual variables we need to understand the capabilities and limitations of each variable of each sense. We need to develop a theory of visualization, particularly focusing on the variables, that is extensible to other senses. For instance, the theories of Bertin [1] and Senay and Ignatus [5] provide some guidelines and principles in visualization, but few other rules exist, and they are less refined for other senses [3].

Thus, many questions remain, both intra-sense and inter-sense. For intra-sense: are Bertin's retinal variables complete? What guidelines are there for each variable? Then between senses: can Bertin's [1] container analysis be extended to other domains? Bertin's 'level of organization' describes whether the observer can notify that multiple objects can be immediately perceived (associative) or where elements can be immediately grouped into categories (selective) or that the elements can be ordered, or compared as being greater or less than another element (quantitative). Is this appropriate for other senses?

#### 6 DESIGN TRANSFERENCE

The challenge here is 'Can we give guidelines of how users can create designs?' What layouts are possible and usable for particular datasets? Furthermore, is it possible to transfer design ideas from one sense to another? Certainly, in haptic visualization (for instance)

<sup>1</sup>We acknowledge some simplifications in this paper. These are used to discuss the concepts in a timely way. For example, we simplify human sensations to five, and touch to include kinesthetic, tactile and pain.

many researchers have directly taken ideas from visualization and applied them to the haptic domain [2, 3, 4]. However is this a sensible approach? What and how much can be transferred or fused between domains?

#### 7 DEVICE INTEGRATION

If we are to develop multi-sensory devices and tools then how can we develop them such that they will be effective? What theoretical underpinning could support the development process? There are certainly challenges with ergonomics, but also with technology and with APIs and software integration. These are principally inter-sensory challenges.

#### 8 SENSORY INTEGRATION – CROSS-MODAL INTERFERENCE

Interaction is one key aspect to visualization, but how does a user explore a multi-sensory information visualization? What do users feel and see? Is it the same data in each sensory output device or different? Will every user understand the data in the same way as the developer had expected? If the developer represents the same data elements in several senses, then does each sense reinforce the other, or do they contradict?

#### 9 CONCLUSION

Currently we have some theories of visualization and understand some principles about how to map information in the visual domain. In the other senses these theories are less established and known. Thus, not only should the visualization theories be expanded, but if we are to move to utilize other senses with visualization then we need to move to a holistic approach, that integrates each of the senses together and understands the limitations and opportunities for displaying information in each sense.

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