# A Framework to Support the Designers of Haptic, Visual and Auditory Displays.

Keith V. Nesbitt

Charles Sturt University, Panorama Av
Bathurst, 2795, Australia
(+61) 2 6338 4262

knesbitt@csu.edu.au

## ABSTRACT

When designing multi-sensory displays of abstract data, the designer must decide which attributes of the data should be mapped to each sense. Because each sense can perceive a number of properties the designer must make further decisions about which of the properties perceived by each sense to use in the mapping. However, the multi-sensory design space is large and complex and issues with sensory bias and sensory conflict can complicate the design process. Furthermore designers would also like to compare and contrast designs that use different haptic, sound and visual properties. Unfortunately this is difficult without a common framework for describing the perceived properties of each sense. This lack of common grounding also makes it difficult for designers to move between sensory modalities. For example, a designer of visual displays is required to learn new concepts if they wish to become proficient with haptic or sound displays.

This paper describes a classification of abstract data displays, that is general for all senses. Called the MS-Taxonomy, the classification uses specialization-generalization and aggregation to define a hierarchical framework with multiple levels of abstraction. In software engineering terms the taxonomy allows a designer to consider mappings at both an abstract architectural level and also at a more detailed component level. At the higher levels, design mappings can be discussed independently of the sensory modality to be used. This allows the same fundamental design to be implemented for each sense and subsequently compared or for data mappings to be interchanged between senses.

## Categories and Subject Descriptors

H.5.2 User Interfaces: *Auditory (non-speech) feedback, Graphical user interfaces (GUI), Haptic I/O*

## General Terms
Design, Human Factors, Standardization

## Keywords
Multi-sensory display, Multi-modal, visualisation, sonification, haptic, sonification, framework, perceptual data-mining



## 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 [6]. For a designer, *Information Visualisation* implies a mapping from selected data attributes to distinct visual properties that the user can perceive. *Information Sonification* is a newly evolving field that uses sound rather than vision to represent abstract data [17]. In this case the designer is concerned with mappings from the data attributes to the distinct properties of sound that user can perceive.

In a similar way, the term, *Information Tactilization* has been proposed to describe the mapping of abstract data to properties of the haptic sense [6]. However, as yet, there has been limited investigation into using haptic feedback to display abstract data. This is not surprising as the haptic sense integrates information from a range of different receptors that respond to a variety of temporal and spatial stimulation patterns. The complex physiology of these receptors is not yet fully understood and the haptic properties that users perceive can be subtle and difficult to categorize. Furthermore, currently available haptic displays are often limited in the range of haptic cues they can support. Available displays can be expensive and require advanced programming skills to ensure refresh times are maintained.

A question often raised, is whether the visual sense is more effective at interpreting patterns in an abstract data display? Is vision somehow 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. Touch on the other hand is unique at integrating complex temporal and spatial signals. In fact, the different senses are well suited for different kinds of tasks. This is supported by what is known as the Modal Specific Theory [9]. 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. Designers of displays may wish to take advantage of those unique qualities when designing displays and so must have an appreciation of the full multi-sensory design space. That is, designers must consider the range of possible mappings between the data attributes and the different sensory properties.

In the field of information display, categorizing 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. Despite more rigorous attempts to categorize the visual display space [2], [5] and the emergence of standard methodologies such as earcons [3] and auditory icons [10], as well as initial attempts to categorize design patterns [1] in the auditory 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 what particular tasks.

The size of the multi-sensory design space has also led to fragmented expertise as many researchers tend to narrow the scope of their work and focus on designing displays for a single sense. Without a common language for describing displays it is difficult for designers to move between sensory domains or to quickly acquire knowledge in a new domain. For example, experts in visualisation will find it difficult to transfer that knowledge to the haptic domain.

Lack of a common framework also makes direct comparisons between haptic, visual and auditory displays difficult. 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 designers could better compare display performance across the senses and, if required, interchange appropriate mappings between the senses.

It is not surprising that a common framework has not emerged, because knowledge concerning the display of abstract data using haptic, visual and auditory cues has developed in relative isolation. The natural division down sensory modalities has proved useful to segment the research into haptic, visual and auditory displays but it has also meant that a common language to describe sensory displays has not been developed. This paper describes a common framework of the multi-sensory design space called the MS-Taxonomy. The classification is based on specialisation-generalisation and describes multiple levels of abstraction. At the higher levels of abstraction the same terminology can be used for describing haptic, visual and auditory displays. This abstraction is based not on sensory divisions but rather temporal, spatial and direct properties that are common to all senses.

