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Designing Pseudo-Haptic Feedback Mechanisms for Communicating Weight in Decision Making Tasks

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Abstract

This paper describes our approach that uses pseudo-haptic feedback as a *shikake* to effectively communicate weight and stiffness with the user who is interacting with objects. Pseudo-haptics is a type of haptic illusion, which occurs when visual properties and tactile properties exhibit inconsistency, or a conflict, in terms of the model of the world a person expects to perceive. We illustrate the approach by describing our prototyped touch-based tool that uses the *omni-viscosity string* mechanism. The tool represents the relationships and constraints among objects connected via invisible omni-viscosity strings by having a user feel the weight and stiffness when dragging some of the objects. Through our experience of exploiting pseudo-haptic feedback for communicating weight in human-computer interaction design, the paper discusses the notions of *illusion* and *feedforward* as key elements in designing a shikake for human-computer interaction.

Introduction

The concept of weight is a powerful scheme for people to communicate a wide variety of aspects of objects, events, activities, states, feeling, emotion, and phenomena. We have learned that “heavy” things are hard to move, change, or important, through our everyday experiences. This seems to hold true across different cultures. Thus, in addition to the literal communication of how much the mass of an object is, we use the concept of weight to describe and explain the importance, priority, modifiability, constraints, hesitation or willingness.

Weight has been communicated primarily through three means in human-computer interaction: symbolic representation (e.g., “240 g”), kinesthetic interaction (e.g., by wearing a physical actuator), or haptic feedback (e.g., by applying low-frequency stimuli to the forearm). Our approach is to use a fourth means: using visual interaction to communicate weight by exploiting pseudo-haptic feedback (Nakakoji, Yamamoto, and Koike 2010).

Pseudo-haptic feedback, which stimulates haptic sensations such as stiffness or friction without necessarily using a haptic interface but incorporating visual feedback, is an effective means to communicate information that may not physically present with the brain (Lecuyer 2009).

Using Haptic Illusion for Communicating Weight

Perception of Weight

Humans do not have an intrinsic sensory channel to perceive weight. Weight is perceived through the integration of multiple sensory channels, mainly vision and haptic information. Although it has not yet been completely understood how a human being perceives weight, the widely accepted view of the perception of weight is as depicted in Figure 1.

A person is about to hold an object in his or her hand. He or she has pre-understanding of how heavy the object would be by looking at the object, and he or she puts force to his or her forearm muscle accordingly. When he or she physically holds the object, the forearm may moves up or down depending on the difference between the actual weight of the object and the foreseen weight. He or she puts more or less force to the forearm to keep the object in a balanced position, and revises his or her understanding of

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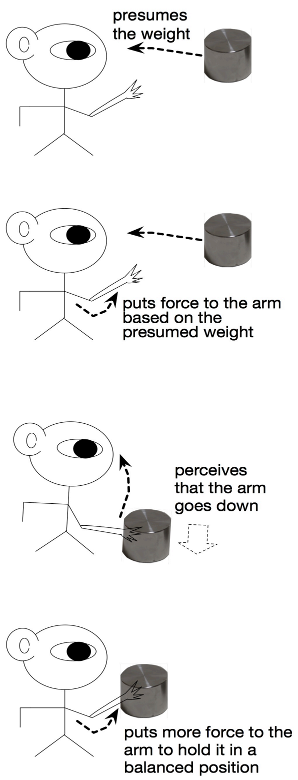


Figure 1. The model of perceiving the weight of an object

the weight. This process of feedforward and feedback iterates very quickly through the visual and tactile channels.

The pre-understanding comes from the person's previous experiences of interacting with a variety of physical objects. We use visual cues such as the size, texture and presumed material to foresee how heavy the object is likely to be. Humans have developed numeric systems to talk about and communicate the weight, or the mass of an object. We learn how to approximate the weight in the numeric system from the perception of weight as we grow up, but often faultily.

Illusion

An illusion is a distortion of the senses, where the information gathered by the senses is processed by the brain to give a percept that is not in correspondence with the actual physical properties of the stimulus source.

