Structured Guidelines to Support the Design of Haptic Displays.

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ABSTRACT

There are a number of motivations for developing guidelines for haptic display. Guidelines can summarize accumulated knowledge in a domain and they can help to hide complexity from the designer. Guidelines can also support the designer by directing the design process and assisting them with design decisions. Another motivation behind using guidelines is to improve the quality of final designs and to communicate and encourage reuse of good design solutions. Finally guidelines can assist in the evaluation of the design outcomes.

However the design process is complex and a designer must work at many levels, sometimes concerned with high-level perceptual design issues and at other time immersed in very detailed design decisions concerned with implementation strategies. To be useful guidelines must assist the designer at all levels. This can lead to large collection of guidelines and this can result in the additional problem of how to index the guidelines to allow eth designer to find the appropriate guideline in an efficient way.

This paper describes a collection of haptic guidelines taken from the *MS-Guidelines*. These guidelines were created to support designers of multi-sensory display. These guidelines are structured using the MS-Taxonomy. This framework acts as an index to allow designers to quickly find the guidelines that are relevant to their current decision making. This paper describes the motivation behind developing guidelines and them provides a number of examples relevant to haptic display.

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.

Categories and Subject Descriptors

H.5.2 User Interfaces: *Graphical user interfaces (GUI), Haptic I/O*

General Terms

Design, Human Factors, Standardization

Keywords

Haptic, Guidelines, Multi-sensory display, Multi-modal

1. INTRODUCTION

This paper describes a group of guidelines to support designers of haptic displays. The guidelines are part of a larger collection of guidelines which have been collected to support designers of multi-sensory displays of abstract data. The guidelines are organized using 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.

The MS-Taxonomy provides a useful division of the multi-sensory design space which can be used to structure the design process or to index a collection of design guidelines. This paper does not describe the MS-Taxonomy or the associated design process (MS-Process). That information is available in a separate paper [57].

The MS-Taxonomy provides designers with a useful division of the multi-sensory design space. Integrated within this structure is a set of guidelines that assist and guide designers who wish to incorporate haptic, visual and auditory feedback in their displays. The focus of this paper is on describing some guidelines (MS-Guidelines) that have been organized around the structure of the MS-Taxonomy.

The current collection of guidelines is large, so only relevant examples of the guidelines that focus on haptic display will be described here. A detailed description of a case study that uses the guidelines is available elsewhere [38]. Although the current collection of guidelines is large they are not complete. However, because guidelines are well structured they support simple addition of further guidelines. Indeed the structured guidelines highlight some areas of the design space where guidelines need to be developed from existing knowledge or new research. It could be argued that the size of the guidelines would detract from usage as designers must navigate through so many. However, because the guidelines are well-structured designers can use the MS-Taxonomy as an index to quickly find the guidelines that are relevant to their current decision making.

It is noted that these guidelines were mainly developed to support designers building haptic displays of abstract data. The term, *Information Tactilization* has been proposed to describe the mapping of abstract data to properties of the haptic sense [11]. Another term that has been suggested is *Information Hapization*. 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.

Before providing the example haptic guidelines, a more general discussion of the motivation behind creating guidelines is provided.

2. MS-GUIDELINES

There are a number of ways that guidelines can assist with the design of information displays and these include:

- guiding a process
- capturing previous experience
- providing structured knowledge
- providing both general and specific principles
- hiding complexity from the designer
- communicating good solutions
- evaluating the design

2.1 Guiding a Process

Sometimes guidelines are general, such as Johnson's guidelines for teaching mathematics [27]. Other guidelines are more specific, such as the guidelines for dumping packages of radioactive waste at sea [39]. However, in both cases the guidelines aim to assist users follow a process and to ensure the quality of the outcome. One goal of the MS-Guidelines is to assist the designer follow the MS-Process and produce a higher quality final design.