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.

The MS-Taxonomy provides designers with a useful division of the multi-sensory design space. For example, this paper will provide an overview of a design process based on the structure of the MS-Taxonomy. Integrated within this structure and process is also a set of guidelines that assist and guide designers who wish to incorporate haptic, visual and auditory feedback in their displays. The current collection of guidelines is large, so relevant examples of the guidelines that focus on haptic display are described in a separate paper [27]. A detailed description of a case study that uses the process and guidelines is also available elsewhere [21].

# 2. THE MS-TAXONOMY

The MS-Taxonomy divides the design space by abstracting the typical types of metaphors that have been used to design mappings between data attributes and sensory properties. The metaphors form three main classes, *Spatial Metaphors*, *Direct Metaphors* and *Temporal Metaphors* (figure 2). These classes are general for all senses. The division of the design space by senses is not lost but rather forms a second, weaker division of the design space (figure 2). In software engineering terms the traditional model of the multi-sensory design space uses the concepts of *Visual*, *Auditory* and *Haptic* for the most general base classes. The MS-Taxonomy however uses *Spatial Metaphors*, *Direct Metaphors* and *Temporal Metaphors* as the most general base classes.

*Spatial Metaphors* relate to the scale of objects in space, the location of objects in space and the structure of objects in space. The key aspect of spatial metaphors is that they involve some perception of properties that depend on 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 organized and interpreted in space.
- *Spatial auditory metaphors* concern the way sounds are organized and interpreted in space.
- *Spatial haptic metaphors* concern the way haptic stimuli are organised and interpreted 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) can be described, the concepts that define a spatial metaphor are general and therefore independent of the senses. It is simply the way that each sense perceives these spatial qualities that may vary.

*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. Because there may be differences in the way we perceive temporal patterns using each sense, Temporal Metaphors can be considered not only generally but also for each of the senses. 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. The lower levels of the taxonomy for Temporal Metaphors are described in more detail in section 5.

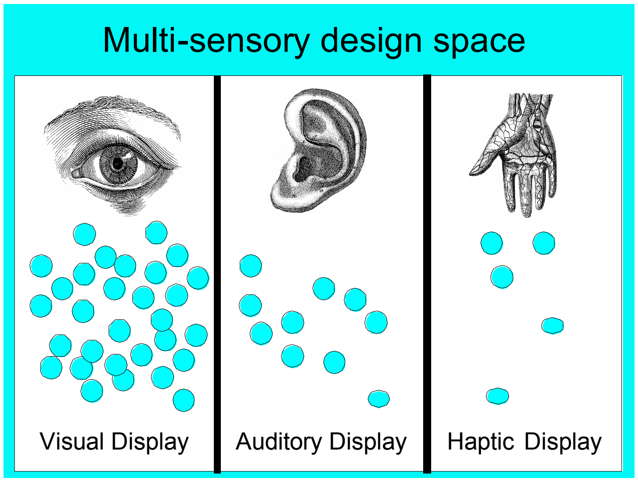


**Figure 1. A typical division of the multi-sensory design space is by sensory modality. Applications of information display then naturally fall into the specific groups focusing on visual, auditory or haptic display.**

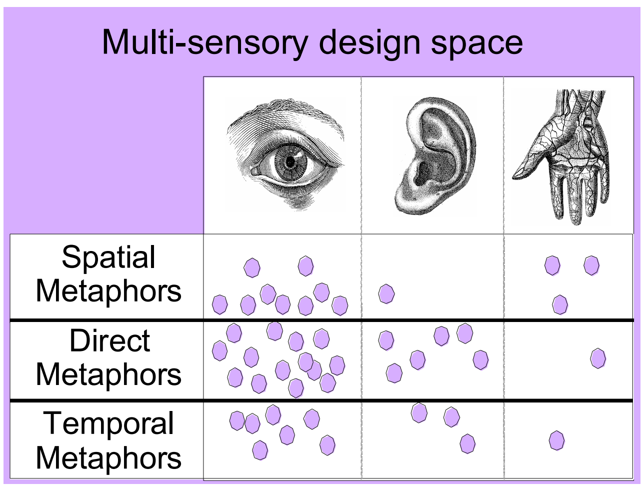


**Figure 2. A novel division of the multi-sensory design space using the types of metaphors that commonly occur in information displays. This division removes the accent on sensory modalities and allows comparison between senses.**

