COMPARING AND REUSING VISUALISATION AND SONIFICATION DESIGNS USING THE MS-TAXONOMY

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ABSTRACT

Comparing designs of sonifications is difficult enough but comparing a visual display with a sound display is much harder. Yet the designer of multi-sensory displays would like to make sensible decisions about when to use each modality. This paper describes a classification of abstract data displays that is general for all senses. This allows the same terminology to be used for describing both visualisations and sonifications. The classification of displays is hierarchical and describes multiple levels of abstraction. In software engineering terms the taxonomy allows a designer to consider reuse at both an abstract architectural level and also a more detailed component level. Thus design mappings can be discussed independently of the sensory modality to be used. This allows for exactly the same design to be implemented for each sense and subsequently compared.

1. INTRODUCTION

Information Visualisation is the term commonly used to describe interactive computer systems that provide the user with external visual models of abstract data [1]. The term, *Information Visualisation*, implies a mapping from the data attributes to the visual parameters. *Information Sonification* is a newly evolving field that uses sound rather than vision to represent abstract data [2]. The term, *Information Sonification*, implies a mapping from the data attributes to the sound parameters.

A question often raised, certainly from people in the auditory display community, is whether sonification is superior to visualization for displaying abstract data? Many people, certainly from the visual display community suggest that vision is the dominant sense. While it is true that vision is highly detailed and well suited to comparing objects arranged in space, it is equally true that hearing is effective for monitoring sounds from all directions, even when the source of the sound is not visible.

In fact, both senses are well suited for different kinds of tasks. This is supported by what is known as the *Modal Specific Theory* [3]. This psychophysical theory states that each sensory modality has distinct patterns of transduction. So, each sense has unique sensory and perceptual qualities that are adept with certain kinds of complex information.

Despite more rigorous attempts to categorise the visual display space [4,5] and the emergence of standard methodologies such as earcons [6] and auditory icons [7] and suggested design patterns[8] in the sonification domain, it is still not clear when designing a display of abstract data what mapping should be used for certain types of data and for particular tasks.

The situation for the designer is further complicated with the growing availability of multi-sensory environments. Hence a designer may wish to develop a mapping from data attributes to both visual and auditory parameters. However, it is not altogether clear what types of abstract data to display to each sense. The situation is further complicated because direct comparisons made of visual and auditory data displays are sometimes flawed. For example, the displays being compared are not equivalent and so it is like *"comparing apples with oranges"*.

A simple example of this is when different types of data are used on the displays. This can bias the user's performance to the display which displays the data most relevant to the tasks being measured. Even where the same data is displayed, a comparison between a well-designed visual display and poorly-designed auditory display is not particularly useful. It would be nice to have a more common description of display mappings, so that we could compare *"visual oranges with auditory oranges*". This might also allow us to pick the best fruit from the auditory and visual trees of knowledge. Of course a cross pollination of ideas also becomes possible. Auditory display mappings can be ported directly to a visual display and visa-versa.

This paper describes a classification of the multi-sensory design space called the MS-Taxonomy. The classification is hierarchical and describes multiple levels of abstraction. At the higher levels of abstraction the same terminology can be used for describing both visualisations and sonifications. Indeed the terminology also applies to other senses, for example touch or haptic displays of abstract data. In software engineering terms the MS-Taxonomy allows a designer to consider reuse of designs at both an abstract architectural level and also a more detailed component level. These reusable patterns can be discussed independently of the sensory modality used in the display. This allows for the same design pattern to be implemented and directly compared between senses.

2. METAPHORS

In the field of information display, categorising the multi-sensory design space is an important first step to assist in the development of general principles of design. This is necessary, as any design should consider the full range of possibilities offered by the design space. A typical division of the multi-sensory design space bases categories around the different senses (see figure 1). This is quite an intuitive division and leads naturally to specialist fields such as visualisation and sonification. However, because this division accentuates the differences of each sense it makes it hard to compare or transfer display concepts between the senses. The MS-Taxonomy however uses a more novel division of the space by considering the different types of metaphors used in information displays. The division of the space by senses is not lost but rather forms a second, weaker division of the design space (see figure 2).

