Proceedings of

# GOTHI'05

# Guidelines On Tactile and Haptic Interactions

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# GOTHI'05 Call for Papers

Interest in tactile / haptic user interfaces is accelerating. This is largely supported by a wealth of research-generated knowledge. The time has come to start to transform this knowledge into a set of basic guidelines which is usable by all interface developers. GOTHI'05 is a first step towards this transformation. GOTHI'05 will lead the way to bringing tactile / haptic interfaces into mainstream computing.

GOTHI'05 is a unique opportunity for a small gathering of experts to move the state of the practice ahead in a significant manner. Participation in GOTHI'05 will be by invitation, based on the acceptance of a suitable paper.

## Topics of Interest

GOTHI'05 welcomes papers that include generalized guidance based on research and practice. Papers can deal with tactile interactions, haptic interactions, or a combination of tactile and haptic interactions.

The following are some of the areas of particular interest:

- reference models useful for understanding, designing, or organizing standards for tactile / haptic
    - interfaces
    - interactions
    - encodings
- guidelines regarding
    - the design/use of tactile/haptic inputs, outputs, and/or combinations of inputs and outputs, including:
        - + general guidance on their design / use
        - + guidance on designing / using combinations
        - + use in combination with other modalities
        - + use as the exclusive mode of interaction
    - the tactile/haptic encoding of information, including:
        - + textual data
        - + graphical data
        - + controls
- requirements placed on users of tactile / haptic interfaces
- customization and adaptation of tactile / haptic interfaces
- temporal issues with tactile / haptic interfaces
- application dependent issues with tactile / haptic interfaces

Please NOTE: We are not expecting submissions to contain complete / comprehensive sets of guidelines (although we will be happy if any submissions do contain attempts at such). We hope that by combining many submissions, each with a few guidelines, that we will be able to make a start towards developing a somewhat comprehensive set of guidelines.

# GOTHI'05Program Committee

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## Refereeing Information

Papers 1 – 12 were refereed by a minimum of 3 reviewers each.
Paper 13 was invited by the program committee.
Paper 14 was developed by participants of GOTHI-05 and was reviewed and improved by the experts involved in the meeting of ISO TC159/SC4/WG9 that followed GOTHI-05. This second group included 5 individuals who were not participants in GOTHI-05.

# Guidance on Tactile Human-System Interaction: Some Statements

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## ABSTRACT

When compared to other kinds of perception, haptic perception has several special aspects. This paper presents a proposal for definitions of haptic perception and tactile interaction. These definitions are designed to support the process of developing interactive systems with haptic perception and tactile interfaces. To give an impression of the complexity of needed guidance, the difficulty of coding tactile information is further illustrated by example.

Tactile communication can be classified into three levels which are suggested as a useful structure of guidance for developers of interactive systems with tactile components. Some proposed general guidelines on designing tactile output should be the basis of further discussion on what guidance seems to be possible at the present stage of knowledge and what further investigation should be done. The summary contains an appeal to use system-oriented approaches. The aim of this paper is to give input for further discussion.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*standardization*

## Keywords

Guidelines, haptic, interface, standards, tactile

## 1. INTRODUCTION

Human-system interaction is based on human activities as a mixture of multimodal perception, cognitive and intuitive mental processes, and motor actions.

Human capabilities to interact with systems are a result of basic resources, learning, and environmental influences. Design and development of interactive systems is based on well defined technologically and economically oriented knowledge and on ergonomic knowledge mostly presented as guidelines. Guidelines for developing computer supported systems have been concentrated on graphical user interfaces for a long time [8, 9, 10, 11, 12, 13].

With the growing impact of information technology in daily life there are at present good reasons for adding some guidance for other types of user interfaces, especially for those containing tactile interactions. Although haptic perception is a very basic human sense some serious reasons exist that the knowledge and methodology for describing tactile interactions is more complicated in comparison to visually dominated interactions. The most important reasons for this are:

- the haptic perception system is not concentrated on two organs like eyes or ears but are distributed — simply spoken — over the whole body,
- the transfer of thermal and mechanical energy from the environment into the human body has to be described not only in one dominating measure (e.g., radiation in the case of vision, pressure in the case of hearing), but in a multidimensional manner (i.e., force, pressure, distance, velocity, acceleration, strain, etc.), and
- there is practically no writing system, like grapheme- or phoneme-based systems, to describe haptic patterns.

The complexity of tactile interaction can be found in handbooks containing commonly accepted traditional knowledge on perception and human performance [1].

***Guidelines are needed for tactile/haptic interactions.***

***Guidelines are needed for documenting and describing tactile/haptic patterns.***

## 2. HAPTIC PERCEPTION AND TACTILE INTERACTION

For human-system interaction it seems to be helpful to distinguish clearly between "tactile" and "haptic". Although some definitions exist for these terms, e.g. [18, p. 204, 228, 229] the following point of view (new contextual definition) has some advantages:

- The term "haptic" should be used in cases of passive perception only. Passive perception means that no motor actions with the purpose of getting the haptic information are involved.
- The term "tactile" should be used in cases of human activities (interactions), based on haptic perception, in combination with purpose oriented (goal driven) motor actions.

Flux of mechanical and/or thermal energy is involved in both cases. That is the beginning of a very difficult matter: How can you describe, in terms and measures of energy flux, the haptic perception and the resulting haptic or (more complicated) tactile pattern recognition.

For some special conditions, well known methods exist for this problem. For example, at a very basic level, the interaction of key stroking can be described as a function $h = f(F, t, c_i)$, where $h$ is distance (height), $F$ is force, $t$ is time, and $c_i$ are other parameters, describing technological influences of interaction. Commonly, some special characteristics of this function are used as deputies for representing the whole function $f$.

Other functions, describing the transmission of signals via a system, are concentrated on dependencies of the interaction from signal parameters like frequency, nonlinearities, noise and other measures of system-signal-theory. This way of describing tactile interaction is applied in biomechanics frequently. The corresponding biomechanical knowledge can be useful for defining peak values of forces and other mechanical measures (e.g., level of mechanical vibrations) but it is not directly usable for guidance on designing tactile interactivity.

***Guidance is needed in the definitions of common terms (e.g., haptic, tactile).***

***Guidelines are needed for documenting and describing pattern recognition of tactile/haptic patterns.***

## 3. PHENOMENOLOGY (CLASSIFICATION) OF TACTILE COMMUNICATION

To distinguish between tactile interaction and tactile communication it can be helpful to define the purpose and context of guidance for tactile human-system interaction.

*Tactile interaction* can be defined as a transfer of haptically perceivable signals in a technological sense.

*Tactile communication* can be defined as tactile interaction including mental processes of understanding coded messages. Tactile communication can be classified into three levels:

*Basic level*:
Tactile communication at a basic level uses exchange of mechanical and / or thermal energy only.
Examples are: grasping a hammer, touching an object in the darkness, reading Braille text.

*Advanced level*:
Tactile communication at an advanced level includes feedback of additional perception channels (like visual or auditory perception) to basic level tactile communication.
Examples are: using pointing devices for positioning the cursor at a computer screen, using a gun, reducing the loudness of a radio.

*Complex level*:
Tactile communication at a complex level includes body language (like gesture and mimic) and emotionally controlled motor actions to transfer messages which cannot be expressed alphanumerically.
Examples are: dancing, hand shaking, playing piano

The existing knowledge of all kinds of tactile communication is very limited in comparison to the human capabilities. Nevertheless this knowledge should be more and more encapsulated into guidance on designing tactile human-system interaction. Therefore a need exists to systematically summarize existing knowledge into categories of artefacts to be designed for tactile input and tactile output (e.g., designing input devices for graphics [19, p. 188], effective text input devices [23], or touch screen interfaces [17]).

***Guidance is needed in the definition of the differences between tactile interaction and tactile communication.***

***Guidelines are needed to organize and summarize existing knowledge of input/output device design.***

## 4. EMPIRICAL KNOWLEDGE AND THE NEED OF GUIDANCE

Guidance on designing tactile human-system interaction should be established as much as possible on commonly accepted models and empirically formulated functions. Some of these would appear obvious, for example, the human movements required of tactile interaction would suggest the need to consider guidance reflecting the Law of Practice which, simply put, states that practice improves performance [7]. Others are not as clear. For instance, scientific publications in human-system interaction often refer to Fitts' Law [5] and Card and Moran's Keystroke-Level Model [2], but can traditional models fit into tactile interaction? How these models can fit into a purely tactile domain and what other models might also be appropriate need to be determined.

To fill the gap between existing models and the challenges of designing a specific tactile interaction process, additional guidance on how to proceed is necessary. Even to develop such guidance, an efficient methodology has to be defined. This may require a model specific to tactile interaction. The question remains, how to encapsulate this experience and knowledge into some guidance or a few guidelines.

***Guidance is needed regarding how to apply commonly accepted human-system interaction models and empirically formulated functions in the tactile/haptic interaction domain.***

***Guidelines are needed to describe how to identify and resolve gaps between existing interaction models and the tactile/haptic interaction process.***

## 5. CODING OF TACTILE INFORMATION

As mentioned in Section 3, tactile communication needs understanding of coded messages. To draw some attention on the challenge behind this statement, consider the following brief example:

A blind student is dealing with modelling in bioinformatics. Typically such modelling needs some experimental investigations, in this case some electrophoretic measurements. The results of agarose gel electrophoresis is usually presented as a grey-level image (see Figure 1). The question is: How to design a tactile representation providing the equivalent information in the sense of web content accessibility guidelines such as WCAG [4].

Guidance relating this this problem has been historically lacking. ISO/TS 16071 [14] provides guidance on software accessibility, but lacks guidance on haptic access [3]. Specific guidance requiring haptic equivalents to information has been added to ISO 9241-171 [15], however no guidance on how to map abstract visual information into a tactile medium is provided. Much knowledge exists about designing tactile information if the referent is spatial (e.g., city maps) or is based on a hierarchical sequence (e.g., train time tables), but higher levels of abstraction need higher levels of guidance (and education).

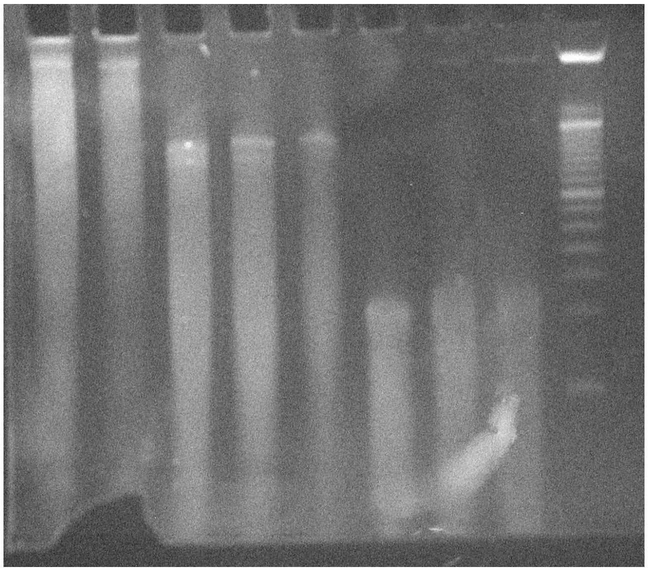

**Figure 1: Example of a grey-level image as a result of electrophoretic measurements to be transformed into an equivalent with tactile components for blind users.**

***Guidance is needed on how to map abstract visual information into tactile patterns.***

# 6. METHODS FOR TACTILE OUTPUT

Devices specifically designed for tactle/haptic output address the somatic senses of the human operator. As such, they should concern more than just touch. Somatic senses, the "senses of the skin", include the sense of pressure, cold, warmth, touch, and vibration [6]. In addition, two more senses, both related to the proprioceptors, are the "sense of position" and the "sense of force" [6].

Proprioceptors are sensory receptors found in muscles, tendons, joints, and the inner ear that detect the motion or position of the body or a limb. They measure the activity of muscles, the stressing of tendons, and the angle position of joints. This sense of proprioception, the ability to feel movements of the limbs and body, is also called kinesthesis [20].

Guidance on haptic and tactile interaction needs to provide coverage across all tactle/haptic output methods available across the somatic senses. Shimoga categorizes these devices by stimulus [21]:

**Pneumatic stimulation** involves using air jets, air pockets, or air rings. Pneumatic devices tend to have low bandwidth. Users may eventually experience muscular fatigue reducing their ability to sense.

**Vibrotactile stimulation** involves using blunt pins, voice coils, or piezoelectric crystals to generate vibration. Vibrotactile devices can be very small and have a high bandwidth. They are often the best way to address the user's somatic senses.

**Electrotactile stimulation** involves using electrical impulses provided via small electrodes attached to the user's fingers.

**Functional neuromuscular stimulation** involves stimulation provided directly to the neuromuscular system of the user. Although this approach has been used to activate paralysed limbs, it has not caught the imagination of most tactile/haptic interaction researchers. This approach is highly invasive and not appropriate for the casual user. The possibility of surgery and the potential liability in case of damage to the neuromuscular system further removes this approach as an attractive alternative method of tactile/haptic interaction.

Haptic interfaces using **heat stimulation** also exist. Thermal stimulation of the skin can be provided using radiation (IR and microwave), convection (air and liquid), conduction (thermo-electric heat pumps), or some combination of these. There is ongoing research into the question of which temperature ranges offer the best resolution [16].

***Guidelines need to provide coverage over the full human somatic sensory range.***

***Guidelines are needed to categorize input/output devices by communication style (as per Section 3) and/or method of stimulus (as per Section 6).***

# 7. BASIC GUIDANCE ON DESIGNING TACTILE OUTPUT

Independent of the existing detailed knowledge of haptic perception, like haptic thresholds and other characteristics, and the theoretical questions of proprioception [22, p. A84], some guidance on a more general level seems to be helpful for developers of interactive systems with tactile components especially with tactile output.

The following subsections contain example draft guidelines.

## 7.1 Clearly document tactile patterns

Provide electronic text explaining the pattern used for tactile output presentation.

NOTE In contrast to visual and acoustic output for tactile output only a few sets of symbols are standardised (e.g., Braille-code in several versions).

EXAMPLE 1 Bursts of tactile vibrations are verbally described as acting in analogy to a ringing bell.

EXAMPLE 2 The vibration pattern of a pointing device with tactile feedback is explained according to the functionality of the selected object.

EXAMPLE 3 The adjusted maximum level of pressure output of a force feedback system is presented as an alphanumerical value via a visual display.

## 7.2 Do not rely on tactile output alone

The system should provide an alternative modality (description) for tactile output signals.

EXAMPLE An end user with a haptic disability can understand the tactile presented message if this message can be presented additional as a verbalized message.

## 7.3 Do not cause injury

The system should enable users to adjust tactile output parameters to avoid injury or pain.

EXAMPLE A user with reduced haptic perception can individually adjust an upper limit for the tactile output of a force feedback system.

# 8. SUMMARY

There is a need to summarize the knowledge on haptic and tactile interaction, beginning with defining a clear vocabulary and ending with guidance on developing and using interactive systems with tactile components. This guidance should be structured analogously to the purposes and context scenarios of the systems in question. For this task a system-oriented approach should be used. The dominating part of such guidance should support the process of designing dialogues based on haptic perception of objects and of tactilely usable functionality.

Such guidance (and the included guidelines and conformance procedures) should not strongly distinguish between those concentrated on software and those concentrated on hardware. The reason for this demand comes from the high complexity of tactile communication — the fact that the most important part of tactile interaction of the human being is not clearly divided into hard- and soft- ware.

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# Two Recommendations for Tactile/Haptic Displays: One for All Kinds of Presentations and One for the Development of Haptic Displays

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## ABSTRACT

Two recommendations are suggested. The first is general for all kinds of tactile/haptic presentations when vision is not available and concerns the need of an overview of the scene. The suggestion is that efforts to facilitate overview should be made in all kinds of tactile/haptic presentations. The second concerns the development of haptic displays. It is suggested that the efforts for improvement should be concentrated to develop displays that present stimulation more similar to the natural one, especially by providing an extended contact area.

## Keywords

Tactile pictures, Haptic displays, Overview, Natural haptics

## 1. THE NEED OF OVERVIEW

It is well known that haptics alone, in contrast to vision, usually does not provide an immediate overview of a scene. There are at least two main disadvantages of the lack of such an overview: (1) The general content of the scene is not apparent at once. (2) When detailed examination is needed, it is not easy to find the locations to be specifically explored.

### 1.1 Methods of Facilitating an Overview with Touch/Haptics

Even if it is sometimes possible to get a rapid overview also via haptics [10], a laborious and time-consuming exploration is very common. It is a number one recommendation always to consider how to facilitate an overview of a scene to be perceived haptically. The methods may concern adaptation of tactile properties, verbal descriptions and instructions for exploration.

#### *1.1.1 Adaptation of Tactile Properties*

Several ways of facilitating an overview by adapting the tactile properties have been suggested. By Edman [3, pp. 113-128] listed a number of (partly overlapping) recommendations for the production of tactile pictures, among others the following:

- Keep the pictures simple by portraying only the most important element(s)
- Do not use unnecessary details
- Keep forms simple and without ornate decoration
- Brake down a too complex figure into a step-by-step series of pictures (four different methods suggested)
- Stress the most characteristic element of the objects / animals / humans
- Make characteristic details noticeable
- Portray objects/animals/humans in their entirety
- Brake down a too complex figure into a step-by-step series of pictures (four different methods suggested)
- Stress the most characteristic element of the objects / animals / humans
- Make characteristic details noticeable
- Portray objects/animals/humans in their entirety

Another feature of tactile stimulation is related to the perception of figure and ground. In visual pictures there is, in most cases, not much trouble of distinguishing between these aspects of a scene. Contours are usually easily identified as belonging to an object in front or as belonging to the background. This is not as evident in touch/haptics [9]. Brambring and Laufenberg [2] discussed the difference in performance with two types of tactile maps as depending on differences between them in figure-ground relations. One way of making a perceptual separation easier is to vary the height of what is figure, for instance by making point and line symbols higher elevated than area symbols [3, pp. 218 f. and 233].

#### *1.1.2 Verbal Descriptions*

A suitable verbal description may function as a vehicle for an overview [16]. Comprehension of the scene is increased when the reader is told what to expect. The description can be made in

Braille or in speech. It is especially useful when the reader is unaided [3, pp. 142-143].

If a reader has earlier acquired knowledge of what is depicted, the understanding may be considerably facilitated by verbal information. For instance, if they know that the form of Italy is similar to a high boot and then get the information that the map content is Italy, they can explore the map more efficiently.

### *1.1.3 Instructions for Exploration*

Touch has a large repertoire of exploratory movements [13]. Such movements may be differently facilitating an overview. The number of available such movements is restricted when information is picked up by movements over a two-dimensional display, but also under these conditions there are several options, and some exploratory movements are more efficient than others.

Berlá [1] found that scanning to and fro the body is more efficient than scanning left and right. When the movements are performed left and right the fingertips come successively to the same area of the display and the risk of skipping parts of it is large. The risk of a similar skipping is not as great when the fingers are moved to and fro the body. This means also that the amount of information is larger in the latter case than in the case when they are moved left and right. The difference is related to the construction of the arms and hands. You can orient your fingers in a left and right sweep such that you get the same information as in a to and fro sweep, but then you must hold your hands in very awkward orientations.

A verbal description may contain general instructions about how to read the display. Such "picture guidance" can be quite elaborate and may be critical for the usefulness of the presentation [4, pp. 54–73], especially when a reader has less advance knowledge. The instructions may, for instance, be of the following kind: start in the upper left corner, follow the slightly oblique contour downwards, and so on.

## 1.2 Application to All Kinds of Displays

Many of the advices above have been considered for two-dimensional displays, such as tactile pictures and maps. However, they are applicable also to three-dimensional displays. During the development of a haptic display for exploration of statues at museums it was expected that it would be especially useful for visually impaired museum visitors for whom visual experience was not available [6]. Even if an evaluation of the haptic display demonstrated its potential for enhancing the experience for its users, it was indicated that the expectation of its special usefulness for visually impaired people was not demonstrated. There were increased potentials of perception of three-dimensional aspects, but the problem with overview was still there. Arrangements compensating for the spontaneous lack of overview, for instance verbal descriptions, are still a necessity for maximum usefulness also of such a device [5].

There are many different ways to facilitate overview and they may differ between situations. The important point is that it should always be considered how to do it.

## 1.3 Recommendation

Efforts to facilitate overview should always be made in all kinds of tactual/haptic presentations.

# 2. THE NEED FOR DEVELOPMENT OF HAPTIC DISPLAYS THAT PROVIDE INFORMATION MORE SIMILAR TO NATURAL HAPTICS

Haptic perception is very efficient in identifying real objects with bare hands [11], but the same cannot be stated when it concerns haptic displays. The main reason is that the information obtained via haptic displays is much restricted compared with what is obtained under natural conditions. Especially, most displays allow only one contact area at a time and this area is in nearly all cases only a tiny point. For instance, information about a larger form can be obtained only after exploration over time.

The information provided is far from the richness of natural haptics. The situation for exploration with a haptic display is often similar to what it would be for visual exploration if we were allowed to see only through small holes in a cover moving over the scene. The problem for touch is to get an integrated perception of an object that is at each time only partially perceptible. These restrictions have considerable effects on the efficiency of the display. Decreasing the number of fingers exploring real objects from five to one impairs performance in identifying objects [12]. The largest effect is obtained between the use of two fingers and one finger [7]. Constraining the amount of information by applying a rigid plastic sheath on a fingertip also impairs the performance considerably [14, 15].

By simulation of technical development by different amounts of restriction of different kinds of information Jansson and Monaci [8] demonstrated that the most important improvement of haptic displays for identification of objects would be to increase the amount of information at each contact area, even if number of contact areas also may have some importance. A study using up to three contact areas of a haptic device got a related result of no improvement for shape perception with number of points [Frisoli, Barbagli, Wu, Ruffaldi, Bergamasco & Salisbury, Personal communication, 2004].

## 2.1 Recommendation

Efforts for improvement of haptic displays should be concentrated to develop displays that present stimulation more similar to the natural one, especially by providing an extended contact area.

# 3. ACKNOWLEDGMENTS

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# Information Access for the Blind – Graphics, Modes, Interaction

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**Abstract:** We describe experiments with various forms of computer-mediated access to technical and graphical information for visually impaired persons. The study involves multimodal and interactive document presentations. We make recommendations for both document specification and rendering systems.

## 1. Beyond Text

For visually impaired persons access to non-textual information is severely impeded even when specialized computer hardware and software is available. Complex graphical scenarios, as are quite common with graphical user interfaces for instance, while manageable with the visual sense, are confusing at best for the haptic and acoustic senses.

In this paper we report on research into methods by which complex documents can be made available *automatically* to visually impaired computer users *in real time.*

This work started nearly 20 years ago when one of the authors (HJ) had a blind student (R. Arrabito) in his computer science classes on data structures and algorithms and on automata, formal languages and computability. Such courses rely heavily on mathematics and on drawings. For mathematics, several Braille codes are available (see e.g. [40, 7, 19, 18, 26, 55, 58] and, hence, at the time we considered the problem of obtaining Braille-encoded mathematics as fairly easy. For drawings, on the other hand, no standards existed; since then some guidelines have evolved (see e.g. [54, 12, 24]).

As a general scenario, we envisage a working environment in which persons with different abilities (or disabilities) share documents. The access to the documents is mediated by computing technology and various input-output devices. In such an environment it is essential that each participant have immediate access to the current version of the document and, subject to data integrity constraints, be able to modify a document. This, essentially, rules out the transformation, by a human, of the document to accommodate special needs and the rendering of the transformed document in hard copy. Instead, the rendering process has to be automatic and instantaneous. Moreover, changes made to the document need to be incorporated without delay and to be made available to all users in their preferred rendering modes.

With the background of a science teaching and research environment at the university level, in this paper we use the typesetting language TEX as the guiding paradigm. We assume documents to be specified in TEX as the common language. This choice is adequate as TEX is not only used by researchers and instructors, but has also been adopted by several of the major science publishers as the preferred submission format for research papers and books. Moreover, TEX provides, through its macro facilities, graphics capabilities, albeit limited, as needed for publications in the sciences. Most importantly, TEX is programmable and provides a powerful processing kernel which can be used for much more than just typesetting printed documents.

The choice of TEX is not restrictive in the sense that with other document processing systems (like Word, for instance) similar experiments can be conducted and similar conclusions can be drawn, the difference mainly arising from implementation issues rather than matters of principle.

Our first and rather optimistic attempt, about 1985, was to create a TEX-to-Braille translation program incorporating a translation of mathematics according to the Nemeth code. This attempt is documented in [2, 3, 4] with the conclusion that a comprehensive translation is impossible due to the fact that both in TEX and in the Nemeth code the document specification is based on lay-out issues and not on the semantics of the constituents of the document; moreover, the Nemeth code is static, that is, it does not provide an automatic mechanism for incorporating new symbols with new meanings or for overloading existing symbols with additional meanings as would be

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required for an open authoring model (see [13]). What became of this project is summarized in Section 6 below.

At about the same time we also started experimenting with the generation of tactile graphics. In the context of this paper, *graphics* means *diagrams*, mainly as used in science: graphs, circuits, trees, flow charts, structure diagrams, histograms, etc. We also investigated other types of diagrams like floor plans, pictograms and maps to some extent. An important step was achieved in Poh's thesis [41] of 1995, which advocates to focus on the meaning of drawings, disregarding their shapes, and to incorporate their active and passive multimodal exploration. Several experimental implementations were completed since then to test these ideas. The system design concepts resulting from these are described in [31]. Details of some of our experiments are described below.

An extensive survey, as of 1996, on tactile graphics is presented in [30]. On this basis a new survey with more than 700 references, addressing issues in mathematics, graphics, user interfaces, web access, haptics etc. for the blind is in preparation [29].

In this paper, we present a summary of work in our research project. We provide only the occasional reference and comparison to related work. For details of this we refer to the surveys mentioned before ([30, 29]).

This paper is structured as follows: After this introductory chapter, in Section 2, we define what we mean by graphics and we outline the vision guiding our research. In Section 3 we describe the laboratory setup. Multimodal interfaces and exploration techniques are discussed in Section 4. Issues of resolution and diagram size are presented in Section 5. A brief account of our work on mathematical documents is given in Section 6. In Sections 7–10, we consider several types of graphical objects and their multimodal rendering. Some conclusions and guidelines are summarized in Section 11.

## 2. Types of Graphics

In this paper, we consider as graphics images which can be rendered by lines, texture and symbols. This excludes, for example, photographs and paintings. The term *image* means this restricted type of object. Typical examples of images are: maps, floor plans, drawings, technical diagrams, statistical diagrams, mathematical drawings.

For the purposes of this paper, we distinguish images in two ways, as continuous or discrete and as real-time or static. For a more comprehensive classification, see [29].

We distinguish images according to their rendering mode as *continuous* and *discrete*. Typically, images on swell paper or formed plastic material are continuous; uninterrupted lines can be rendered at any angles and with any curvature, the latter subject only to the resolution of the tactile sense. On the other hand, images created by a braille embosser or displayed as raised dots on a tactile display are discrete. Lines are represented by sequences of dots, typically about 2.3 mm apart horizontally and vertically; areas can be represented by dot patterns. For continuous images, many different heights of the features can be used thus using three dimensions, albeit in some limited sense; a discrete image normally uses only two heights, high or low.[3]

We also distinguish between images which are *real-time* and images which are *static*. We consider the rendering of images by computer. A real-time image is always shown in its most up-to-date version and changes to the image are incorporated in its rendered version instantaneously. For text, a Braille output line is a device for real-time rendering; for images, this task can be performed by a dot-matrix display as described below. Static images, on the other hand, can be embossed on paper or rendered on swell paper or formed plastic.

We envisage the usage of images in a document sharing environment – say, a real estate office or a hardware design laboratory. In such an environment, it is essential that images be real-time and that they can be modified by any user involved, with changes immediately available to every other user.

The focus of this paper is on real-time images. The limitations of the present technology force us to consider discrete images – in this case as rendered on a tactile display. For the tactile sense, in addition to the basic information of whether a dot is raised or not, also vibration of dots could be used to some extent.

While we emphasize the issues arising with real-time discrete images we also review related problems concerning static or continuous images; we also briefly discuss the rendering of mathematics, because we believe, that even for that purpose tactile images can be a useful means to present information.

## 3. Experimental Setup

For our experiments we use the following specialized equipment, aside from the necessary computers and software.

(1) A Metec dot-matrix display (see Figure 3.1): This device, of which only a few units exist, has 60 rows with 120 raisable dots each. The distance between dots is that of Braille dots, that is, approximately 2.3 mm both horizontally and vertically. Our unit has two finger-position sensors. There is a way of selecting position-sampling modes to compensate for the inevitable fuzziness of the position information. To communicate with the computer, the user

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[3] The *tiger* embosser is an exception: It provides dots at different raised heights and also different spacings of dots.

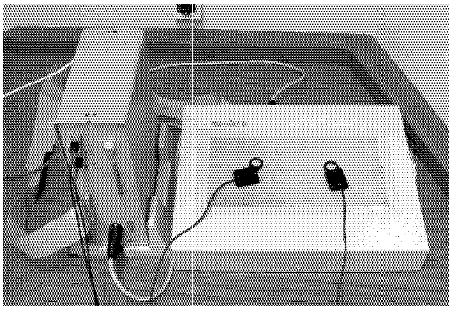

**Figure 3.1.** The METEC tactile display DMD 120060. The picture shows two finger-position sensors on the display area; on the left, one sees the control unit. The display is made by METEC GmbH, Stuttgart, Germany.

will either have to move the hands to a keyboard or will use voice input.

The company offered also a smaller and a larger version of this device with 30 or 120 rows, respectively. To our knowledge, only the 60-row version was ever produced.

In our laboratory, the unit serves as an experimental device, mainly to test issues related to finger-position feed-back, exploration strategies and to experiment with resolution, scrolling and zooming.