There needs to be some clarification with Temporal Metaphors, as all sensory perception involves some time component. For example, to perceive sound pitch we need to interpret a signal composed of air pressure changes over time. To interpret surface hardness with the haptic sense we must process information about the surface compliance in relation to a force we apply over time. Indeed all sensory perception requires some finite time for processing the signal. However, Temporal Metaphors, specifically concern how information is encoded in changing patterns within the perceived signal. So, for example, if the pitch or hardness changes over time then that is categorised as a Temporal Metaphor. The distinction is not as fuzzy as it may seem for the designer will normal make a decision to deliberately display information as a signal that changes over time.

*Direct metaphors* are concerned with direct mappings between sensory properties and some abstract information. The key aspect of Direct Metaphors is that they involve some perception of properties that depend directly on the sensory receptors involved. For example, sensory properties such as a colour for vision, pitch. for hearing or surface hardness for the haptic sense. 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 perception of haptic properties.

Unlike *Spatial and Temporal Metaphors*, *Direct Metaphors* are highly specific for each modality. Each sense perceives distinct sensory properties that are independent of space and time and directly related to the sensory receptors involved. These sensory properties can be used to display data and such mappings are described as Direct Metaphors. While the classes of Direct Visual Metaphors, Direct Auditory Metaphors and Direct Haptic Metaphors are specific to each sense, the more general concept of a Direct Metaphor applies across all senses. Thus, for example, it is possible to compare or exchange a direct property of one sense with another.

Despite their generality, the abstract general classes of Spatial Metaphors, Direct Metaphors and Temporal Metaphors are useful concepts for designers. For example, we know that the cortex for both visual and haptic processing are arranged in a spatial configuration, while the auditory cortex is arranged according to pitch [12].This provides a physiological basis for suggesting that both haptic and visual displays will be better suited than auditory displays for Spatial Metaphors. On the other hand the auditory sense has been shown to be adept at detecting short-term patterns in sound [17], suggesting that auditory display may be superior for Temporal Metaphors.

The MS-Taxonomy at this level is general but detail is not sacrificed. At the lower levels the taxonomy is comprehensive, allowing display mappings to be described to the level of a single perceptual concept or a single sensory property. 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 [14]. That is, sometimes a designer is worried about the "big picture" and at other times they are immersed in the detail of the design task.

The more detailed levels of the MS-Taxonomy are described in the following sections. Section 3 describes in more detail the lower level concepts of a Spatial Metaphor. Section 4 describes Direct metaphors and Section 5 describes in more detail the concepts that make up Temporal Metaphors.

## 3. 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 to locate a sound in space or use the haptic sense to judge position.. 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 haptic metaphor to create a haptic scatterplot. On the haptic scatterplot a user would feel rather than see the position of points.

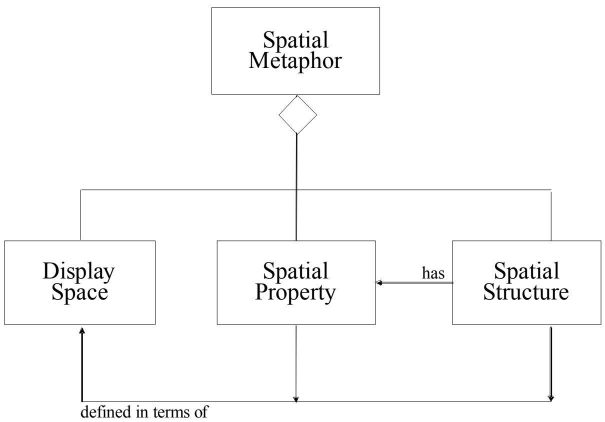


**Figure 3. A UML diagram showing the high-level components of spatial metaphors.**

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 would change the way the user interprets the relationships between point positions.