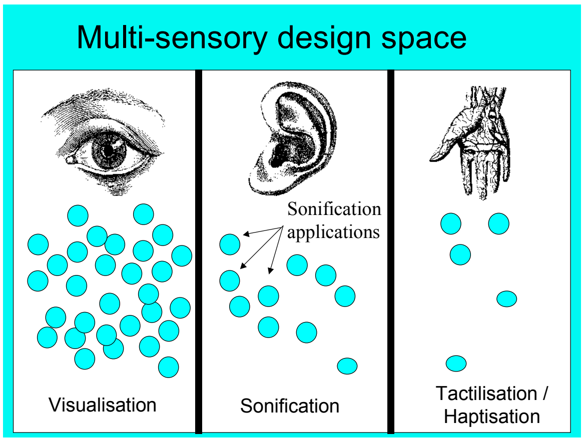

Figure 1. A typical division of the multi-sensory design space is by sensory modality. Applications of information display naturally fall into a specific groups, such as visualisation or sonification.

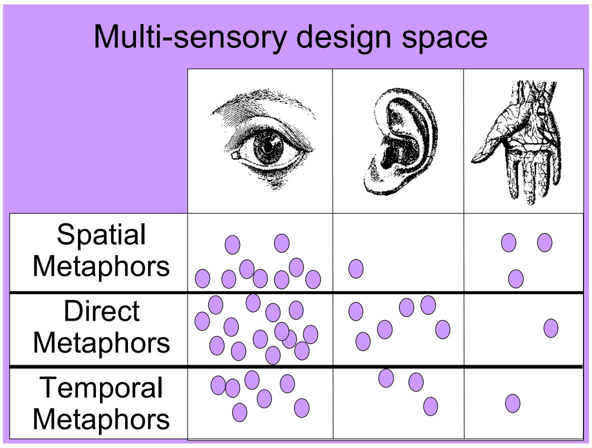

Figure 2. A novel division of the multi-sensory design space using the types of metaphors that commonly occur in information displays. This division removes the accent on sensory modality.

A metaphor is defined as "a figure of speech in which a word or phrase is applied to an object or action that it does not literally denote in order to imply a resemblance" [9]. The role of metaphors in the user interface were defined by Hutchins to occur at three different levels [10]. The MS-Taxonomy is based on what Hutchins describes as *Task domain metaphors*. These metaphors provide a framework for understanding a particular task. They include models or mappings that describe how the raw data attributes are displayed as sensory artefacts. In the context of data, a metaphor can be considered as an information mapping from the real world that is applied to the abstract application domain.

Why use metaphors at all to categorise the design space? Metaphors can provide cognitive models to help users to browse unfamiliar information spaces. In an exploration mode the user may be seeking to build up a conceptual model of a new information space [1]. This is an iterative process of interaction and exploration that allows the user to form a mental model [1]. Metaphors provide a useful starting point for the formation of this mental model. It is presumed that *good* metaphors give users a *good* mental model and so enable *good* displays of abstract data.

Furthermore, metaphors help us to mimic interactions in the real world and everyday we interact with objects in the real world to do tasks. We interact with all our senses. Our senses have evolved to do this and have been trained to work in this way. In fact our perceptual skills have developed to cope with the demands of this world. Metaphors can provide a mapping from an abstract information space to real world spaces thus making it possible to use our existing perceptual skills in a sensible way and without conflict. Hence we can use our senses to explore the abstract world in the same way we explore the real world. This has been called an ecological approach to design and this approach has, for example, been described for designing sound displays [11].

The idea of using metaphors to represent abstract information is not new. These metaphors have developed from the 1800s and Tufte describes the evolution of some 2D displays for statistical graphics [12]. By the end of the 1990s, *task domain metaphors* were frequently being used to develop domain-specific displays of information [13]. Barrass also describes a metaphor approach to designing sound displays [14]. However, the MS-Taxonomy devises a new meta-abstraction of metaphors into three main classes, *Spatial*, *Direct* and *Temporal (Figure 2)*. These classes are discussed in more detail in section 4.

Most importantly for design, the taxonomy is defined at multiple levels. At the higher levels the classes are more abstract and general than previous works and also general for all senses. However, detail is not sacrificed and at the lower levels the taxonomy is comprehensive, allowing display mappings to be described to the level of a single perceptual concept. Thus using these metaphor classes allows the designer to work with concepts that are suitable for both overview and detail. These two levels of work have previously been described as fundamental modes of operation in related fields such as software design [15].

3. SENSES

While the MS-Taxonomy is derived from considering metaphors it does not ignore the natural division of the human senses (figure 2). The basic function and capability of each of the senses needs to be understood when designing information displays. Therefore the sensory divisions still occur in the MS-Taxonomy but are given less importance than the metaphor divisions.