Illusions of color are probably most familiar to us. As an example, we perceive the color orange when yellow stripes are put over the pink area surrounded by the thick blue border, while we perceive the color purple when blue stripes are put over the same pink area surrounded by the yellow area (Figure 2; reproduced based on (Color Illusion 12)).

A size-weight illusion is a tactile illusion where a larger object is generally perceived lighter than a smaller object if they have the same weight. Ross has found that the perceived weight of an object is a linear function of the logarithm of its density when only the volume is changed and weight being constant (Ross 1969). The study has also found that the material of an object affects the expectation of how it weighs, and tins are perceived slightly heavier than polystyrene blocks (Ross 1969).

Although an illusion is "an erroneous perception of reality" (American Heritage Dictionary), it is based on an "adjustment" made by the brain during perception, and commonly shared by most people. Illusions are "errors committed by the brain rather than by the senses" (Goldstein 1999 as cited in Lecuyer 2009).

On one hand, illusion can be misleading and has been something to pay an attention to in human-computer interaction. For instance, people might make a mistake in interpreting information in colored graphs as a result of a color illusion. On the other hand, illusion can be something to take an advantage of in interaction design.

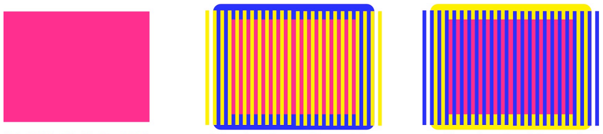
For instance, with the above color illusion example, we do not need to use orange in order to make people perceive orange; by appropriately placing the colors pink, blue and yellow, we could produce either the "orange" or "purple" effect.

Our approach in the design of human computer interaction is to take an advantage of the existence of such illusions as a property of human perception system, something to nurture.

Pseudo-Haptics

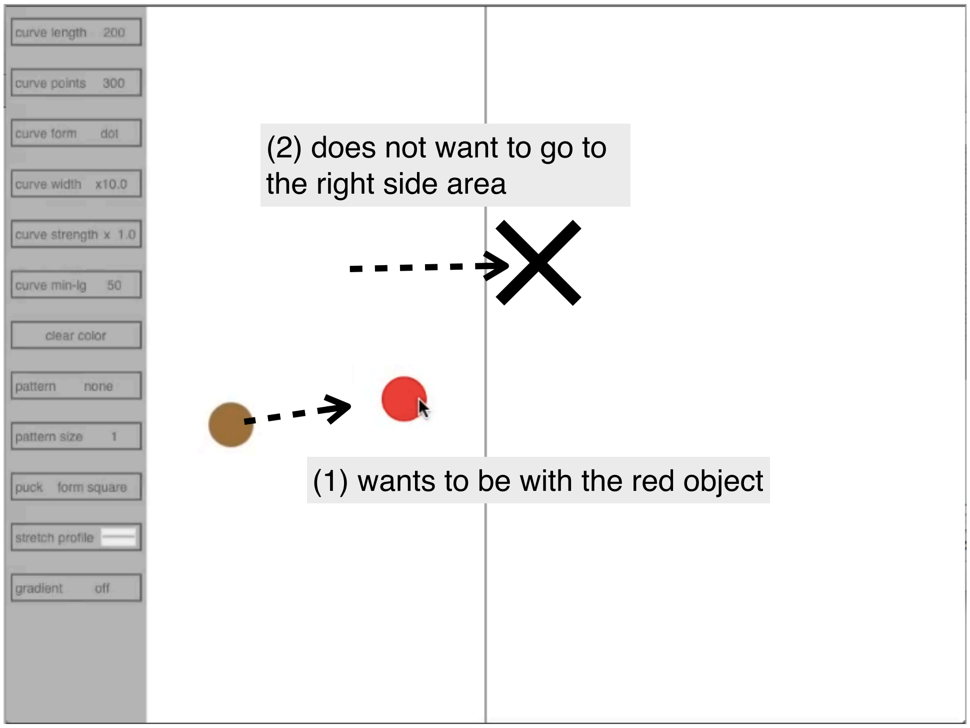
The human brain has its peculiar nature of integrating information coming through different sensory channels to construct a consistent model of the world. Some sensory systems dominate other sensory systems, and when information given through two sensors has inconsistency, the information through a dominant sensory system (e.g., vision) overwrites that of a recessive sensory system (e.g., touch). This may result in the situation when the person senses what is not physically present through the recessive sensory channel.