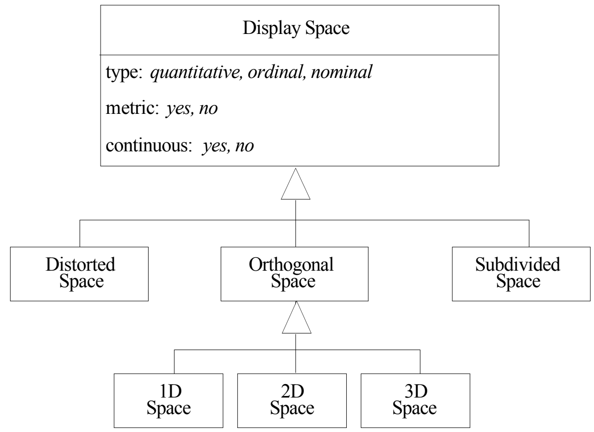


**Figure 4. The types of display space**

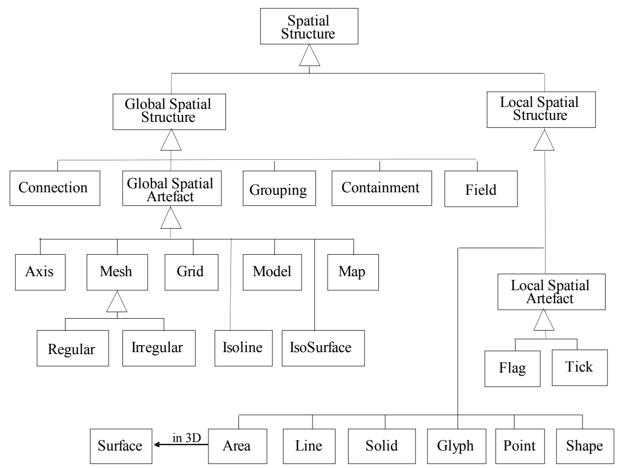


**Figure 5. The types of spatial structure.**

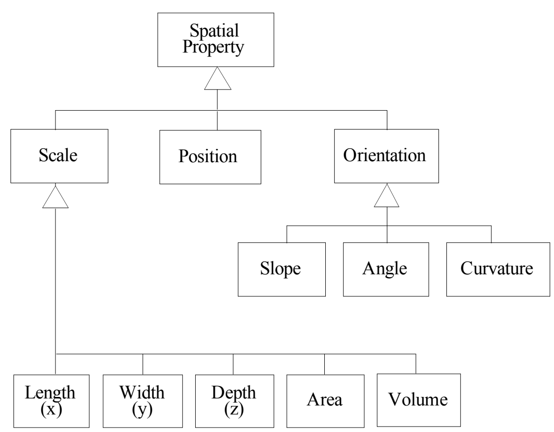


**Figure 6. The types of spatial properties.**

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.

In the MS-Taxonomy, the objects that occupy the display space are described as 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. The spatial properties used for presenting information include position, scale and orientation. Spatial properties describe qualities that are interpreted 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.

There are some points to note about spatial properties. Firstly these spatial concepts applied to the auditory sense are not as intuitive as the application of the same concepts to the visual or haptic 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 than spatial relationships [9]. By contrast both visual and haptic perception are strongly base around interpreting space. This interpretation is supported by a distribution of cortical neurones that are organised according to the way they respond to stimuli in space [12]. Cortical auditory neurones are organised in a tonotopic way, that is, they are grouped according to how they respond to pitch [12].

## 4. DIRECT METAPHORS

In the real world a great deal of useful information is perceived directly from the properties of sights, sounds and surfaces. For example, an object may have a particular hardness or surface texture. Objects in the real world may also be recognised on the basis of visual properties such as colour or lighting or interpreted on the basis of auditory properties like pitch and timbre. 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 hardness with a haptic display.

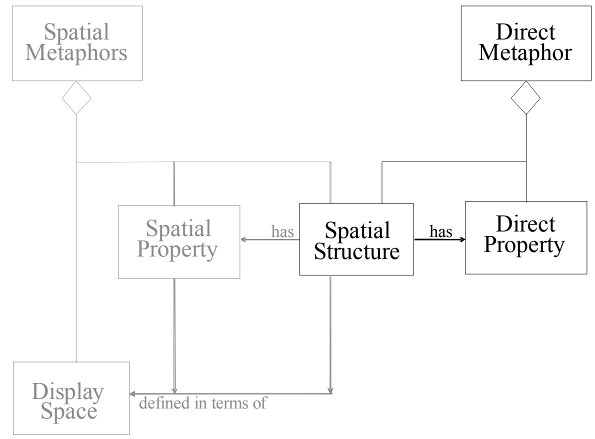


**Figure 4. The general concepts that describe Direct Metaphors. These concepts are very specific to the properties of the world that each sense perceives.**

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, or a haptic surface may be too small for the user to feel.