Using guidelines to assist engineering design processes is well established. It is not uncommon to find guidelines for designing both hardware and software. There are general guidelines, such as the *"Human Engineering Design Considerations for Cathode Ray Tube-Generated Displays"* [3]. Quite specific guidelines have been developed, for example, to assist in the design of auditory alarms in the work place [26] or for developing software for a specific computer platform [1]. Once again the motivation for providing guidelines for engineering design is to assist users follow a complex process and to try to ensure a level of quality in the outcomes.

2.2 Capturing previous experience

Designing user-interfaces is certainly a complex process and often the business success of a computer system relies on the quality of its interface. Not surprisingly, guidelines to assist in designing user interfaces are often proposed. For example, guidelines have been suggested for designing data displays [47], user-interfaces [9], screen messages [45] and application screens [18]. Shneiderman notes, *"a guidelines document can help by promoting consistency among multiple designers, recording practical experience, incorporating the results of empirical studies, and offering useful rules of thumb"* [46].

However, even the idea of guidelines to assist with the design of abstract data displays is not new. For example, a number of guidelines have been suggested for both visual display [52], [31] and auditory display [30], [40], [13]. Where possible, the MS-Guidelines aim to incorporate the knowledge from such existing guidelines.

To capture previous experience, report objective findings and provide useful hints are further goals of the MS-Guidelines. Because the design of information displays encompasses a wide range of disciplines the MS-Guidelines are extracted from a variety of sources. These include the fields of perceptual science, human computer interaction, information visualisation and user-interface design.

2.3 Providing structured knowledge

It is not an aim of the MS-Guidelines to propose another set of completely new guidelines. Rather the aim of the MS-Guidelines is to collect existing knowledge and order it in a useful way. This ordering is achieved by using the structure of the MS-Taxonomy. Thus the guidelines can be indexed by the concept they are related to. For example guidelines to do with using colour are indexed under the concept of "Colour".

It is expected that knowledge in the field of abstract information display will expand over the future years. Hence it is necessary to consider that the MS-Guidelines will also expand. By using the generic structure of the MS-Taxonomy, new guidelines can always be incorporated at the appropriate level.

2.4 Providing general and specific principles

One problem with guidelines is that they can be hard to interpret [34]. Some guidelines are very specific and detailed while others are more general and abstract in scope. Specific guidelines are precise but are usually numerous. For example, Smith and Mosier provide a very detailed list of almost 1000 guidelines for interface design [47]. The sheer number of guidelines can make it difficult to find the right guideline for any situation. As Wright and Fields note, to be tractable, guidelines need to be relatively small and thus they tend to be general [56]. Because general guidelines are often few in number but they may be tend to be so abstract that they must be interpreted for each situation. For example, Tufte recommends that the display should *"focus on displaying the data"* [52]. While this is a general and useful guideline, it doesn't provide concrete information about how to focus on the data.

Both specific, detailed guidelines and more abstract, general guidelines can be useful in design. Sometimes the very specific guidelines can assist with fine-tuning the display performance, while more general principles may help set the overall direction or philosophy of the design. Both types of guidelines can be useful at different stages of the design process.

Rather than adopting a single approach, the MS-Guidelines provide a number of levels of complexity and abstraction. These levels have already been defined within the structure of MS-Taxonomy. The different levels of the MS-Taxonomy allow the designer to choose guidelines for a general display concept or guidelines that target a very specific concept. For example, there are general guidelines about designing spatial visual metaphors. and more detailed guidelines for lower level concepts in the MS-Taxonomy such as hue. By using the structure of the MS-Taxonomy the MS-Guidelines are indexed by the relevant design concept.

2.5 Hiding complexity from the designer

The design of information displays is complex and this provides a further motivation for using guidelines [56]. For example, Rasmussen and Vicente use a detailed model of human information processing to manage error in user inputs to software systems [43]. However, they argue that this model is too difficult for software engineers to understand. To solve this problem they simply extract from their model some human factor guidelines for the software designers to use.