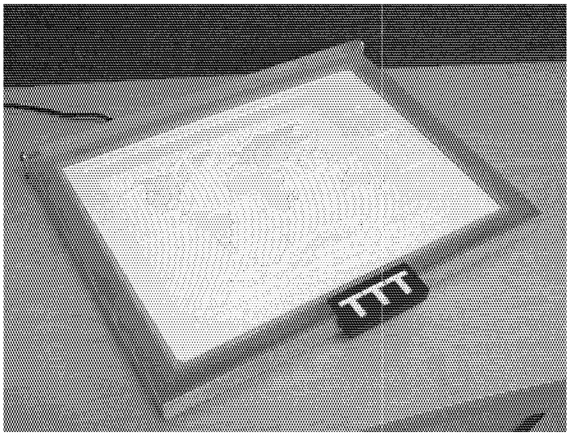

**Figure 3.2.** The Talking Tactile Tablet by Touch Graphics, Inc. [34].

(2) A Talking Tactile Tablet (see Figure 3.2): This tablet senses the positions of fingers, which information can be used for multi-media assistance in exploring a tactile image or for guidance of such an exploration. For this purpose, a tactile image is placed on the tablet. Software prepared with image-specific information is then used during the tactile exploration. It is one of the goals of our project to identify methods by which such information can be generated and linked to the image automatically.

(3) A touch-screen computer (Toshiba M200 Tablet PC): This computer serves for simulation and demonstration. A proposed tactile interface can be simulated and tested by a sighted person before an implementation for the tactile devices is attempted.

(4) Voice and sound input and output: Voice and sound output are used to complement the tactile information, possibly also to guide the exploration of the tactile image. Voice input is used in the preparation of information data and as an interaction medium for blind users, so that they do not have to move their hands off the tactile image.

Other equipment, like a Braille embosser, as well as software for Braille are available to us at the centre for students with disabilities of the University of Western Ontario.

## 4. Multimodal Interfaces for Blind Persons, Exploration Techniques

For a survey of computer-mediated access to information for blind persons see [30, 29]. In this paper we focus on technical or scientific documents and on real-time access methods. We envisage a working environment of persons with different abilities. In such a setting the computer will act as an intermediate to enable communication.

Every user will have a preferred individual working environment. From this point of view, visually impaired users are just a special case. User-centered interface design *should* accommodate any type of users.

Given the present technology, we assume that the blind user will have a tactile display (preferably real-time), finger-position input, voice or sound output and voice input – in addition to standard input-output devices.

To facilitate communication, the rôles of the various modes need to be determined. For sighted users the present quasi-standards for interfaces, forced on users by industry, are hardly acceptable and far too inflexible. Given the opportunity to design interaction modes for blind users, one should not make the same mistakes by proclaiming standards too early. The community of blind users is diverse. Interfaces will need to be tailored to the users. Thus, while guidelines are useful, standards might actually hurt progress.

Our experiments include a combination of tactile and acoustic information, provided interactively. We use the METEC dot-matrix display for real-time graphics and the Talking Tactile Tablet for exploration techniques.

Early experiments with the METEC dot-matrix display concerned access to the *videotext* system [56], multimodal graphics [65] and, using the finger-position sensors, gesture input [63, 62, 64]. We have used this device to experiment with circuit diagrams, automaton diagrams, mathematical graphs and statistical diagrams. The finger-position sensors are used as feed-back to guide the diagram exploration [53].

We also use a Talking Tactile Tablet to investigate exploration techniques. We have experimented with the software of several similar tablets finding that it can be easily 'tricked' into nonsensical output, stammering, useless repetitions etc. To make the software misbehave does not actually require a trick, but just a slightly unsteady hand. The mouse paradigm is not applicable to the exploration of an area using ten fingers. The older METEC display simplifies this issue by providing two identifiable sensors to be carried on two different fingers.

As discussed in [41], the rendering of a tactile image can be *active* or *passive*. In an active system, the user is guided towards features. For instance, while exploring a tree diagram, the user might be told:

> *This node has label A. Please move slightly to the right and down. You will find a branch with two nodes labelled B and C* . . .

Such an interaction mode could be most useful when the user has little experience with the type of diagram. On the other hand, a passive system would only react to the user's hand movements. It might either provide information spontaneously, as determined by the movement of the hands,[4] or supply information on demand.[5]

The active and passive modes are extremes. A user may wish to use a mixture of these techniques and even change the mixture. Our findings re-enforce the point that the choice of the interaction mode must be left to the user.

This sounds like a triviality; it is, however, far from practice in the prevailing current systems for sighted users. Their accessibility packages certainly do not add flexibility.

Multi-modality and exploration should not be an afterthought – they should be essential constituents of document design. As a professional typesetter designs books for beauty and readability, as an author writes novels to thrill the readers – documents need to be specified with their presentation to a varied usership in mind. We propose some simple guidelines: information contents of a document is important; appearance can vary; documents may be used in unforeseen ways. This suggests a layered document specification method in which information is clearly separated from rendering (see e.g. [14, 13] for mathematical documents). The system design as proposed in [41] can serve as a first approximation.

## 5. Resolution and Size Limitations

One of the most serious problems arises from the low resolution of the tactile sense. The precise limit is not that important. The resolution is too low to put any realistically complicated image as tactile graphics into a reasonable area. For circuit diagrams, flow charts, transition graphs, automaton diagrams, spread sheets etc. only toy examples can be represented completely. For continuous media this problem is severe, for discrete media this problem seems unsurmountable.

The literature concerned with discrete tactile graphics tends to side-step this problem. Some attempts in our project (see e.g. [1, 17, 23, 37, 38, 41, 42]) suggested various modes of scrolling. Scrolling is, however, rather confusing. Similarly, using different levels of detail and some kind of zooming, has turned out to be far less helpful than expected. Our present line of thought is to use tactile graphics for providing global information only and to use acoustic cues for the details, possibly combined with an active or passive exploration system.

For tables, an ingenious solution was proposed by Raman [49]: To use stereo sound and different speaker identities to read the table by rows. Obviously, this method is limited to a single way of working with a table. The typical usage of a table is quite different from this organized approach. Thus, even for such simple objects as tables [5], there is a need for thorough investigation.

Difficult test cases, which we want to try next, include large circuit diagrams and spread sheets.

## 6. Mathematics: TEX to Nemeth and Other Codes

The conclusion of [3] was that a *complete* TEX-to-Braille translation including all macro features was impossible. On the other hand, Raman's work [47, 49] demonstrated that a limited translation would be feasible. Raman's system translated LATEX files into voice output, assuming *standard* LATEX without user-defined macros as input. With Braille output substituted for the voice output, this would provide a feasible LATEX-to-Braille translation path. This approach, however, ignores the inherent extensibility of TEX or LATEX and the context-dependence of the semantics of mathematical notation.

In subsequent studies, we attempted various parts of a complete TEX-to-Braille translation including mathemat-

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[4] As mentioned, such systems have a serious synchronization problem. The ones we have seen could be made to behave erratically with a few rather innocent movements of the hands.

[5] At this point, no system seems to exist which provides this feature with ease. If a new tactile display were designed, it should incorporate this type of feed-back, equivalent to a mouse click, in addition to finger-position information. Moreover, it should provide a means for distinguishing fingers.

ics.[6] The approach taken is as follows: The macro package of plain TeX is rewritten so as to eliminate nearly all usage of concrete measurements; all remaining dimensions are expressed in terms of small values of TeX's basic unit, the `sp`[7] [21, 25]. The Braille rendering program (dvi driver) will then equate 1 `sp` to the distance between Braille dots. Thus, two pixels spaced 1 `sp` apart will be rendered as two Braille dots.[8] A special Braille font created with Metafont contains Braille characters and the relevant dimension information; thus, for TeX, a 6-dot Braille character occupies a rectangle of $3 \times 2$ `sp` [21]. Special macros redefine TeX's manipulation of mathematics.

We expect to have a functioning TeX-to-Braille translation system by the end of 2005. The translation process works as follows: TeX is started on the input document with the *Braille macros* instead of the *plain macros.* The resulting `dvi` file is translated by the Braille driver to create output for screen preview or a Braille device. An extension to LaTeX or any other TeX variant would only require that the corresponding macros be modified.

The advantage of this approach, compared to Raman's, is that TeX itself is used for processing the document. Therefore, user-defined constructs do not constitute an obstacle in principle. The fundamental limitations identified in [3] are not lifted, of course. A greater obstacle than these, however, are bad mark-up habits of authors and bad style descriptions of publishers.

Non-tactile presentation of mathematics has been under consideration for quite some time. This ranges from voice-only rendering as in Raman's system [47, 49] to multimodal presentation (see e.g. [57]) and even to general sound (see e.g. [52, 44]). For a survey on mathematics rendering systems see [32].

A new proposal for rendering mathematics using both, a tactile display and voice output, and for guided exploration of mathematical formulæ is presented in [43]. The output is distributed to the modes roughly as follows: structural information of a formula is rendered on the tactile display as a tree-like diagram using a representation technique similar to the one explained further below. The details of the formula – e.g. the actual symbols – are provided by voice output. The voice output is "synchronized" with the movement of the reading fingers.

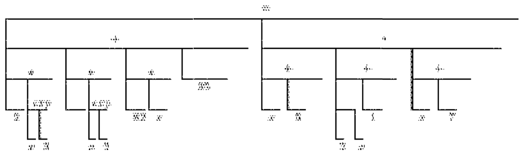

**Figure 6.1.** The formula $(x+5)(2x+1)(x+7)$ displayed according to [43]. Only the lines would show on the tactile display; the symbols belong to the spoken output.

This proposal is consistent with our general strategy for assigning rôles to media. The tactile image provides global structural information; the details are supplied by other means. A general methodology for implementing this type of mathematics system is described in [14, 13]. In Figure 6.1 a formula is displayed in a form which imitates the tactile display.

## 7. Graphs, Automata, Circuits, Trees

Diagrams for automata, circuits, data structures – mathematical graphs – are one of the main test examples. We have tried various representation methods [1, 17, 23, 36, 37, 38, 41, 42]. The outcome of this work can be summarized in two statements:

- The visual shape of the tactile diagram is not important at all; it is much more important that it be easy to explore.
- Active or passive guidance needs to be provided for the exploration of such diagrams.

It should be emphasized, that our system is intended to generate the rendering information *automatically* from the document specification and that, to maintain document integrity, we do not rely on specifics for tactile documents.

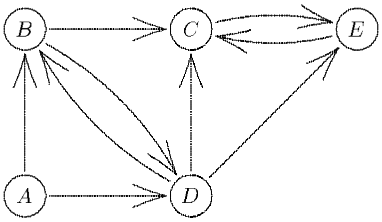

**Figure 7.1.** A directed graph [20].

For graph-like structures, as in Figure 7.1, Poh [41] proposed to use a tactile representation as shown in Figure 7.2. Nodes are represented by squares of raised dots; directed edges are straight lines originating at a node and ending above or below a node. With two-handed exploration, one hand can record the position on the margin

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[6] For mathematics, the target is the Nemeth code [40]. Once this has been achieved, it would be easy to replace the Nemeth module by a module for a different mathematics code.

[7] In normal usage of TeX, 1 `sp` is 1/65536 `pt`, where 1 `in` (inch) is approximately 2.54 `cm` or 72.27 `pt`. Thus, dots of size 1 `sp` are practically invisible.

[8] Using a screen driver, we can also simulate the Braille display.

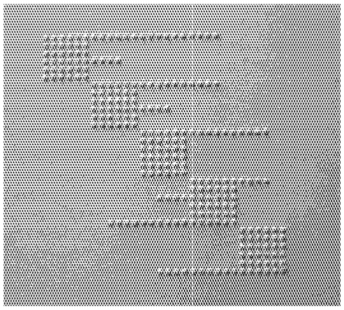

**Figure 7.2.** The squares, read diagonally from left to right, represent the nodes $A$ through $E$ of the graph. The horizontal lines represent the edges. It is assumed that the tactile diagram is explored with two hands. Spoken information is supplied as the hands move [20].

of the display (a line not shown in the figure) while the other hand follows the lines and the acoustic guidance.

To apply this type of representation to other kinds of diagrams, one may have to change the rendering of the nodes.

While the problem seems to have been solved in principle, one major practical issue remains. We need a path from the usual representation of such diagrams to the representation required by this work. An attempt on these lines was made in [37, 38] where a translation of VHDL specifications of hardware diagrams into multimodal rendering was implemented. A slightly more general approach was taken in [42]. The need is easily formulated:

- We need a specification language for graphs (in the sense of graph theory) such that both the translation from specific languages (like VHDL) and the translation into multimodal renderings are easy.

Guidance for how to design such a language can be found in [37, 38, 42, 30].

## 8. Statistical Diagrams

Statistical diagrams can take many shapes. A summary of display techniques is available in [59] including aesthetical and psychological evaluations of these. For tactile displays nearly all such techniques are useless. The focus has to be on conveying the essential information.

With this restriction, the diagram will present quantitative information only, both in terms of absolute numbers and in terms of relative numbers. A division of the rôles for the rendering media seems nearly obvious: absolute numbers and explanations are given to the voice output; comparative information is presented as a tactile diagram. Moreover, on a tactile dot-matrix display or an embossed page, only rectangular shapes are easily understood. This rules out pie charts, for instance. One is left, essentially, only with histograms – and even those can be too complicated.

The framework for statistical diagrams should therefore be as follows: the input document is a statistical diagram providing all relevant data; for a sighted person this document may include generic rendering information. For the blind reader the rendering information is completely ignored. The actual statistical data are used to create the multi-modal output *automatically.*

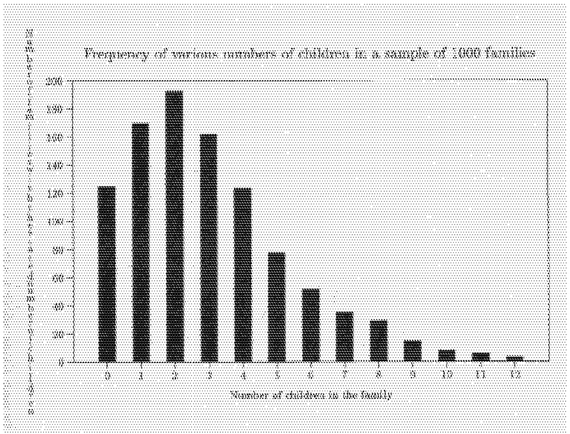

**Figure 8.1.** Histogram as printed for a sighted person [39].

```
\input visicht
%\input audicht
%\input tactcht
\setparameter {} to {} endtext
\charttitle Frequency of various numbers
of children in a sample of 1000
families endtext
\abstitle Number of children in the family
endtext
\ordtitle Number of families with the
stated number of children unit {} endtext
\data labels 0,1,2,3,4,5,6,7,8,9,10,11,12
values 125,170,193,162,124,
78,52,35,29,15,8,6,3
enddata
%\saychart
```

**Figure 8.2.** Input for histogram from [39].

A prototype of such a system was designed and implemented in [39].[9] An example of a histogram is shown in Figure 8.1. The input file is displayed in Figure 8.2. When processed by TEX with the `visicht` macros for visual output, a file is generated which will print as shown in Figure 8.1. In the input file several lines have been

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[9] In [9] a predecessor of this system is documented.

commented out which would afford the switch between the macros for various output modes. With the `audicht` macros activated, the system of [39] would generate approximately the following voice output *automatically* from the input file:

> *This is a summary of the chart entitled: Frequency of various numbers of children in a sample of 1000 families. The horizontal axis represents: Number of families with the stated number of children. The vertical axis represents: Number of children in the family. The table of values is . . .*

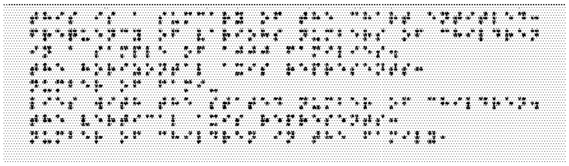

**Figure 8.3.** First page of tactile output for the histogram of Figure 8.1 from [39].

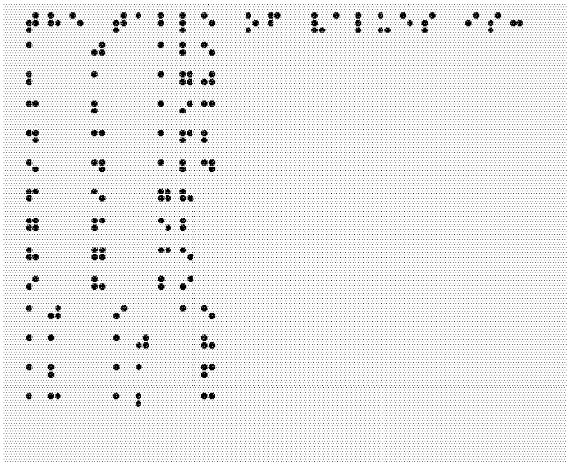

**Figure 8.4.** Second page of tactile output for the histogram of Figure 8.1 from [39].

As tactile output, using the `tactcht` macros, three pages are generated as shown in Figure 8.3, Figure 8.4 and Figure 8.5. In the tactile representation, to reduce potential confusion, the bars of the histogram are not separated; this simplifies the comparison of the heights of the columns. A vertical line in the middle of each column identifies the column and guides the fingers to the axis and corresponding labels.

The main findings of this work can be summarized as follows:

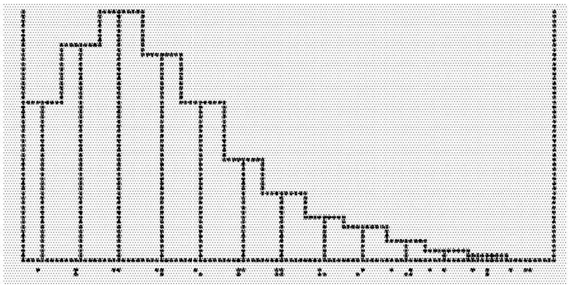

**Figure 8.5.** Third page of tactile output for the histogram of Figure 8.1 from [39].

- The tactile graphics must be simplified to the extreme; a resemblance to the visual presentation may be less important than a clear and simple expression of meaning.
- The comparison information is represented in the tactile diagram; the explanations and actual numbers are handled by voice output.
- Continuous guidance must be provided for the fingers. Much detail is just confusing.
- A method (language) for specifying statistical information is required which clearly identifies the statistical data and separates the rendering issues from the actual information.

In [39] a language fragment – as shown inFigure 8.2 – using TEX and, in addition, the TEX macros was designed by which these goals were achieved for the purpose of experiments, that is, as a proof of principle.

## 9. Pictograms, Metaphors

To break language barriers, pictograms (or icons) appeal to a common cultural background. They are, essentially, metaphors conveying a meaning by analogy. That there is a common cultural background, is important for the pictograms to be understood. The symbol used to represent a file folder in the Windows systems has no meaning on its own in Europe. Such file folders are simply not used there. For a blind person, depending on the experience before becoming blind, pictographs may have little meaning or none at all. Hence, why would one even bother to attempt representing computer icons as graphics? A blind person may have to talk about these things with a sighted person – but why else? Hence, there is no compelling reason why pictograms or icons need to be made available as graphical objects with any resemblance to the visual objects. The obvious solution is to look for communications modes which best convey the intended information to the specific individual, regardless of what is used for sighted persons.

## 10. Maps, Plans

Maps, floor plans and similar kinds of drawings do not usually change frequently. Thus, one can relax the requirement of real-time graphics and thus employ more permanent tactile media like swell paper or formed plastic. This also implies that continuous lines can be used, increasing the variety of recognizable and distinguishable shapes. Many systems exist – mostly still at some stage of prototyping – which combine such tactile diagrams with various input-output modes, like voice or sound output and guided exploration. We briefly review two examples showing that our proposals for discrete real-time tactile graphics apply also to the seemingly less complicated case of maps and floor plans. We keep this discussion brief, as it does not concern the main issues of this paper.

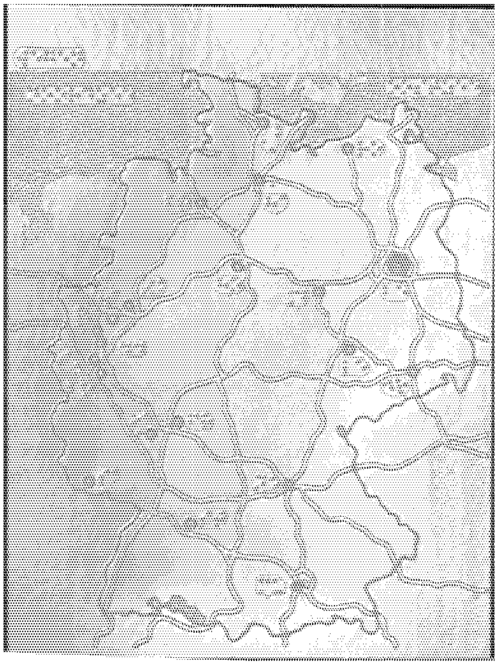

**Figure 10.1.** Map of Germany: formed plastic material (source unknown).

Figure 10.1 shows a tactile map of Germany.[10] It combines Braille and several features of tactile graphics: (1) texture is used for the North Sea and the Baltic Sea; (2) neighbour countries are rendered at a lower level; (3) major cities are indicated by big round hills with Berlin being represented by a special one; for no apparent reason the hills for Munich and Hamburg are also different;[11] (4) city names are indicated by two-symbol labels in Braille; (5) major roads, *Autobahnen,* are represented by raised lines about 2 mm wide; (6) Lake Constance, *Bodensee,* is rendered as a kind of staircase.

This map is confusing and misleading – not just for the blind reader – for several reasons: (a) small Dutch and Danish islands are shown while German islands are not shown at all or, as in the case of the islands of *Fehmarn* and *Rügen,* shown as being part of the main land; (b) there is no apparent reason for the selection of cities and roads shown; in particular, sometimes useless detail is shown like the small triangle between Munich and Stuttgart or the partial double ring around Berlin, where one of them in reality passes right through the city; (c) close to cities the roads seem to be interrupted; this is most notable in the case of Magdeburg and in the Cologne area; (d) the Braille labels are neither horizontal not vertical, but printed at various angles depending on the space available; (e) the areas containing the Braille labels is raised slightly, but cut off where characters do not use all dots; (f) the abbreviations in the labels are non-standard; for instance, BE is used for Berlin, ES for Essen, MB for Magdeburg, NE for Nuremberg *(Nürnberg)*, MU for Munich *(München);* these abbreviations are not even systematic;[12] (g) if the purpose of the map is to show the network of major roads in Germany, far too much detail is provided both regarding the country's borders and shorelines and the bends and intersections of roads; (h) there does not seem to be an indicator for map orientation.

A significantly simplified map would serve the same purpose. If the map were presented in a multi-media environment acoustic information could be provided (replacing, in particular the Braille labels), possibly coupled with feed-back through finger-position sensors.

In Figure 10.2, a map of Canada is shown.[13] It also combines Braille and several features of tactile graphics: (1) wavy lines are used as texture to indicate water areas (lakes and oceans); (2) Canadian lands are surrounded by heavy raised solid lines (problematic with islands); (3) Other countries – USA and Greenland – are indicated by heavy raised dashed lines; (4) Canadian provinces are separated by less heavy raised solid lines; (5) country names are provided in Braille; (6) provinces and the state of Alaska are labelled by their standard abbreviations

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[10] Unfortunately, we do not know the source of this map, which was obtained from an exhibitor at the Second International Conference on Tactile Diagrams, Maps and Pictures held in Hatfield, UK, 2002.

[11] This could be a manufacturing defect.

[12] One would have expected to see the abbreviations used for vehicle licenses, that is, B for Berlin, E for Essen, MD for Magdeburg, N for Nuremberg, M for Munich.

[13] Designed by Mapping Services Branch, Natural Resources Canada; printed by Tactile Vision, Inc.

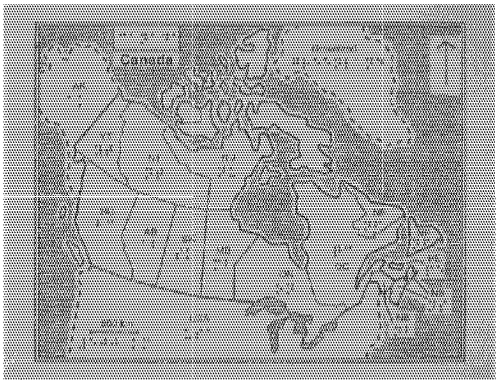

Figure 10.2. Map of Canada.

in Braille; (7) guiding lines connect labels with their features, when the latter are too small as is the case for PE, NS and NB; (8) an arrow indicates the orientation of the map; (9) the scale is indicated by a raised line with end markers and an explanatory label in Braille; (10) all Braille labels have the same orientation; (11) the map has a definite two-line frame.

This map is far less confusing than the one shown in Figure 10.1. Some further simplification could probably make it even easier to use without any loss of essential information: (a) the contours of borders and shore-lines could be straightened even further; this applies, for instance, to the border between the Yukon and the North-West Territories, the shapes of the Great Lakes, the shapes of islands; (b) there should be a better separation between the mainland and island parts of Nova Scotia; (c) the provincial borders on two of the northern islands are a bit confusing; (d) some smaller northern islands could have been omitted; (e) the US border leading into Lake Ontario can be confused with a river; (f) the cut-off in the west of Alaska and the north of Greenland is a bit confusing; (g) occasionally the wavy lines interfere with the dashed boundaries of Greenland and Alaska.

However, despite these issues, the Canada map, by focussing on essentials, conveys the intended information clearly enough.

Tactile maps, tactile floor plans and so on serve many different purposes including those of reading, reference and planning material and of orientation guides. In the former cases, as their usage would be stationary, they could be combined with a multi-media information system, like the tactile tablet described above. In the latter case, they might be carried around and must, therefore, provide the relevant information through mobile (light) equipment and possibly connections to relay stations.

*Challenge:* In principle it should be possible to create portable maps with intelligent interaction built-in. Ignoring the weight of the power supply, the additional weight for the electronics could probably be kept at less than 100 g.

There are some lessons to be learnt which are equally relevant for any kind of tactile graphics, with or without multi-modal assistance:

- One needs to focus on the relevant information; everything else, interesting as it may be, needs to be simplified to the extreme.
- Orientation and coherence need to be provided.
- Labels must be consistent, appear at predictable spots, and be uniformly oriented.
- Object separation may have to be exaggerated.

In summary, even when shape carries information, it is important to simplify shapes to make perception and forming a mental image easier. The limitations of resolution and overall size are less severe for continuous tactile graphics than for discrete tactile graphics. However, more detail put into the same area does not necessarily provide more information.

## 11. Conclusions, Guidelines

It is an elementary requirement of a human-machine interface that it be easily tailored to the specific needs of the individual user. This applies to any kind of user, not just users with disabilities. Conceptual background and experience, in addition to perception capabilities determine to a large extent, which way of rendering a document is most adequate. To illustrate this point: the pictogram used to indicate a file folder in the Windows interface is quite meaningful to a North American user; to a German user it is puzzling, because folders look quite differently there.

A blind person who has seen and been working with mathematics and circuit diagrams before turning blind may prefer to find known shapes rather than encodings, whereas someone lacking this experience may actually find it easier to work with abstract encodings and simplified abstract shapes. Thus, it does not seem adequate to force a specific type of rendering on the users if there is a choice of methods to convey the same information. If the relevant information is *readily* available in the document specification, the necessary translation and rendering can be provided easily. This leads to the first general guideline:

- Objects in a document must be specified by their meaning. The rendered appearance of the objects and the document is afforded by an interpretation (a filter) of the specification according to the user's needs.

In essence, this statement extends the principle of semantic markup-up to objects like formulæ, drawings, general graphics and even multi-media objects in a document.

The OpenMath or MathML concepts can serve to illustrate this guideline albeit in a rather limited sense.

The variation of rendering extends to the choice of modalities and, possibly, their interaction. A low-vision person may prefer to be presented with only a sketch of a drawing with voice-output providing the details; a deaf-blind person may have to rely completely on the tactile representation. Different strategies and capabilities for memorizing and organizing perceptions can influence the choice of presentation. This leads to a second requirement:

- The document specification must not prejudice the choice of rendering mode, but enable an automatic translation into various modalities and even combinations thereof.

Again, this is possible if enough content information is present in the document specification. We have shown above how this can be achieved for mathematics or simple diagrams.

As the experience and background of users differ, a graphical representation which makes sense for one person may be meaningless for the next one:

- By the rendering of objects, it is their meaning which must be conveyed, not necessarily their shape.

Thus, rendering a pictogram as such for a blind person may not be particularly useful. Similarly, horizontal lines put into a tactile histogram – as discussed in [10] may be more confusing than helpful if the same information can be conveyed by voice output.

Blind persons explore tactile graphics in various ways (see e.g. [8, 60]):

- Exploration strategies, both active and passive, need to be investigated systematically. A study should also identify the means by which a blind person determines a *global* mental image when exploring tactile graphics.
- For real-time interactive tactile displays, an input mode must be provided which does not require the user to move the position of the hands.
- For dot-matrix displays or embossed paper, a systematic study of which shapes can be recognized and which separation between objects is needed, given the low resolution, should be conducted.

A document designed for a specific set of rendering processes may become unusable when technology changes. For example, nobody thought of using the mathematics in a printed book as input to a computer algebra program twenty years ago. Being able to do so has turned out to be quite useful. For mathematics encoded as such (as in TEX) and not just as symbols to be printed it is quite easy to write the required translation program. This leads to our final guideline (see also [14, 13]):

- The document specification must be open to applications not envisaged at the time when the document is prepared.

In summary, rather than suggesting *specific* recommendations for how to render tactile graphics and how to use multi-modal interfaces we advocate an open system design in which the document is specified without any regard to rendering and where the rendering itself is achieved using appropriate filters. In particular, the document specification method must allow for the introduction of new object types, a method by which to attach meaning to objects and a framework for the construction of rendering filters (see [31]).