Pseudo-haptics, a type of haptic illusion, occurs when visual properties and tactile properties captured through the sensory channels exhibit inconsistency, or a conflict, in terms of the model of the world a person (i.e., his or her brain) expects to perceive (Lecuyer 2009). The visual sense



(R=255, G=0, B=127) blue border, yellow stripes yellow border, blue stripes

Figure 2: A Color Illusion Example
(reproduced based on (Color Illusion 12))


curve length 200
curve points 300
curve form dot
curve width x10.0
curve strength x 1.0
curve min-lg 50
pattern none
pattern size 1
puck form square
gradient off

(2) does not want to go to the right side area

(1) wants to be with the red object

Figure 3: The Prototyped Tool

is dominant over the tactile sense, and the person perceives tactile properties differently from the actual physical properties so that the perceived visual and tactile properties would produce a coherent view of the world.

Pseudo-haptics on texture has been widely applied by changing the size and the speed of the mouse cursor displayed on a screen in terms of the user's mouse movement (Lecuyer, Burkhardt, and Etiennne, 2004). Watanabe and Yasumura (2003) have exhibited the force of the wind, harsh surface, and wavy tin-roof, by changing the visual size of the mouse cursor.

Designing pseudo-haptic feedback mechanisms

Lecuyer (2009) describes steps to design a pseudo-haptic system that simulates a given haptic property (p.51):

(1) identify a law that controls that haptic property and associates it with spatial parameters;
(2) set up a visuo-haptic sensory conflict focusing on a spatial parameter associated with this haptic property; and
(3) modify the perception of the targeted haptic property and create pseudo-haptic feedback by simply modifying the visual feedback of this spatial parameter.

In modifying the visual feedback, the notion called C/D (Control/Display) ratio is introduced (Lecuyer, Burkhardt, and Etiennne 2004), which refers to how to change the speed of hand movement (Control) in relation to the speed of cursor movement (Display).

In order to communicate a designated weight by using pseudo-haptic feedback mechanisms, we need to understand how to design such C/D ratio.

A Prototyped Tool for Communicating Weight in Decision Making Tasks

Our approach uses pseudo-haptic feedback for communicating weight when a user interacts with a visually represented object. We have been building TCieX (Touch-Centric interaction embodiment eXploratorium), which is a collection of simple interaction test suites that help us experience different combinations of multimodal interactions (Nakakoji et al. 2011). In TCieX, a user produces a variety of temporal, visual, and auditory representations for different types of object movement with different C/D ratios and mapping profiles, and interacts with the objects to experience how one feels the weight and stiffness.

This section describes one of the TCieX tools we have prototyped. When the user is dragging an object by using a fingertip or a mouse, its visual movement and/or the visual representations of other related objects are deliberately made inconsistent with the user's finger-tip movement, making the user experience the priority and constraints among objects through the pseudo-haptic feedback.