The MS-Guidelines work in the same way to help hide the complexity of some domains. For example, the MS-Guidelines include findings from perceptual science. However, it is not expected that the designer needs detailed knowledge of human perception to apply the guidelines.

2.6 Communicating good solutions

User interface designers have found that some design problems often occur over and over again. When a good solution to a common problem has been devised it is desirable to reuse this solution. The issue however, often becomes how to communicate the solution amongst user interface designers. Guidelines have been suggested as a way of overcoming this communication issue [24]. In a emerging field of information display it is desirable that guidelines act to communicate good solutions to the common problems that can arise when designing information displays.

2.7 Evaluating the design

A final motivating factor for developing guidelines is to act as a means of evaluating the process outcomes. For example, it has been found that guidelines provide a useful method for evaluating software applications [2]. In another example, Bastien and Scapin developed ergonomic criteria for evaluating software [5]. The MS-Guidelines provide a series of checks that can be applied formally or in a more formative fashion to evaluate designs.

3. EXAMPLE GUIDELINES

Currently the collection of MS-Guidelines contains over two hundred guidelines. This section provides a brief overview of some example guidelines and in particular focuses on those that impact on haptic display. Guidelines dealing with the other senses and a broader discussion of each guideline and referencing information is available elsewhere [38].

Table 1 The two parts that make up the MS-Guidelines

General Guidelines
General Guidelines for Perception
General Guidelines for Information Display
General Guidelines for Multi-Sensory Display

MS-Taxonomy Guidelines		
	Guidelines for Spatial Metaphors	
		Guidelines for Spatial Visual Metaphors
		Guidelines for Spatial Auditory Metaphors
		Guidelines for Spatial Haptic Metaphors
	Guidelines for Direct Metaphors	
		Guidelines for Direct Visual Metaphors
		Guidelines for Direct Auditory Metaphors
		Guidelines for Direct Haptic Metaphors
	Guidelines for Temporal Metaphors	
		Guidelines for Temporal Visual Metaphors
		Guidelines for Temporal Auditory Metaphors
		Guidelines for Temporal Haptic Metaphors

Table 2 A summary of general perception guidelines.

General Perception
GP-1 Perception is shaped by neural processing and physiology. GP-1.1 Neural maps assist spatial perception of touch and vision. GP-1.2 Neurones respond to specific influences. GP-1.3 There are parallel pathways of perception. GP-1.4 Perception is influenced by individual physiology.
GP-2 Perception is approximate.
GP-3 Perception is influenced by cognitive processes. GP-3.1 Perception is influenced by expectations. GP-3.2 Perception is influenced by knowledge. GP-3.3 Perception may be influenced by recognition. GP-3.4 Perception is influenced by attention. GP-3.5 Perception is influenced by context.
GP-4 Perception remains constant.
GP-5 Perception can be biased towards one sense. GP-5.1 Attention can affect sensory bias. GP-5.2 Learning can affect sensory bias.
GP-6 Perceptual responses have thresholds. GP-6.1 Weber's Law GP-6.2 Steven's Power Law
GP-7 Perception groups small elements into larger elements.
GP-8 Seven is a magic number.

Table 3 A summary of general Information Display guidelines.

Information Display
GD-1 Emphasise the data.
GD-2 Simplify the display.
GD-3 Design for a task.
GD-4 Iterate the design process. GD-4.1 Avoid designer bias.

3.1 General Guidelines

The MS-Guidelines are divided into two parts (table 1). The first part deals with general guidelines. These guidelines contain higher level support for designers and in particular deal with issues of perception (table 2), information design (table 3) and multi-sensory display (table 4). Complete descriptions of each of these guidelines is available [38] and take the form of:

> **GP-2 Perception is approximate.**
> Our perception does not always accurately match the physical stimulus. For example, a light that remains the same intensity becomes brighter during dark adaptation , two identically coloured squares appear different when they are surrounded by different coloured backgrounds [22, p64] and with touch, when two points that are close together touch the skin it may feel like a single point [22, p65]. The implication is that a stimulus generated by an information display may not be perceived precisely.