Finally, in designing interfaces for persons with special needs we should not attempt to imitate ‘normal’ interfaces. There is no reason to assume that information rendered by graphics for a sighted person should also be rendered as graphics for a blind person. While how to provide tactile graphics continues to be an extremely difficult issue, one should not forget to ask when tactile graphics makes sense. To put this pragmatically: Not the presentation but the use of information is the issue.

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# Braille, Innovations, and Over-Specified Standards

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## ABSTRACT

The new Tiger embossing technology, developed in the author's research group, produces more readable braille than conventional embossers. The better readability traces to a smaller diameter embossed dot than that made by conventional technology. Some sighted braille experts initially levelled criticism at the new technology on the grounds that this dot diameter is smaller than what is required by a published "standard". The criticism has died away in the face of strong acceptance by blind people, but it stands as an example of the danger of over-specifying standards.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*standardization*

## Keywords

Braille, guidelines, standards, tactile

## 1. INTRODUCTION

Well-founded standards can be a boon in many ways. They can assure that technologies are compatible, thus assisting further developments that do not need to continue to solve the same problems over and over. Standards can promote better communication, better data access, and in general a better life for human beings. However there is a human tendency to over-specify details that can be harmful by suppressing innovation. This paper describes one such real-life instance of an over-specified standard.

Braille characters consist of six tactile dots arranged in two columns and three rows. This is a universally-recognized standard. The dot patterns assigned to the 26 lower case letters a-z by Louis Braille in the early nineteenth century are also universally accepted. Little else about braille is universal. Braille contractions and shorthand used in one language have little resemblance to those used in other languages. Codes for math and science also differ radically among languages, and there are often several codes in use within one country. Since losing his sight in 1988 this author has led an information accessibility research team whose goals have included development of alternatives and extensions to braille that may eventually reduce the mystery and confusion that prevent many people from learning and using braille. The focus of this paper is on tactile aspects of the research that have resulted in a new technology for producing tactile materials. This new technology produces braille cells that are substantially different in some aspects from the "standards" but that are found by users to be as readable, and often much more readable, than braille made by more conventional technologies.

## 2. BRAILLE CELL DIMENSIONS

The spacing of dots within a cell, the inter-cell and inter-line spacing, and the size of dots defined as "standard" for various countries are summarized by [1] and differ substantially from country to country. Generally there are standards for "normal" braille, micro-braille, and jumbo braille. Micro-braille is used extensively in Japan, and jumbo braille is made for people with reduced tactile sensitivity.

"Normal" braille standards define the dot spacing within a braille cell to be between 2.3 and 2.5 mm, the cell to cell spacing to be 6.0 to 6.2 mm, and the dot height to be 0.25 to 0.53 mm. Micro-braille differs mostly in having inter-cell dot spacing of 2.0 to 2.1 mm, and jumbo braille generally has dot spacings of order 25% larger than standard braille. Nearly all braille materials produced in western countries are the "normal" size. Few braille readers can distinguish the subtle differences in dot size/spacing of the various forms of normal braille,

The author's observation is that although most braille readers find normal braille comfortable, a substantial fraction of blind people find normal braille difficult to read. People with diabetes and many elderly people have reduced fingertip sensitivity and consequently have more difficulty learning braille than others. These people can read jumbo braille more easily, but jumbo braille is seldom encountered except in very special circumstances. Westerners find micro-braille difficult to read. Some Japanese authorities hold the private opinion that microbraille is too small for many Japanese readers and that it is only Japanese tradition that continues to support its use. Although micro-braille is still dominant, much braille material in Japan is now being made in normal braille size.

## 3. TIGER BRAILLE

In 1996, Mr. Peter Langner, an MS student in the author's Science Access Project, developed a novel method for embossing dots on paper and other media. Mr. Langner was searching for a way to emboss dots at 20 dots per inch resolution. 20 dpi is a "magic" resolution that would produce much higher resolution tactile graphics than had been possible before and that could emboss braille with inter-cell dot spacing of 2.54 mm and inter-cell spacing of 6.25 mm, values that qualify as normal braille. He and the author thought that the braille quality was excellent, an observation confirmed quickly by several blind scientists who were good braille readers. Mr. Langner received the Collegiate Invention of the Year award [2] in 1996 for this new technology that was dubbed Tiger (TactIle Graphics EmbosseR). The technology was patented by Oregon State University [3], licensed to the spin-off company ViewPlus Technologies (`http://www.ViewPlus.com`), and the first Tiger embossers were developed and shipped in 2000.

The quality of the braille turned out to be even better than initially believed. People with reduced tactile sensitivity found it far more readable than normal braille, even than jumbo braille. The author's hypothesis is that Tiger braille is more readable because the dots have a smaller diameter than made by most braille embossers, so the dots feel better resolved, even though their dot to dot spacing is the same as normal braille.

The Tiger technology was found to have additional advantages over other embossing technologies. It was possible to make controllable variable height dots, permitting excellent tactile graphics to be printed from almost any figure. The default graphics mode is to print black areas with tall dots and light areas with progressively smaller dots. Interpoint braille (braille printed on both sides of the page) made with Tiger technology is not as rough-feeling as normal interpoint, since the "dimples" are significantly smaller.

The Tiger developers were surprised when their new better technology was roundly criticized by many sighted braille transcribers, special educators, and other braille "experts". These experts had grown accustomed to the visual appearance of standard braille and described Tiger dots as "ugly". Many initially refused to approve the purchase of Tiger embossers for their students. This attitude has largely disappeared in the United States and other countries where ViewPlus has established a strong user base but is still encountered in new markets. A number of those who opposed the new embossing technology based their criticism on the failure of Tiger embossers to meet one minor "standard" for braille. In addition to the dot spacing and height parameters, the standards also specify a dot base diameter, generally in the range 1.2 to 1.5 mm. Dot base diameters of Tiger dots are smaller than this value. Braille readers touch the tops of braille dots, not their base, so this standard value is rather meaningless, but it was obviously of importance to some critics. In the end, the only tactually-perceivable difference between Tiger dots and conventional braille is that the Tiger dots have stronger curvature of the top. The curvature itself is not really perceivable tactually, but the finger can perceive that Tiger dots have more space around the dots. It is the extra space that makes Tiger dots easier for people with poor tactual sensitivity to perceive. The extra space has apparently not been any kind of hindrance to good braille readers [4, 5], and the author does not understand why the new technology created such controversy initially. This should be taken as a warning that standards need to be devised carefully and should not be over-specified. If the research director had not been a confident blind person and had consulted sighted braille experts initially instead of blind braille readers, he might have elected to abandon the Tiger concept. The world would be the poorer for it.

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# Conference System using Finger Braille

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## ABSTRACT

In this paper, we propose a conference system using text and finger braille. Finger braille is one of the communication methods for deaf-blind people. Since some of them have serious impairments of the visual and auditory senses, they communicate with others using tactile sensation. We have analyzed the features of finger braille. The functions required for the system were examined and implemented in the conference system. The validity of the functions was ascertained by an evaluation experiment. As a result, the number of utterances of a deaf-blind person was almost the same as that of a sighted-hearing person. The result of a simulated conference confirmed the validity of the proposed system.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O.*

## General Terms

Language

## Keywords

Finger braille, deaf-blind, conference system, haptic input/output device.

## 1. INTRODUCTION

People who are both deaf and blind are called “deaf-blind”. They suffer much inconvenience in their everyday lives due to the social handicap. In particular, the deaf-blind with serious impairments are not able to obtain sufficient information necessary for living, something which a hearing and sighted person can do easily. To obtain information for living, they use tactile sensation instead of auditory and visual sensation.

Finger braille is a communication means using tactile sensation. Some deaf-blind people are able to communicate with sighted-hearing people through finger braille interpreters. However, many issues remained to be solved before deaf-blind people can come autonomous and enjoy conversations with others without interpreters.

We focused on a conference system using finger braille as an interactive communication method for deaf-blind people. Using a conference system, deaf-blind people are able to speak with both deaf-blind and sighted-hearing people directly without finger braille interpreters. Moreover, it gives deaf-blind people a chance to converse with others in a group.

Since finger braille is coded similar to Braille, it is easy to apply to digital information devices and equipment. Equipment for finger braille has been proposed [3]. However, there has been no conference system by which deaf-blind and sighted-hearing people can converse. We designed a conference system in which participants use finger braille or text characters. In the system, problems may arise due to language processing through different communication media: text and finger braille. In designing the system, the difference must be taken into account.

In this paper, we describe the features of finger braille, comparing text and speech, in section 2, the design of the conference system in section 3 and the evaluation of the conference system in section 4, and present discussion in section 5, and finally the conclusions and future work in section 6.

## 2. OVERVIEW OF FINGER BRAILLE

### 2.1 Communication Methods of Deaf-Blind

Typical communication methods for the deaf-blind are (1) print-on-palm (tracing letters on the palm of the deaf-blind), (2) tactile sign language and finger alphabet, (3) “Bulista”, which prints out braille on tape, and (4) finger braille using a Braille code. In finger braille, the fingers of the deaf-blind are regarded as the keys of a brailler. A person types the Braille code on the fingers of the deaf-blind (Figure 1). Of these methods, finger braille using a Braille code seems appropriate for real-time communication [2].

**Figure 1: Typing finger braille**

## 2.2 Characteristics of Finger Braille

We considered the characteristics of finger braille by comparing speech and text communication.

### 2.2.1 *Coded System*

A braille code consists of combinations of six dots. The Japanese braille code system consists of 46 codes which express kana characters (voiceless syllable), and some special codes. It is much easier to process this code using digital devices than print-on-palm or tactile sign language and finger alphabet.

### 2.2.2 *Transmitted Speed*

A skilled deaf-blind person is able to receive about 350 characters per minute from a finger braille translator. Compared with oral transmission of 350-400 letters per minute, finger braille is adequate for real-time communication.

### 2.2.3 *One-Dimensional Media*

Sensations receive two types of information: information that spreads in two- or three-dimensional space, and one-dimensional information that changes with time. Tactile sensation receives one-dimensional information as dose auditory sensation.

The information transmitted by finger braille is one-dimensional compared with text which has a spatial spread. [1]. For example, in the case of information expressed in a tabular form, in speech, it is necessary to explain the position of text in the table and to provide information in addition to the text information.

### 2.2.4 *Passive Media*

Because tactile media expand in time series, a person receives information chronologically. Therefore, deaf-blind people must receive information passively while the information is displayed, whereas sighted-hearing receive visual information actively. Auditory information is also passive.

### 2.2.5 *Volatility*

Finger braille is a volatile medium like speech [1]. In the case of speech, since speech disappears simultaneously with an utterance, the listener is required to memorize the contents of the utterance, and must ask for verification. Similarly, in the case of finger braille, only at the moment an interpreter's finger is touching a deaf-blind's hand will the information be apparent, and it will disappear the moment the fingers are withdrawn.

# 3. SYSTEM DESIGN

## 3.1 Problems

To design a conference system wherein deaf-blind people are able to participate, we focused on the characteristics of finger braille described in the previous section: “one-dimensional medium”, “passive medium” and “volatility”. We noted the difference in the characteristics of each medium. It may cause the problems which cause a deaf-blind person to miss the opportunity to make utterances and to fall behind in the conversation. In order to establish smooth communication between deaf-blind and sighted-hearing people, we examined each problem, as below.

### 3.1.1 *Slow Receiving Rate*

As we described above, finger braille provides one-dimensional information. If the utterances are shown at the same time in text and finger braille, text characters are displayed much earlier than finger braille. Furthermore, a sighted-hearing person might make an utterance before the deaf-blind person finishes reading. Therefore, sufficient time to understand the utterances of others and to prepare for his/her own utterance is not secured for the deaf-blind person. Thus a deaf-blind person’s opportunity to speak may become less than that of sighted-hearing people. In order that all participants may follow the flow of a conference, it is necessary to align the timing to enable understanding.

### 3.1.2 *Alternating Input and Output*

In finger braille, both transmitting and receiving information use haptic sensation. Thus, a deaf-blind person is not able to perform input and output operations on the system simultaneously. Deaf-blind people must switch the mode from input to output and *vice versa*. Therefore, it takes more time for the deaf-blind person to make an utterance. Utterance opportunity for the deaf-blind should be secured.

### 3.1.3 *Disappearance of Past Information*

Since the information received in finger braille is volatile, the same as in speech, information can be easily lost. Optimizing the presentation speed of utterances will reduce a deaf-blind person's psychological stress related to receiving information.

When it is difficult for a deaf-blind person to read text, they must depend only on the information obtained by finger braille, therefore, a support function for receiving and memorizing the contents is expected.

## 3.2 Solutions

Here, we propose the functions of the conference system, based on the discussion on the previous subsections.

### 3.2.1 *Selection of Speaker*

To provide an opportunity for all participants to speak, the concept of “the speaker” is considered. “The speaker” is the participant who holds a right to speak. Only one participant is able to speak during a conference. In order to realize the idea, the system assigns the right to speak. When a participant wishes to speak, he/she requests his/her turn beforehand and wait until “the speaker” is assigned. “The speaker” right is granted to only one person at a time, and it is held until the person yields it.

In order to give participants an equal opportunity to speak, a different order level of “speaker’s priority” is defined for every participant. A person who has spoken only slightly is given a high priority. When two or more participants request “the speaker” right simultaneously, the participant with the highest priority is given the opportunity to speak.

Moreover, the system has the function that the speaker is presented with the list of names of participants that have made requests to speak so far. Thereby, the speaker can comprehend the condition of other participants.

### 3.2.2 *Aligning Receiving Rate*

In order that all participants can follow the flow of a conference, it is necessary to align the timing of understanding. To unify the timing of understanding, the system has two functions. One is the function for aligning the time of the end of an utterance in finger braille with the text. That is, the complete text sentence and the last character of finger braille are displayed at the same time.

Another function is to align the receiving rates of finger braille among deaf-blind people. The receiving rate of finger braille for deaf-blind people is set to the slowest receiver's rate.

### *3.2.3 History of Utterance*

Because of the one-dimensional characteristic and volatility of finger braille, the deaf-blind participant is not able to check his/her previous utterance. To check the previous utterance, the system has the function to show past utterances. Deaf-blind participants are able to request the presentation of past utterances anytime using the function. Therefore, participants are able to gain a better understanding of the whole conference.

## 3.3 Implementation

The system consists of a server and clients. The client for the deaf-blind participants is connected to the input/output device for finger braille called "Ubitzky" (Figure 2) [4]. The client for sighted-hearing participants is connected to a keyboard and display. We developed a prototype system which was implemented with the functions proposed in the previous section.

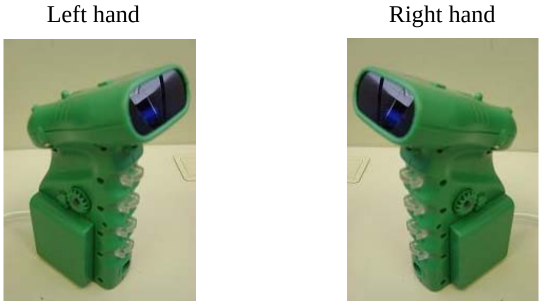
Left hand
Right hand

**Figure 2: "Ubitzky" (Input/output devices for finger braille)**

## 3.4 Preliminary Experiment

In order to check the functions of the system, a conversation experiment was conducted by four sighted-hearing subjects. Two subjects used a display and keyboard. The other two subjects pretended to be deaf-blind subjects. Since they were not skilled in finger braille, they used a display and keyboard. To reproduce features of finger braille, such as the volatility and one-dimensional characteristic, only one character which corresponded to a braille code was displayed at a time for the dummy deaf-blind subjects. After being displayed for a while, the character disappeared.

The subjects were given 20 minutes to discuss a given subject. The contents of each utterance were recorded during the experiment, and comments on the use of the conference system were recorded.

From the results of the preliminary experiment, we obtained the following conclusion and points for improvement. A dummy deaf-blind subject became anxious because there was no feedback to what he had transmitted. Because simultaneous transmission and reception are difficult with finger braille, the contents of the utterance cannot be checked by a deaf-blind person during an utterance. This problem could be solved by using a function that enables the contents of an utterance to be displayed at any time, and one that sends a vibration signal to indicate that the transmission of utterance from the deaf-blind person is complete.

Moreover, a subject wished to see the reservation status of "the speaker" even when he was not making an utterance. When we designed the system, we considered that some deaf-blind people might become overloaded with too much information were the reservation status to be displayed, which might increase the psychological stress on a deaf-blind person. Therefore, we had designed the system so that the deaf-blind person received the minimum necessary information for understanding an utterance. However, it seems that always providing additional information is indispensable in the conference situation.

The result of the preliminary experiment confirmed the importance of this additional information. Also, it is necessary to incorporate a function which allowed a deaf-blind person to acquire information actively.

## 4. EVALUATION EXPERIMENT

In the evaluation experiment, we checked the validity of the functions supporting the understanding and utterance of deaf-blind people in the proposed system.

The subjects were one deaf-blind person and two sighted-hearing people, who had approximately 20 minutes to talk about a plan for traveling abroad. Start and end times, the speaker's name, and the contents of the utterance were recorded for each utterance. Moreover, the number of reservations and the duration of "the speaker" were also measured for each subject.

The utterance results are shown in Table 1. The rate of "the speaker" acquisition is expressed as the number of "the speaker" acquisitions divided by the number of reservations. The results of the questionnaire after the experiment are shown in Table 2.

**Table 1: Results of the experiment**

| | **D.B.*** | **S.H. ** 1** | **S.H.** 2** | **mean value** |
|---|---|---|---|---|
| Num. of utterances | 3 | 3 | 3 | 3 |
| Num. of "the speaker" reservations | 4 | 5 | 4 | 4.67 |
| Rate of "the speaker" acquisitions | 75% | 60% | 75% | 70% |
| Duration of "the speaker" (sec) | 580 | 191 | 334 | 368 |
| Num. of Characters | 508 | 56 | 193 | 252 |

* Deaf-blind person

** Sighted-hearing person

**Table 2: Results of questionnaire***

| | **D.B.** | **mean value among S.H.** |
|---|---|---|
| 1. Could you keep up with the flow of the conversation? | 5 | 5 |
| 2. Could you understand the conversation? | 5 | 5 |
| 3. Were you irritated not to have chance to speak? | 3 | 1.5 |
| 4. Were you irritated because the conversation was interrupted often? | 1 | 1.5 |

*The responses were given on a scale of one to five.

## 5. DISCUSSION

The number of utterances was not different between the deaf-blind person and sighted-hearing people. All participants were able to speak at almost the same ratio. Since the opportunity and priority of an utterance were secured, the participants were able to speak regardless of their receiving and transmitting speeds.

The deaf-blind person had a long duration of utterances and had a large number of text characters in utterances. This means that participants were fully able to participate in the conversation. In particularly, since interruptions by sighted-hearing people did not occur while deaf-blind subject was making an utterance, 508 characters were recorded in three utterances. From this result, it is considered that sufficient utterance time was fully secured for the deaf-blind subject.

Both the deaf-blind and sighted-hearing subjects were satisfied with the flow of conversation, as shown in Table 2. Before the experiment, we had expected the evaluations of question 3 and question 4 to be low since sighted-hearing participants would not be able to speak freely due to “the speaker” function. However, the result unexpectedly indicated a high degree of satisfaction among sighted-hearing participants. The reason was that the sighted-hearing participants knew who was speaking even if there had been no utterance. Consequently, the sighted-hearing people knew that the speaker had the intention to utter, and they could wait for the deaf-blind person’s utterance without any sense of annoyance, not being annoyed.

After the experiment, the deaf-blind subject mentioned that she was satisfied about being able to present her opinions fully. We to speak that she felt comfortable to having ample opportunities for making utterances without being interrupted by others' utterance, as a result of “the speaker” the function.

Smooth conversation between deaf-blind and sighted-hearing people was achieved with our conference system.

## 6. CONCLUSION

In this study, we considered the functions in a conference system. We designed the system to help a deaf-blind person to understand and to speak in a conversation, by considering the difference between tactile media and visual media based on their volatility and one-dimensionality. In the evaluation experiments using the proposed system, a deaf-blind person attained almost the same number of utterance as did sighted-hearing people, and even exceeded the number of utterance characters in an utterance. Therefore, the feasibility of the proposed system was confirmed from the result that satisfactory conversation with other participants was achieved.

In the future, we will focus on the prosody of finger braille that had been analyzed in our previous work [2]. Implementing prosody information will aid deaf-blind people to better understand the utterances of other participants.

## 7. ACKNOWLEDGMENTS

The authors are grateful to Japan Ecology Co., Ltd., for making “Ubitzky”. We also thank the volunteer subjects for their assistance.

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# Prosody Rule for Time Structure of Finger Braille

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## ABSTRACT

Finger braille is one of the communication methods for the deaf blind. The fingers of the deaf blind are regarded as keys of a brailler. Finger braille seems to be the most suited medium for real-time communication and for expressing the feelings of a speaker. We are trying to develop a finger braille receiver for teletext broadcasting system which will help the deaf blind to use current mass media. We assume that prosodic information is strongly needed to transform letters to finger braille. In this study, we analyzed the time structure of finger braille and found that it is influenced by the structure and meaning of the sentences. Based on the results, we construct a prosody rule for time structure. The validity of the rule was confirmed in an output experiment.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O.*

## General Terms

Language

## Keywords

Finger braille, deaf-blind, prosody, haptic input/output device.

## 1. INTRODUCTION

People who are both deaf and blind are called “deaf-blind”. They suffer much inconvenience in their everyday lives due to the social handicap. In particular, the deaf-blind with serious impairments are not able to obtain sufficient information necessary for living, something which a hearing and sighted person can do easily. To obtain information for living, they use tactile sensation instead of auditory and visual sensation.

Finger braille is a communication means using tactile sensation. Some deaf-blind people are able to communicate with sighted-hearing people through finger braille interpreters. However, many issues remained to be solved before deaf-blind people can come autonomous and enjoy conversations with others without interpreters.

Typical communication methods for the deaf-blind are (1) print-on-palm (tracing letters on the palm of the deaf-blind), (2) tactile sign language and finger alphabet, (3) “Bulista”, which prints out braille on tape, and (4) finger braille using a Braille code. In finger braille, the fingers of the deaf-blind are regarded as the keys of a brailler. A person types the Braille code on the fingers of the deaf-blind (Figure 1). Of these methods, finger braille using a Braille code seems appropriate for real-time communication.

**Figure 1: Typing finger braille**

About 350 codes can be transmitted between a skilled deaf blind and a finger braille translator. As compared to oral transmission of 350-400 letters, finger braille is adequate for real-time communication.

Spoken languages employ all types of prosody, which enhance the real-time comprehension of the utterances [2][3]. We believe that a real-time communication method such as speech should convey not only linguistic information but also paralinguistic and nonlinguistic information . Here, we assume that finger braille as a real-time communication method also contains not only braille codes as linguistic information but also paralinguistic and nonlinguistic information. We call it the prosody of finger braille. By examining the prosodic information of spoken languages, we are able to determine such factors as the sentence structure, sentence type (e.g., question, declaration, etc.), and prominence. We suggested that there is similar prosodic information in finger braille.

Equipment for finger braille has been proposed [1][5]. However, no consideration has been given to the prosody. We undertake to develop a finger braille output unit, which can transmit not only braille codes but also the timing structure, so that the deaf blind is able to understand finger braille well.

To accomplish this, we first analyze the timing structure of finger braille. An input and output system for finger braille is developed for communication of the deaf blind, and a prosody rule for finger braille is proposed. Finally, subjective experiments are performed to evaluate the rule.

**Table 1: Example of vocalization code**

| | Mora with voiced consonant | = | Vocalization code | + | Mora with voiceless consonant |
|---|---|---|---|---|---|
| | *ji* | = | V* | + | *si* |
| Braille** | | | ——<br>—●<br>—— | + | ●—<br>●●<br>—● |

***We use V for vocalization code for instance**

****A black circle indicates raised dot and a bar indicates flat dot of Braille.**

**Table 2: Example of numberization code**

| | Number | = | Numberization code | + | Kana code |
|---|---|---|---|---|---|
| | *3* | = | N* | + | *u* |
| Braille** | | | —●<br>—●<br>●● | + | ●●<br>——<br>—— |

***We use N for vocalization code for instance**

****A black circle indicates raised dot and a bar indicates flat dot of Braille.**

## 2. JAPANESE BRAILLE CODE SYSTEM

A braille code consists of combination of six dots. Japanese braille code system consists of 46 codes which express kana characters (mora with voiceless consonant), and some special codes. There are two types of special codes: Codes to change consonant and codes to change character set. These codes have to be put before the modificated codes. Table 1 shows the example of a function of a vocalization code which changes a mora with voiceless consonant to a mora with voiced consonant.

Codes to change character set have the function to change code set of kana character to the other code set such as number or alphabet. Table 2 shows the function of the code which changes kana character to number.

## 3. ANALISYS OF THE TIMING STRUCTURE OF FINGER BRAILLE

## 3.1 Data Recording 1: Prominence Word

### *3.1.1 Data Recording*

To examine the time structure of finger braille, we have developed a new instrument for measuring the prosody of finger braille (Figure 2). Force-sensitive resistors were adopted to detect finger pressure. The output from the six sensors (three for each hand such as in the case of a brailler) was input to a PC every 10 milliseconds.

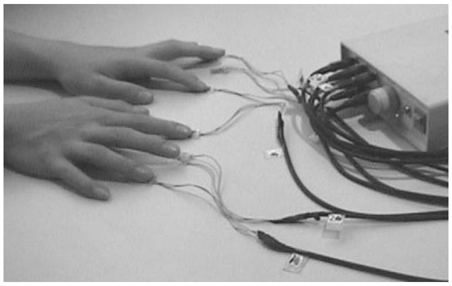

**Figure 2: Measuring instrument**

A finger braille translator participated as a subject in the recording. The subject was asked to answer questions using the same sentence as followed.

**Answer**: *3 jini chibaekino higashiguchidesu.*
(At the east exit of Chiba station at 3 o'clock)
**Question 1**: *nanjini chibaekino higashiguchidesuka* ?
(At what time will we meet ?)
**Question 2**: *3 jini donoekino higashiguchidesuka* ?
(At which station will we meet ?)
**Question 3**: *3 jini chibaekino dokodesuka* ?
(At which exit will we meet ?)

The answers by the subjects to all the questions put forth comprise the same words; however, the positions of prominent words changed according to the particular question.

### *3.1.2 Data Analysis*

Figure 3 shows the recorded pressure over time. The duration between the onset of pressure of one typed finger code and the onset of the next one was defined as the duration of the typed code. The duration of all typed codes of the sentence is shown in Figure 4. The sentence was the answer for question 1 described in the previous section. The graph shows that the duration of the last code of each phrase was longer than that of other codes (shown in 91 % of all recording). It also shows that the duration of the last code of the prominent word and the code just before the prominent word were appreciably longer than the others (shown in 73 % of all recording). These results indicate that the long duration clarifies the boundary of each phrase or prominent word.

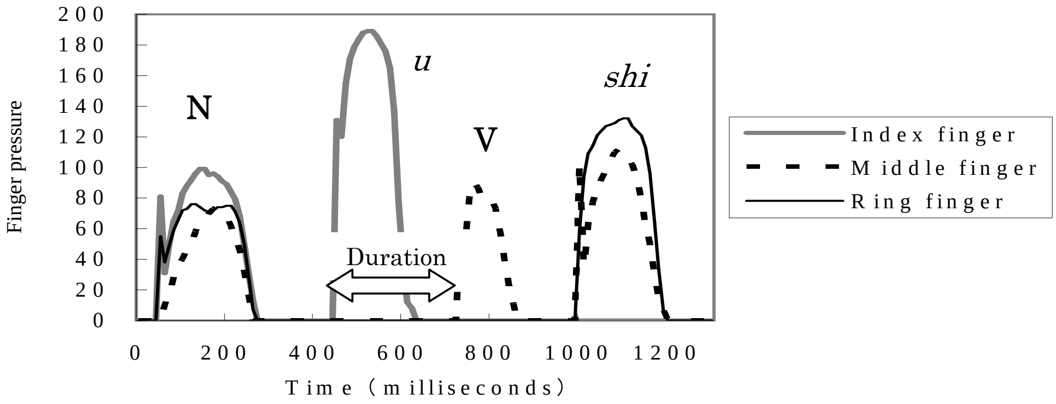

**Figure 3: Examples of finger pressure over time**

**(N : Numberization code, V : Vocalization code)**

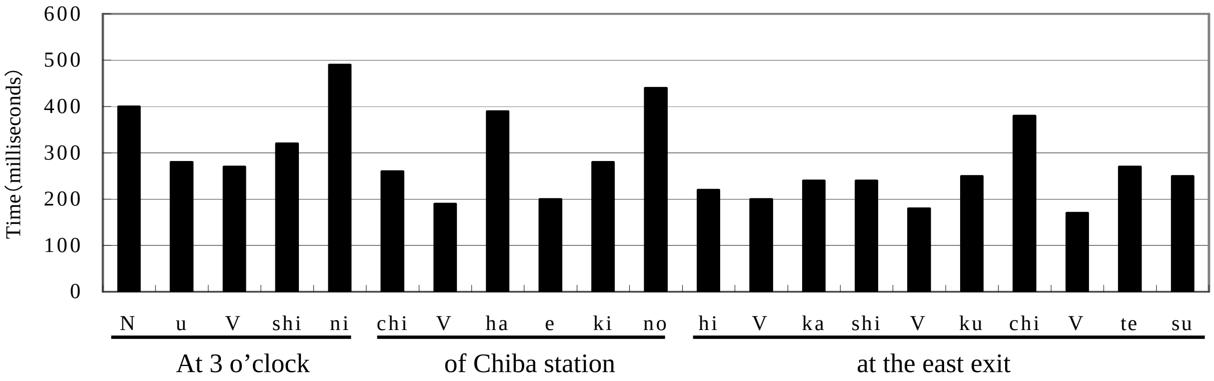

**Figure 4: Examples of duration of each code**

## 3.2 Data Recording 2: Ambiguous Sentence

### *3.2.1 Data Recording*

A finger braille translator participated as a subject in the second recording. The subject was asked to type the ambiguous sentences, (sentences which have two meanings) so as to discriminate their meanings (same code sequences but different meaning). The example of the recorded sentences is as followed.