There are also other ways the senses are distinguished by using the Metaphor classification. The class of *Direct Metaphors* best captures the traditional sensory differences that a display designer needs to consider. On the other hand *Spatial* and *Temporal Metaphors* consider properties that are more common to all senses, concerning as they do the perception of space and time. However, it seems intuitive to expect some sensory differences to occur. The *Modal Specific Theory* [3] is a psychophysical theory that maintains each sense has a unique method of transferring information. Thus each sense is adept with certain kinds of complex information. Vision is described as a *spatial* sense and so is adept at interpreting *spatial* relationships. Hearing is a *temporal* sense and so is adept at interpreting *temporal* relationships. The immediate intuition from this comparison is that vision should be best for *Spatial Metaphors* and hearing should be best for *Temporal Metaphors*.

4. THE MS-TAXONOMY

The name MS-Taxonomy is used because the categorisation is based on types of metaphors (M) and types of sensory (S) displays. Indeed, the MS-Taxonomy is derived by combining the three general types of information abstraction (metaphors) with the different senses (sensory) used for information display (figure 2, figure 3, figure 4).

Spatial Metaphors relate to the scale of objects in space, the location of objects in space and the structure of objects in space. For example, *Spatial Metaphors* concern the way pictures, sounds and forces are organised in space and can be described for the visual, auditory and haptic senses. Thus different types of spatial metaphors may be described for each sense:

- *Spatial visual metaphors* concern the way pictures are organised in space.
- *Spatial auditory metaphors* concern the way sounds are organised in space.
- *Spatial haptic metaphors* concern the way forces are organised in space.

Spatial metaphors involve the perception of a quality (space) that is not associated with any particular sense. Although different classes of spatial metaphors (visual, auditory and haptic) ca n be described, the concepts that define a spatial metaphor are general and therefore independent of the senses. *Spatial metaphors* are discussed in more detail in section 5.

Direct metaphors are concerned with direct mappings between sensory properties and some abstract information. For example, sensory artefacts such as a specific colour, the volume of sound or the hardness of a surface may be used to represent a particular data attribute. Once again, a class of direct metaphors can be defined for each sense. This leads to different subclasses of direct metaphors:

- *Direct visual metaphors* concern the perceived properties of pictures.
- *Direct auditory metaphors* concern the perceived properties of sounds.
- *Direct haptic metaphors* concern the perceived properties of touch.

Unlike *Spatial Metaphors*, *Direct Metaphors* are highly specific for each modality. Each sense is described by it's own capability to perceive sensory properties. For example, the eye perceives colour, the ear perceives pitch and the haptic sense can perceive the hardness of an object. These different sensory capabilities are described as direct properties. However, the concept of a direct property is general for all senses. Thus, for example, it is possible to compare or exchange a direct property of one sense with another. Direct metaphors are discussed in more detail in section 6.

Temporal Metaphors are concerned with how we perceive changes to pictures, sounds and forces over time. The emphasis is on displaying information by using the fluctuations that occur over time. Once again Temporal metaphors can be considered for each of the senses and this leads to appropriate subclasses:

- *Temporal visual metaphors* concern the way pictures change with time.
- *Temporal auditory metaphors* concern the way sounds change with time.
- *Temporal haptic metaphors* concern the way haptic stimuli change with time.

Temporal metaphors are like *Spatial Metaphors* in that they involve the perception of a quality (time) that is not associated with any particular sense. Though the three different classes of temporal metaphors (visual, auditory and haptic) are described, the concepts that define a temporal metaphor are general and therefore independent of the senses.

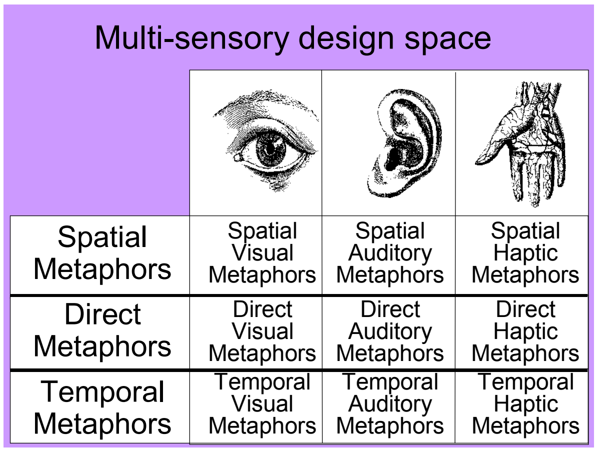

Figure 3. The Metaphor-Sensory-Taxonomy defines six main classes within the multi-sensory design space.