Table 4 A summary of general MS-Taxonomy guidelines.

Multi-sensory Display
MST-1 Use each sensory modality to do what it does best. MST-1.1 Vision emphasises spatial qualities. MST-1.2 Hearing emphasises temporal qualities. MST-1.3 Haptics emphasises movement. MST-1.3.1 Point force-feedback only provides temporal information. MST-1.3.2 Tactile displays are not readily available.
MST-2 Use the spatial visual metaphor as a framework for the display.
MST-3 Increase the human-computer bandwidth. MST-3.1 Use complementary display. MST-3.2 Avoid redundant display. MST-3.3 Avoid conflicting display.
MST-4 Consider sensory substitution. MST-4.1 Adapt spatial visual metaphors to spatial auditory metaphors. MST-4.2 Adapt spatial visual metaphors to spatial haptic metaphors. MST-4.3 Adapt temporal auditory metaphors to temporal visual metaphors. MST-4.4 Adapt temporal auditory metaphors to temporal haptic metaphors.

3.2 MS-Taxonomy Guidelines

While the first part of the MS-Guidelines deal with general design issues, the second part of the MS-Guidelines are structured according to the MS-Taxonomy. The aim is to abstract each guideline to the highest possible level in the MS-Taxonomy, thus also making it as general as possible. However, some guidelines are very specific and naturally belong with a specific design concept.

A summary of guidelines that apply to the haptic sense are provided below and are structured according to the MS-Taxonomy concepts that describe haptic display. The summary of guidelines for designing spatial haptic metaphors are shown in table 5. The summary of guidelines for designing direct haptic metaphors are shown in table 6. The summary of guidelines for designing temporal haptic metaphors are shown in table 7. The full form of these haptic guidleines are provided in section 4.

Table 5 A summary of guidelines for Spatial Haptic Metaphors, including the haptic display space, haptic spatial properties and haptic spatial structures.

Haptic Display Space
SH-1 Haptic space is useful for displaying constraints in the data.
SH-2 Haptic feedback can be used to display temporal-spatial data.
SH-3 Haptic space can be at a different resolution to visual space. SH-3.1 Haptic feedback augments display of global visual models. SH-3.2 Haptic space provides a finer level of resolution than vision.
Haptic Spatial Properties
SH-4 Haptic spatial properties should be consistent with visual properties. SH-4.1 Visual shape overrides haptic shape. SH-4.2 Visual size overrides haptic size. SH-4.3 Visual orientation competes with haptic orientation.
SH-5 Haptic feedback provides information about position in space. SH-5.1 Human spatial resolution is about 0.15mm. SH-5.2 We lose track of spatial location. SH-5.3 There is a spatial map in the cortex. SH-5.4 Visual location overrides haptic location
SH-6 The JND of length varies between 1-4 mm.
SH-7 Sensitivity to rotation varies between joints.
Haptic Spatial Structures
SH-8 Use spatial haptic metaphors to represent local spatial structures. SH-8.1 Point force feedback is very localised.

Table 6 A summary of guidelines for Direct Haptic Metaphors

Direct Haptic Metaphors
DH-1 Direct haptic metaphors are the third choice for displaying categories. DH-1.1 The visual model affects the perception of haptic properties. DH-1.1.1 Visual attention can affect the tactile response. DH-1.2 The auditory model affects the perception of haptic attributes.
DH-2 Individuals have very different haptic perceptions. DH-2.1 Use large differences to display categories.
Force
DH-3 Force is an ordinal property. DH-3.1 The JND for force is about 7%. DA-3.2 Force fields can display vector fields. DA-3.3 Strong forces distract attention.
Haptic Surface Texture
DH-4 Haptic surface texture is an ordinal property.