**Sentence**: *Wakai otokoto onnaga aruiteiru.*
(young man and woman are walking)
**Recording A**: If only the man is young

**Recording B**: If both the man and the woman are young

The sentence does not give sufficient information to distinguish whether the word *wakai* (young) applies to only the man or both the man and the woman. However, in oral transmission, the meaning can be distinguished from the change of pitch, power and timing structure of the sound (prosody of spoken language). We assumed that the timing structure of finger braille had the same function. Seven different sentences that each has two meanings, like the example, were recorded. During the recording, the subject consciously typed the sentences to transmit two different meanings to the deaf blind person. For each meaning, the recording was performed twice.

### *3.2.2 Data Analysis*

The result of the first recording suggests that a short duration indicated a strong combination between two codes. Hence we prepared a "prosodic tree" by combining the codes according to the duration as followed.

***Step 1*** Line up the letters of typed sentences from the left to right.

***Step 2*** Consider the letters at the end of the sentence to be the trunk.

***Step 3*** Consider the length of each duration to be the length of the branch, and connect it to the longer branch on its right side.

***Step 4*** Repeat Step 3 until the process is completed for all letters.

The resulting trees (Figure 5; Figure 6) represent the semantic structure of the recorded sentences. It was suggested that the timing structure of finger braille was affected by not only the structure of sentences but also the meaning of the sentences. These findings support our assumption.

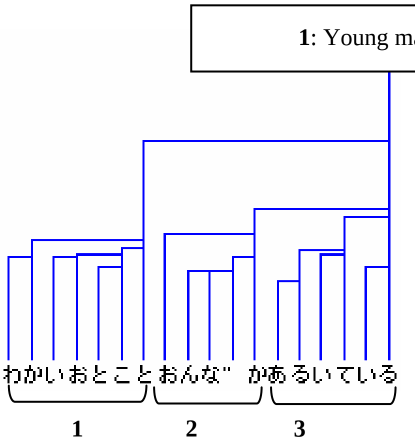

Figure 5: The tree based on recording A

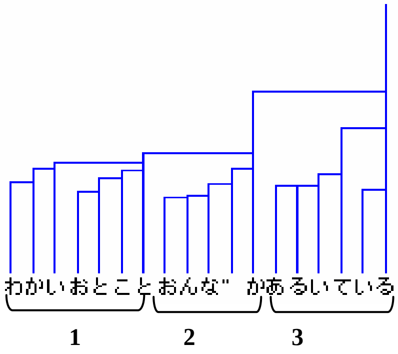

Figure 6: The tree based on recording B

## 3.3 Data Recording 3: Paragraph

### *3.3.1 Data Recording*

Three finger braille translators participated as a subject in the third recording. The subjects were asked to type short paragraphs from a news program in order to determine the parameter of the prosody rule. The subjects listened to the news and type the paragraph simultaneously.

### *3.3.2 Data Analysis*

Table 3 shows the average duration of the last code of phrases and sentences, and some special codes. For example, the code which acted to change an unvoiced consonant into a voiced consonant had a short duration, while the code which changed the coding system had a long duration. The result indicates that the length of duration has much to do with the function of the special codes. If the deaf blind person fails to read the vocalization code, he/she will misread a following code only. However, if he/she skips the numberization code, it is possible that more than two codes will not be transformed to number and likely misread. It causes a serious effect on understanding of the sentence. Therefore, duration of transform codes became longer, so the codes would no be skipped.

### *3.3.3 Prosody Rule for Timing Structure*

From the results, we derived a rule to model the prosody information of finger braille. The structure of the sentence and the type of the code determined a length of duration of a braille code. The code was previously analyzed whether it was the end of a phrase or a sentence, and whether it was a special code. Each code was given the average values as its duration.

**Table 3: Average values of duration by codes**

| Types of the code | Duration (milliseconds) |
|---|---|
| Last code of phrase | 790 |
| Last code of sentence | 697 |
| Vocalization code | 343 |
| Palatalized code | 357 |
| Code to change character set | 587 |
| Others | 377 |

## 4. OUTPUT EXPERIMENTS

## 4.1 Conditions

An experiment has been performed to evaluate the effect of the prosody rule. We examined whether the deaf blind have a better understanding when prosody information is added to finger braille output. We have developed a new instrument for output of finger braille (Figure 7). It is available to control the time structure of output by PC.

Figure 7: Output instrument

The subject was a deaf blind who uses the finger braille as her major communication means. Before the experiment, there was a rehearsal. The subject could read all the sentences both with and without prosody. In the experiment, to compare two outputs effectively, the parameter was set as half the recorded time, so the output speed became twice the recorded time.

Without prosody, each code was output for 210 ms. With prosody, each code was output for the half of the duration described in Table 3. Each output includes a pause with half of its duration. Four essays about animal lives were output. One essay had 450-500 Braille codes and consisted of three paragraphs. Two essays had prosodic information and two had no prosodic information. There were 10 questions concerning each essay, so 20 questions were prepared for each output. A finger braille translator typed the questions, and the subject answered orally. The questions were repeated until the subject understood completely.

## 4.2 Results

Table 4 shows the results of the experiment. The subject exhibited a better understanding of the output with the prosody rule. The subject felt that the output by prosody was more natural and understandable as to the timing structure of sentences. The similar results were shown in a study of prosody of spoken languages [4]. The result confirms the validity of the prosody rule.

**Table 4: Results of the experiment**

| Output | Percentage of correct answers |
|---|---|
| With prosody | 85 % (17 correct answers) |
| Without prosody | 50 % (10 correct answers) |

## 5. FINGER BRAILLE RECEIVER FOR TELETEXT BROADCASTING SYSTEM

With inclusion of the prosody rule, our output system can be a real-time communication method that can help the deaf blind to obtain information. We developed a prototype of finger braille receiver for teletext broadcasting system which could help the deaf blind to use current mass media. Similar system has recently been proposed [5]. However, no consideration has been given to the prosody.

In our system, a PC receives the teletext and Braille codes are output according to the durational rules. The outline of the process is (1) receiving teletext, (2) converting kanji text into kana characters, (3) converting kana characters into braille codes, (4) carrying out morphological analysis and syntactic analysis of the teletext sentence, and (5) applying the durational rules.

## 6. CONCLUSIONS

In this paper, we analyzed the time structure of finger braille. Based on the recording, the prosody rule for finger braille was proposed. Finally subjective experiments were performed and the results show that the prosody rule for finger braille is effective. We are currently analyzing strength of movement in each finger to detect other prosody in finger braille.

## 7. ACKNOWLEDGMENTS

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# Haptic and Tactile Feedback in Directed Movements

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## ABSTRACT

Directed movements with a user's arms and hands are the basis of many types of human-computer interaction. Several previous research projects have proposed or studied the idea of haptic and tactile feedback in directed movement-based interaction with computer systems. In this paper we collect and review existing recommendations for haptic feedback in both single-user and collaborative situations, and derive a design space for haptics in this area.

## Categories and Subject Descriptors

H.5 [**Information Interfaces And Presentation**]: H.5.2 User Interfaces: Haptic I/O.

## General Terms

Performance, Design, Experimentation, Human Factors.

## Keywords

Haptic and tactile feedback, tangible computing, directed movement, target acquisition, handoff.

## 1. INTRODUCTION

Current mouse-and-windows interfaces involve several types of low-level actions that involve the mouse pointer. These directed movements have to date used only visual means to assist the user in the completion of the movement. However, other modes of feedback are possible: in particular, tactile and audio feedback.

Previous research has shown that extra-visual feedback is useful in some circumstances, but for normally-sighted users in normal viewing conditions, the benefits are not large. Therefore, designers should consider the user, the situation, and the task carefully before deciding to use additional feedback. In this paper, we gather a set of possible guidelines from our own and others' previous experience with haptic and tactile feedback.

Before stating the guidelines, we summarize basic issues in the design space for extra-visual feedback, including definitions for haptic and tactile feedback, the basics of directed movement, and a discussion of the idea of interaction bandwidth.

## 2. BACKGROUND

There are several different types of feedback that are possible in the domain of haptic and tactile computing. In this paper, we will use *tactile feedback* to refer to information that can be interpreted by the skin's sense of touch (e.g., texture, vibration, and pressure); *force feedback* to refer to information that is interpreted by larger-scale body senses (muscular, skeletal, and proprioceptive senses); and *tangible media* to refer to the use of real-world objects in a computational setting. Tangible computing brings in many types of tactile feedback as part of the real-world nature of the object, but in most cases force feedback is not part of these objects.

### 2.1 Directed Movement

Directed movements in window-and-pointer systems are those where the user carries out some action using the spatial location of the pointer. There are two main types of directed movement: targeting, and steering; in addition, we also discuss handoff, a composite type of motion seen in shared environments.

### *2.1.1 Targeting*

Targeting is the act of moving the pointer to a particular location on the screen. Many direct manipulation actions in graphical interfaces begin with a targeting task, such as pressing a button or dragging a file to a folder icon, all begin with the same user action of moving and positioning the mouse pointer. When the pointing device in the interface has an on-screen pointer (as opposed to a touchscreen or a light pen), we can divide targeting into three distinct stages: *locating*, *moving*, and *acquiring*. Locating is the act of finding the mouse pointer on the computer screen when its position is unknown. Moving is the act of bringing the pointer to the general vicinity of the target, and requires the user to track the pointer as it travels across the screen. Acquiring is the final stage, and is the act of precisely setting the pointer over the target and determining that the pointer is correctly positioned.

Targeting performance is governed by Fitts' Law, which determines a relationship between targeting difficulty and the size of a target and its distance from the starting point (Mackenzie 1992). The way that a user carries out the directed motion in a targeting action is similarly governed by principles of human motor control. Targeting motions are usually a series of submovements of decreasing size: the first movement is large and fast, and subsequent motions (as the pointer nears the target) are smaller.

The details of this kinematic process are summarized by McGuffin and Balakrishnan (2002): the movement involves "an initial, open-loop, ballistic impulse; followed by a corrective, closed-loop, 'current control' phase; [these] later, corrective submovements are performed under closed-loop control." McGuffin and Balakrishnan showed that people are able to make use of sensory input (visual) during these late-stage open-loop motions, suggesting also that other forms of feedback, such as tactile information, may also be of use.

Targeting motions are slightly simpler in absolute-positioning environments, either those that use pointing devices such as touch screens, or environments that use tangible blocks as the work artifacts, and thus allow real direct manipulation by the user's arms and hands. In absolute environments, locating is less of a problem, and the user needs only to move their hand directly to the target. Although the same kinematic process occurs, people are generally faster and more accurate with their hands than they are with a relative positioning devices such as a mouse.

When considering tactile exploration in the absence of a visual channel, Fitts' law no longer accurately predicts the targeting task. Unlike the visual task, the user must identify any intermediate objects encountered during the approach to the target. These objects must be internalized by the user and serve as landmarks in the search process, indicating the relative distance from the starting position and to the final target. Due to the time required to digest this information, a linear model such as that proposed by Friedlander et al. (1991) better characterizes the targeting task under these conditions.

### *2.1.2 Steering.*

Steering, like targeting, is a basic component of many interactive tasks in 2D workspaces. Steering is integral to tracing, drawing, freehand selecting, gesturing, navigating menus, and pursuit tracking. The mechanics of 2D steering have been studied extensively by Accot and Zhai (e.g., 1999, 2000, 2004), who showed that performance can be predicted by an extension to Fitts' Law called the Steering Law. The Steering Law relates completion time to two factors: the length and width of the path. The steering law has been shown to accurately predict completion time over several path types, input devices, and task scales.

Where there are three stages to targeting, there is really only one stage in a steering motion: the user moves their pointer along the path, making sure that they do not stray outside the boundaries. The kinematics of steering tasks are similar to those of targeting, but the user spends almost all of their time in closed-loop motion, where they are continuously evaluating whether the pointer is still within the path boundaries.

### *2.1.3 Handoff*

Object transfer is one of the low-level actions that allows people to carry out a shared task as a group (Pinelle *et al.*, 2003). Handoffs occur for two reasons: first, because people cannot reach all parts of the workspace, and it is easier to divide the task of reaching an object than it is to walk around the table; and second, because when a space is divided into territories (Scott *et al.*, 2004), it is often more polite to ask for an object from another person's work area than it is to reach in and take it yourself.

Handoff can be characterized as a multi-person target acquisition task. The first person brings the object or tool towards the second person, and holds it in position until the second person grabs it. The second person then moves the object to a target region somewhere in their work area. The target for the first person, however, is variable, and may change based on the table or the activities of the receiver.

## 2.2 Types of Feedback

Based on two main types of feedback (tactile and force), two types of directed motion (targeting and steering), and three possible stages of motion (locating, moving, acquiring), we can set out a number of possible types of feedback.

| Feedback Description | Type of Motion | Type of Haptic Feedback |
|---|---|---|
| Pointer crosses target boundary | Acquisition | Tactile |
| Pointer crosses path boundary | Steering | Tactile |
| Feedback mapped to screen areas | Location | Tactile gradient |
| Texture trail | Motion | Tactile |
| Gravity wells | Acquisition | Force |
| Gravity paths | Steering | Force |
| Use of tangible blocks for targeting | Location, Motion, Acquisition | Tactile |

Table 1. Types of tactile and force feedback in various forms of directed motion.

## 2.3 Interaction Bandwidth

Haptic, tactile and tangible information constitute a very interesting alternative to the visual and auditory channels. Although most of the human perceptual channels are interrelated, the touch channel is perceived by humans as an independent source of input, just as sound is clearly distinguished from vision. This leads us to think that using the touch channel could help us reduce clutter in either the visual or auditory spaces, allowing for an increased number of simultaneous distinguishable signals to be perceived by the user.

However, the tactile channel's particularities should be taken into account when designing interaction. For example, although tactile feedback is readily perceived by humans without much delay, it is not able to communicate large numbers of different symbols or many fast changes (i.e., the bandwidth of the haptic channel is low). This will restrict the use of haptic, tactile and tangible feedback to represent variables that do not change rapidly and that do not have many different states. Besides, tactile and haptic signals can potentially interfere with muscular and proprioceptive functions associated with control, resulting in undesired side effects. A clear example of this is using vibratory cues in a mouse that could affect accuracy in pointing and selecting tasks. The signals should be thus placed and designed with care not to hinder other aspects of interaction.

In the field of direct manipulation interaction techniques, the use of haptic, tactile and tangible feedback provides a very valuable alternative means to give information to the user when the primary perceptive spaces (visual and auditory) are already cluttered or when the visual and auditory spaces cannot be used at all.

A very simple example is the signaling of mode changes or state in interaction techniques with several modes or in systems that use potentially overlapping interaction techniques. A good representative of this is using haptic feedback to indicate mode in pen-based tabletPCs (Li *et al*., 2005). When using pen-based devices there are two main modes of interaction with the pen: electronic ink and commands. The transition between those two is problematic, among others, because it is difficult for the user to know in which mode they are, issuing commands to the system (e.g., cut, copy, paste, go to the top, scroll) or drawing content (i.e., electronic ink). Using visual information to tell the user the current mode by, for example, changing the properties of the strokes of the pen, will interfere with the graphical nature of drawing tasks. If, instead, we provide a feel of different surfaces for each mode, the user will instinctively know if she changed the mode correctly or not, and it could prevent errors.

Another set of situations in which touch-based feedback could be invaluable are those where attention has to be split into several loci. For example, when driving a car, we can perceive haptic information about the steering of the car (or any other) while remaining attentive to possible hazards in the roadway. In a similar way, we can use haptic or tactile feedback when it is not possible to provide coherent visual feedback. For example, in a multi-display system, tactile information can be used to tell the user if the cursor is in a visible position or not.

# 3. PROPOSED GUIDELINES

Based on an analysis of previous work, and our own experiences and experiments, we propose several guidelines that can be used to aid the design of haptic and tactile feedback for directed movements. We organize the guidelines into three groups, following the three types of directed movement introduced above; in addition, we include a general category where guidelines apply to more than one type of motion.

## 3.1 General

1. *Haptic and tactile feedback are best used to inform about narrow bandwidth signals.*

The nature of the human touch perceptive system makes it difficult and/or annoying to convey large amounts of information through the touch channel, however, touch signals are very salient and have the potential to very easily draw attention. Haptic and tactile signals should thus be used mainly to represent variables that don't change very often, but that require attention.

2. *Tactile feedback is of particular use in visually stressed conditions or for visually impaired users.*

When the bandwidth of the visual channel is reduced, the value of having another channel is increased. For users with visual impairments, tactile and other forms of non-visual feedback should be effective in many more cases than for normally-sighted users; similarly, tactile feedback should be effective in difficult environments (e.g., outdoors, variable lighting, high glare, etc.).

3. *Tactile representations can be abstract.*

Users can be trained to recognize abstract representations of complex information through the sense of touch in the same way that the visual sense processes iconic information. The most recent example of this can be seen in the experiments by Brewster and Brown (2004) involving tactile icon representations.

4. *Tactile feedback can be used on the torso.*

Several researchers have studied the use of high-resolution vibrotactile feedback to augment the reduced visual fields common in many high-stress tasks. On most occasions vibrotactile cues were provided to the users' torso since the users' hands could be occupied in other tasks. The results of these studies suggest that feedback to the torso can be effective in improving users' spatial awareness (Weinstein, 1968; Veen *et al*., 2000). The research also found that users are more sensitive to feedback in the front of the torso than in the back.

5. *Maintain stimulus-response compatibility.*

A general principle in applying tactile feedback has been the stimulus-response (SR) compatibility. Akamatsu *et al* (1995) note that when a cursor moves over a target the correct way to convey this sense to the operator is through a touch sensation in the controlling limb. In an experimental comparison of target selection tasks with tactile, visual and auditory feedback [5] the authors found that tactile feedback allowed users to use a wider area of the target and to select targets more quickly once the cursor is inside the target.

6. *Haptic and tactile feedback should be avoided when they can interfere with control functions.*

Haptic and tactile feedback signals can affect motor abilities and should be carefully designed so that they don't interfere with other tasks in the system, for example, by detaching the location of feedback from the parts of the body that exert control of the system or by providing a very subtle signal.

7. *Haptic and tactile feedback should be considered when splitting of attention is required or when the primary feedback channels are unavailable or busy.*

The distinctive, distributed quality of touch perception makes it the ideal channel for situations where the attention has to be divided. The visual channel has a very broad bandwidth, but it is constrained to one spatial attention location at the same time. This limitation can be overcome by using the tactile or haptic feedback channel concurrently or instead of the visual channel provided that the information conveyed by these corresponds to the user's touch perception bandwidth.

8. *Haptic and tactile feedback in isolation are insufficient for object identification.*

When visual information is not available, it has been shown that exploration of complex objects in the scene through touch alone does not lead to an adequate conceptual model to identify real world objects. As a result, all tactile/haptic exploration tasks should be augmented through either visual or audio stimuli (Colwell *et al*., 1998).

## 3.2 Targeting

9. *In normal viewing conditions, extra-visual feedback may not improve targeting performance.*

As discussed above, in situations where there is adequate visual feedback, and the user is able to attend to the signal, additional feedback is unlikely to improve speed or accuracy (Akamatsu *et al*., 1995). However, users do not generally dislike the extra feedback, and it does not detract from performance, at least in sparse target environments.

10. *The effects of feedback in multiple-target environments are not well understood.*

Most studies have taken place on sparse target environments (one or a few targets), and those that have used more cluttered presentations show mixed results for targeting feedback. In general, the additional information from other targets reduces the salience of the feedback for the target.

11. *Buttons on tangible objects can interfere with positioning.*

The Heisenberg effect of spatial interaction (Bowman, 2002) refers to the phenomenon that on any tracked tangible or tactile input device, using a discrete button will disturb the position of the input device. In the case of using a wand, stick or TractorBeam (Parker *et al*., 2005) to position cursors on a remote display placing a selection button on the positioning device can lead to errors in target selection.

12. *Gravity wells are useful aids for motion-impaired users*

Computer users with hand or upper body tremors such as cerebral palsy or Parkinson's disease find gravity wells as useful aids for target selection (Hwang *et al*., 2003). Gravity wells are attractor-forces situated at the center of targets. When the cursor approaches the target area the haptic device pulls the cursor towards its center allowing the users to perform the act of clicking whilst the cursor is held steady.

## 3.3 Steering

13. *Haptic and tactile feedback are useful as aids in general steering tasks.*

When considering navigation through a narrow channel, forces pushing from the boundary areas can serve to correct erroneous movement which would lead the user out of the channel. In this case, a delicate balance must be struck to ensure that the forces are strong enough to correct errors, but not so strong as to limit the movement of the user (Dennerlein *et al*., 2000).

## 3.4 Handoff

14. *Use tangible representations for objects that need to be transferred frequently or quickly.*

Previous research shows that handoff is considerably faster and easier with tangible techniques than for digital pointing techniques (Liu *et al*., 2005). When sender and receiver coordinate together to handoff object by digital representation, the handoff process requires considerable hand-eye coordination for both the sender and the receiver. The sender and the receiver rely on visual information to accomplish the handoff. By using tangible representations, the users benefited greatly from the haptic feedback. This advantage suggests the designers that they are going to use tangible representations for objects, if they design a system which handoff activity happened frequently.

15. *The difficulty of the receiver's task in handoff motions influences the handoff location more than the difficulty of the sender's task.*

For smaller target sizes, the handoff location is closer to the receiver than for larger target sizes – that is, users automatically adjust the handoff location to balance the workload between the sender and the receiver. Designers should understand that the handoff location will alter if they design different size of targets for sender and receiver to acquire.

16. *Both sender and receiver should be able to perceive when and where the handoff action is going to occur.*

Compare with the inner-handoff when single user transfers object from his one hand to another, extern-handoff takes more time for sender and receiver to negotiate to transfer the object. It is because the sender can not predict where receiver is going to get the object, and receiver can not predict where the sender will move the object for him to pick it up. Designing a system which can give both sender and receiver perceptions about when and where the collaborators are going to transfer object will help users to achieve handoff task much easier.

## 4. CONCLUSION

Directed movements make up a large fraction of a user's interaction with a graphical interface. As direct-manipulation interfaces become more common, and as input devices become more powerful, haptic and tactile feedback for directed motions will likely become commonplace. Although the costs and benefits of adding haptic feedback are not yet fully understood, there is already a reasonable body of literature that can suggest design guidelines in this area. In this paper, we have collected sixteen principles from previous research and from our own experiments. These principles can be used to inform the design of feedback for targeting, steering, and handoff interaction techniques. However, it is clear that much more research needs to be done – particularly in studying the effects of haptic feedback in cluttered environments (such as many everyday interfaces).

## 5. ACKNOWLEDGMENTS

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# Guideline for Tactile Figures and Maps

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## ABSTRACT

The purpose of this research is to propose a guideline for tactile maps and figures. At present, there are no unitary standard for manufacturing tactile figures and maps in Japan. In this research, first of all, I proposed the guidelines for tactile figures and maps based on the characteristics of the tactile perception. Secondly, I proposed how the Tactile-Mapping- Practice should be conducted. Finally, two experiments were conducted to evaluate the usefulness of the Guidelines and the tactile-mapping-practices. From these usability test-results, I was convinced of the usefulness of the Guideline and the Tactile-Mapping-Practices.

## Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Ergonomics, Standardization

## General Terms

Experimentation, Human Factors, Standardization

## Keywords

Tactile Maps, Tactile Figures, Guideline, Haptic Characteristics, Tactile-Mapping-Practice

## 1. INTRODUCTION

When the blind goes out solely, “buildings, stores, fence, and wall”, “listening to someone else”, “textured paving blocks”, “sounds of daily life”, “public guiding sounds”, “audio spoken assists”, and “Braille assists” are all useful for providing needed information for the blind [1]. In Japan, only very small numbers of the blind get out solely, because of the concern that most of them believe that getting out solely has a high-risk of being injured. One of the reasons for such beliefs is the blind are difficult to obtain enough information for walking around solely.

There are three types of presenting information by Tactile/Haptic information during walking; 1) Prior Information (someone gives needed information beforehand), 2) Real-time Information (someone gets information during walking), 3) Learned Information (someone receives information after walking).

Tactile map is the map which is embossed or written in Braille, thus user can get necessary information of the map tactually. There are three types of notation systems for common map; 1) Overall viewing map (presenting a broad overview of commodious premises), 2) Fragmentary viewing map (presenting a part of the commodious premises, like floor maps), 3) Detailed viewing map (presenting a piece of the commodious premises, like a guest room or a toilet). There are same types of notation systems in tactile maps.

In this paper, I proposed Guideline for Tactile Figures and Maps and the Tactile-Mapping-Practice based on the guideline. Usability tests were conducted to compare the existing styles of tactile maps and the new style of tactile maps based on the Tactile Mapping Practice. As the results, we validated availability of the Guideline and the Tactile Mapping Practice.

## 2. PRESENT STATE OF TACTILE MAPS

### 2.1 Tactile Map

Tactile Maps are the map for the blind person. On the tactile map, streets, landmarks and figures for buildings are printed with a slight protuberance to present information tactically. User touches the tactile map to read the information of the maps. There are two kinds of slight protuberance ways; 1) Printing lines by Braille dots, and 2) Embossing all figures. Braille dots could be printed on paper which then could be sent by mail. In contrast, the embossing technique is usually used on with metals and figulines, thus the map size will be larger.

### 2.2 Tactile Map Classification

There are no standard for presenting tactile maps. I classified tactile maps in the following categories: 1) Visual Dominance Embossed Effect Map, 2) Visual dominance Braille Effect Map, 3) Landmark Dominance Effect Map, and 4) Arrangement in Space Dominance Effect Map [2].

#### *2.2.1 Visual Dominance Embossed Effect Map*

Visual Dominance Embossed Effect Map (VDEEM) (see Figure 1) depends on the visual map, and is created with the embossing techniques. When the sighted use VDEEM visually, they can understand their meanings. However, when the blind persons use the VDEEM, configured with many tactile figures, they cannot understand their meanings.

**Figure 1. A sample of VDEEM.**

### *2*

Visual Dominance Braille Effect Map (VDBEM) (see Figure 2) depends on the visual map, and is created with Braille dots. Parts of Landmarks and roads are enclosed by Braille dots. When the sighted use VDBEM visually, they can understand their meanings. However, when the blind persons use the VDBEM, which are configured with many dots, they cannot understand its meanings.

**Figure 2. A sample of VDBEM.**

### *2.2.3 Landmark Dominance Effect Map*

Landmark Dominance Effect Map (LDEM) (see Figure 3) places emphasis on Landmarks with deformation. These LDEM are given emphasis to be used for entertainment and therefore usually used in amusement spots. LDEM are configured with many tactile figures, thus the blind person cannot understand their meanings.

**Figure 3. A sample of LDEM.**

### *2.2.4 Arrangement in Space Dominance Effect Map*

Arrangement in Space Dominance Effect Map (ASDEM) (see Figure 4) places emphasis on space dominance, and is created with embossing techniques. These ASDEM consider the space is the most dominant factor and eliminate other elements such as distance information, landmark information, etc. These ASDEM give emphasis to major locations such as station premises, administrative institutions, etc. ASDEM are configured with too many tactile figures that the blind person cannot understand their meanings.

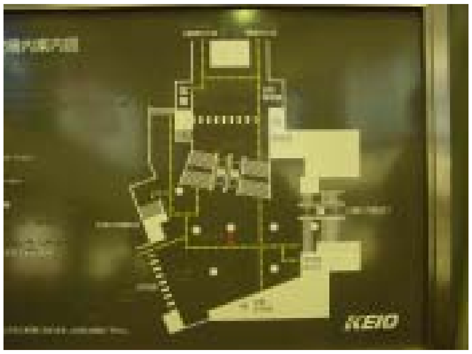

**Figure 4. A sample of ASDEM.**

## 3. Guidelines for Tactile Figures and Maps

## 3.1 Outline of the Guideline

These Guidelines for Tactile Figures and Maps explain the basic philosophies, the general principles, and the implementation structures of helping human walking by tactile figures and maps. It is necessary that all users can use tactile figures or maps easily to understand their meanings. This guideline was summarized for produce more easily comprehensible and useful information more correctly. When producers produce the tactile figures or maps, they have to take into account the characteristics of the handicapped, and should use this guideline to appropriate presentation of information by tactual figures effectively. Furthermore, if the users can use the tactile figures and maps well, the handicapped people will be free to take individual action more freely and safety.

## 3.2 How the Guidelines are Organized

This document includes fifteen guidelines, or general principles of accessible designs. Each guideline includes:

- The guideline number.
- The statement of the guideline.
- The rationale behind the guideline and the opinions of some groups of users who have benefited from it.

## 3.3 Guideline for Tactile Figures and Maps

### *3.3.1 Use Easily Comprehensible Tactile Figures*

Produce tactile figures or maps with figure's size thickness and size standards. [PRIORITIES 1]

The tactile figures or maps have to be produced with constant thickness. Using different thickness figures will complicate the tactile figures or maps. It is preferable that use the standard size to express as landmarks [PRIORITIES 2]. However, when producing the tactile figures or maps, producers are free to use different size of figures if expressing as actual location or destination.

### *3.3.2 Use Tactile Figures' Shapes as Needed*

Use separate figure shapes to express as actual location, destination, and landmarks [PRIORITIES 2].

It is easy to recognize each figure's meaning that uses separate figure shape to express as actual location, destination, and landmarks. The pyramidal shape is the shape which is easiest to recognize; therefore, use pyramidal shape for expressing the actual location.

### *3.3.3 Use Minimum Amount of Information*

Think about how many figures might be in the tactile figures or maps, and use minimum amount of figures to express as landmarks [PRIORITIES 1].

The number of information has to be limited to five for one touch [PRIORITIES 1].