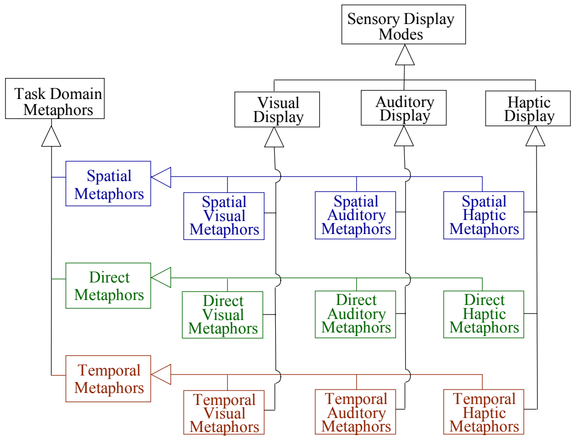

Figure 4. A UML diagram shows the high-level architecture of the MS-Taxonomy. In software terms this is a multiple inheritance hierarchy.

In this section of the paper the discussion of the MS-Taxonomy has been general to the three senses of vision, hearing and touch. In further sections only the auditory and visual senses will be discussed. For interested readers a further discussion of these concepts with haptic display is available elsewhere [16]. It is also noted that while no detailed discussion of the olfactory sense is made the intuition is that these concepts also apply to that sense.

5. SPATIAL METAPHORS

In the real world a great deal of useful information is dependent on the perception of space. For example, driving a car requires an understanding of the relative location of other vehicles. Parking the car requires a comparison of the size of the car with the size of the parking space. Navigating the car requires an understanding of the interconnections and layout of roadways. Real world information is often interpreted in terms of spatial concepts like position, size and structure. Abstract information can also be interpreted in terms of these spatial concepts.

The general concepts that describe spatial metaphors are independent of each sense. It is simply the different ability of each sense to perceive space that needs to be considered. Because the concepts abstract across the senses it is possible for spatial metaphors to be directly compared between senses. For example, the ability of the visual sense to judge the position of objects in space can be compared with the ability of hearing to locate a sound in space. This sensory independence also enables concepts to be reused between senses. For example, a spatial visual metaphor, such as a scatterplot, can be directly transferred to a spatial auditory metaphor to create an auditory scatterplot. In this case an auditory scatterplot would use the position of sounds in space to mark points of abstract data.

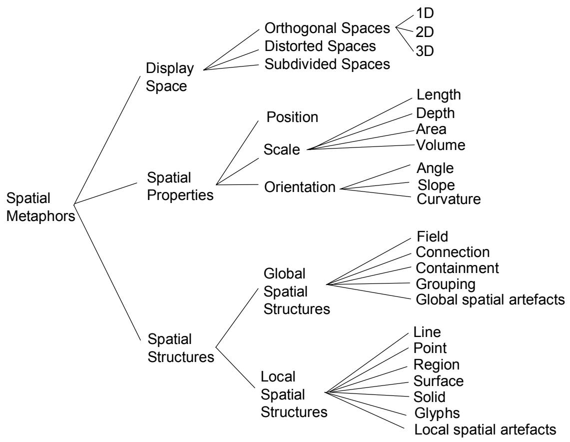

Figure 5. The general concepts that describe Spatial Metaphors. These concepts are most intuitive to vision but can still be applied to the auditory domain.

The design space for spatial metaphors can be described using the following general concepts:

- the display space
- spatial structure
- spatial properties.

The display space is the region where the data is presented. All spatial metaphors have as their basis an underlying display space that is used to arrange the display elements. For example, the scatterplot defines a 2D orthogonal display space by mapping data attributes to the x and y axis. Points are then interpreted in terms of this display space. In the real world, space is perceived as constant, however in an abstract world the properties that define the space can also be designed. For example, one axis of the scatterplot could be defined as a logarithmic space. This has the effect of changing the way the position of points is interpreted.

There are a number of strategies for designing the display space when presenting information and these include using orthogonal spaces (1D, 2D, 3D), distorted spaces and subdivided spaces.

The entities that occupy the display space are described spatial structures. For example in the scatterplot, the points are spatial structures. Spatial structures also describe the arrangement of entities within the display space. For example, a group of points in the scatterplot can be considered a more global spatial structure. The MS-Taxonomy distinguishes two levels of organisation for presenting information and these are global spatial structures and local spatial structures.

Spatial structures may have spatial properties. Spatial properties describe qualities that are defined in terms of the display space. For example, in the scatterplot the position of points is used to convey information. This information is interpreted in terms of the abstract space defined by the x and y axis. The spatial properties used for presenting information include position in space, scale in space and orientation .