DH-4.1 Touch is equal to vision for comparing surface smoothness. DH-4.2 Visual surface texture affects haptic surface texture.
Direct Haptic Shape
DH-5 Direct haptic shape is a nominal property. DH-5.1 Direct haptic shape is biased by vision. DH-5.2 Visual shape recognition is faster than touch.
Compliance
DH-6 Compliance is an ordinal property. DH-6.1 The JND of compliance depends on the type of surface. DH-6.2 The visual model affects perceived stiffness. DH-6.3 The auditory model affects the perceived stiffness. DH-6.4 Fast haptic rendering is required for rigid surfaces.
Friction / Viscosity
DH-7 Viscosity is an ordinal property. DH-7.1 The JND for viscosity is about 12%.
Weight
DH-8 Weight and inertia are ordinal properties. DH-8.1 The JND for weight is 10-20%. DH-8.2 Temperature of objects affects perception of weight. DH-8.3 The visual model affects the perception of weight.
Vibration
DH-9 Vibration is an ordinal property. DH-9.1 Detection threshold for vibration depends on frequency.

Table 7 A summary of guidelines for Temporal Haptic Metaphors

Temporal Haptic Metaphors
TH-1 Use temporal haptic metaphors to display time series data.
Display Space Events
TH-2 Use temporal haptic metaphors for task-assisted navigation.
Transition Events
TH-3 Haptic feedback can detect a wide range of frequencies. TH-3.1 Force feedback models should be simple. TH-3.2 Very fast changes to force can be detected.
Movement Events
TH-4 Haptics is concerned with movement. TH-4.1 Vibration can create the illusion of movement.
Temporal Structure
TH-5 Consider transferring temporal auditory metaphors to haptics.

4. HAPTIC GUIDELINES

This section contains the full version of guidelines that were summarised in the previous section. Only guidelines relevant to the design of haptic display are shown. However, the reader is reminded that the purpose of the MS-Taxonomy is to support designers of multi-sensory displays. The more abstract levels of this taxonomy allow design concepts to be exchanged and compared between sensory modalities. As such, these same abstract concepts may seem irrelevant when the guidelines for a single sensory modality are listed, as they are here.

4.1 Guidelines - Spatial Haptic Metaphors

4.1.1 Guidelines for the Haptic Display Space

SH-1 Haptic space is useful for displaying constraints in the data.
Haptics can be used to display local structures such as boundaries, limits, ranges, or constraints that occur in data. While this does not provide precise quantitative measures it provides a general range of values and is a natural metaphor.

SH-2 Haptic feedback can be used to display temporal-spatial data.
Because haptics is adept at both sensing both spatial and temporal properties it may be used for displaying information that evolves over both space and time. For example force fields evolve over space and time and have traditionally been difficult to display visually [50].

SH-3 Haptic space can be at a different resolution to visual space.
It is possible to overlay a different resolution of haptic space on the visual space. For example, one measure of visual space may equate to 10 measures of haptic space.

SH-3.1 Haptic feedback augments display of global visual models.
Haptic feedback can augment global visual models that are too difficult to display in detail locally.

SH-3.2 Haptic space provides a finer level of resolution than vision.
The sense of touch has a higher spatial resolution than vision [22]. Therefore for very fine detail touch may be effective where vision is not.

4.1.2 Guidelines for Haptic Spatial Properties

SH-4 Haptic spatial properties should be consistent with visual properties.
The visual perception of objects can perceptually bias the haptic perception of objects. Visual information can alter the haptic perception of object size, orientation and shape [48].

SH-4.1 Visual shape overrides haptic shape.
For shape perception the visual perception of shape biases the haptic perception of shape [55].

SH-4.2 Visual size overrides haptic size.
The visual estimate of size and length of objects overrides the haptic perception of size and length [55].

SH-4.3 Visual orientation competes with haptic orientation.
Whether haptic or visual perception of an object's orientation is dominant varies between users [55].

SH-5 Haptic feedback provides information about position in space.
In the real world haptics (and sound) signal contact with an object and thus verify the position of an object in space. It is sometimes

difficult to resolve the exact depth of objects in 3D space. Haptic feedback can assist by providing an accurate depth cue.