It is difficult to create cognitive map that information which is complicated on tactile figures or maps. Therefore, producers must other than the landmarks, roads or streets, around the actual location, and destination. The haptic information capacity is five plus or minus one, so that producers have to create the tactile figures or maps with not more than five informations for each one touch [3].

### *3.3.4 Use Braille or Embossing Words with Written Words*

Producing the tactile figures or maps includes Braille or embossing words and written words [PRIORITIES 1].

Remember only the minority of the blind can read Braille. The majority of the blind are people who have posteriori lost their sight. Therefore, some of the blinds read embossed words more easily than Braille. If necessary, the sighted read the blind to written information on the tactile figures or maps, therefore producer has to use either Braille or embossed or written words.

### *3.3.5 Use Power Exponent for Presenting distance information*

Use power exponent for presenting distance information [PRIORITIES 2].

Use power exponent suitable for use with each situation [PRIORITIES 2].

The cognitive distances are differences between cognitive level and somatic cognitive level, therefore, tactile power exponent must be used on presenting "distance information". The power exponents are difference between each using situation, therefore, use different suitable power exponent for use with each situation; inside, outside, portable map, or installation map.

### *3.3.6 Standard Distance Mark of Scale Should be Printed in Lengthwise*

Produce standard distance mark of scale vertically for reducing any distance error [PRIORITIES 3].

On the visual map, the standard distance mark of scale is located crosswise. On the tactile figures and maps, however, standard distance mark of scale is preferably located vertically for reducing distance error. If it is possible that producers use the distance between actual location and the first landmark for the standard scale distance mark for that particular area [PRIORITIES 3].

### *3.3.7 The Blind Should Select Landmarks*

The blind should select landmarks [PRIORITIES 1].

The alternative for landmarks is the difference between the blind and the sighted during walking. The sighted depends on visual information for landmarks, while, the blind does not depend on visually information for landmarks. The blind usually depend on auditory information, olfactory information, and tactile information for landmarks. Therefore, the blind should select the landmarks to produce the tactile maps.

### *3.3.8 Landmarks Should Be Located Correct Placement of Each Actual Landmark*

Landmarks should be located relative placement for real situation to keep users safe [PRIORITIES 1].

The blind often use the placement of landmark on the tactile map and their relative distances during walking. Consequently, the located relative placement and relative distance are most important to present information to the blind. The tactile maps put the blind in jeopardy because of the haphazard placement.

### *3.3.9 Use Color Effectively*

Use colour effectively for the assistance of amblyopia [PRIORITIES 4].

The majority of the blind are amblyopia. They can get the visual information in some small measure. Usually tactile figures and maps are used with tactile sense, however, when the amblyopia uses tactile figures and maps, they use visual information effectively. When producer produces the tactile figures or maps, they must be noted that colours of contrast are of significant aid to the amblyopia.

### *3.3.10 Should not be Depended on Visual Map when Designing Tactile Figures or Maps*

Producer must be recognized the difference of visual map characteristics and tactile maps characteristics [PRIORITIES 1].

It is difficult to understand their meanings that the tactile map was produced from visual map with written in embossing words and Braille manners. Producer must be recognized the difference of visual map characteristics and tactile maps characteristics. Producer must not cannibalize the visual figures or maps to tactile figures or maps.

### *3.3.11 Should not be Depended on Only Audio Assist when Designing Tactile Figures or Maps*

The audio assist work on the presenting information, however, it does not work useful by location [PRIORITIES 2].

The audio assist works on the presenting information, however, it does not work useful by location; noisy cross-point, in front of a station, etc. The audio assist can take longer time to present information. The audio assist is useful to present name of landmarks. The audio assist must be use for only assist to present tactile map.

### *3.3.12 Map size Should be Smaller than Range of Human Brachium Movement*

Map size should be produced smaller than the range of human brachium movement [PRIORITIES 2].

If the map size is produced larger the regular than range of human brachium movement, the user of the map could not get enough information. Only the maps scale down, however, there are too many information on the tactile figures or maps, therefore, user could not understand their meanings. Producer must carefully consider the details of the information capacity and function of presenting areas (see 3.5.3). Producer, furthermore, must carefully consider the details of using several tactile figures or maps separately to present larger area.

### *3.3.13 Set Up High and Range Should be Adjustable*

Producer should be carefully considered the details of set up high and range of tactile figures and maps adjustably [PRIORITIES 3].

Users' high and length of their arms are unequal. It is preferred that the tactile figures or maps could be height-adjustable and range-adjustable. If user could not adjust oneself, producer must produce the tactile figures or maps' high ranged between 5-95%ile of average height and ranged between 5-95%ile of average range of human brachium movement.

### *3.3.14 Set Up Tactile Map and Real Field Palewise*

When set up tactile figures or maps, a main street which is on the tactile map should be perpendicular to the real field [PRIORITIES 3].

Producer must carefully consider the details that set up angle of tactile figures or maps work on building human cognitive maps. The actual location should be placed on the bottom-centre of the tactile figures or maps, and the destination should be placed on the top of the tactile figures or maps. When set up tactile figures or maps, a main street which is on the tactile map should be perpendicular to the real field, the actual location should be placed on the bottom-centre of the tactile figures or maps.

### *3.3.15 Should not be Depend on Only Textured Paving Block*

On the derivation to the tactile figures or maps, producer should be not depend on only textured paving block, therefore, should be use the auditory information or olfactory information [PRIORITIES 5].

Usually use the textured paving blocks are used to direct the blind to the tactile figures and maps. However, on the some kinds of environmental status, the blind could not use the textured paving blocks. Producer should be carefully considering the details of using auditory information or olfactory information. Furthermore, Producer should be carefully considering the details of using colour effectively to be thoughtful of amblyopia

### 3.4 Priorities

Each checkpoint has a priority level assigned based on the checkpoint's impact on accessibility.

[PRIORITY 1] The producer of tactile figures or maps must satisfy this checkpoint.
[PRIORITY 2] The producer of tactile figures or maps should satisfy this checkpoint.
[PRIORITY 3] The producer of tactile figures or maps may satisfy this checkpoint.
[PRIORITY 4] The producers of tactile figures or maps might satisfy this checkpoint.
[PRIORITY 5] The producers of tactile figures or maps may wish to satisfy this checkpoint.

## 4. DISCUSSION

## 5. CONCLUSION

The Guidelines for Tactile Figures and Maps were proposed. Furthermore, the Tactile-Mapping-Practice based on the guidelines were proposed. Two usability-testings were conducted on the tactile maps which were produced based on the Tactile-Mapping-Practice.

First, usability-testings were conducted according to "the usability-flow-chart-evaluation" which was formulated by the Guidelines. As the results, the tactile maps which were produced based on the Tactile-Mapping-Practice scored "AAA". On the other hand, the tactile maps which were produced based on VDEEM were scored "A". The scores consist of five grades, namely, "AAA", "AA", "A", "B", and "C".

The second usability-testing was conducted by ten sighted subjects. The subjects touched each of the tactile maps which were produced on the basis of Tactile-Mapping-Practice and were produced basis on VDEEM, then subjects represented the maps on A3 sized paper by the Sketch-Mapping Method. The results showed on the correct answer rate of number of figures, shape of figures, relative position of figures, and relative distance of each figure, the tactile map which were produced based on the Tactile-Mapping-Practice received higher scores than the other tactile maps.

On these results, the tactile maps which were produced based on the tactile-Mapping-Practice were easier to understand than the tactile maps which were produced based on the VDEEM for the blind. Basically, the Guidelines and the Tactile-Mapping-Practice would be useful.

It would be important to continue to work on standardizing the Guidelines for tactile figures and maps.

## 6. ACKNOWLEDGMENTS

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# A Tactile/Haptic Interface Object Reference Model

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## ABSTRACT

In this paper, we describe present a reference model for evaluating and designing individual tactile or haptic objects and groups of such objects. This model provides an understanding of the many facets involved in individual and groups of tactile or haptic interaction objects.

## Categories and Subject Descriptors

H.5.2 User Interfaces, *Ergonomics, Haptic I/O, Input devices and strategies,* D.2.0 Software Engineering General, *Standards*

## General Terms

Human Factors, Standardization

## Keywords

Tactile, haptic, interactions, interface object, reference model, standards.

## 1. INTRODUCTION

User interest in tactile and haptic interaction has grown considerably based on large volumes of recent research. However, developers require more than just user interest, they require guidance on how to successfully design and construct sets of tactile and/or haptic objects.

A reference model can help to standardize the design and construction of tactile or haptic interactions, by ensuring that all relevant aspects of these interactions are taken into consideration. Reference models are increasingly used within user interface design.

Lynch and Meads [1] advocated that user interface reference models should "provide a generic, abstract structure which describes the flow of data between the user and the application, its conversion into information, and the auxiliary support which is needed for an interactive dialogue". Recently reference models have been used to define the major components of accessible icons [2], organizing ergonomic and user interface standards [3], [4], and to evaluate the accessibility of systems [5].

## 2. ASPECTS OF INTERACTION OBJECTS

Figure 1 (based on Figure 1 from ISO/IEC 19766 [2] also created by this author) presents a high level framework for modeling tactile and haptic objects. It shows that there are four major interacting aspects that need to be considered in design: the *identity* of the object, user-*information attributes* that describe the object, *representation attributes* that are used in rendering the object, and *operations* performed on the object. It also recognizes that these objects are often located and used within a group, rather than just used individually, and therefore involve group level operations.

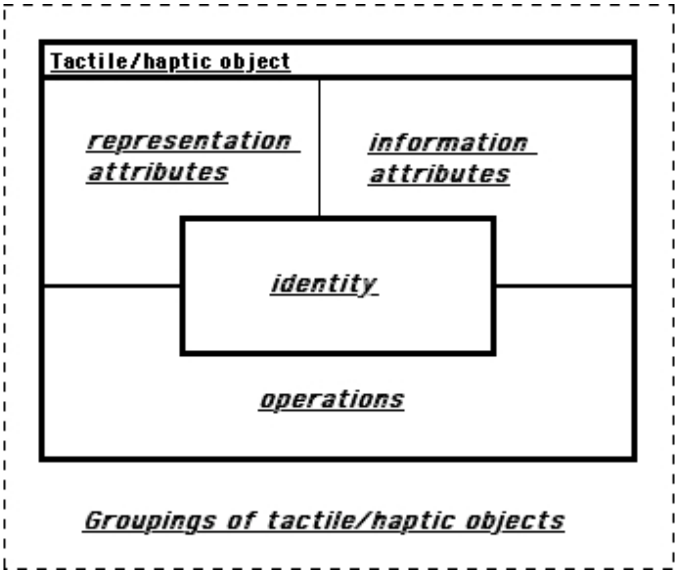

**Figure 1. The main aspects of tactile and haptic objects**

Figure 2 provides a detailed framework for understanding tactile and haptic objects that expands each aspect (identify, description attributes, representation attributes, and operations) into a number of specific components. This paper discusses each of the components and why it is important for evaluating and designing individual tactile or haptic objects and groups of such objects.

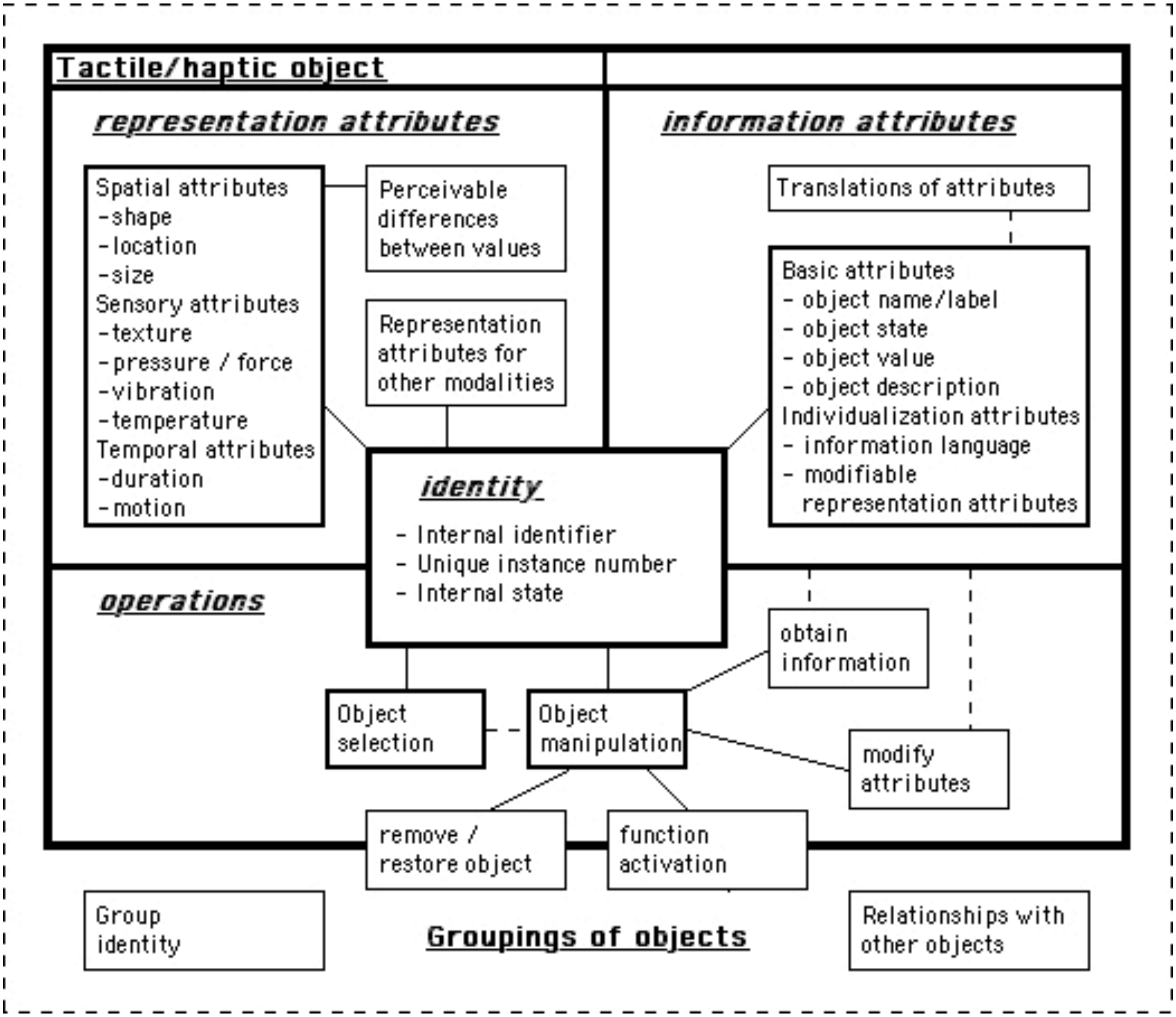

**Figure 2. A Tactile/Haptic Interface Object Reference Model**

## 3. OBJECT IDENTITY

All objects in a system require unique identities to provide the controlling software with the ability to recognize and distinguish between objects. They also can support alternate media renderings of an object, including renderings by assistive technologies. These identities are not intended for direct use by end users, who should interact with the other object attributes and operations. Object identities involve both an internal identifier and a state specification.

### 3.1 Internal Identifier

An internal identifier is a machine readable code that uniquely identifies the functionality that the tactile/haptic object represents. It identifies a class of objects that have either been defined by some international or national standard or that have been defined within an organization or a particular application.

It is expected that GOTHI-05 will start the identification of tactile and haptic interaction objects that are candidates for standardization in order to improve the compatibility of interactions across interfaces, applications, and systems. Use of this reference model will help to ensure that the resulting standards provide sufficient information to ensure the consistent application of these standards across applications. It is further expected that these standards will define unique object (type) identifiers in accordance with ISO 11580 [4] to allow for the automated identification of objects by assistive technologies.

### 3.2 Unique Instance Number

It is possible for a number of the same type of tactile/haptic objects to be used within an application. Each specific instance of an haptic/tactile object in an application can be identified by a combination of the object's internal identifier and a unique instance number. The instance identifier can be used to distinguish between multiple instances of the same type of haptic/tactile object within an application.

## 3.3 State

Many objects behave differently depending on the current state of the object. Recognizing the significance of an object, therefore, requires recognizing both the object and the current state that it is in. Some states of controls include but are not limited to: available, selected, and unavailable. Sub-states may also be relevant, for example: selected and ready for input, selected but read-only. Some states of data containers include but are note limited to: system stored value not available for input; system stored value available for new input; and user entered value not yet stored by system.

An object's state can be based on one or more attributes of the object and/or the environment in which the object occurs. It is expected that future standards for tactile and haptic objects will define applicable object states in accordance with ISO 11580 in a manner that will support the automated identification of the state by assistive technologies.

# 4. INFORMATION ATTRIBUTES

Information attributes are intended to assist the user in finding out about the object. Information attributes are defined as text attributes so that they can be formatted and presented to the user via the widest possible variety of media / modalities. The basic set of information attributes includes a name/label, an object state, an object value and an object description. Additional information attributes that support individualization of objects can include: the default language that is used for the information attributes, information on the adjustable representational attributes of the object and translations of one or more other information attributes. Depending on the application, some or all of the information attributes of an object may be user modifiable. This is most likely for the object value and some or all of the representational attributes.

## 4.1 Object Name / Label

Object names / labels are short names that can be used by the user to identify and/or interact with an object. Each name / label needs to be unique within the context in which it is used. NOTE: this is the external, user accessible counterpart to the state that is part of the internal identify. Default object names / labels may be defined in various object information languages. However, it is acceptable for the user and/or the developer to customize an object name / label for use in a specific context of use.

Object labels may be presented as part of the object, on demand to supplement the object, or on their own in place of the object. Where labels are presented, users and assistive technologies should be able to use the label for interaction in a manner that is similar to interacting with the main object. The presentation and use of labels should be consistent for all tactile/haptic objects within a group.

## 4.2 Object State

All objects, regardless of whether they are controls or data containers have states. (Data containers are either able to be used for input or not.) Information about the state of an object is the first component of an object value. The value of the state is not directly user modifiable, since it results from the object's reaction to various other user operations. NOTE: this is the external, user accessible counterpart to the state that is part of the object identify and can be generated automatically from it.

## 4.3 Object Value

Tactile/haptic objects that contain data have an object value that is a textual representation (or equivalent) of the data they contain. Because not all objects contain data, information about the value of the data contained is the second (and optional) component of an object value.

## 4.4 Object Description

Object descriptions are textual information that is presented on demand to provide further elaboration on the purpose and/or use of a tactile/haptic object. The specific contents of descriptions may very between applications. Standardized tactile/haptic objects should have standardized descriptions that will be included in, but need not be the entirety of, the object description used by an application.

## 4.5 Object Information Language

The object information language is the default natural language used for storing and presenting information attributes. This provides a basis for understanding and translating information attributes. Different objects can be presented in different languages, where appropriate.

Changes to the object information language used to present the object value of a tactile/haptic object should not change the actual internal representation of that data but only be used to facilitate its translation.

Object information language only applies to the language used for textual representation of information attributes. Any language(s) involved in the encoding via shape of the object are dealt with as part of the spatial representation attribute dealing with the object's shape.

ISO 639-2 [10] describes a three-character code set identifying approximately 400 individual languages.

## 4.6 Modifiable Representation Attributes

The main purpose of representation attributes (as discussed below) is to convey information about the identity and values of an object to the user in a tactile/haptic manner. This purpose is already served by the object label and object value. However, there is a need to be able to access information about the particulars of representation attributes when these attributes are subject to modification by the user. In order to be available to assistive technologies, there is a need to provide textual information on representation attributes.

## 4.7 Translations

All information attributes may be translated to provide cultural and linguistic accessibility to tactile/haptic objects they relate to. Where explicitly developed, these translations can be stored with a tactile/haptic object as optional additions to the set of information attributes. This should not preclude the ability to create automatic translations where standardized translations have not been explicitly developed and stored.

# 5. REPRESENTATION ATTRIBUTES

Representation attributes identify the various properties of a tactile/haptic object that the user is intended to physically perceive, including (but not limited to): the identity/name of the object, the state of the object, and/or the data value of the object.

Representation attributes involve both the tactile/haptic coding of objects and additional attributes containing requirements for perceptual differences between various instances of this coding. Tactile/haptic coding can subdivided into: spatial attributes, physical attributes, and temporal attributes, each of which can be further subdivided.

This framework recognizes that it is possible to develop alternate representations (e.g. icons) for tactile/haptic objects that can be used in non-physical media. Such representations could be stored with an object as optional additions to the set of representation attributes. However, the current focus is only on the tactile/haptic representation of objects.

## 5.1 Spatial Attributes

All tactile/haptic objects involve the spatial attributes of: shape, location, and size. Each of these attributes also exists for visual/graphic forms of interaction. Encodings used for these attributes should be consistent across all media where they apply.

Shape is the most commonly used representational attribute. Simple shapes (e.g. circles, rectangles, etc.) are often used to distinguish a particular type of object from other types of objects (e.g. to distinguish control "buttons" from data entry "boxes"). Abstract and/or complex shapes (e.g. Braille characters) that are recognizable by their intended users may used for specific objects (e.g. particular characters in a specific language).

Location and size may be specified in absolute and relative terms. Their absolute specification can either be used to permanently anchor objects within space or as default values that the user and/or system can restore. Relative specification can be used to maintain relative position and size of an object in relation to other objects (or groups of objects) when part or all of an interface is scaled in size.

Location within a group of objects can be based on various meanings. ISO 9241-14 [6] provides recommendations on ordering menus and ordering items in a menu. ISO 14915-2 [7] provides recommendations on the use of various semantics for structuring content. Similar semantics may also be used to assign a semantic meaning to different sizes of objects.

ISO 1503 [8] provides guidance on the design and use of spatial orientation of objects relative to the user.

## 5.2 Physical Attributes

Whereas, spatial attributes can be conveyed just as easily via graphical media, physical attributes make use of the unique aspects of touch in tactile/haptic interactions. Physical attributes that may be used for coding include: texture, pressure/force, vibration, and temperature. Each of these physical attributes may or may not be present in tactile/haptic objects. Where they are used for coding, their absence may convey information in the same way that their presence does.

While each of these attributes is often used to provide realism, they may also be used to encode other types of information. Because of their unique applicability to tactile/haptic interactions, there has yet to be any standardization of how they are used to encode information.

It is expected that GOTHI-05 will provide further guidance on the organization and use of physical attributes.

## 5.3 Temporal Attributes

There are many temporal aspects that may be involved in a tactile/haptic interface. Temporal attributes used for coding include: duration and motion.

Duration is most obvious in real time interactions, where the duration of a tactile/haptic object should be directly related to its relevance to the real time scenario in which it is used. Duration is also important for the use and reuse of tactile/haptic objects, such as the presentation of a sequence of Braille characters by a single object. In both cases there is a need for the duration to be of sufficient length for the user to perceive and act upon the object. Likewise, there is often a need for an inactive spacing between co-located objects or values of objects to ensure that the user recognizes the differences between them.

Motion involves changes in location and/or other spatial and/or physical attributes over time. It can be realistic motion or motion that is intended to represent/code a particular piece of information (such as to draw the user's attention to some area of the interface).

ISO 14915-2 [7] provides general guidance on the use of temporal issues in the design of controls and especially links. ISO 9241-171 [9] provides guidance on the accessibility of temporal objects.

## 5.4 Perceptual Differences

Spatial, physical, and temporal encodings may be less clearly distinguishable from one another than letters and numbers appear to be when they are presented visually in a clear typeface. There is a need to ensure that any spatial, physical, and/or temporal encoding is perceivable on its own and from similar encodings that represent different values of objects. There is a further need to use this information to warn / guard users against modifying the values of these attributes in a manner that would make resulting objects or object values indistinguishable.

Different attributes have different needs in terns of what a perceptual difference is. In some cases, such as shape differences, these differences need to be determined outside the system and implemented as a list of distinctive values (shapes). In other cases, differences can be specified numerically in terms of a fixed interval between values, or in terms of one value being some percentage grater than the preceding value, or in some combination of these two concepts.

Perceptual differences in one attribute may also be influenced by the values of other attributes used in combination with that attribute. Additionally some users may have disabilities which will make selected spatial, physical, and/or temporal encodings difficult or impossible for them to perceive.

There is a need for standardized guidance in the area of utilizing perceptual differences in determining appropriate spatial, physical, and tactile encodings.

## 5.5 Combinations

Combinations of spatial, physical, and temporal attributes can be used: to encode different types of information, to redundantly encode the same information, or in combination together to determine the unique encoding of a single piece of information.

It is important that different representational attributes be used consistently and unambiguously throughout an application. This includes their use within combinations.

Because of the vastness of possible combinations, it is not anticipated that detailed guidance will be forthcoming to guide developers in the specific use of different combinations of representational attributes. However, some specific combinations may become de facto standards over time and thus become candidates for specific standardization.

# 6. OPERATIONS

This model separates object selection from various forms of manipulation (including: activating functions, inputting values, obtaining information, and removing/restoring the object) to provide the user with an appropriate level of controllability and thus to increase accessibility.

## 6.1 Object Selection

Object selection is considered a separate operation in this model in recognition of its common prerequisite to other operations. In practice, object selection takes place when a user moves some body part (or prosthesis) to a position where interaction with a specific object is possible.

Where a user makes use of vision to select tactile/haptic objects this is a trivial operation that does not require computer support. However, in some circumstances the user needs to be able to tactilely move across a number of objects to the intended object, without inadvertently activating or otherwise manipulating the objects moved across. Achieving this requires a separate computer operation for selection, so that only intentional manipulations are performed.

## 6.2 Object Manipulation

Tactile/haptic object manipulations include: obtaining (outputting) information, modifying (inputting) attributes, activating processing functions, and removing the object from / restoring the object to the interface. This framework recognizes that there may be various versions of some of these manipulation operations.

### *6.2.1 Obtain Information*

Operations for obtaining information about an object allow a user to find out about the object without activating it. Since there are various types of information about a tactile/haptic object that could be obtained, obtaining information involves determining the desired information attribute(s) and presenting it/them in the desired object information language.

There are a various possible implementations that could be used for determining the desired information, including: using a pre-selected default, having the user select from a list, or using separate operations to obtain each type of information. If pre-selected defaults are used, they need to be user modifiable (as discussed in the previous operation).

The presentation of information about a tactile/haptic object (in response to an obtain information operation) should not get in the way of the user activating the object. Since information attributes are stored in text format, they can be rendered in various modalities. The modality used for presenting information attributes may be based on a user modifiable default.

The method used for obtaining information about tactile/haptic objects and the modality for presenting this information should be consistent for all tactile/haptic objects within an application.

### *6.2.2 Modify Attributes*

Modifying operations can be used to modify the value of a tactile/object object or to modify other attributes of the object. Depending on the needs of the application and the particulars of the implementation, these other attributes may include: representation attributes, default values for other operations, and the object information language.

The most common modifying operation is to modify the value of the tactile/haptic object. A specific "modify value" operation should be provided to easily modify the value of the object currently selected tactile/haptic object.

Since many other associated attribute values might also be modifiable, a separate "modify attribute" operation (or set of operations) should be used to allow the user to select which attribute is to be modified.

The methods used for modifying values and for modifying attributes should be consistent for all tactile/haptic objects within an application.

### *6.2.3 Function Activation*

Many tactile/haptic objects are used as controls that allow the user to perform particular functions. These controls require an unambiguous method of activating them that easily facilitates quick activation while it minimizes the possibility of accidental activation. Because activation is often not the only possible manipulation operation, this method may need to be separate from but work efficiently with object selection.

The demands of real-time applications (such as virtual reality) may require some controls to combine selection and activation into a single user action. In these cases, other forms of object manipulation need to be initiated externally to the tactile/haptic object that is to be manipulated. Such instances are not precluded by the model presented in this paper, since it focuses on different types of operations involving tactile/haptic objects without prescribing how they are implemented.

### *6.2.4 Remove / Restore Object*

Users may be provided the ability to remove or restore individual tactile/haptic objects within an interface. While removing can be implemented as an operation of the particular object, restoring has to be implemented at some level outside the object.

Other operations on a tactile/haptic object, including changing the position and size of an object may be meaningful (as discussed in spatial attributes) and thus should be handled as a form of modifying attributes.

## 7. GROUPINGS OF OBJECTS

Tactile/haptic objects may be organized in groups and thus be subject to various group level operations. In addition to identifying the group that a tactile/haptic object belongs to, there may be a number of attributes that describe the relationship (in terms of size, position, spacing, and interaction) with other members of the group. Reconfiguring the interface and/or activating a function may affect the group as well as an individual tactile/haptic object within the group, and thus these two operations are illustrated on the border between the individual object and the group of objects.

While this model recognizes the potential for groupings of tactile/haptic objects, it does not provide a detailed model of all of the attributes or operations involved in these groupings.

## 8. USES OF THIS MODEL

The reference model discussed in this paper can be used both to define unique tactile/haptic objects and to define tactile/haptic implementations of other objects (such as icons) which have been defined for other types of media. This model can be used to help improve the quality of tactile/haptic user interfaces, both indirectly, via standardization efforts, and directly, via implementation activities.

This model is intended to provide a comprehensive format that includes the major attributes and operations that should be defined within standardization efforts relating to tactile/haptic objects. It is compatible with and provides a unique tactile/haptic elaboration to ISO/IEC 11580. It is expected that standardized definitions of tactile/haptic objects based on this model will be placed in the ISO/IEC user interface object registry that will be developed to implement ISO/IEC 11580 compliant user interface object standards.

This model can also be used in the design and construction of instances of these objects. In addition to leading to the development of standardized tactile/haptic objects that they can directly implement, it provides developers with a framework to develop additional tactile/haptic objects that can be implemented (and documented) in a similar manner.

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

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## 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.