There are some obvious points to make. Firstly these spatial concepts applied to the auditory sense are not as intuitive as the application of the same concepts to the visual sense. There are also a much greater number of examples of spatial metaphors to be found in the field of visualisation. This is not surprising as hearing is predominantly temporal and is more adept at identifying temporal relationships rather than spatial relationships [3]. The auditory display space is continuous and can be designed to display quantitative, ordinal or nominal data. However, auditory position is not a very accurate way of representing data [17]. To overcome this problem a categorical subdivision of the auditory display space is more appropriate.

A number of areas of the auditory design space have not been explored. These include the use of distorted and subdivided space. Hence there are possible opportunities for developing new types of auditory designs. In particular, adopting strategies from the better explored domain of spatial v*isual* metaphors could lead to new types of spatial auditory displays. Although the lower resolution of the auditory display space needs to be considered when transferring these designs from the visual domain.

In terms of spatial properties, the problems with accurate identification of auditory position, other auditory spatial properties, such as auditory scale and auditory orientation are not recommended for displaying information. The scale of a sound is a good example of a less intuitive concept for sounds. However it has been suggested real sound sources are rarely point sources and usually have some scale or extent to them [18]. For example, the sounds of wind or the ocean waves have a size, although rarely is the auditory scale or for that matter auditory orientation ascribed much importance in design.

Perhaps the least intuitive from an auditory perspective are the concepts of auditory structure. A fundamental problem with auditory representations is that sounds are transient and so do not provide an external representation on which the person can form a spatial mental model [18]. Kramer notes that the edges of an *audible object* are defined when a sound appears to move from one location to another or the subject moves through the sound [2]. For a subject to scan a single object or looking back and forth between objects is a simple task visually but judging spatial extent by listening to multiple sounds moving from edge to edge is not [2]. There have been some investigations into displaying spatial structure using sound. For examples, subjects were tested for their ability to perceive geometric shapes and characters displayed as sound [19]. The intuition is that spatial properties are not as effectively displayed to a temporal sense like hearing compared to a spatial sense like vision.

6. DIRECT METAPHORS

In the real world a great deal of useful information is perceived directly from the properties of sights and sounds. For example, a sound may have a certain loudness or pitch. Objects in the real world may be recognised on the basis of visual properties such as colour or lighting. Real world information is often interpreted in terms of properties like pitch and colour. Abstract information can also be interpreted in terms of these direct properties.

An important distinction between spatial metaphors and direct metaphors is that direct metaphors are interpreted independently from the perception of space. While the concepts of spatial metaphors apply generally for each sense this is not true for direct metaphors. There is very little intersection, for example; between the low level concepts of direct visual metaphors and the low level concepts of direct auditory metaphors. This is not surprising as direct metaphors relate to the properties that the individual sensory organs can detect.

Direct metaphors are concerned with direct mappings between the properties perceived between each sense and some abstract information. Direct metaphors consider the following design concepts (figure 6):

- spatial structure
- direct properties.

Spatial structures are a component of spatial metaphors that can be used to convey information. These structures can be encoded with additional information by using a directly perceived property of any sense. For example, colour can be used with a visual display or pitch with a sound display.

The key component of direct metaphors is the direct property used to convey the information. In terms of design, the effectiveness of a direct metaphor is independent of the display space and the spatial structure. However, in some cases there needs to be consideration for the size of the spatial structure. For example, very small areas of colour may not be visible to the user.

The ability to accurately interpret direct properties varies between senses and properties. In general, the perception of all direct properties is of insufficient accuracy to allow accurate judgement of quantitative values [17]. This suggests that direct properties should only be used to encode ordinal or nominal categories of data. Because direct properties such as colour or pitch are continuous they can easily be mapped to continuous data. However, it should not be assumed that a user is capable of interpreting exact data values represented as direct properties.

The MS-Taxonomy distinguishes between direct visual and direct auditory metaphors. At a low-level of the hierarchy, the concepts do not abstract across the senses (figure 6). This makes it difficult for direct metaphors to be directly compared between senses. For example, it makes little sense to compare the ability of the visual and auditory sense at judging the *pitch* of sounds. However, at a higher level, the concept of a direct property does apply across the senses. Therefore at a conceptual level the designer can consider substituting one direct property with another. For example, the direct visual property of colour could be substituted with the direct auditory property of timbre for representing categories of data.

Direct visual metaphors use direct mappings from the attributes of data to the perceived properties of sight. These properties include colour hue, colour saturation and visual texture (figure 6).