SH-5.1 Human spatial resolution is about 0.15mm.
The spatial resolution on the finger pad is about 0.15mm. Two points can be distinguished when they are about 1 mm apart [16].

SH-5.2 We lose track of spatial location.
The human haptic system tends to lose track of absolute spatial location [44]. This makes accurate tracking of position in space difficult.

SH-5.3 There is a spatial map in the cortex.
The sense of touch is organised around a spatial map. In the somatosensory cortex there is a map of the human body in which neighbouring neurones represent neighbouring parts of the body. However this map is distorted so that more space is allocated to parts of the body that are more sensitive to stimulation [22].

SH-5.4 Visual location overrides haptic location
There is an overwhelming bias of vision over haptic information about spatial location [55]. This is an example of one modality overriding another so that a single uniform event is perceived. For example, when subjects viewed a stationary hand viewed though a 14 degree displacing prism, it immediately feels as if it is located very near its seen (optically displaced) position [55].

SH-6 The JND of length varies between 1-4 mm.
For discriminating the length of objects the JND is about1mm for objects around 10mm in length. This increases to 2-4 mm for objects that are around 80 mm in length [16].

SH-7 Sensitivity to rotation varies between joints.
Humans can detect joint rotations with different degrees of sensitivity. Proximal joints have greater sensitivity to rotation than more distal joints. The JND is about 2.5 degrees for wrist and elbow and about 0.8 degrees for the shoulder [16].

4.1.3 Guidelines for Haptic Spatial Structures

SH-8 Use spatial haptic metaphors to represent local spatial structures.
In the real world visual and haptic combine to give overview and low level structure. Spatial perception may not be inherently visual or haptic. Contours may be interpreted the same way whether they come from vision or touch [22]. Haptic feedback provides a good reinforcement of spatial structure but is only effective over smaller areas because large structures must be temporally integrated into a whole. For example, subjects who had to navigate a maze performed best with a large visual-haptic ratio, that is, a large visual display and small haptic workspace [48].

SH-8.1 Point force feedback is very localised.
Current haptic devices only allow for point force feedback. With such feedback the stimulus is generated at a single point and thus the display of shapes and other structures requires greater temporal integration. It is like using a finger tip to scan tactile information about a very restricted part of a broader picture. This requires piecing together momentary samples and this puts a huge load on a person's short-term memory [44].

4.2 Guidelines - Direct Haptic Metaphors

DH-1 Direct haptic metaphors are the third choice for displaying categories.
Direct visual properties such as colour and shape are generally better for displaying data because they can be easily be compared. Direct auditory properties such as pitch and timbre are also effective for displaying data categories. However, because auditory properties are not orthogonal, only a few can be used. Direct haptic properties such as hardness and surface texture provide a third choice for displaying categorical data.

DH-1.1 The visual model affects the perception of haptic properties.
Visual information has been shown to alter the perception of haptic properties such as stiffness [49] and shape [48].

DH-1.1.1 Visual attention can affect the tactile response.
For some tasks visual attention can affect the tactile response [22]. The implication is that in multi-sensory displays visual attention may be focused on visual properties of the display and this reduce the effectiveness of displaying haptic properties.

DH-1.2 The auditory model affects the perception of haptic attributes.
Auditory information has been shown to alter the perception of haptic properties such as surface stiffness [49].

DH-2.0 Individuals have very different haptic perceptions.
The individual differences in many measures of haptic perception are large [50].

DH-2.1 Use large differences to display categories.
Because of the large differences between individuals, it is safer to use large categorical differences between haptic properties.

4.2.1 Guidelines for Force

DH-3 Force is an ordinal property.
Force is ordered but it is not judged precisely; this makes it useful for displaying ordinal categories.