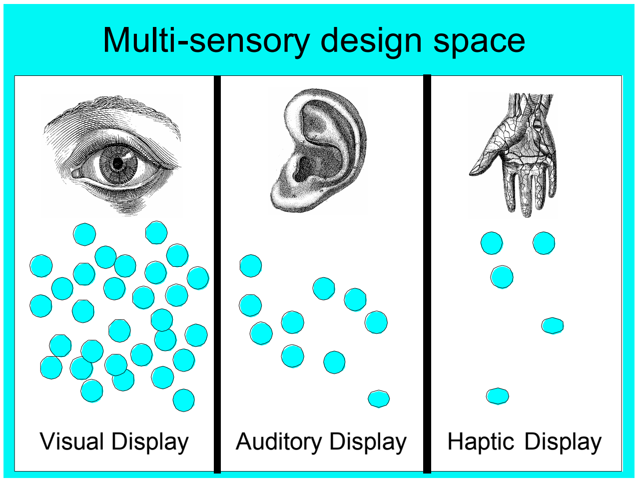

**Figure 1. A typical division of the multi-sensory design space is by sensory modality. Applications of information display then naturally fall into the specific groups focusing on visual, auditory or haptic display.**

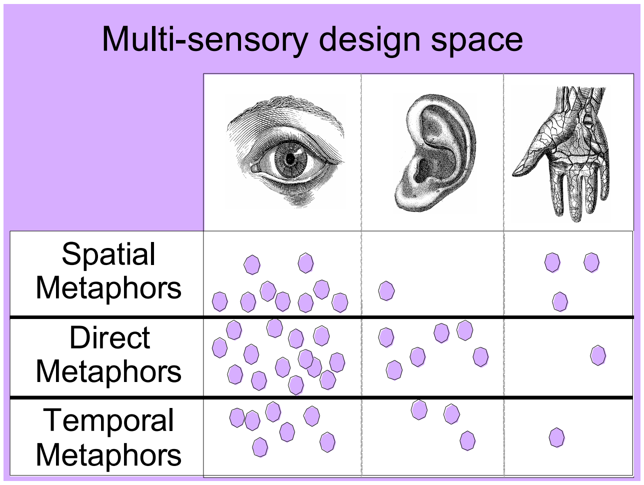

**Figure 2. A novel division of the multi-sensory design space using the types of metaphors that commonly occur in information displays. This division removes the accent on sensory modalities and allows comparison between senses.**

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.

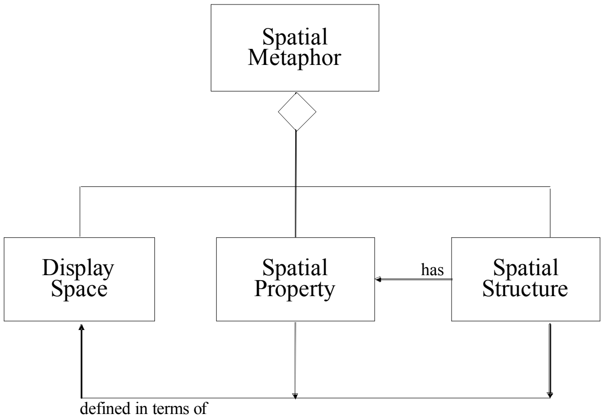

**Figure 3. A UML diagram showing the high-level components of spatial metaphors.**

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.

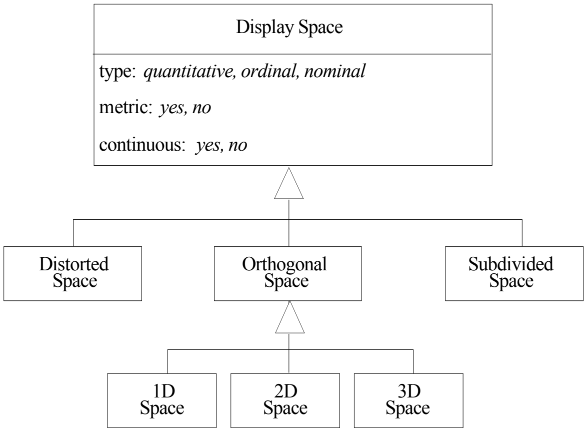

**Figure 4. The types of display space**

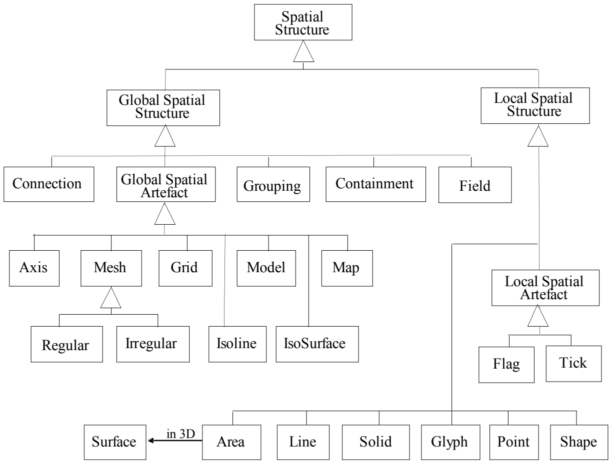

**Figure 5. The types of spatial structure.**

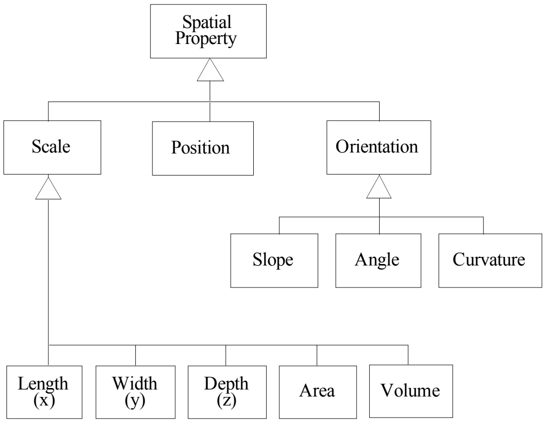

**Figure 6. The types of spatial properties.**

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.

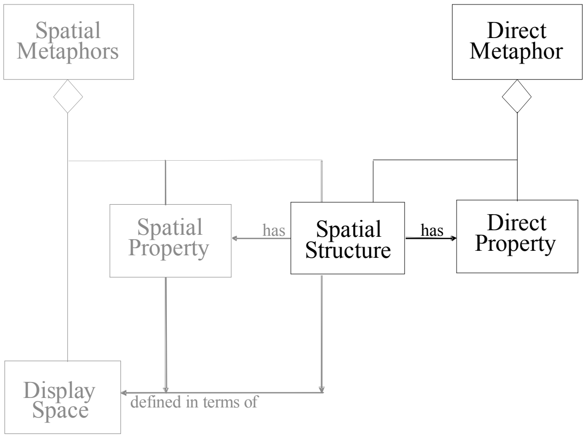

**Figure 4. The general concepts that describe Direct Metaphors. These concepts are very specific to the properties of the world that each sense perceives.**

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.

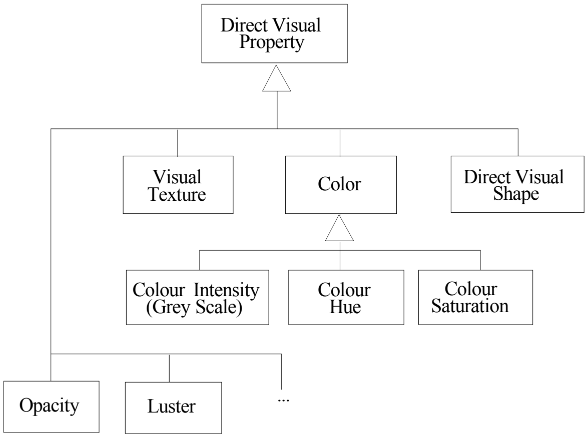

**Figure 5. Direct Visual Properties**

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.

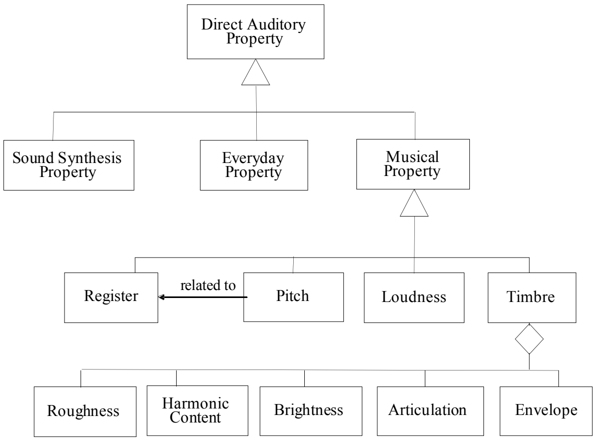

**Figure 6. Direct Auditory Properties**

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.

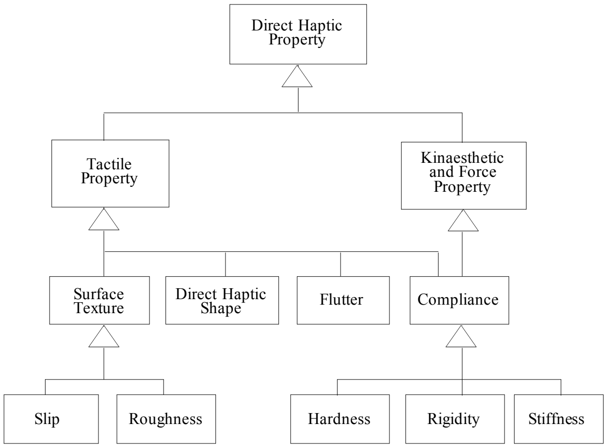

**Figure 7. Direct haptic properties associated with tactile stimuli**

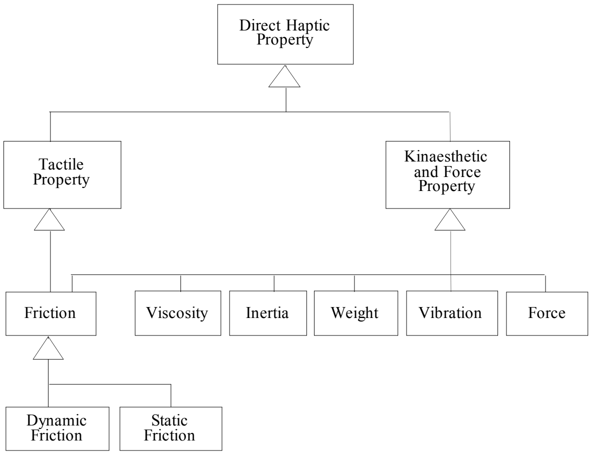

**Figure 8. Direct haptic properties associated with kinaesthetic and force stimuli.**

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)

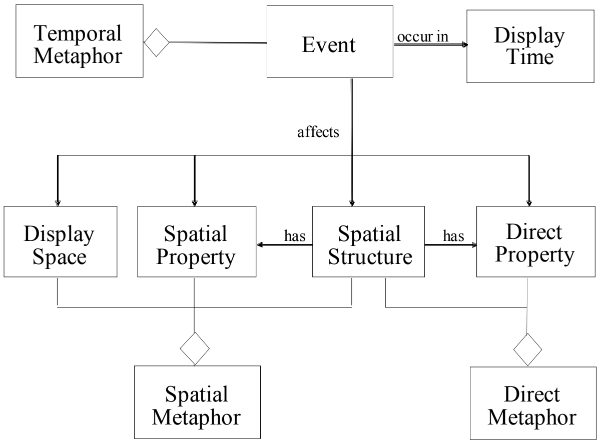

**Figure 9. Temporal metaphors are dependent on the perception of time and are characterised by events that modify spatial and direct properties.**

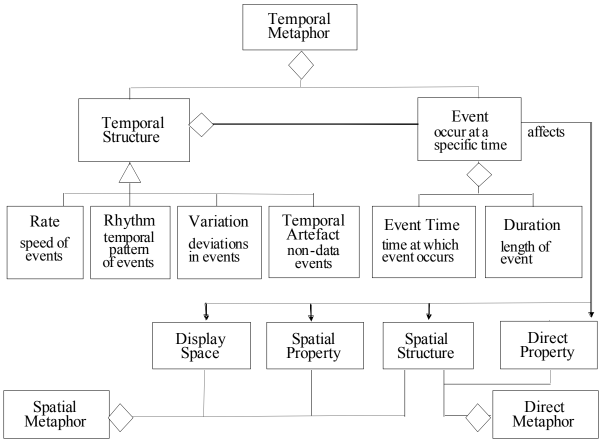

**Figure 10. Temporal metaphors are often composed of a number of events that have some temporal structure.**

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]

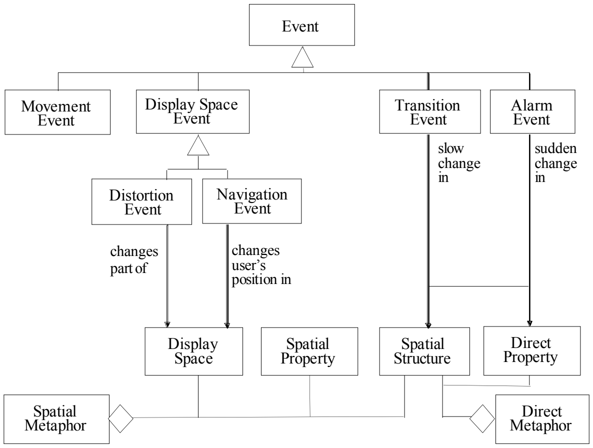

**Figure 11. The different types of events used to categorise Temporal Metaphors.**

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.

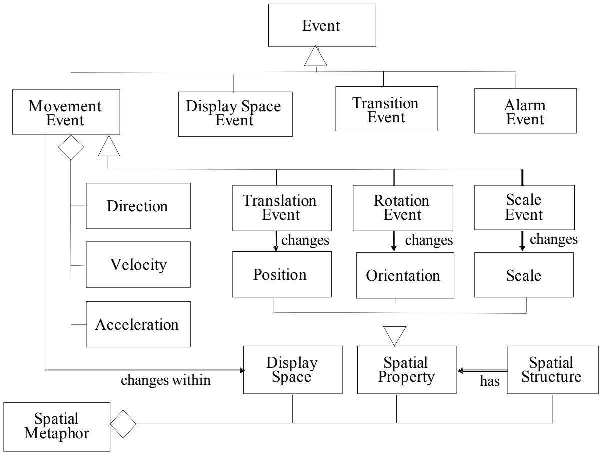

**Figure 12. Movement events may have properties of direction, velocity and acceleration. Movement events are defined in terms of the spatial properties of position and orientation**

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.

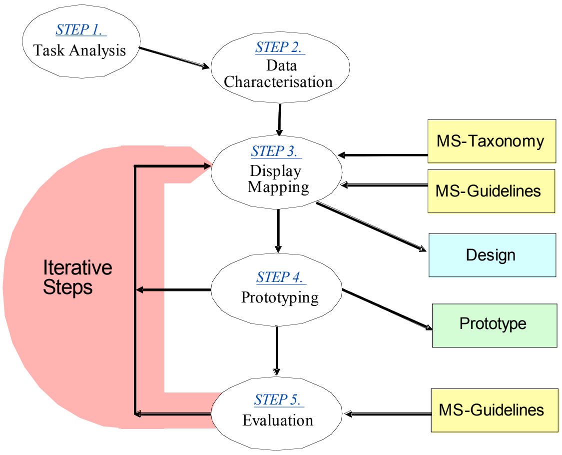

**Figure 13. A simple process for designers. The display mapping is structured using the MS-Taxonomy and guidelines support display mapping decisions and evaluation.**

**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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# 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<br>Guidelines for Spatial Auditory Metaphors<br>Guidelines for Spatial Haptic Metaphors |
| Guidelines for Direct Metaphors | |
| | Guidelines for Direct Visual Metaphors<br>Guidelines for Direct Auditory Metaphors<br>Guidelines for Direct Haptic Metaphors |
| Guidelines for Temporal Metaphors | |
| | Guidelines for Temporal Visual Metaphors<br>Guidelines for Temporal Auditory Metaphors<br>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.<br>GP-1.1 Neural maps assist spatial perception of touch and vision.<br>GP-1.2 Neurones respond to specific influences.<br>GP-1.3 There are parallel pathways of perception.<br>GP-1.4 Perception is influenced by individual physiology. |
| GP-2 Perception is approximate. |
| GP-3 Perception is influenced by cognitive processes.<br>GP-3.1 Perception is influenced by expectations.<br>GP-3.2 Perception is influenced by knowledge.<br>GP-3.3 Perception may be influenced by recognition.<br>GP-3.4 Perception is influenced by attention.<br>GP-3.5 Perception is influenced by context. |
| GP-4 Perception remains constant. |
| GP-5 Perception can be biased towards one sense.<br>GP-5.1 Attention can affect sensory bias.<br>GP-5.2 Learning can affect sensory bias. |
| GP-6 Perceptual responses have thresholds.<br>GP-6.1 Weber's Law<br>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.<br>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.<br>MST-1.1 Vision emphasises spatial qualities.<br>MST-1.2 Hearing emphasises temporal qualities.<br>MST-1.3 Haptics emphasises movement.<br>MST-1.3.1 Point force-feedback only provides temporal information.<br>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.<br>MST-3.1 Use complementary display.<br>MST-3.2 Avoid redundant display.<br>MST-3.3 Avoid conflicting display. |
| MST-4 Consider sensory substitution.<br>MST-4.1 Adapt spatial visual metaphors to spatial auditory metaphors.<br>MST-4.2 Adapt spatial visual metaphors to spatial haptic metaphors.<br>MST-4.3 Adapt temporal auditory metaphors to temporal visual metaphors.<br>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.<br>SH-3.1 Haptic feedback augments display of global visual models.<br>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.<br>SH-4.1 Visual shape overrides haptic shape.<br>SH-4.2 Visual size overrides haptic size.<br>SH-4.3 Visual orientation competes with haptic orientation. |
| SH-5 Haptic feedback provides information about position in space.<br>SH-5.1 Human spatial resolution is about 0.15mm.<br>SH-5.2 We lose track of spatial location.<br>SH-5.3 There is a spatial map in the cortex.<br>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.<br>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.<br>DH-1.1 The visual model affects the perception of haptic properties.<br>DH-1.1.1 Visual attention can affect the tactile response.<br>DH-1.2 The auditory model affects the perception of haptic attributes. |
| DH-2 Individuals have very different haptic perceptions.<br>DH-2.1 Use large differences to display categories. |
| **Force** |
| DH-3 Force is an ordinal property.<br>DH-3.1 The JND for force is about 7%.<br>DA-3.2 Force fields can display vector fields.<br>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.<br>DH-4.2 Visual surface texture affects haptic surface texture**.** |
| **Direct Haptic Shape** |
| DH-5 Direct haptic shape is a nominal property.<br>DH-5.1 Direct haptic shape is biased by vision.<br>DH-5.2 Visual shape recognition is faster than touch. |
| **Compliance** |
| DH-6 Compliance is an ordinal property.<br>DH-6.1 The JND of compliance depends on the type of surface.<br>DH-6.2 The visual model affects perceived stiffness.<br>DH-6.3 The auditory model affects the perceived stiffness.<br>DH-6.4 Fast haptic rendering is required for rigid surfaces. |
| **Friction / Viscosity** |
| DH-7 Viscosity is an ordinal property.<br>DH-7.1 The JND for viscosity is about 12%. |
| **Weight** |
| DH-8 Weight and inertia are ordinal properties.<br>DH-8.1 The JND for weight is 10-20%.<br>DH-8.2 Temperature of objects affects perception of weight.<br>DH-8.3 The visual model affects the perception of weight. |
| **Vibration** |
| DH-9 Vibration is an ordinal property.<br>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.<br>TH-3.1 Force feedback models should be simple.<br>TH-3.2 Very fast changes to force can be detected. |
| **Movement Events** |
| TH-4 Haptics is concerned with movement.<br>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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# Initiating Guidance on Tactile and Haptic Interactions

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## ABSTRACT

The Guidelines On Tactile and Haptic Interactions Conference (GOTHI-05) is the result of the realization of the need for the International Organization for Standardization (ISO) to standardize guidance on tactile/haptic interactions. This paper reviews existing international standards on tactile/haptic interactions and suggests ways to construct a relevant ISO standard. It proposes potential dimensions and boundaries for a future standard and provides a preliminary collection of draft tactile/haptic interactions guidelines based on available guidance.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*standardization*

## Keywords

Guidelines, haptic, interface, standards, tactile

## 1. BACKGROUND:

### 1.1 Initiating work on guidance on tactile and haptic interactions

Guidance on tactile and haptic interactions potentially fall within the scope of two committees of the International Organization for Standardization (ISO). ISO TC159/SC4 "Ergonomics of Human-System Interaction" has developed standards for various other modalities of human-computer interaction (especially for interactions using more traditional computer components such as displays, keyboards, and mice). ISO/IEC JTC1/SC35 "User Interfaces" has developed standards for various user interface elements (especially keyboards and icons). However, neither of these committees currently have any standards dealing with tactile and haptic interactions or the user interface components used for these interactions.

Serious consideration of the need for ISO to standardize guidance on tactile and haptic interactions began with the Canadian position on expanding ISO TS 16071 [12], which recognized that all types of media interactions need to be considered in order to support the widest possible accessibility [4]. This led to the creation of the Universal Access Reference Model [5], which provided a model for identifying, "guidance relating to channels (devices) not already covered in ISO TS 16071". As part of the process of expanding ISO TS 16071 into the international standard ISO 9241-171 [14], Fourney prepared a set of tactile and haptic guidelines on behalf of Canada [7]. These guidelines were largely adapted from ETSI EG 202 048 [6]. When the committee drafting ISO 9241-171 considered these guidelines they noted that they were not limited to accessibility issues and suggested that they be used as the basis of a new standard on tactile and haptic interactions.

At the 2004 meeting of ISO TC159/SC4, Canada proposed that work commence on a standard on tactile and haptic interactions. SC4 invited Canada to prepare a new work item proposal, which was prepared [18] and is currently out for international ballot. At the same time, Canada undertook to organize a conference, which has become GOTHI-05.

### 1.2 Existing guidance in International Standards

ISO TC159/SC4 is currently expanding the 9241 series of Ergonomics of Human-System Interaction standards. The original series contained 17 parts and was supplemented by a number of other standards including ISO 14915 [10, 11, 13] and ISO TS 16071. Of these various standards, only ISO 9241-9 [9] contained any guidance directly relevant to tactile or haptic interactions. This guidance is contained in a set of, "basic ergonomic principles that apply to all input devices." These principles are:

- operability (obviousness, predictability, consistency, compatibility, efficiency, effectiveness, feedback, satisfaction);
- controllability (responsiveness, non-interference, grip surface, device access, control access); and
- biomechanical load (postures, effort, user training).

There is a notable lack of recognition of tactile or haptic interactions in ISO 14915-3 [11] which deals with "media selection and combination" only in terms of audio and visual media.

The new, considerably expanded, structure for the ISO 9241 series was also created without an explicit location for tactile or haptic guidance. It has maintained the previous differentiation between software standards (now the 100 series of parts), input devices (now the 400 series of parts), and display hardware (now the 300 series of parts). However, the new structure of the ISO 9241 series is expandable to allow for future additions that hopefully will include the newly proposed work on tactile and haptic interactions.

As parts are developed for this new structure, there is an increasing awareness of the need to consider all possible types of modalities. In part 171 (which will replace 16071) there are now 3 tactile/haptic specific recommendations. Other recommendations in part 171 have been worded or given specific examples so that they apply to all modalities of interactions, including tactile and haptic interactions. In part 400 [15], the part 9 principles, which are worded as general guidance for developers, are reworded to make them requirements that must be complied with by developers.

While the focus of ISO TC159/SC4 is on the ergonomics of interactions, ISO/IEC JTC1/SC35 focuses on standard elements of these interactions. In addition to the new work item being balloted by SC4, there is the potential for SC35 to become involved in defining the syntax and semantics of particular tactile or haptic elements that would be widely used to present defined types of information in a standardized manner or to act as standardized controls.

ISO/IEC JTC1/SC35 does have two standards that can provide models which can be adapted to describing tactile and haptic interactions, a new work item that provides a format for describing user interface objects, actions, and attributes [3] and a framework for designing accessible icons [19].

Although ISO is the senior of all international standardization organizations, there are many other international organizations, fora, and consortia involved in developing standards for their members and for the general public. ETSI 202 048, as already discussed, is a major source of useful guidance.

Two additional sources of potential guidance were examined because of their potential impact on any resulting tactile / haptic standard. Section 508 of the US Rehabilitation Act [1] is increasingly being used as a de facto standard for accessibility expectations. However, despite the importance of tactile and haptic assistive technologies, it does not provide any guidance on this area. Part 1193 of the U.S. Telecommunications Act contains much more detailed guidance than Section 508, including various guidelines relating to tactile and haptic interactions [2].

## 1.3 Creating a draft standard

Section 2 of this paper presents a brief summary of different dimensions of analysis that could be used to construct a reference model. It also includes a subsection of existing and potential definitions that should be considered.

Section 3 of this paper presents an initial collection of potential guidance, based on the guidance available from the international standards identified above. Individual guidelines were extracted, combined with similar guidelines, reworded for consistency and to meet ISO wording expectations, and structured in the format of an initial working draft of a potential standard. Additional descriptive text (that would be included in a standard) and comments (included only for readers of this paper) were added to clarify the resulting draft.

Our initial starting point for organizing this guidance was the "topics of interest" in the GOTHI-05 call for participation. The contents of the "topics of interest" structure were primarily intended to help encourage contributions to the conference, which is intended to develop a more suitable structure. We have modified this structure, where necessary, to better contain the available guidance and potential further guidance. We have not made major revisions to the structure, since the final structure to be used for the standard will need to take into account all the guidance that it will contain.

# 2. ESTABLISHING THE BOUNDARIES AND BASIS FOR STANDARDIZATION

Detailed guidelines need to be substantially complete and consistent to be useful. This section identifies three high level components (reference models, a scope, and a set of definitions) of a possible tactile and haptic interaction standard that can help ensure a reasonable level of completeness and consistency and can aid developers in applying detailed guidelines. While we deal with reference models before the other two, a formal ISO standard would deal with reference models after scope, normative references, and definitions.

## 2.1 Reference models

Reference models can help ensure that a standard or set of standards cover the breadth of their intended scope and can identify the main terms requiring definition. Lynch and Meads advocated the use of reference models of human computer interactions as a basis for the development of standards. They state that a reference model should, "provide a generic, abstract structure which describes the flow of data between the user and the application, its conversion into information, and the auxiliary support which is needed for an interactive dialogue" [21].

### *2.1.1 Interfaces*

According to ISO 9241-400, interfaces can be considered in terms of the, "bodily part used for operation." It identifies the following types of controls, which it uses, "to group the provisions for certain types of input devices":

- Hand and finger controlled,
- Foot controlled,
- Speech controlled,
- Eye controlled,
- Motion controlled.

While ISO 9241-400 chose this model to use, we do not recommend it as the main basis for understanding tactile or haptic interactions. This model violates a number of accessibility considerations. It assumes a user with no disabilities and an environment with no handicaps, and does not consider substitution of one body part for another. It also does not model the total capacity for a given user to interact with multiple different tactile or haptic controls at one time.

### *2.1.2 Interactions*

ISO 9241-400 identified a "typology by task primitive" that is helpful for classifying different interactions, regardless of how they are instantiated:

- Code entry,
- Pointing,
- Dragging,
- Selecting,
- Tracing.

ISO 9241-9 also contains guidelines relating to the following interactions: anchoring, resolution, repositioning, and button activation.

ISO/IEC 19766 defines a similar set of interaction primitives:

- Icon selection (comparable to pointing in ISO 9241-400)
- Icon manipulation
  - Move icon (comparable to dragging in ISO 9241-400 and anchoring and repositioning in ISO 9241-9)
  - Remove / restore icon

    - Obtain description
    - Modify pallet
    - Select language
    - Other manipulations
- Function activation (comparable to selecting, code entry, and tracing in ISO 9241-400 and button activation in ISO 9241-9)

The ISO/IEC 19766 set of interaction primitives identifies the need to go beyond the ISO 9241-400 set. By comparing the 19766 set with guidelines in Section 3 of this paper, we can suggest that:

- "Remove / restore icon" suggests reconfiguring a tactile / haptic interface.
- "Obtain description" suggests obtaining the description of a tactile / haptic control without activating it.
- "Modify pallet" and "Select language" suggests modifying the parameters used for tactile / haptic objects (including resolution in ISO 9241-9).

We believe that it is important to be able to distinguish between different types of interactions. Further investigation is required to identify the optimal classification of different types of interactions.

### *2.1.3 Encodings*

ISO 9241-400 identified two aspects of encoding information; a "typology by the property sensed":

- Pressure,
- Motion,
- Position;

and a "typology by number of degrees of freedom":

- Single dimension,
- Two dimensions,
- Three dimensions.

ISO 9241-9 also contains guidelines relating to the following encodings: button force, button displacement, consideration of handedness, pressure points, signal speed, stability, surface temperature, weight, and gain.

An examination of the guidelines in Section 3 of this paper shows that both time and changes over time are not covered by the various topologies presented in ISO 9241-400. Further investigation is required to identify the optimal classification of the different types of encodings.

### *2.1.4 Using the ISO/IEC format for describing user interface objects, actions, and attributes*

The ISO/IEC JTC1/SC35 new work item on a format for describing user interface objects, actions, and attributes combines both interactions and encodings. It also provides for translation between tactile/haptic modalities and other possible modalities and for discussing permissible variations that still satisfy the standard. This format can be summarized in terms of:

- Identification
    - External label
    - Internal identifiers
- Interaction
- Representations (encodings)
    - Graphic representation
    - Tonal representation
    - Tactile and Haptic representation
- Variations

We suggest that this format be used as the basis for organizing a reference model for tactile and haptic interactions, which takes into account the other models discussed above.