Using direct visual properties to represent information has been well studied. Bertin described the basic properties of visual objects as *retinal properties* [4]. Bertin's *retinal properties* include the scale and orientation of objects. These concepts are dependent on the visual space and so are included in the MS-taxonomy as visual spatial metaphors. However, Bertin's other *retinal properties* are all concepts within direct visual properties. They are:

- colour - hue
- colour - saturation
- colour - intensity (grey scale, value)
- visual texture
- direct visual shape.

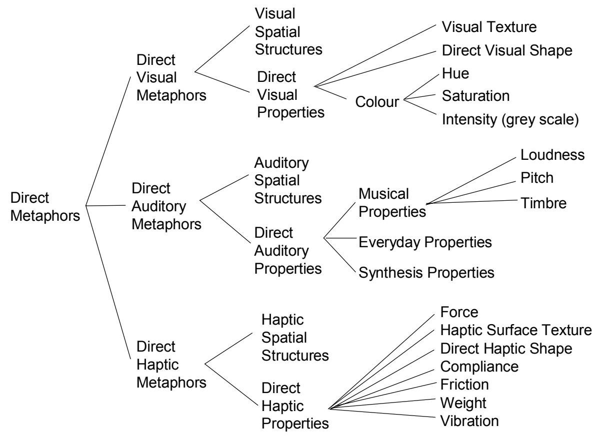

Figure 6. The concepts that describe Direct Metaphors.

Direct auditory metaphors use direct mappings from the attributes of data to the perceived properties of sound. The use of direct auditory properties for representing abstract data is a relatively recent field of study. Many of the perceived properties of sound are not well understood [20]. The direct auditory properties are less generally agreed on than the *retinal properties* of Bertin [21]. The commonly used properties of sound include loudness, pitch and timbre. These direct auditory properties have also been referred to as *musical properties* [22]. The direct auditory properties are not independent or orthogonal. For example, the pitch of the sound affects the perceived loudness of the sound [17]. Furthermore, both pitch and loudness are not equally prominent to the listener [23].

The area of Direct Auditory metaphors is also complicated because other ways of defining sound properties have been used. However a designer of sound displays may which to consider everyday properties or sound synthesis properties as adjuncts to the design space. Musical properties are interpreted by directly listening to the qualities of the sound itself. This contrasts with the concept of *everyday listening* where sound properties are interpreted in terms of the objects and events that generate the sounds [22]. Using mappings of information to these events provides an alternative way of designing.

Some sound synthesis algorithms have been developed for displaying abstract data. In some cases the metaphors can be described in terms of the parameters that define these algorithms. So another way to consider this part of the design space is to describe it using the actual parameters used to synthesise the display sound [24]. For example, Kramer suggests creating a sound field with input data controlling randomness, density, loudness and timbre of sound [25]. Other examples of sound synthesis methods include frequency modulation, non-linear distortion and granular synthesis [26].

Direct metaphors map data directly to a sensory property. Although accuracy varies between direct properties, in general, it is not possible for users to make accurate judgements about sensory properties [17] Many direct properties are continuous and ordered and can be used for displaying quantitative data.

However, it cannot be assumed that a user will make an accurate judgement of the value of a property. Therefore, it is more appropriate to use ordered properties for displaying ordinal data. The exceptions are those direct properties that have no ordering and these are better suited for displaying nominal data.

7. TEMPORAL METAPHORS

In the real world a great deal of useful information is dependent on the perception of time. For example, a pedestrian crossing a busy road is required to interpret the amount of time between vehicles. The rate and frequency of traffic may also impact on the pedestrian's decision of when to cross. Temporal concepts like duration, rate and frequency can also be used to encode abstract information.

Temporal metaphors relate to the way we perceive changes to pictures, sounds and forces over time. The emphasis is on interpreting information from the changes in the display and how they occur over time. Temporal metaphors are also closely related to both spatial and direct metaphors. For example it is changes that occur to a particular spatial metaphor or direct metaphor that displays the information.

Of course all the senses require some amount of time to interpret a stimulus. This is very fast for vision, while with hearing most sounds are more prolonged events with some temporal structure. A sound stimulus is perceived by interpreting changes that occur in air pressure over time. Even a single sound event, such as a bottle breaking, contains a complex temporal pattern that is perceived over a short period of time. However, with temporal auditory metaphors the focus is on how changes that occur in sound events are used to represent abstract information. The focus with temporal metaphors is how temporal changes convey information. They therefore involve the user's perception of events in time.