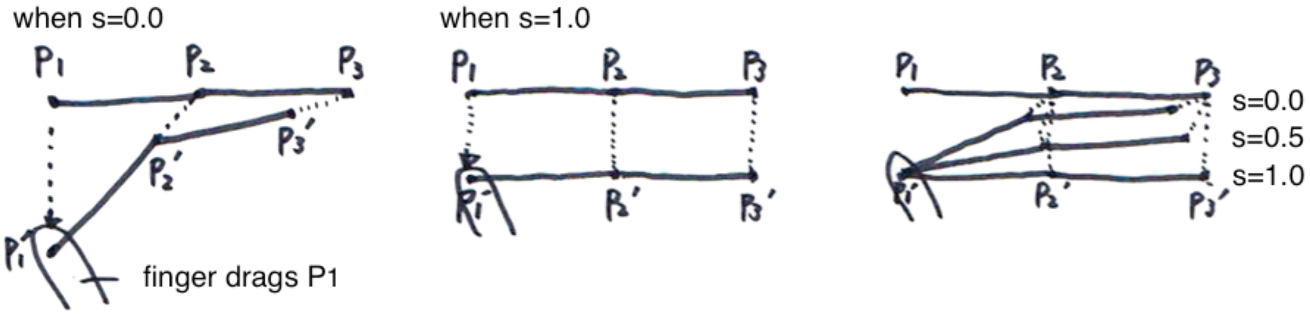


Figure 4: The Mechanism of an Omni-Viscosity String

The Tool

The tool is designed by taking a simple group assignment task as an object-to-think-with.

Suppose there are two objects, a red one and a brown one, to place in one of two adjacent rectangular areas (see Figure 3). Assume that there are two conditions for the brown object. First, the brown object wants to be in the same area with the red object. Second, the brown object does not want to go into the area on the right side.

When a user drags the red object and moves it around in the left side area, the brown object traces the red object's movement in a short fixed distance. When the user drags the red object from the left area into the right area, the brown object slows down and the distance to the red object gradually increases so that the brown object stays within the left side area. If one keeps dragging the red object further right, the brown object slowly comes into the right area following the red object. As soon as the brown object enters the right side area, it traces the red object again in the short distance.

Underlying Mechanism: the Omni-Viscosity String

The interactive visual behavior of the two objects is implemented by using what we call the *omni-viscosity string* mechanism.

The omni-viscosity string dynamically changes its length and stiffness. The string is designed as a connected sequence of equally distributed N points, where N is a fixed natural number (more than 2), which determines the length of the string.

When a user drags any of the N points of an omni-viscosity string, the other points on the string follow the dragged point based on the parameter controlling the stiffness of a string.

The visual representation of the stiffness of the omni-viscosity string is similar to drawing a spline. Figure 4 describes the mechanism of the omni-viscosity string.

When a user drags the point Pn(x, y) to Pn', the adjacent point Pn-1 moves to Pn-1'. The distance and direction of the movement of Pn-1' is determined by the stiffness parameter *s*, where s is a real number between 0.0 and 1.0. The movement of one point of an omni-viscosity string is propagated to the other points one by one along the string toward the two ends of the string. The string is the most flexible when s=0 (i.e., when a user drags a point on a string, the string moves as if it is a silk thread), and becomes the hardest when s=1 (i.e., when a user drags a point on a string, the string moves as if it is a piece of steel wire).

The two objects are connected via an omni-viscosity string, where each of the two objects is located on the string's each end. In the prototyped tool, the visual representation of the string can be switched off, making the connecting string invisible.

How one of the two objects moves when a user drags the other object depends on how stiff and how long the connecting omni-viscosity string is set, which can dynamically be changed as the user drags the object:

- When the two objects are connected with a short stiff omni-viscosity string, the relative location of the two objects stays the same. When a user drags the red object, the brown object strictly follows the red object (Figure 5(a)).
- When the two objects are connected with a short flexible omni-viscosity string, the brown object follows the red object when the distance to the red object exceeds the length of the string (Figure 5(b)).
- When the two objects are connected with a long flexible omni-viscosity string, the brown object barely moves when a user drags the red object (Figure 5(c)).