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 [24]. This suggests that direct properties should only be used to encode ordinal or nominal categories of data. Because direct properties such as colour, pitch or hardness are continuous they can 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, for the designer the higher level concept of a direct property is still relevant as it applies across all 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 haptic property of hardness for representing categories of data.

Many of the concepts in described direct properties are familiar to display designers as they overlap with existing sensory-based models of the design space. Much previous work has been done in the area of direct visual properties and to a lesser extent direct auditory properties. Because haptic display is a relatively new area and involves a complex range of sensations, describing the concepts that make up direct haptic properties is difficult. Arguably the MS-Taxonomy needs some discussion and refinement centred around the low level concepts that make up direct haptic metaphors.

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* [2]. 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.

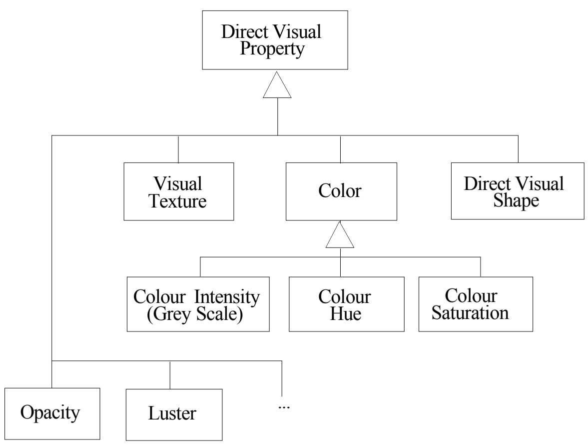


**Figure 5. Direct Visual Properties**

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 an embryionic field of study. Indeed many of the perceived properties of sound are not well understood [17] and the direct auditory properties are less generally agreed on than the visual properties. The most commonly used properties of sound are:

- loudness
- pitch
- timbre.

These direct auditory properties have also been referred to as *musical properties* [11]. The direct auditory properties are not independent or orthogonal. For example, the pitch of the sound affects the perceived loudness of the sound [24] Furthermore, both pitch and loudness are not equally prominent to the listener [4].

Alternative ways for defining sound properties have been developed. In particular musical listening contrasts with the concept of *everyday listening* where sound properties are interpreted in terms of the objects and events that generate the sounds [11]. For example, the sound from a stick hitting an empty can provide information about the objects involved and the forces used to create the sound. This approach is arguably more intuitive for the user.

However, the MS-Taxonomy uses musical properties to define the design space of direct auditory metaphors. These musical properties, which are interpreted by directly listening to the qualities of the sound itself, are intuitive and simple concepts for the designer to use. Furthermore the mappings between properties and data are simple to describe. However, it should be noted that users may have a wide range of abilities and levels of training in interpreting musical properties.

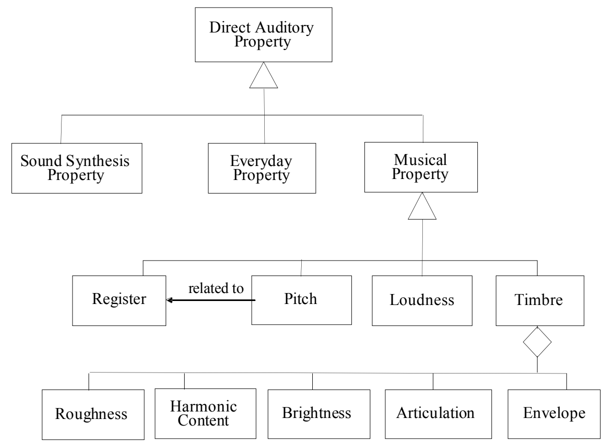


**Figure 6. Direct Auditory Properties**

Direct haptic metaphors use direct mappings from the attributes of data to the perceived properties of the haptic sense. These properties include surface texture, force and compliance. Figure 7 shows the different types of direct haptic properties that are principally associated with the *tactile* sense. Figure 4-19 shows the different types of direct haptic properties that are principally associated with the *kinaesthetic* and *force* sense. Some of the direct haptic properties, such as compliance and friction, require the combined perception of *tactile*, *kinaesthetic* and *force* stimuli. As previously noted, defining the concepts that make up direct haptic properties is somewhat rudimentary and probably requires further consideration. The MS-Taxonomy currently uses the following direct haptic properties:

- force
- surface texture
- direct haptic shape
- compliance
- viscosity
- friction
- inertia
- weight
- vibration
- flutter.