DH-3.1 The JND for force is about 7%.
The JND for contact force is 7% [48], although a range of 5-15 % is possible [16]. A variation of 0.5 Newtons can be detected [50].

DA-3.2 Force fields can display vector fields.
In some domains, such as *scientific visualisation,* vector fields are often modelled. The temporal and spatial nature of these fields suggests that force should be a natural metaphor for displaying them.

DA-3.3 Strong forces distract attention.
If force is mapped to a data attribute, the sudden occurrence of a strong force can surprise and distract a user.

4.2.2 Guidelines for Haptic Surface Texture

DH-4 Haptic surface texture is an ordinal property.
Surface texture can be experienced as slip on a smooth surface like glass through to the roughness of more abrasive surfaces such as sandpaper. This property is ordered from smooth to rough but it is not judged precisely. This makes it useful for displaying ordinal categories.

DH-4.1 Touch is equal to vision for comparing surface smoothness.
It has been shown that touch and vision provide comparable levels of performance when observers attempted to select between smooth surfaces [37].

DH-4.2 Visual surface texture affects haptic surface texture.
Using vision and touch improves the discrimination of surface texture [37]. Thus a combined display may increase the number of categories that can be displayed.

4.2.3 Guidelines for Direct Haptic Shape

DH-5 Direct haptic shape is a nominal property.
Shape is an unordered haptic property and this makes it useful for displaying nominal categories.

DH-5.1 Direct haptic shape is biased by vision.
Touch is usually dominated by vision when they are placed in conflict with one each other for shape perception tasks. This is known as *intersensory dominance*. For example, in an experiment to test for this effect subjects were asked to view objects through a distorting prism. The object was square in shaped but looked like a rectangle through the distorting prism. While viewing the object the subject could also feel the square shape of the object. Most subjects reported that seeing and feeling a rectangle shape [22, p210].

DH-5.2 Visual shape recognition is faster than touch.
Vision registers shape more accurately and rapidly than touch [22, p209]

4.2.4 Guidelines for Compliance

DH-6 Compliance is an ordinal property.
Surface compliance of objects is an ordered property that cannot be judged precisely. This suggests compliance is useful for displaying ordinal categories.

DH-6.1 The JND of compliance depends on the type of surface.
Discrimination of compliance depends on whether the object has a deformable or rigid surface. It is more difficult to judge the compliance of rigid surfaces. The JND of deformable surfaces in a pinch grasp is about 5-15%. The JND of a rigid surface is about 23-34% [16].

DH-6.2 The visual model affects perceived stiffness.
Changing the visual representation of the object can alter the perceived haptic stiffness of a spring [49].

DH-6.3 The auditory model affects the perceived stiffness.
Using sound in conjunction with haptics can alter the perceived stiffness of a surface [15].

DH-6.4 Fast haptic rendering is required for rigid surfaces.
The haptic rendering rate on force feedback devices must be maintained at 1000Hz to create the illusion of a rigid surface [48]. Rendering at rates slower than this can create the impression of a soft yielding surface.

4.2.5 Guidelines for Friction and Viscosity

DH-7 Viscosity is an ordinal property.
Viscosity is ordered but it is not judged precisely; this makes it useful for displaying ordinal categories.

DH-7.1 The JND for viscosity is about 12%.
Users can discriminate viscosity categories with a JND of about 12% [48].

4.2.6 Guidelines for Weight and Inertia

DH-8 Weight and inertia are ordinal properties.
Weight and inertia are ordered but cannot be judged precisely; this makes them useful properties for displaying ordinal categories.

DH-8.1 The JND for weight is 10-20%.
The JND required to distinguish between weights is reported as 10% of the reference value [16]. An alternative source estimates that the JND is 20% [48].

DH-8.2 Temperature of objects affects perception of weight.
The temperature of an object affects its perceived weight. Cold objects feel heavier than warm objects with the same weight [16].

DH-8.3 The visual model affects the perception of weight.
Larger objects are judged to be heavier than smaller objects even if they weigh the same. For example, subjects make systematic errors in discriminating objects of similar weights when the size was not related to weight. The subjects judged bigger objects as being heavier [54].