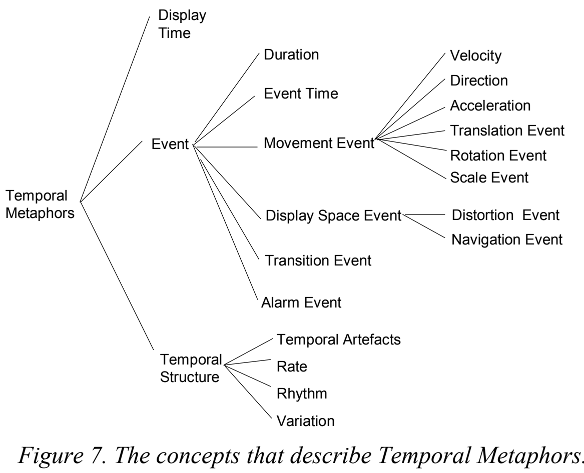

Figure 7. The concepts that describe Temporal Metaphors.

The MS-Taxonomy distinguishes between temporal visual and temporal auditory metaphors. However the general concepts that describe temporal metaphors are independent of sensory modality (figure 7). It is simply the ability of each sense to perceive changes over time that need to be considered. Because the concepts abstract across the senses it is possible for temporal metaphors to be directly compared between senses. For example, the ability of the visual sense to identify a visual alarm event can be compared with the ability of hearing to identify a sound alarm.

The design space for temporal metaphors can be described using the following general concepts (figure 7):

- the display time
- an event
- the temporal structure.

Temporal metaphors are composed of events that occur within the *display time* (figure 7). The *display time* provides the temporal reference for the data events that are displayed. This is analogous to the way a metronome is used in music to provide a background measure of time. The display time is not usually considered as part of the design space, but simply assumed to be constant. However, it is possible to consider the display time during the display design. For example, changing the display time could speed up or slow down the rate at which data is displayed.

Events have two main properties, the event time and the duration of the event (figure 7). Both the event time and event duration are interpreted in relation to the display time. These events affect changes to the visual or auditory or display. It is these changes and the timing and duration of these changes that are interpreted by the user as information. An event can affect a change to the display space, a spatial property, the spatial structure or a direct property in the display. This allows events to be categorised by reusing many of the concepts described for spatial metaphors and direct metaphors. The MS-Taxonomy defines the following types of event (figure 7):

- a display space event
- a movement event
- a transition event
- an alarm event.

Display space events cause a change to the perceived display space (figure 5-5). For example, a distortion event can change the metric at a location in the display space. A navigation event can affect a change in the user's position in the display space and is usually associated with user interaction.

Movement events are related to changes in spatial properties of structures and can be characterised by properties such as direction, velocity and acceleration (figure 7). Distinct types of movement events include; translation events, rotation events and scale events. Translation events involve a change to the spatial property of position. Rotation events involve a change to the spatial property of orientation. Scale events cause a change to the spatial property of scale.

The other types of events are transition events and alarm events. Transition events cause a slow change to either spatial structures or direct properties. By contrast alarm events cause a very sudden change to either spatial structures or direct properties.

A user may interpret information based on a single event. For example, a visible object changing position may be interpreted in terms of the old position and the new position, as well as the speed of movement. However, information may also be interpreted based on patterns that occur in a sequence of events. This is described as temporal structure. Types of temporal structure include the rate of events, the rhythm of events and the variations between events.

The concepts of temporal metaphors are very intuitive when described for the auditory sense. This is not surprising as hearing is usually identified as a temporal sense [3]. Indeed many of the concepts described in temporal auditory metaphors have been developed within the field of music. While these concepts are generally well described in the domain of music they are less commonly associated with information displays for the other senses. The intuition is that the both the terminology and the skills of musical composition can be transferred to the domain of abstract data display. Indeed much work in sonification domain is based on this idea [27,28,29,30,31,32].

Temporal auditory metaphors provide some advantages over visual temporal metaphors. Sound has been identified as a useful way for monitoring real time data as audio fades nicely into the background but users are alerted when it changes [33]. Kramer makes many other observations about sound [2]. Other objects do not occlude sounds. Therefore, an object associated with the sound does not have to be in the field of view for the user to be aware of it. Sounds act as good alarms and can help orientate the user's vision to a region of interest. Auditory signals can often be compressed in time without loose of detail. Because of the high temporal resolution of the auditory sense, events can still be distinguished.

One consideration with the design of temporal metaphors is the general perception of events over time. Comparing events or perceiving relations between events requires that past events be held in short term memory. There is an often quoted limit of seven on the number of items that can be held in short term memory [34]. Another general aspect of perception that can influence the interpretation of temporal metaphors is known as *perceptual constancy* [17]. When a slow change occurs to a sensory signal it may not be perceived.