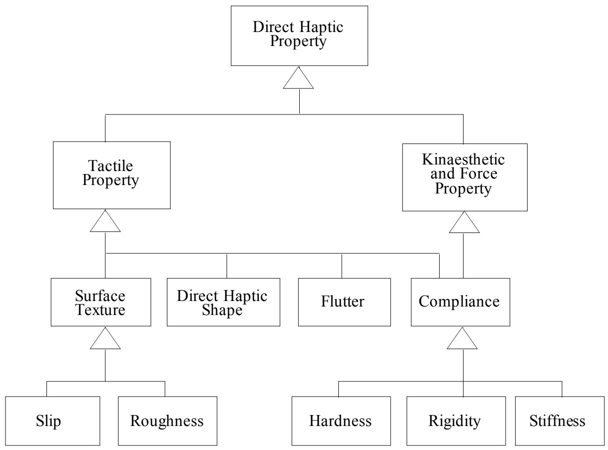


**Figure 7. Direct haptic properties associated with tactile stimuli**

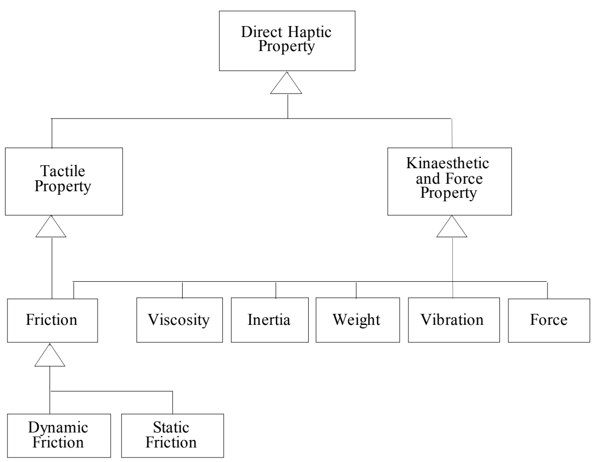


**Figure 8. Direct haptic properties associated with kinaesthetic and force stimuli.**

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 [24]. 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 (colour, timbre, direct haptic shape) and these are better suited for displaying nominal data.

## 5. 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 haptic stimuli 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. (Figure 9)

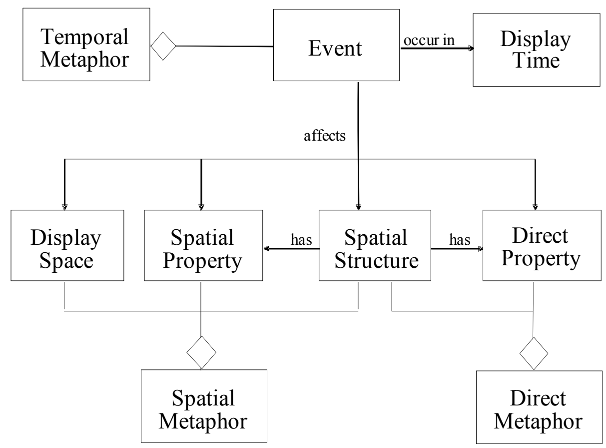


**Figure 9. Temporal metaphors are dependent on the perception of time and are characterised by events that modify spatial and direct properties.**

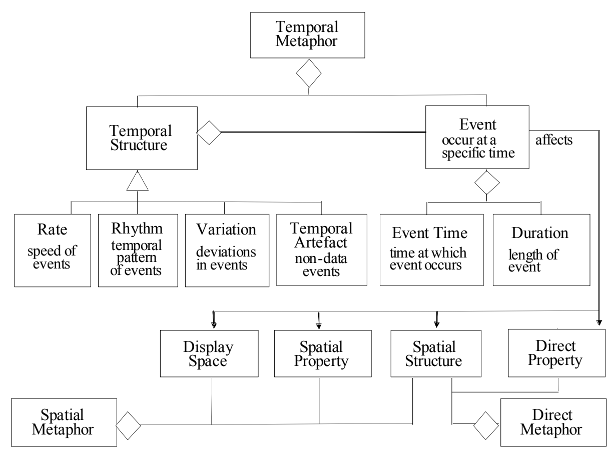


**Figure 10. Temporal metaphors are often composed of a number of events that have some temporal structure.**

Of course all the senses require some amount of time to interpret a stimulus. This is very fast for vision, while with hearing and haptics most stimuli are more prolonged events with some temporal structure. For example, 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 metaphors the focus is on how changes that occur in events are used to represent abstract information. That is, the focus for the designer is how temporal changes and patterns can be used to convey information. Designing temporal metaphors is analogous in many ways to the design of music.