## 2.2 Scope

An international standard requires a scope statement. The new work item proposal for Guidance on Haptic and Tactile Interactions [18] includes the following initial scope statement:

> *This standard will contain ergonomic requirements and recommendations for haptic and tactile hardware and software interactions. It will provide guidance related to the design and evaluation of hardware, software, and combinations of hardware and software interactions. It will include guidance on:*
>
> - *the design/use of tactile/haptic inputs, outputs, and/or combinations of inputs and outputs, including:*
>     - *general guidance on their design / use*
>     - *guidance on designing / using combinations*
>     - *use in combination with other modalities*
>     - *use as the exclusive mode of interaction*
> - *the tactile/haptic encoding of information, including:*
>     - *textual data*
>     - *graphical data*
>     - *controls*
> - *requirements placed on users of tactile / haptic interfaces*
> - *customization and adaptation of tactile / haptic interfaces*
> - *temporal issues with tactile / haptic interfaces*
> - *application dependent issues with tactile / haptic interfaces*

## 2.3 Definitions

There is a notable lack of ISO definitions of "tactile" and "haptic" interactions. Many aspects of tactile / haptic interactions are described in the various models discussed in Section 2.1, but are not officially defined in the definition sections of applicable standards. It will be essential to provide a suitable set of definitions for the new standard.

There are relatively few ISO definitions that provide the basis for a standard on tactile and haptic interaction. ISO 14915-3 provides definitions of a static medium and a dynamic medium, which could be involved in defining tactile and haptic media. ISO 9241-9 and 9241-400 provide definitions of kinaesthetic feedback and resolution/resolving power. ISO 9241-400 provides additional definitions of tactile feedback and reach envelope.

## 3. DRAFT GUIDELINES

The following guidelines are based on existing guidelines we have found in major international sources. We have refrained from adding guidelines not based on major international sources, even where we clearly recognize the need for such additional guidelines.

## 3.1 Tactile/haptic inputs, outputs, and/or combinations

### *3.1.1 General guidance*

#### *3.1.1.1 Provide information on tactile elements*

"Where tasks require access to the visual content of user interface elements beyond what a label provides, software should provide user interface element descriptions stored as accessible text, that are meaningful to users, whether those descriptions are visually presented or not" [14].

#### *3.1.1.2 Provide navigation information*

The system should provide navigational information support to assist users in navigating haptic space [6, 7].

NOTE: Providing navigational information keeps users from becoming "lost in haptic space".

Rationale: Different users may have differing mental models of how the virtual space is defined and what part(s) of the tactile device is "touching" a virtual object [6].

#### *3.1.1.3 Safeguard accessibility features*

"Inadvertent activation or deactivation of accessibility features should be prevented." [14]

#### *3.1.1.4 Provide undo or confirm functionality*

"A mechanism should be provided that enables users to undo at least the most recent user actions and/or confirm that action" [14].

### *3.1.2 Guidance on combinations of inputs and outputs*

Our review of current standards did not reveal any guidance regarding combinations of inputs and outputs. Guidance on input/output combinations is considered important because of the several instances where tactile/haptic devices can be seen as both a mechanism for information output as well as input. For example, Braille personal digital assistants (e.g., BrailleNote) often combine tactile input and output.

### *3.1.3 Guidance on combinations with other modalities*

#### *3.1.3.1 Provide alternative text input*

"Software shall enable users to perform all input functionality, including navigation, using only non-time dependent keyboard (or keyboard equivalent) input." [14]

"Exception: Input that requires analogue, timed movement (such as watercolor painting where the darkness is dependent on the time the cursor spends at any location.)" [14]

#### *3.1.3.2 Provide alternative text output*

"Electronic text should be provided explaining the pattern used for tactile output presentation" [14].

"NOTE In contrast to visual and acoustic output presentation for tactile output only a few sets of symbols are standardized (e.g. Braille-code in several versions)" [14].

#### *3.1.3.3 Provide alternative input strategies*

The system should enable users to accomplish the same function in multiple ways including at least one method not requiring fine manipulation skills on the part of the user [2].

Rationale: The most efficient, logical or effective input/control mechanism for a majority of users may be difficult, if not impossible, to use by individual users with certain disabilities.

#### *3.1.3.4 Provide additional information to support exploring complex objects*

When haptically exploring a complex object users should be enabled to explore the complex object using information provided by other media [6].

NOTE: Multimedia information may be required to give a sense of complex objects and what they mean.

Rationale: Users may not understand complex objects from purely haptic information [6].

#### *3.1.3.5 Exploration of complex objects*

Complex objects made up of component objects have very small spaces between them into which the haptic pointer may slip. The system should either: a) prevent the haptic pointer from slipping into such spaces, or b) enable users to easily move the pointer from the gap to continue to explore the next component object [6].

NOTE: Users may be confused when finding unexpected gaps in objects.

## 3.2 Tactile/haptic encoding of information

### *3.2.1 General encoding guidance*

#### *3.2.1.1 Use familiar encodings*

"Well known tactile patterns (familiar in daily life) should be used for presenting tactile messages." [14]

"NOTE: A person without special knowledge in tactile coding (e.g. like Braille-code, Morse-code etc.) will be mostly well experienced in tactile patterns of daily life" [14].

#### *3.2.1.2 Make tactile messages self-descriptive*

Tactile messages should be self-descriptive. Self-descriptiveness is described in ISO 9241-110 [16].

Rationale: Generally, people are not familiar with the tactile signals used in human computer interaction. Most users experience low tactile continuity (i.e., they do not experience tactile signals continuously), limiting their opportunities to learn the meaning of tactile messages. This means that tactile messages must, if at all possible, be self-descriptive [6, 7].

#### *3.2.1.3 Mimic the real world*

To the extent possible, tactile messages should mimic the real world [6, 7].

NOTE: In the real world, touch is used to perceive: mass, size, structure, resistance, pressure, orientation, edges, etc.

#### 3.2.1.4 Virtual objects need not follow the laws of physics

Where the task allows, virtual objects need not follow the same laws of physics as real objects. However, the physics utilized should a) remain consistent throughout the application and b) be made explicit to the user [6, 7, 14].

EXAMPLE Users can push through the surface of an object.

NOTE: Current technological constraints mean that virtual objects may not be able to simulate all aspects of their real world equivalents [6, 7].

#### 3.2.1.5 Combining multiple tactile components

Well-known, meaningful components should be used when composing complex tactile messages [6, 7].

NOTE: Combining different vibro-tactile signals may unintentionally alter the percept. This is analogous in the physical world to combining two waves, as their sum is out of phase with the original waves.

### 3.2.2 Spatial Encoding

Spatial encoding applies to both tactile and haptic devices. Spatial encoding refers to the identity of activated sensory receptors.

Major concepts in the spatial encoding of tactile/haptic interfaces include apparent location, apparent position, and apparent motion. Tactile illusions can be used to either help or mislead users when using tactile/haptic interfaces. Each of these concepts use tactile illusions to help the user perceive information correctly.

*Apparent location* is a tactile illusion used to indicate direction in a tactile display [24]. It is caused when the percept of a single stimulus is induced by the simultaneous activation of two stimuli to different locations. The apparent location is perceived to be in between the two stimulus locations and depends on the relative magnitude [6, 24].

*Apparent position* maintains relative position within a scaled environment. This includes environments where spatial resolution is enlarged to create a more acceptable tactile illusion for the user [24].

*Apparent motion* refers to a set of tactile illusions that can be used to indicate movement in a tactile display. Apparent motion occurs when tactile stimuli are sequentially presented to two or more points on the skin with a certain inter-stimulus timing such that a single stimulus is perceived to move continuously from one point of stimulation to the next. One example is the tactile illusion known as the *cutaneous rabbit effect* where a properly timed and distributed train of taps creates the illusion of a phantom tap ‘hopping’ between two or more points on the skin [8].

Although perceptual illusions are used in tactile displays, care must be taken since, if stimuli are presented too closely in time and space, the intended percept may be altered and possibly result in a completely new unintended percept.

#### 3.2.2.1 Higher resolution can be allowed for trained users

Where the task allows, displays designed for trained or expert users, may use higher density of stimuli [6, 7].

#### 3.2.2.2 Virtual object dimensions can differ from real world dimensions

Where the task requires users to perceive size accurately, scaling may be used such that the size of a virtual object differs from its real world dimensions [6, 7].

Rationale: Research suggests that users a) perceive the sizes of larger virtual objects more accurately than those of smaller virtual objects and b) feel virtual objects to be bigger from the inside and smaller from the outside. This suggests that, if a task requires users to perceive size accurately, an object’s virtual representation may need to deviate from its real-world dimensions [6].

#### 3.2.2.3 Virtual object shape

Our review of current standards did not reveal any guidance regarding virtual object shape.

#### 3.2.2.4 Use distal body parts if a high spatial resolution is required

Where high spatial acuity is needed, the system should only interact with the distal body parts [6, 7].

EXAMPLE: A refreshable Braille display uses spatial location as an important parameter in design.

Rationale: Tactile display designs may rely on spatial location as an important parameter. Research suggests that where cortical representation of the skin is great, tactile acuity is fine [26]. Thus, only the distal body parts (e.g., the fingers, the toes) will suffice for designs requiring high spatial acuity.

#### 3.2.2.5 Use of apparent location

Where the task requires access to a greater number of stimulus sites without increasing the number of actuators, apparent location may be used [6, 7].

#### 3.2.2.6 Keep apparent location stable

When using apparent location, both stimuli should be in phase to evoke a stable apparent location [6, 7].

#### 3.2.2.7 Use of apparent position

Apparent position may be used to enlarge the spatial resolution [6, 7].

NOTE: Use of apparent position is questionable where the density of actuators is close to the spatial acuity.

### 3.2.3 Sensory Encoding

Sensory encoding applies to both tactile and haptic devices. Two major concepts in this section require definition: a) intensity and b) subjective magnitude.

*Intensity* refers to the magnitude of force or energy used per unit of surface, charge, mass, or time. It is analogous to the acoustic notion of volume — the greater the intensity, the “louder” the experience of the stimulus.

Different users have different experiences of magnitude. The concept of *subjective magnitude* captures this. Subjective magnitude is a “scale” based on a user’s estimation of their experience of actual magnitude. It can be defined as a non-linear function of amplitude [6]. For a given individual, this scale may change with each experience of the tactile device as well as over the duration of the device's use.

#### *3.2.3.1 Enable users to easily discern different simulated textures*

The system should enable users to easily discriminate between different simulated textures [6, 7].

NOTE 1: Different users have different experiences of a tactile texture, physical variations in roughness are not always easily detected or discriminated from one another.

NOTE 2: Different users have different experiences in their perception of texture, both in the degree of the differences they can detect and in the way they feel textures (e.g., what is rougher, what is smoother).

#### *3.2.3.2 Using frequency to encode information*

No more than nine (9) different levels of frequency should be used for coding information [6, 7].

Rationale: Since the capacity of short term working memory is around seven items plus or minus two [22], the effective channel capacity of a number of human cognitive and perceptual tasks is between 5 and 9 items. This suggests a maximum of nine different levels of frequency can be used such that a user is able to distinguish one from the other in task memory.

#### *3.2.3.3 Maintain suitable distanced between frequency levels*

Each frequency above the lowest frequency should be at least 20% higher than the previous frequency [6, 7].

#### *3.2.3.4 Use a frequency between 50 and 400 Hz*

When encoding tactile messages, tactile output should be kept at frequencies between 50 Hz and 400 Hz [6, 7].

NOTE: There is great variability in how different users experience the sensitivity of the human tactile channel. While, the human tactile channel is typically only sensitive to frequencies between 10 Hz and 600 Hz, these thresholds are high with some users experiencing their lowest threshold at 250 Hz. Limiting frequencies between 50 Hz and 400 Hz ensures access for a large range of users [6].

#### *3.2.3.5 Encoding using pressure / force / temperature*

Our review of current standards did not reveal any guidance specific to pressure, force, or temperature. These areas are important because they are used in tactile/haptic device design. Guidelines relating specifically to pressure, force, and temperature would encompass concerns that are unique to these areas.

#### *3.2.3.6 Avoid using too many levels of intensity to encode information*

Since, the number of intensity levels available to encode information is limited, not more than four (4) different levels should be used between the detection threshold and the pain/comfort threshold [6, 7].

#### *3.2.3.7 Encoding physical entity properties via intensity differences*

Where the task requires, intensity differences to encode information should be dependent on the physical entity, at least 10% for force and mass, and 100% for stiffness and viscosity [6, 7].

Rationale: When using a tactile / haptic device, one's kinaesthetic system uses signals about force, position, and movement to derive information about the mechanical properties of objects in the virtual environment (e.g., stiffness and viscosity) [20].

#### *3.2.3.8 Using subjective magnitude to encode information*

Subjective magnitude of a stimulus can be used to encode information.

NOTE: Research suggests that there are two ways of enlarging the subjective magnitude of a stimulus: a) enlarging the intensity for intensities near the threshold, and b) enlarging the area of stimulation [6, 7].

#### *3.2.3.9 Limit acoustic output of tactile display*

The system should be designed to prevent unintentional acoustic energy emissions or acoustic energy emissions that could interfere with tactile/haptic interactions [6].

Rationale: In some environments acoustic output may interfere with nearby equipment and/or persons not using the tactile display.

#### *3.2.3.10 Prevent vibration of non-activated vibrators*

Prevent non-activated vibrators from vibrating due to activation of a nearby vibrator [6].

NOTE 1: There is an especially high risk of unintentional vibration where the nearby actuator vibrates at the same resonance frequency.

NOTE 2: Installing a rigid surround is one way to reduce the spreading of vibration.

Rationale: The occurrence of unintended vibration can mislead the user with an unintended percept and/or irritate the user with an unexpected stimulus.

### *3.2.4 Temporal Encoding*

Temporal encoding applies to both tactile and haptic devices. For tactile devices, temporal encoding refers to the timing between tactile signals. For haptic devices, temporal encoding refers to the real time use of the device. Two major issues in tactile/haptic interfaces are temporal enhancement and temporal masking.

Generally, "masking" is the reduced ability to detect a stimulus in the presence of a background stimulus [25]. *Temporal masking* occurs when two stimuli are presented to the same location asynchronously [7]. The onset of the target (i.e., "masked") stimulus is typically within -100 ms up to +1200 ms from the onset of the "distracter" stimulus [6].

Generally, "enhancement" occurs when the presence of a brief stimulus causes a second stimulus to appear to be of greater intensity than when it is presented alone [25]. *Temporal enhancement* occurs when two stimuli in the same frequency band are separated by a short duration, typically 100ms to 500ms [6], such that the they are perceived to be one longer, stronger stimulus.

#### 3.2.4.1 Temporal enhancement affects the subjective magnitude of separated stimuli

Where the task requires, prevent unintentional temporal enhancement of a second stimulus [6, 7].

NOTE 1: Temporal enhancement of a second stimulus occurs when two stimuli are separated by 100ms to 500ms.

NOTE 2: Temporal enhancement typically occurs when the stimuli are in the same frequency band.

Rationale: Temporal enhancement can result in a higher subjective magnitude of the stimulus. In situations where the desired effect is for the user to experience two different stimuli, then an inter-stimulus interval greater than 500ms will be needed.

#### 3.2.4.2 Provide user control of temporal presentations

“Whenever moving, blinking, scrolling, or auto-updating information is presented, the user shall be enabled to pause or stop the presentation.” [14]

#### 3.2.4.3 Provide pauses between consecutive signals

Where the task requires a single actuator of a tactile display be used to encode information in a temporal pattern, there should be at least 10 ms between consecutive signals of the temporal pattern [6, 7].

#### 3.2.4.4 Prevent temporal masking

The system should prevent the occurrence of temporal masking [6, 7].

Rationale: Temporal masking can distort the perception of multiple stimuli.

#### 3.2.4.5 Use frequency to prohibit temporal masking

The system should use low and high frequencies to encode temporal patterns to prevent temporal masking [6, 7].

#### 3.2.4.6 Use stimulus location to prohibit temporal masking

The system should present stimuli to different loci to prevent temporal masking [6, 7].

## 3.3 Content-specific Encoding

### 3.3.1 Encoding and using textual data

Our review of current standards did not reveal any guidance regarding encoding and using textual data. Guidance on textual data encoding is of interest to support devices such as Braille displays.

### 3.3.2 Encoding and using graphical data

#### 3.3.2.1 Provide exploring strategies

The system should provide the user with methods for exploring virtual objects [6, 7].

#### 3.3.2.2 Simulating actual motion

Apparent motion may be used to simulate actual motion [6, 7].

EXAMPLE: Tracking displays

NOTE: When using apparent motion, the most important parameters are the duration of bursts (minimum 20 ms) and the interval(s) of time between the onsets of the consecutive stimuli.

### 3.3.3 Encoding and using controls

#### 3.3.3.1 Use size and spacing of controls to avoid accidental activation

The system should provide buttons and controls sufficiently large and sufficiently spaced, to reduce the likelihood that a user will accidentally activate an adjacent control [2].

#### 3.3.3.2 Usable controls

The system should avoid using very small controls or controls which require rotation of the wrist or pinching and twisting [2].

#### 3.3.3.3 Allow users to adjust time required for activation of controls

To help separate between inadvertent motions or bumps and desired activation, the system shall enable the user to individualize the delay during which a control is activated before the input is accepted [2, 14].

#### 3.3.3.4 Avoid simultaneous activation of two or more controls

The system should enable users to avoid the use of control combinations requiring simultaneous activation of two or more controls [2, 14].

#### 3.3.3.5 Allow users to sequentially activate composite controls

Where the task requires the use of control combinations, the system shall enable users to lock or latch each control such that multiple control combinations can be entered sequentially rather than by simultaneously pressing multiple controls [2, 14].

EXAMPLE: For keyboards, chorded key-presses can be sequentially enabled using StickyKeys.

#### 3.3.3.6 Allow users to reposition controls

The system should provide a control option that moves all of the controls for the product such that it can be positioned optimally for the individual [2].

#### 3.3.3.7 Allow users to re-map controls

The system should enable users to re-map all controls [14].

EXAMPLE: As an analogy, a keyboard user who has a left arm and no right arm might switch frequently used functions from the right to the left side of the keyboard.

Rationale: The ability to re-map controls allows the individual to reposition the most used controls in a way that favors their environment and mobility. This strategy may reduce repetitive strain injury.

#### 3.3.3.8 *Allow users to use a remote control*

The system should provide a remote control option that moves all of the controls for the product together to a separate unit that can be positioned optimally for the individual [2].

NOTE: The "Universal Remote Console" is a proposed standard communication format that may allow the use of alternate remote controls for those who cannot use the standard remote control [17].

Rationale: The use of a remote control allows the individual to operate the product without having to move to it.

## 3.4 User Individualization of Tactile / Haptic Interfaces

### 3.4.1 *Intentional Individualization*

#### 3.4.1.1 *Enable user to change modalities*

The system should enable the user both to disable tactile output and/or to reroute output to another modality [6, 7].

NOTE: Tactile stimuli may annoy users, as they are hard to ignore if the user does not want to use them.

#### 3.4.1.2 *Enable user to individualize tactile parameters*

The system should enable users to adjust tactile output parameters, including:

- stimulus intensity,
- timing,
- frequency,
- location, and
- size/dimension

[6, 7, 14].

### 3.4.2 *Unintentional User Perception*

#### 3.4.2.1 *Beware of adaptation*

Where the task allows, the system should avoid situations where user adaptation to stimuli might occur [6, 7].

NOTE: Adaptation effects only occur for stimuli within the same frequency range.

Rationale: Adaptation occurs as a result of prolonged tactile stimulation. Adaptation can decrease a user's absolute threshold and change their experience of subjective magnitude. This is a gradual process caused by prolonged stimulation and can take up to 25 minutes to occur [6, 7, 25].

#### 3.4.2.2 *Recovery from adaptation*

The system should enable the user to recover from adaptation to stimuli [6, 7].

NOTE: A user's recovery time is about half as long as the adaptation time [6, 7, 25].

#### 3.4.2.3 *Use frequency to prevent adaptation*

Adaptation to stimuli may be prevented by using different neurophysiological channels (i.e., different frequencies) [6, 7].

NOTE: One approach to preventing adaptation is switching between a frequency below 80 Hz and one above 100 Hz.

#### 3.4.2.4 *Be aware of the occurrence of perceptual illusions*

The system should avoid the occurrence of unintended perceptual illusions [6, 7].

NOTE: Pauses between percepts is one strategy to avoid perceptual illusions.

## 4. CONCLUSION

Our collection of guidance shows that several potential candidate guidelines exist that can be used in a proposed ISO standard on tactile/haptic interactions. Of note, ISO 9241-171 contains several candidate guidelines that with, in some cases, no modification may apply to tactile/haptic use. However, there remain several areas where our search for relevant guidelines revealed little.

Although, our research found several guidelines that apply in general to tactile/haptic interactions and the use of vibration in particular, there is little guidance specific to other modes of tactile/haptic interaction such as the use of temperature or force.

Our research found no guidelines that were specific to the tactile encoding of text. It is quite likely that there are international or other guidelines on the design of tactile devices such as Braille displays. However, it is also important to note that there are other ways to tactilely encode text than the use of Braille. For example, the Moon alphabet is a system of embossed type that is often taught to people who have become Blind later in life and/or cannot master the small dots system of Braille [23].

This paper provides a beginning to a potential international standard on tactile/haptic interactions. The new standard will need to go beyond this collection of guidance to incorporate information from other available research, including the research presented at GOTHI-05.

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# Research Based Tactile and Haptic Interaction Guidelines

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## ABSTRACT

In this paper, we survey guidance on tactile and haptic interactions provided by various researchers who were not in attendance at GOTHI-05. Its main purpose is to identify potential guidelines that might be incorporated into an international standard on tactile and haptic interaction. This survey also identified a number of controversial areas that will need to be dealt with in developing such a standard. Results are presented in a manner consistent with a companion paper "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8].

## Categories and Subject Descriptors

H.5.2 User Interfaces, *Ergonomics, Haptic I/O, Input devices and strategies,* D.2.0 Software Engineering General, *Standards*

## General Terms

Human Factors, Standardization

## Keywords

Tactile, haptic, interactions, interface object, reference model, standards.

## 1. INTRODUCTION

Tactile and haptic interaction is becoming increasingly important both in assistive technologies and in special purpose computing environments. While there is a very large body of research involving haptic and tactile interactions, there is a current lack of guidance relating to the particulars of tactile/haptic interactions that can be used by developers who are not also researchers in this field. ISO TC159 / SC4 Ergonomics of human - system interaction has recently initiated work to develop a set of ergonomic standards that will provide this guidance.

The Guidelines On Tactile and Haptic Interactions Conference (GOTHI-05) is a first step at accumulating potential guidance. The preparations for GOTHI-05 included identifying leading experts in the field and inviting them to submit papers focused on technology-transfer of their research findings into potential guidelines. While a number of experts accepted this invitation, it is with great regret that a number of others were unable to accept. This paper surveys the research of many of those not able to attend and starts the process of transforming their research findings into guidelines that can be used by a wider range of software developers.

### 1.1 Limitations of This Survey

Any survey of this nature is limited due to the particular research papers that it included. Since it was infeasible to examine all research papers in the area of tactile and haptic interaction, this survey limited itself to those papers which could be identified to include: guidance, guidelines, principles, recommendations, requirements, standards, or similar concepts.

Significant attempts were made to identify research including candidate guidance via a number of Web search engines and scholarly journal search engines. Further efforts were made to follow promising references in the papers which were examined.

This survey also did not consider any of the formal sets of standards and guidelines that were considered in the companion paper, "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8], which is also being presented at GOTHI-05.

It is recognized that these two papers present only a starting point, to be used along with the other papers of GOTHI-05 and much further research, along the road to developing a comprehensive set of guidance regarding the ergonomics of tactile and haptic interactions.

### 1.2 Structure of this Paper

This guidance and discussions presented in this paper are structured similarly to the guidance presented in "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8], for ease in the future consideration and combination of these two sets of guidance. However, due to the contents applicable to the two papers, there is not an exact correspondence between subsections. Each paper contains some subsections not found in the other.

# 2. HIGH LEVEL GUIDANCE

## 2.1 Layered Models of Haptic Interaction

In addition to the models presented in other GOTHI-05 papers, there are various models that can be applied to analyzing and developing haptic interactions. Popescu, Burdea, and Treffz [13] present a layered model that involves: applications, interaction tasks, interaction techniques, events, and input devices. Bowman [1] investigated a two level model involving interaction tasks and interaction techniques. Agreeing upon the appropriate layers to be considered is more important than the actual contents of any particular level. This is especially true, since the models investigated are all from the domain of virtual reality.

### *2.1.1 Interaction task models*

Interaction tasks are the outcomes which the user is trying to accomplish on an object or a set of objects.

Popescu et. al. name, but do not explain, the following set of interaction tasks: "navigation, move, identification, selection, rotation, scale, modification". [13]

Bowman identified four general types of interaction tasks: (1) navigation, "which includes both the actual movement and the decision process involved in determining the desired direction and target of travel (wayfinding)"; (2) selection, "which involves the picking of one or more virtual objects for some purpose"; (3) manipulation, which "refers to the positioning and orienting of virtual objects"; and (4) system control, which "encompasses other commands that the user gives to accomplish work within the application". [1]

Stanney et. al. suggest that usability criteria associated with interaction can be classified as: wayfinding (i.e., locating and orienting oneself in an environment); navigation (i.e., moving from one location to another in an environment); and object selection and manipulation (i.e, targeting objects within an environment to reposition, reorient and/or query)". [16]

These different models can all be combined into a model consisting of three general tasks: navigation (including wayfinding) between objects, selection of a single object or group of objects, and manipulation (including activation) of the selected object(s).

The above only deal with interaction tasks from the user's perspective. However, there is at least one important interaction task from the system's perspective, that being feedback. Feedback is an important system task, as can be seen from the large amount of guidelines related to it that are presented later in this paper [4, 9, 11, 12, 13, 16].

### *2.1.2 Interaction technique Models*

Interaction techniques are general types of user actions performed in order to accomplish interaction tasks. Bowman recognized that, "for each of these universal tasks, there are many proposed interaction techniques." [1] Popescu et. al. name the following set of interaction techniques: "grabbing, releasing, pointing, gesture language, 3D menu, speech commands", and further identified the following set of interaction events: "hand gestures, 3D motion, button click, force, 2-D motion, torque, spoken units". [13] It is unclear how they distinguish between these two sets.

While much work may be needed to develop a suitable set of interaction technique categories, it is expected that various items of guidance may uniquely apply to individual interaction techniques.

## 2.2 Definitions

### *2.2.1 Definitions of tactile and haptic*

There is no consensus over the definitions of tactile and haptic interactions. Some authors use tactile as the main category and haptic as a special case of tactile, while other authors use haptic as the main category and use tactile as a subcomponent of haptic. In either case, tactile generally is used to refer to static aspects of touch while haptic includes dynamic aspects of touch.

While authors use the two terms in identifiable manners within their papers, few authors actually define either term explicitly. Stanney et. al. [16] define tactile as, "information received through nerve receptors in the skin which convey shapes and textures" and define kinesthetic as the active aspects of touch; "information sensed through movement and/or force to muscles and joints." Hale and Stanney [9] define haptic interaction as relating "to all aspects of touch and body movement and the application of these senses to computer interaction."

### *2.2.2 Definitions of specific interaction tasks*

There is a need to organize the set of, and to define, individual interaction tasks and related concepts.

The area in which the most existing work was found relates to navigation. As already discussed, there are various definitions of what all that navigation involves. Stanney et. al. [16] define navigation as travel that, "is necessary to allow users to move into position to perform required tasks." Schomaker et. al. [14] have a somewhat broader concept of navigation, "as a process of movement and orientation, yielding a trajectory that is directed towards a given goal."

Darken and Sibert [6] identified three different types of navigation:

- Exploration is "where the primary goal is gaining familiarity with the environment'
- Naïve search is where the user is searching for a known object whose location is not known
- Informed search is where the user has 'some knowledge of the location of the object'

Stanney et. al. [16] define wayfinding as the ability to maintain knowledge of one's location and orientation while navigating throughout a designed space.

Selection, which is the most narrow concept, is the least controversial to define. Stanney et. al. [16] define object selection as involving "users designating one or more virtual objects for some purpose."

While manipulation is not defined, and may include a number of different specific tasks, Stanney et. al. recognize that, "object selection is followed by subsequent manipulation of specified objects." [16]

### *2.2.3 Definitions of tactile objects*

Brewster and Brown define tactons or tactile icons as, "structured, abstract messages that can be used to communicate messages non-verbally." [3]

According to Brewster and Brown "Tactons have the potential to improve interaction in a range of different areas, particularly where the visual display is overloaded, limited in size or not available, such as in interfaces for blind people or in mobile and wearable devices." [3]

### *2.2.4 Definitions of perceptual effects*

"Spatial masking means that the location of a stimulus is masked by another stimulus. Spatial masking may occur when stimuli overlap in time but not in location." [7]

"Apparent location is the percept of a single stimulus induced by the simultaneous activation of two stimuli at different locations. The apparent location is in between the two stimulus loci and depends on their relative magnitude. Both stimuli should be in phase to evoke a stable percept." [7]

Sensorial transposition is "the provision of feedback to the user through a different channel than the expected one." [13]

# 3. PROSPECTIVE GUIDELINES

## 3.1 Tactile/haptic inputs, outputs, and/or combinations

### *3.1.1 General guidance*

#### *3.1.1.1 Using appropriate interaction styles*

"Interaction should be natural, efficient, and appropriate for target users, domains, and task goals." [16]

#### *3.1.1.2 Using efficient movement controls*

The system should enable users to interact with and control their movement throughout a virtual environment in a natural, streamlined fashion [16].