8. DISCUSSION

The MS-Taxonomy is a structured group of concepts that describes the multi-sensory design space for abstract data display. When validating the MS-Taxonomy, the question is: does the MS-Taxonomy provide a good categorisation of the multi-sensory design space? A good categorisation would :

- model the full multi-sensory design space
- provide multiple levels of abstraction
- define a useful structure.

One concern with developing the MS-Taxonomy is whether or not it adequately covers the full multi-sensory design space. This question has been investigated elsewhere by using the concepts of the MS-Taxonomy to review existing literature [16]. This review serves to illustrate the concepts that make up the MS-Taxonomy and to demonstrate how existing applications of information display can be described under the taxonomy. This review found no areas of the multi-sensory design space that are not covered by the MS-Taxonomy. In contrast, the MS-Taxonomy covers a number of areas of the multi-sensory design space that have yet to be considered for displaying abstract information. For example, the use of distorted spaces for auditory display [16].

A major issue with the multi-sensory design space is that it is very complex. The MS-Taxonomy attempts to provide abstractions of the concepts that make up the design space. Higher level abstractions are useful for hiding some of the complexity of the design space. It is also expected that good abstractions should support the comparison and reuse of concepts across the different senses.

At the highest level the MS-Taxonomy provides a simple description of the design space in terms of nine metaphor classes. Even with this simple view of the multi-sensory design space it is possible to develop a useful design process and to incorporate some sensible high-level design guidelines [16].

An important feature of the MS-Taxonomy is that the concepts that describe spatial and temporal metaphors are general and apply across the different senses. This allows direct comparison of these types of displays. For example, a visual spatial metaphor can be compared to an auditory spatial metaphor. In this example, it is only the ability of each sense to perceive spatial relations that needs to be compared. By contrast, with direct metaphors it is less appropriate to compare displays between senses as it is the individual properties of each sense that defines the display.

The abstractions described by the MS-Taxonomy also encourage the transfer of display concepts between senses. For example, the domain of temporal auditory metaphors is well developed and these concepts can be transferred to temporal visual and temporal haptic metaphors. During a detailed review of the MS-Taxonomy a number of such opportunities are highlighted [16].

The MS-Taxonomy provides multiple levels of abstraction that mask complexity and can be used to compare general design concepts at different levels. The MS-Taxonomy provides a framework that encapsulates the lower-level complexity of the multi-sensory design space. It is the lower level concepts of the MS-Taxonomy that are most likely to generate debate. In particular some lower level concepts may need to be refined.

Does the MS-Taxonomy provide a useful structure? This is a question that can only really be answered after many years of empirical evidence is gathered. However, the structure of the MS-Taxonomy has been evaluated by using it as a framework to develop both the MS-Guidelines and the MS-Process [16].

The MS-Guidelines bring together guidelines for information display from many fields, including perceptual science, user-interface design, visualisation and sonification research. The structure of the MS-Taxonomy provides a convenient and intuitive organisation for these guidelines. For example some guidelines suggest general principles of information display and so are applicable at a high level in the structure. Other guidelines concern detailed design issues and fit lower in the taxonomy.

The MS-Process is an iterative design process for engineering multi-sensory displays. In particular the MS-Process considers the following engineering factors:

- the user's requirements
- the nature of the abstract data
- designing a display mapping
- the limitations of development tools
- the specific nature of target environments
- a range of evaluation methods.

Once again the structure of the MS-Taxonomy was successfully used to define the display mapping step of the MS-Process. During a case study of this design process [16] the structure of this step was found to support the way designs are created and then formalised. The designer can work at different levels as appropriate. For example, alternating between high-level design issues and very detailed design questions. These different levels are supported by the structure of the MS-Taxonomy.

9. CONCLUSION

This paper has introduced a categorisation of the multi-sensory design space called the MS-Taxonomy. This taxonomy is not based on sensory modality but rather on high-level information metaphors. This meta-abstraction, results in three general classes of metaphors called spatial metaphors, direct metaphors and temporal metaphors. These three general classes of metaphors are applicable to every sense. The contention is that this conceptual framework better allows display mappings to be transferred and compared between sensory modalities.

The MS-Taxonomy aims to provide an structured model of display concepts. While it generally succeeds, there is not doubt that some concepts (such as auditory scale) are unusual. Refining the MS-Taxonomy, especially at the lower level is the subject of further research.

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