The MS-Taxonomy distinguishes between temporal visual, temporal auditory and temporal haptic metaphors. However the general concepts that describe temporal metaphors are independent of sensory modality (figure 9). 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 or touch to identify a haptic alarm.

The design space for temporal metaphors can be described using the following general concepts (figure 9):

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

Temporal metaphors are composed of events that occur within the *display time* (figure 9). The *display time* provides the temporal reference for the data events that are displayed. This is analogous to the way *tempo* 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 10). 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 11):

- 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 10). 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 11). 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 [9]. 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 [13], [18], [19], [23], [25], [26]

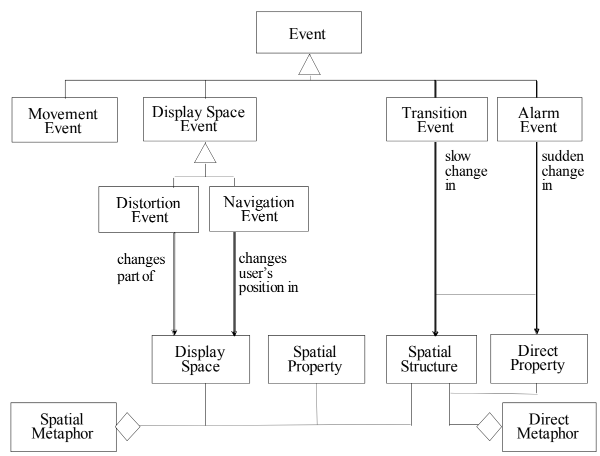


**Figure 11. The different types of events used to categorise Temporal Metaphors.**

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 [7]. Kramer makes many other observations about sound [17]. 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.

Many haptic perceptions also require an integration of both spatial and temporal properties and it is expected that many temporal auditory metaphors can be directly transferred to the haptic domain.

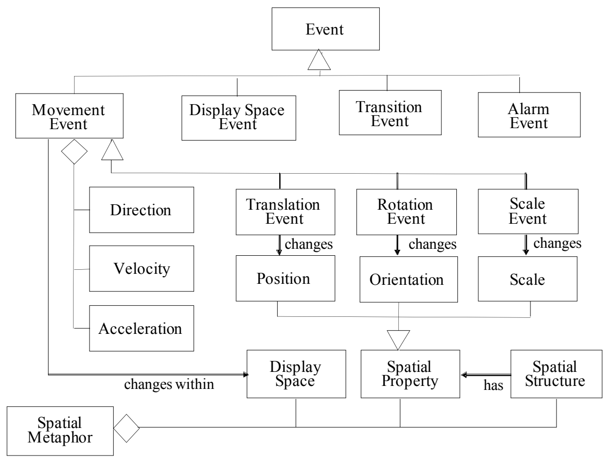


**Figure 12. Movement events may have properties of direction, velocity and acceleration. Movement events are defined in terms of the spatial properties of position and orientation**

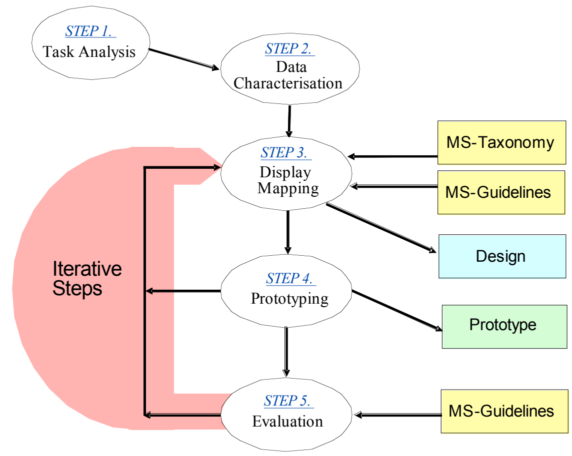


**Figure 13. A simple process for designers. The display mapping is structured using the MS-Taxonomy and guidelines support display mapping decisions and evaluation.**

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 [20]. Another general aspect of perception that can influence the interpretation of temporal metaphors is known as *perceptual constancy* [24]. Therefore when a slow change occurs to a sensory signal it may not be perceived.