By applying different stiffness parameters, the two objects movement demonstrate a rich variety of behavior. By interacting with the prototype tool, we have found that we often associate the two objects behavior with social

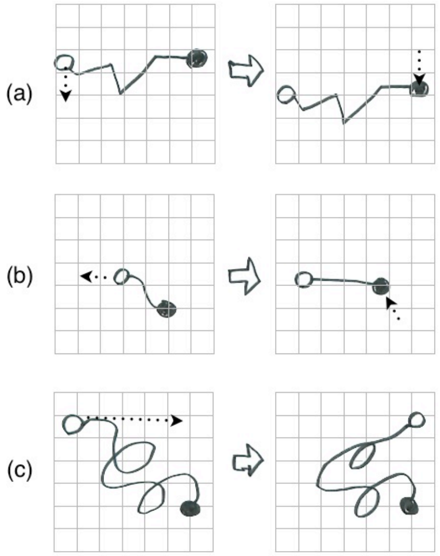


Figure 5: Three kinds of the movement of the object

relationships, such as by saying “the brown object likes the red object,” “the brown guy stalks the red guy,” or “the brown one is not willing to go to the other area.”

Discussion

We are interested in the notion of *shikake* in the context of human-computer interaction design, where we use haptic illusion in one type of shikake. In designing and building the prototyped tool, we ponder how to design visual interactivity so that a user would perceive the world through multiple sensory channels in a designated manner. The physical world is not necessarily an ideal situation for a user. We may need to alternate information on some of the sensory channels so that the user would perceive the world more effectively for a particular purpose in a particular situation.

In designing a system with multimodal interaction, the visual, audio, haptic, olfactory, and even gustatory information displays become much more complex than the traditional keyboard, mouse and LCD-based interaction because we do not have much understanding on how the brain interprets the information coming through multiple sensory channels. As interaction designers, our job is not to understand the mechanics of the brain, but to understand how the brain interprets and models the world so that we can take an advantage of the nature.

In this sense, we are interested in designing a shikake for brain. It is not about brain interface as generally perceived. Designing multimodal interaction needs to take into account such nature of the human brain in terms of how it models the external world by using information coming through different sensory channels. Multimodal interaction systems use a person’s sensory systems as instruments for the brain.

Through our experience of exploring the use of pseudo-haptic feedback in communicating weight, we think that there are two notions that need to be studied from the shikakelogy point of view: illusion and feedforward.

Illusion. Multi-modal environments have tried to enforce more immersive, more realistic feedback, such as through organic user interfaces, where input equals output (Vertegaal, and Poupyrev 2008). Illusions have been regarded as something to be taken care of in interaction design. Illusion may cause a wrong interpretation of the information presented to a user, and therefore, something not desirable and should be avoided.

The use of illusion, such as the pseudo-haptic feedback, however, makes us consider how a user perceives the world through multiple sensory channels. The physical world is not necessarily the ideal situation for a user, and we may need to alternate information on some of the channels so that the user would perceive the world more effectively. We think that properly situated illusion should be more explored and used as shikake in interaction design.

Feedforward. People interact with the external world based on the pre-understanding of the world. The human brain plans how much force to put to on the muscles of the forearm before holding a book so that the arm neither tosses up the book nor drops the book. This planning is only possible by looking at the book, with the pre-experienced knowledge of the relation between the look of a book and its weight.

The notion of feedforward becomes essential in guiding, persuading, or eluding a user’s certain actions. Pseudo haptics occurs only when the user has built a model between the hand movement and the movement of the visual object. Such setting is necessary for the subsequent weight illusion to take place.

Interaction design has focused on how to present feedback for a user’s action so that the user understands how the user's action has been interpreted by the system, and what the system has been doing in what context. Based on this feedback, the user plans for the next action. The same presentation of the information might be viewed as feedforward information for the user’s subsequent action.

The notion of direct manipulation and feedback based on the truthful reflection of the physical world may no longer be the guiding framework for designing tangible, embedded, and embodied interaction. HCI designers (as well as brain scientists) have very limited understanding on how the brain models the external world by using multimodal information.

Existing human-computer interaction primarily uses symbols and diagrams to communicate information with a user. If we combine haptic illusory feedback to conventional human-computer interaction, would it significantly affect a user's behavior? We argue that studying the roles, effects, and design methods of shikake in the context of human-computer interaction would help us better address the question.

Acknowledgements

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