4.2.7 Guidelines for Vibration

DH-9 Vibration is an ordinal property.
Vibration is ordered but it is not judged precisely; this makes it useful for displaying ordinal categories.

DH-9.1 Detection threshold for vibration depends on frequency.
The intensity of a vibration required for detection depends on the frequency (table 8).

Table 8 Detection thresholds for vibration [16].

Threshold (dB)	Frequency (Hz)
28	0.4-3
decreases by -5 each octave	3-30
decreases by -12 each octave	30-250
increases	> 250

4.3 Guidelines - Temporal Haptic Metaphors

TH-1 Use temporal haptic metaphors to display time series data.
Touch is both a temporal and spatial sense. Because of its temporal nature it is good for detecting changes over time.

4.3.1 Guidelines for Haptic Display Space Events

TH-2 Use temporal haptic metaphors for task-assisted navigation.
Any action involving movement can be constrained or assisted with force feedback. This may be useful to assist a user to follow a difficult path. This may assist for training or improving task efficiency.

4.3.2 Guidelines for Haptic Transition Events

TH-3 Haptic feedback can detect a wide range of frequencies.
A wide range of force frequencies can be perceived, from fine vibrations at 5,000-10,000Hz up to coarse vibrations of 300-400Hz [50]. This allows haptics to be used for detecting a wide range of temporal patterns.

TH-3.1 Force feedback models should be simple.
The recommended speed of force feedback devices is 1000Hz [48]. This is the speed required to give the illusion of hard

surfaces. The implication is that perceived properties are very dependent on the rate at which forces are displayed. Most devices will operate at this speed provided the control loop at each step is short. This places some emphasis on the designer to maintain a simple force model.

TH-3.2 Very fast changes to force can be detected.
The rate of 1000Hz is very fast compared to the visual rate which is 60Hz [16]. This may provide opportunities for speeding up time for haptic displays. So for example, 10 minutes of data may be displayed over 1 minute and still allow the user to resolve temporal differences.

4.3.3 Guidelines for Haptic Movement Events

TH-4 Haptics is concerned with movement.
Touch is both a temporal and spatial sense and is designed to both instigate and detect movement [55]. The haptic sense can respond specifically to objects that change position in space with a specific temporal pattern [22]. This suggests that haptic movement events may be an appropriate way to display information.

TH-4.1 Vibration can create the illusion of movement.
When vibration is imposed on muscles and tendons, the corresponding limbs are perceived to be moving [16]. Therefore, using both movement and vibration may not be a reliable way to display information.

4.3.4 Guidelines for Haptic Temporal Structure

TH-5 Consider transferring temporal auditory metaphors to haptics.
Both hearing and touch can detect signals repeated at regular rhythms. They are also useful where a sudden change to constant information needs to be detected. A number of temporal structures have been explored for sound and these could also be applied to haptic monitoring. For example, the musical concepts of rhythm, meter and inflection

5. CONCLUSION

This paper has introduced some guidelines based on a categorisation of the multi-sensory design space called the MS-Taxonomy [57]. This taxonomy is not based on sensory modality but rather on high-level information metaphors. The MS-Taxonomy aims to provide a structured model of display concepts. that have previously been used to define a process for designing displays called the MS-Process [57].

The MS-Taxonomy is also used to structure a series of guidelines called the MS-Guidelines. These guidelines provide both high-level principles and low-level detailed support for designers. The intention is to support designers in both a top-down and bottom-up design process. The MS-Guidelines are not complete and are designed to be expanded upon. Indeed one important outcome of using the MS-Taxonomy to structure the guidelines is that it highlights areas of the display space where existing guidelines are sparse. It is probably not surprising, given that commercial haptic displays have only recently become available, that many more guidelines dealing with haptic display need to be developed.

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 multi-sensory displays of stock market data [38].

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