## 6. MS-PROCESS

We have discussed a framework of the multi-sensory design space which provides the designer with general knowledge about the design possibilities. However the space is reasonably complex and it may be daunting for inexperienced designers to consider all possibilities. To assist with this aspect of design the MS-Process is defined. The MS-Process is based around the structure of the MS-Taxonomy. It is not intended to act as some absolute definition of how displays should be designed. Rather the intention is describe a fairly representative series of steps that can be followed to develop an information visualisation. The aim of using a process is to provide a common context for capturing experience and then passing it on to other designers.

A desirable outcome from all design is to arrive at a quality solution. Using a process as the basis for developing a quality product is the foundation of *Quality Principles* [8], [15]. Quality principles have been formulated in a number of places. The principles are often described as TQM (total quality management) and since 1985 many manufacturing companies have adopted this approach to improving their products and services [16]. Defining and following a process is fundamental to qualuty concepts as it allows *"us to examine, understand, control, and improve the activities that comprise the process"* [22]. Software engineering has progressed by adopting processes and the information visualisation design process has many obvious overlaps with software design. Given the immaturity of the field of information visualisation and the difficulty with designing good solutions, adopting a process provides a pragmatic way to move forward.

**Table 1. Entry and exit criteria for the MS-Process.**

| **Entry Criteria** | | **Exit Criteria** |
|---|---|---|
| user goals<br>previous work | STEP 1.<br>Task analysis | task list<br>sample data<br>current methods<br>user requirements |
| task list<br>sample data<br>current methods<br>user requirements | STEP 2.<br>Data characterisation | data types<br>data priorities<br>data sources |
| task list<br>current methods<br>user requirements<br>data types<br>data sources<br>data priorities<br>**MS-Guidelines** | STEP 3.<br>Display mapping | design |
| design<br>sample data | STEP 4.<br>Prototyping | prototype<br>platform limitations |
| prototype<br>sample data<br>**MS-Guidelines** | STEP 5.<br>Evaluation | evaluation results<br>recommended change<br>new guidelines |

The main steps (figure 13, table 1) of the MS-Process are:

Step 1. Task analysis

Step 2. Data characterisation

Step 3. Display mapping

Step 4. Prototyping

Step 5. Evaluation

The first two steps of the MS-Process (Task analysis, Data characterisation ) are designed to understand both the application domain and specific data requirements. The design is driven from a traditional HCI perspective of tasks. Therefore the task for which the visualisation is being designed should be understood in as much detail as possible. The last three steps of the process (Display mapping, Prototyping, Evaluation) are iterative as it is expected that a number of attempts may be required to arrive at the final design.

More detail on the MS-Process is available elsewhere [21]. The key in this context is to recognise two distinguishing features of the MS-Process. Firstly the display mapping step is structured around the MS-Taxonomy. During display mapping it is desirable to consider the full range of possibilities from the design space. By using the structure of the MS-Taxonomy and following the MS-Process the designer is directed to consider all such possibilities. Secondly the MS-Process incorporates the MS-Guidelines at two places (Table 1). During the display mapping the guidelines help to direct design decisions (figure 7). During the evaluation step the guidelines also serve as a checklist for critical assessment of the design (figure 9). The guidelines are also organised using the structure of the MS-Taxonomy and can therefore be quickly indexed during the design process.

# 7. 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 a structured model of display concepts. While it generally succeeds, there is not doubt that some concepts (such as auditory scale) are unusual and probably of little value in information design. Furthermore, refining the MS-Taxonomy, especially at the lower levels of direct haptic metaphors may be required.

The MS-Taxonomy is use to define a process for designing display called the MS-Process. The taxonomy can also used to structure a series of guidelines called the MS-Guidelines [27]. These guidelines provide both high-level principles and low-level detailed support for designers.

In summary the MS-Taxonomy, MS-Process and MS-Guidelines provide a comprehensive toolset to support the designer of multi-sensory displays. There is no contention that these tools are the only or best way to approach the design task, simply that they are useful. Interested readers may wish to refer to a case study describing how these tools were used to design a multi-sensory displays of stock market data [21].

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