#### *3.1.1.3 Flexibility of movement controls*

The system should provide sufficient movement controls to support all aspects of the task. [16]

#### *3.1.1.4 Using multimodal output*

Where multimodal output is used, information presented in each modality should be readily understood, unambiguous, and necessary to complete the task. [16]

#### *3.1.1.5 Use clear haptic output*

Haptic information presented to users should be readily understood, unambiguous, and necessary to complete the task. [16]

#### *3.1.1.6 Seamless integration of haptic output*

Where the task allows, haptic output should be seamlessly integrated into the user's task. [16]

#### *3.1.1.7 Preventing task display conflict*

The system should avoid discord between the user's task and the haptic display. [16]

#### *3.1.1.8 Using manageable haptic display*

The system should avoid cumbersome, awkward haptic display. [16]

#### *3.1.1.9 Providing reliable interaction*

The system should provide consistent, accurate haptic interaction. [16]

#### *3.1.1.10 Using intuitive haptic interaction*

The system should provide intuitive haptic interaction. [16]

#### *3.1.1.11 Avoiding minute, precise joint rotations*

The system should avoid requiring minute, precise joint rotations, particularly at distal segments. [9]

#### *3.1.1.12 Avoiding or Minimizing fatigue*

a. The system should avoid causing user fatigue. [16]

b. The system should avoid requiring static positions at or near the end range of motion to minimize kinesthetic interaction fatigue. [9]

c. The system should ensure user comfort over extended periods of time. [7]

#### *3.1.1.13 Using high spatial resolutions*

The system should use very high spatial resolutions to increase haptic device ease of use. [16]

#### *3.1.1.14 Effective presentation of haptic information*

The system should encode haptic information using combinations of strength, speed, high-resolution force, and position that are effectively presented. [16]

### *3.1.2 Uni-modal use of tactile / haptic interaction*

#### *3.1.2.1 Using haptic feedback when other senses fail*

The system should effectively use haptic feedback in areas where other senses are unusable. [16]

NOTE: Haptics is rarely used for spatial discrimination by itself (except in dark environments). [13]

### *3.1.3 Multi-modal use of tactile / haptic interaction*

While the guidelines in all other subsections (other than 3.1.2) relate to both the uni-modal and the multi-modal use of tactile / haptic interactions, there is additional guidance that applies specifically to multi-modal use.

According to Popescu et. al., "multisensory feedback is not just the sum of visual, auditory and somatic feedback, since there is redundancy and transposition in the human sensorial process." [13]

#### *3.1.3.1 Complex haptic object presentation*

The system should use multimedia information when presenting complex haptic objects.

NOTE Users may not understand complex objects when only presented haptic information. [7]

#### *3.1.3.2 Using multiple senses to support haptic tasks*

The system may enhance haptic tasks by using other senses and vibratory cues. [16]

#### *3.1.3.3 Using haptics during non-haptic tasks*

The system may make use of tactile stimuli to convey additional information, beyond that presented via other modalities. [9]

EXAMPLE A user performing a visual spatial attention task uses tactile information to communicate warnings. [9]

#### *3.1.3.4 Using of cross-modal cueing effects in multimodal displays*

Cross-modal cueing effects in multimodal displays should follow an external spatial frame of reference. [9]

NOTE Information received visually can be used to reorient tactile perception and information received tactilely can be used to accurately reorient visual attention. [9]

### *3.1.3.5 Using haptics to minimize visual modality overload*

If the visual modality is overloaded, the system may provide object identification information haptically. [9]

NOTE Although switching from tactile to visual stimulus does not seem to increase visual load, switching from visual to tactile stimulus can. [9]

### *3.1.3.6 Consistent combinations of vision and haptics*

The system should maintain consistency of combinations of vision and haptics across modalities, for tasks involving size, shape, or position judgment. [9]

NOTE Vision will often dominate the integrated percept. [9]

### *3.1.3.7 Maintaining coherence between modalities*

The system should impose the coherence of spatio-temporal representations for tactile and kinesthetic channels. [13]

EXAMPLE A user of a multimodal visual/haptic display finds the roughness of a surface evaluated through the visual display haptically matched by the rugosity information provided by the tactile display. [13]

### *3.1.3.8 Maintaining conceptual coherence*

The system should maintain coherence in the haptic and visual displays of information related to the physical properties of a virtual environment. [13]

### *3.1.3.9 Avoiding time lags between modalities*

The system should avoid time lags between visual and haptic loops in multimodal displays. [9, 13]

NOTE Time lags can causes confusion and control instabilities in multimodal systems. [9, 13]

### *3.1.3.10 Using cognitively linked vision and touch stimuli with care*

If touch is potentially response-relevant, the system should ensure that vision and touch stimuli are not cognitively linked. [9]

NOTE 1 If vision and touch stimuli become cognitively linked, the effectiveness of conveying additional tactile information can be hindered. [9]

NOTE 2 During spatial attention tasks, it is possible to decouple tactile stimuli from other modalities but only when the tactile signals are considered irrelevant. [9]

### *3.1.3.11 Combining vision and haptics to enhance location memory*

The system may add haptic location information to a visual display to enhance target placement memory. [9]

#### *3.1.3.11.1 Using sensorial transposition*

The system may use sensorial transposition to provide sensorial redundancy. [13]

EXAMPLE A multimodal system communicates the same feedback information through multiple channels to reinforce the original message. [13]

#### *3.1.3.11.2 Mapping sensorially redundant feedback*

The system should ensure that mapping feedback information through different channels avoids causing sensorial contradictions, sensorial overload, or an increased task completion time. [13]

### *3.1.4 User perceptions*

According to Popescu et. al., "haptic channels constitute by themselves complex coupled systems. There is a very tight coupling between force and touch feedback." [13]

### *3.1.4.1 Enabling user perception of roughness variation*

The system should enable the detection of physical variation in roughness of virtual textures. [5]

NOTE Virtual textures may not be perceived in the same way as their real counterparts. [5]

### *3.1.4.2 Assisting users in virtual texture detection*

The system should enable users to adjust the size of the differences they can detect in their perception of virtual textures.

NOTE Users “vary in their perception of virtual texture in terms of the size of the differences which they can detect.” [5]

### *3.1.4.3 Supporting accurate size perception*

Where accurate perception of size is required, the system should allow virtual objects to deviate from their real world dimensions. [5]

NOTE 1 “Users may perceive the sizes of larger virtual objects more accurately than those of smaller virtual objects.” [5]

NOTE 2 “Users may feel virtual objects to be bigger from the inside and smaller from the outside (the "Tardis" effect).” [5]

### *3.1.4.4 Helping users find virtual space*

The system should enable users to determine where virtual space is located. [5]

NOTE It is possible for users to “have differing mental models of where virtual space is located.” [5]

NOTE Users' mental models may vary in relation to what part of the device is "touching" a virtual object. [5]

### *3.1.4.5 Violating the laws of physics*

The system should avoid violating the laws of physics, unless such violation is necessary to the task. [5]

NOTE Although being able to push through the surfaces of objects does not greatly disturb users, care is needed when violating other laws of physics. [5]

### *3.1.4.6 Helping users understand the virtual environment*

The system should allow users to move about the virtual environment to obtain different views and acquire an accurate “mental map” of their surroundings. [16]

### *3.1.4.7 Making complex haptic information easy to perceive*

The system should ensure that the simultaneous presentation of complex haptic patterns, sensations, and objects is easy to perceive. [16]

#### *3.1.4.8 Multiple haptic intensity levels*

The system should avoid presenting and semantically binding a large number of haptic intensity levels. [16]

#### *3.1.4.9 Ensuring accurate limb position*

The system should use active movement to ensure more accurate limb position. [9]

NOTE Active movement of limb position is more accurate than passive movement. [9]

## 3.2 Tactile/haptic encoding of information

### *3.2.1 General encoding guidance*

Brewster and Brown [3] identified the following general basic parameters that can be used for encoding information in *tactons*: frequency, amplitude, waveform, duration, rhythm, body location, and spatio-temporal patterns.

#### *3.2.1.1 Using self-explaining tactile messages*

Tactile messages should be self-explaining. [7]

#### *3.2.1.2 Mapping sensorial transpositions*

#### *3.2.1.2.1 Allowing easy user adaptation when using sensorial transposition*

To produce easy user adaptation, the system should use sensorial mappings that are as simple as possible. [13]

NOTE The level of user adaptation needed in the mappings involved in the sensorial transposition may feel "natural" or require user training. [13]

#### *3.2.1.2.2 Using strong sensorial transposition mapping domains*

The system should provide sensorial mappings that use the strongest representation domains (visual-spatial domain, auditory-temporal, frequency, tactile-temporal, etc.) of the transposed channel. [13]

NOTE Sensorial mapping needs that is as simple as possible helps to produce easy user adaptation. [13]

### *3.2.2 Spatial Encoding*

#### *3.2.2.1 Gestures*

The system should minimize requirements for frequent, awkward, or precise gestures. [9]

NOTE 1 Such gestures, if used too often, can promote user fatigue. [9]

NOTE 2 Making accurate or repeatable gestures without tactile feedback is difficult. [9]

#### *3.2.2.2 Intuitive and simple gestures*

Gestures should be intuitive and simple. [9]

### *3.2.3 Sensory Encoding*

#### *3.2.3.1 Force*

#### *3.2.3.1.1 Control resolution*

The forces displayed by the device should be controllable to at least the level at which humans can sense and control force. [2]

#### *3.2.3.1.2 Considering target skin location sensitivity to stimuli*

Haptic devices that are to be used across various skin locations should adjustable to take into account differences to stimuli sensitivity. [9]

NOTE The two-point threshold grows smaller from palm to fingertips. Spatial resolution is about 2.5mm on the index fingertip. [9]

#### *3.2.3.1.3 Activating cutaneous pressure sensors*

The force exerted on a target skin location should be greater than 0.06 to 0.2 Newtons per $cm^2$ in order for users to detect it. [9]

#### *3.2.3.1.4 Haptic information transfer*

To effectively promote haptic information transfer, the system should:

a) use a surface stillness of 400 Newtons per meter, [9] or
b) use an end-point force of 3 to 4 Newtons. [9]

#### *3.2.3.1.5 Allowing pressure limit individualization*

The system should enable the user to individualize pressure limits. [9]

NOTE: The gender of the user can impact the allowable pressure limit. [9]

EXAMPLE 1 A woman's face has a just noticeable difference pressure limit of 5 mg. [9]

EXAMPLE 2 A man's big toe has a just noticeable difference pressure limit of 355 mg. [9]

#### *3.2.3.1.6 Encoding information using intensity*

When encoding information using different intensity levels, the system should use not more than four (4) different levels between the detection threshold and the comfort / pain threshold. [7]

#### *3.2.3.1.7 Direction of tactile force*

The system should vary the direction of the tactile force based upon the direction the user moves the device. [4]

NOTE In effect, the tactile force applied by a device is "user-inspired".

#### *3.2.3.1.8 Supporting high bandwidth force reflection*

The system should support high bandwidth force reflection with high stiffness between master and slave devices. [16]

#### *3.2.3.2 Vibrations*

#### *3.2.3.2.1 Using vibratory feedback*

High frequency vibratory feedback may be important for haptic tasks involving: inspection, exploration, and direct manipulation. [13]

#### *3.2.3.2.2 Using vibration with force feedback*

Force feedback systems should include vibratory feedback. [13]

NOTE The addition of vibration to force feedback systems can increase performance in manipulation tasks. [13]

#### *3.2.3.2.3 Coding information by frequency*

When coding information by frequency, the system should:

a) use not more than nine (9) different levels of frequency, and
b) use a difference of at least twenty percent (20%) between levels. [7]

NOTE If presented with the same amplitude, the different levels of frequency will also lead to different subjective magnitudes. [7]

###### *3.2.3.2.4 Vibratory probe perception*
The vibration from any single probe should exceed 28 decibels (relative to a 1-microsecond peak) for 0.4 – 3 Hz frequencies. [9]

###### *3.2.3.2.5 Preventing spatial masking*
When presenting simultaneous stimuli in different loci, the system should use stimuli with different frequencies (one below 80 Hz and one above 100Hz). [7]

NOTE: This may prevent spatial masking. [7]

###### *3.2.3.2.6 Maintaining control of virtual objects*
The maximum level of vibration should allow the user to easily control an object without corrupting the user's perception of the virtual environment. [2]

### *3.2.4 Temporal Encoding*

#### *3.2.4.1 Haptic display frame rate and latency*
The system should use high frame rates and low latency for haptic outputs. [16]

##### *3.2.4.1.1 Perception of distinct signals*
The stimuli of individual signals should be at east 5.5 ms apart. [9]

#### *3.2.4.2 Coding information by temporal pattern*
When using a single actuator of a tactile display to encode information in a temporal pattern, the time between signals should be at least 10 ms. [7]

NOTE The temporal sensitivity of the skin is very high, 10 ms pulses and 10 ms gaps can be detected. [7]

#### *3.2.4.3 Effects of temporal coding*
The system should avoid presenting two stimuli closely in time. [7]

NOTE This helps avoid the percept being altered (i.e., by temporal masking, temporal enhancement, and/or adaptation). [7]

#### *3.2.4.4 Spatial-temporal interactions*
The system should avoid presenting stimuli too closely in time and space. [7]

NOTE This helps avoid creation of unintended percepts. [7]

### *3.2.5 Composite Encodings*

#### *3.2.5.1 Graphical and haptic object behavior implementation and display*
The system should implement and synchronously display to the user virtual object physical behavior both in graphics and haptics. [13]

#### *3.2.5.2 Synchronizing surface deformation with force calculation*
To provide immersion in the virtual environment, the system should synchronize object surface deformation with force calculation. [13]

#### *3.2.5.3 Behavior of "soft" balls*
"A "soft" ball (small forces applied to the user's finger when squeezing) should also be highly deformable." [13]

#### *3.2.5.4 Virtual wall behavior*
The system should provide virtual walls that resist very high forces and have no visual surface deformation when being pushed. [13]

#### *3.2.5.5 Plastically-deformed object behavior*
The system should allow plastically-deformed objects to present a hysteresis behavior both in shape deformation and in the associated force profile. [13]

#### *3.2.5.6 Matching force resolution with human sensing resolution*
The force resolution that a system is capable of producing should match or exceed human sensing resolution. [2]

NOTE Matching or exceeding human sensing resolution helps users to perceive the force displayed by the device. [2]

#### *3.2.5.7 Varying force according to speed*
The system should vary force according to speed. [12]

NOTE Slow motions require low forces. [12]

#### *3.2.5.8 Size and density effects on object strength*
"The maximum strength used for any widget, or set of widgets, should be dependent on both the size of the widgets and density of arrangement that they are presented in." [12]

NOTE "A dense arrangement of small widgets requires small forces, as large forces will severely hamper motion from one widget to an adjacent one." [12]

#### *3.2.5.9 Supporting virtual object targeting*
The system should increase the strength of forces applied to match increases in approach speeds to maximize targeting. [12]

NOTE Users often approach large spatially distributed widgets at considerable speed. [12]

#### *3.2.5.10 Maintaining similar strength ratios across users*
The system should keep the general strength ratios between different sizes and densities of widgets the same for all users. [12]

NOTE "Irrespective of the maximum strength a user chooses, the proportions between the magnitude of the forces applied over a large target, and of that applied over a small target seem likely to remain the same." [12]

## 3.3 Content-specific Encoding

### *3.3.1 General tactile / haptic encoding*

#### *3.3.1.1 Using haptics to represent both physical and spatio-temporal object properties*
The system may use haptics to represent information related to the physical properties of the virtual object as well as their spatio-temporal properties. [13]

### *3.3.2 Encoding and using textual data*
No text specific guidance was found in the sources surveyed.

### *3.3.3 Encoding and using graphical data*

#### *3.3.3.1 Using rounded edges and corners*
The system should use rounded shapes rather than sharp edges and corners. [15]

NOTE: When felt from the "outside", sharp edges and corners are more difficult to feel and understand than rounded shapes. [15]

*Sharp edges and corners are much more difficult to feel and understand than rounded shapes when they are felt from the "outside". [15]*

### *3.3.3.2 Maintaining separation between walls*

Objects should be sufficiently separated so that the user is able to perceive the boundaries between individual ocjects. [15]

NOTE If walls or edges are very close there is a risk that the finger passing through a wall or edge, will also unintentionally pass through an adjacent wall or edge. [15]

### *3.3.3.3 Using kinesthetic information to enhance spatial location*

The system may use kinesthetic information to enhance the spatial location of a virtual object. [9]

### *3.3.3.4 Accurately reorient attention*

### *3.3.3.4.1 Using tactile information to draw visual attention*

The system may use dynamic tactile information to accurately reorient visual attention. [9]

### *3.3.3.4.2 Using visual information to draw tactile attention*

The system may use dynamic visual information to accurately reorient tactile attention. [9]

### *3.3.4 Encoding textural data*

### *3.3.4.1 Encoding hard surfaces*

The system should maintain active pressure after initial contact when users feel a "hard" surface. [9]

### *3.3.4.2 Encoding soft surfaces*

The system should maintain a slight positive reaction against the skin after initial contact when users feel a "soft" surface. [9]

### *3.3.4.3 Using relative motion to display texture*

The system should use relative motion between the haptic surface and the skin to accurately display texture. [9]

### *3.3.5 Encoding and using controls*

### *3.3.5.1 Haptic pushbutton design*

A haptic pushbutton should consist of an initial springy region where the force increases linearly with displacement, followed by a sudden decrease in resistive force and transition to a deadband where the resistive force is constant, followed by a hard stop where the resistive force approximates that of a hard surface. [10]

## 3.4 User Individualization of Tactile / Haptic Interfaces

### *3.4.1 Intentional Individualization*

### *3.4.1.1 Enabling force feedback override*

The system should allow any force feedback applied to a user to be overridable. [12]

NOTE User override of tactile force can be achieved by "fighting through" or "sidestepping" a constraint. [4]

### *3.4.1.2 Enabling individualization of force*

The system should enable the user to individualize the amount of force applied. [4, 12]

NOTE Users vary in the amount of force that can overpower or "be too strong" for them. [4]

### *3.4.1.3 Enabling stimulus intensity individualization*

The system should enable the user to individualize stimulus intensity. [7]

NOTE 1 There is a high variation in thresholds of sensation and pain both among individuals. [7]

NOTE 2 Since spatial and temporary acuity degrades with aging, an individual's variation in thresholds of sensation and pain will vary over the life span. [7]

## 3.5 Interaction Tasks

### *3.5.1 Navigation*

Navigation techniques and actions may be dependent on the size and density of the real or virtual space through which the user must navigate. According to Darken and Sibert [6]:

- A small world is a world in which all or most of the world can be seen from a single viewpoint such that important differences among objects in the world can be discerned.
- A large world is one where there is no vantage point from which the entire world can bee seen in detail.
- An infinite world is one in which we can travel along a dimension forever without encountering the 'edge of the world'.
- A sparse world has large open spaces in which there are few objects or clues to help in navigation.
- A dense world is characterized by a relatively large number of objects and cues in the space.
- A cluttered world is one in which the number of objects is so great that it obscures important landmarks or cues.
- As the distribution approaches uniformity, the positions of objects become more predictable.

### *3.5.1.1 Allowing path planning based on current view*

The system should enable the user to use the current view to plan the shortest path to a target. [16]

### *3.5.1.2 Providing well designed paths*

The system should ensure that paths between objects have a clear structure and clear start/end points. [16]

### *3.5.1.3 Making landmarks easy to identify and recognize*

The system should ensure that landmarks are easily identifiable and recognizable with a prominent spatial location. [16]

### *3.5.1.4 Providing navigation*

The system should provide navigation mechanisms that allow users to move into position to perform tasks. [16]

### *3.5.1.5 Providing easy to use navigation techniques*

The system should provide navigation techniques that are easy to use and not cognitively cumbersome or obtrusive. [16]

### *3.5.1.6 Physical interaction and touch*

### *3.5.1.6.1 Enabling virtual environment search and survey via touch*

The system should enable users to actively search and survey the virtual environment through touch. [5]

### *3.5.1.6.2 Enabling easy identification of objects via haptics*

The system should enable users to easily identify objects through physical interaction. [5]

### *3.5.2 System Feedback*

### *3.5.2.1 Providing haptic feedback*

The system should provide haptic feedback. [12]

NOTE Haptic feedback reduces errors through guidance and provides forces to support the motions that a user is undertaking. [12]

### *3.5.2.2 Providing natural kinesthetic feedback*

The system should integrate "tools with mass". [16]

NOTE: This is one way to provide users with natural, gravitational, and inertial kinesthetic feedback. [16]

### *3.5.2.3 Providing feedback of impending transitions*

The system should use feedback to indicate, not preclude, an impending transition. [11]

### *3.5.2.4 Using applied forces as feedback*

The system should use the forces applied as a means of feedback. [12]

### *3.5.2.5 Providing force as feedback based on user's input*

The force of feedback should be based on, but control, the user's input." [11]

### *3.5.2.6 Providing force feedback in proportion to user input*

The system should provide only force feedback that is directly proportional to the input forces applied by the user. [11]

### *3.5.2.7 Haptic menu navigation*

When navigating a menu haptically, the system should provide a slight counter-force as the user moves from one menu item to another. [4]

NOTE This technique gives the effect of "ridges" separating menu items. [4]

### *3.5.2.8 Direct manipulation task haptic feedback*

The system should accompany tactile feedback with force feedback during direct manipulation tasks. [13]

### *3.5.2.9 Manipulation task vibratory feedback*

The system should provide vibratory feedback for manipulation tasks. [13]

### *3.5.2.10 Using tactile cues as alerts*

The system should use tactile cues as simple alerts. [9]

EXAMPLE Tactile cues created via vibrations or varying pressures alert the user to changes in the interface that were made by the system.

### *3.5.2.11 Haptic target behavior*

The system may use a "snap-to" behavior to actively capture the cursor as it passes over a target and that requires the user to exert effort to move beyond the target. [12]

NOTE Haptic targets are often presented as walled areas or wells of attractive force. [12]

### *3.5.2.12 Using augmented haptic widgets*

Haptic widgets may be augmented with attractive basins or haptically walled areas. [12]

NOTE Such augmentations typically provide performance improvements. [12]

### *3.5.2.13 Haptic feedback for a widget*

Widget haptic feedback design should consider the:

a) shape of the widget, and

b) likely path a user will take over the widget. [12]

### *3.5.2.14 "Anticipation" haptic feedback*

The system may use haptics to provide a "breakable" force resisting the user's motion and indicating the imminence of a qualitative change in the user's input before the user makes such a change. [10]

NOTE 1 This mechanism allows the user to retreat from the change if it is not desired. [10]

NOTE 2 The term "breakable" describes a force that the user can overcome to "break though" it. [10]

### *3.5.2.15 "Follow-through" haptic feedback*

The system may use haptics to indicate that an attempted qualitative change has actually been accomplished. [10]

NOTE This mechanism allows a user an opportunity to correct their motion if they do not get this feedback. [10]

### *3.5.2.16 "Indication" haptic feedback*

The system may use haptics to provide an indication that a continuing condition remains in effect, possibly with quantitative information about the condition. [10]

### *3.5.2.17 "Guidance" haptic feedback*

The system may use haptics to adapt the user's input with a bias towards some set of possible inputs. [10]

### *3.5.2.18 Using anticipation and guidance feedback to distinguish direction*

The system may use haptics to allow the user to make a clear distinction between locally orthogonal directions. [10]

NOTE This technique can be used to map different (but possibly related) controls onto different dimensions of the same input mechanism. [10]

## 4. FURTHER INFORMATION OF POTENTIAL STANDARDS USE

The potential guidelines above contain some physical measurements [7, 16]. However, Bresciani, Drewing, and Ernst provide tables of useful physical information for:

- thresholds for different physical parameters in different modalities

- the range of force of human performance for actions involving arm', hand' and finger's joints
- the control resolution of human performance for actions involving arm', hand' and finger's joints

## 5. CONCLUSION

This paper identifies guidance in a number of areas not covered by the existing standards surveyed by Fourney and Carter [8]. It also attests to the large amount of potential guidance that can be obtained from existing published research. It is expected that a much more thorough analysis of the literature will identify a number of further guidelines that should be considered in the development of the new ISO standard on Guidance on Tactile and Haptic Interactions.

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# The GOTHI Model of Tactile and Haptic Interaction

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## ABSTRACT

The paper presents the GOTHI model of tactile and haptic interaction. The GOTHI-05 workshop (October 2005) brought researchers together to develop a collection of ergonomic guidance and a framework for organizing this guidance. After a number of individual presentations, the participants worked together to develop a model of tactile and haptic interaction. The inaugural meeting of ISO TC159/SC4/WG9 further refined this model and adopted it as the basis for a new standard ISO 9241-920 Ergonomics of human-system interaction — Guidance on tactile and haptic interactions.

## Categories and Subject Descriptors

H.5.2 User Interfaces, *Ergonomics, Haptic I/O, Input devices and strategies,* D.2.0 Software Engineering General, *Standards*

## General Terms

Human Factors, Standardization

## Keywords

Tactile, haptic, interactions, interface object, reference model, standards.

## 1. INTRODUCTION

The participants of GOTHI-05 (Guidelines on Tactile and Haptic Interactions) set about to construct a model that can be used to organize guidance on and development of various tactile and haptic interactions. They recognized that different models can apply depending on the perspective of their intended audiences. Procurers / buyers / managers need simple answers and want to apply the model without needing to understand it. Developers (including students learning to be developers) need to understand what is needed but may not want to be constrained to specific programming details. Programmers need specific programming details. The resulting model is aimed at the needs of developers and students learning to be developers. However, it is recognized that people fulfilling other roles may benefit from this organization of information.

This paper provides the first report of the model that they developed and which was reviewed and adopted, with minor enhancements, by ISO TC159/SC4/WG9 further refined this model and adopted it as the basis for a new standard ISO 9241-920 Ergonomics of human-system interaction — Guidance on tactile and haptic interactions.

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## 2. THE GOTHI-05 MODEL

The following model was developed for organizing guidance on tactile and haptic interactions. It can also be used to review whether or not all of these topics have been considered in the design of tactile / haptic interactions.

### 2.1 The High Level Model

The main components of the GOTHI-05 model include:

- Tactile/haptic inputs, outputs, and/or combinations
- Attributes of tactile/haptic encoding of information
- Content-specific Encoding
- Interaction Tasks
- Interaction Techniques

Additionally, it is recognized that there may be different requirements and recommendations that apply to specific haptic devices. However as yet, there is no clear classification of different haptic devices.

Likewise, while feedback is just a special case of output, it is important enough to present a separate category for consideration.

### 2.2 Tactile/haptic inputs, outputs, and/or combinations

This section organizes high-level and general considerations of tactile/haptic inputs, outputs, and/or combinations, including:

- General guidance
- Uni-modal use of tactile / haptic interaction, including the use of multiple tactile devices
- Multi-modal use of tactile / haptic interaction
- Intentional Individualization
- Unintentional user perceptions

### 2.3 Attributes of tactile/haptic encoding of information

Tactile/haptic interactions can be developed utilizing a rich variety of individual encoding techniques. Consideration of attributes of Tactile/haptic encoding of information can be divided into general guidance and attribute specific guidance.

General guidance can be further divided into:

- Using properties of objects
- Using spatial attributes
- Using temporal attributes
- Using perceptual attributes
- Combining attributes

Tactile/haptic interaction has a large number of attributes that may be used individually or in combination. Specific tactile/haptic attributes include:

- Force
- Shape
- Size
- Friction (including slipperiness and viscosity)
- Texture
- Mass / weight
- Hardness/softness (Compliance)
- Temperature
- Orientation
- Location
- Vibration
- Duration
- Motion
- Deformation

### 2.4 Content-specific Encoding

The selection of attributes can depend on the type of content to be encoded. Consideration of content-specific encoding includes:

- General tactile / haptic content encoding
- Encoding and using textual data
- Encoding and using graphical data, including:
    - Maps
    - Pictures
    - Figures / charts
    - Textures
    - Animations
- Encoding rhythms
- Encoding subjective data
- Encoding and using controls

### 2.5 Interaction Tasks

Tasks may require multiple different forms of interactions. There are three main types of interaction tasks: navigation, selection, and manipulation.

Navigation tasks include:

- Browsing / wayfinding – exploring
    - Exploring the structure of the environment
    - Exploring the object
- Targeting – going directly to the target
- Searching – with a search function
- Zooming – changing scale of space
- Reorienting – changing coordinates of space

Selection tasks include:

- Object selection
- Group selection (for a defined group)
- Space selection (user defined portion of total space)
- System property selection

Manipulation tasks include:

- Function Activation
- Creation and deletion

- Getting information, including
    - Objective / factual information
    - Subjective / feeling / motivation information
- Modifying information (Attributes & Relationships)
- Managing alternatives / Individualization / Personalization

## 2.6 Interaction Techniques

Interaction techniques deal with physical actions required of the user in order to accomplish various interaction tasks. There are five main types of interaction techniques:

- Moving relative to the object
- Moving the object
- Possessing the object
- Touching the object
- Gesturing

Moving relative to the object includes:

- Tracking (moving to / from / with / by the object)
- Tracing (moving across / around / along the surface of the object)
- Entering the object
- Pointing at an object

Moving the object includes

- Dragging
- Pushing / pulling
- Displacing the object (shaking / tilting / twisting/ rotating)
- Directing object motion

Possessing the object includes:

- Grabbing / grasping (e.g. on mouse down)
- Holding / gripping (e.g. continued mouse down)
- Releasing (e.g. on mouse up)

Touching the object includes:

- Tapping / hitting
- Pressing / squeezing / stretching
- Rubbing the object

While gesturing can be performed without physical contact, it should be considered when used with tactile devices, such as data gloves.

# 3. Application of the GOTHI-05 Model

The GOTHI-05 model has been used as the basis for a new standard ISO 9241-920 Guidance on Tactile and Haptic Interaction. The first working draft of ISO 9241-920 has used this model to structure 191 guidelines obtained from 40 research papers and 10 ISO standards.

The GOTHI model is the first model to identify the many dimensions of tactile/haptic output encodings and of tactile/haptic interaction tasks. Even without referencing the many ergonomic guidelines in ISO 9241-920, it can be used by developers to ensure that their analyses and designs have fully considered the possibilities and constraints of tactile/haptic interactions. Once they decide upon various encodings and interactions, this model can help them find the appropriate ergonomic guidance in ISO 9241-920 to support design and evaluation.