Building a Haptic Language: Communication through Touch

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Abstract

Designing haptic signals to enrich technology interactions requires a clear understanding of the task, the user and the intricate affordances of touch. This is especially true when the haptics are not implemented as direct renderings of real world forces and textures, but as new interactions designed to convey meaning in new physical ways and support communication. The overall goal of our group's research is to provide the foundations for haptic interactions that are simple, usable and intuitive and that fit within the context of the user's life.

In this paper, we describe three avenues through which our group is exploring and building a haptic language that will effectively support communication: signaling and monitoring, expressive communication and shared control. We use scenarios to illustrate where this approach could take us, and emphasize the importance of process and appropriate tools and representations.

Keywords: H.5.2.q User-centered design, H.5.2.h Input devices and strategies

1. Introduction

Today's technology has created a paradox for human communication. Slicing through the barrier of physical distances, it brings us closer together – but at the same time, it insulates us from the real world to an extent that physicality has come to feel unnatural.

New systems bridge distances between people, and make machines more personable and interactive. Instant messaging, emails, cell phones and shared remote environments help to establish a fast, always-on link among communities and between individuals. Technology attempts to promote collaboration by deliberately supporting it, and to enhance everyday life experiences by taking repetitive and tedious tasks out of our way. On the other hand, technology dilutes our connection with the tangible material world. Typing on a computer keyboard is not as natural as writing with a nice pen. Talking to a loved one over the phone does not replace a warm hug. Congratulating a peer for a success via instant messaging does not carry the same personal meaning or warmth as shaking her hand in person.

Our haptic, or touch, sense plays a key role in our everyday life experiences *outside* the computer world [12, 14, 21]. It provides us with *feedback* required for *high-precision motor tasks* such as holding a fragile glass without breaking it. Distributed forces that are felt across the hand's skin and muscles inform our brain of the appropriate amount of finger pressure to apply, so we neither drop the glass or crush it. Similarly, touch guides our movements in the *control of dynamic systems*. We physically guide a car's steering wheel, while unconsciously parsing subtle vibrations that warn of slipping tires. It is constantly used to *monitor states,* such discerning when a pencil is sharp. Touch is also a *source of pleasure* that is available when stroking a richly textured fabric, or using a finely balanced tool. Physical personal contact is often key to the enrichment and development of *social interactions*; for instance in shaking a hand or touching a shoulder [15]. These examples illustrate the significant physical communication present in our interactions in the real world. This rich mode of communication is absent in our interactions with technology.

Full integration into computer interactions means *designing* synthetic haptic interaction as a schema of expression and communication with its own set of rules and operators. The haptic system is different from the other sensory modalities. It is bidirectional, providing us with the close-coupled feedback required for active dynamic control. It is distributed over our entire body through skin (tactility) and muscle and joint receptors (kinesthesia) [7]. Finally, our sense of touch is very intimate and personal. While others can *"see what I see"* or *"hear what I hear"*, they do not *"feel what I feel"*. If we are to design successful artificial haptic sensations that are rich in emotional content and meaning, we first need to build a haptic language that is suited for communication through touch – and this language is going to be different from the one computers use now.

1.1 Key Research Challenges

In this paper, we present three core areas (Figure 1) in which haptic feedback can contribute to human communication with and through everyday technology in ways that mimic or go beyond haptic interaction in the real world.

- **Signaling and monitoring**: When other senses are overloaded, we can receive and parse abstract information haptically; but to build an iconic language for touch, we need to know more about the limits of our tactile perception, our cognitive models for associating signals with meanings, and the role attention and workload play in what gets through.

- **Expression of affect**: Touch may be a channel through which technology can directly receive and speak to our emotions. What is the basis of our pleasure in or dislike of the things we touch? How, specifically, do we use touching to "emote" to other people? Knowing this, we can design interfaces to haptically support affect.

- **Sharing control with intelligent systems**: There is a fundamental challenge in getting data derived from "smart" systems to the user without disturbance or distraction, regardless of modality. Can we create force feedback models that allow us to receive suggestions nondisruptively, and then act as we choose?

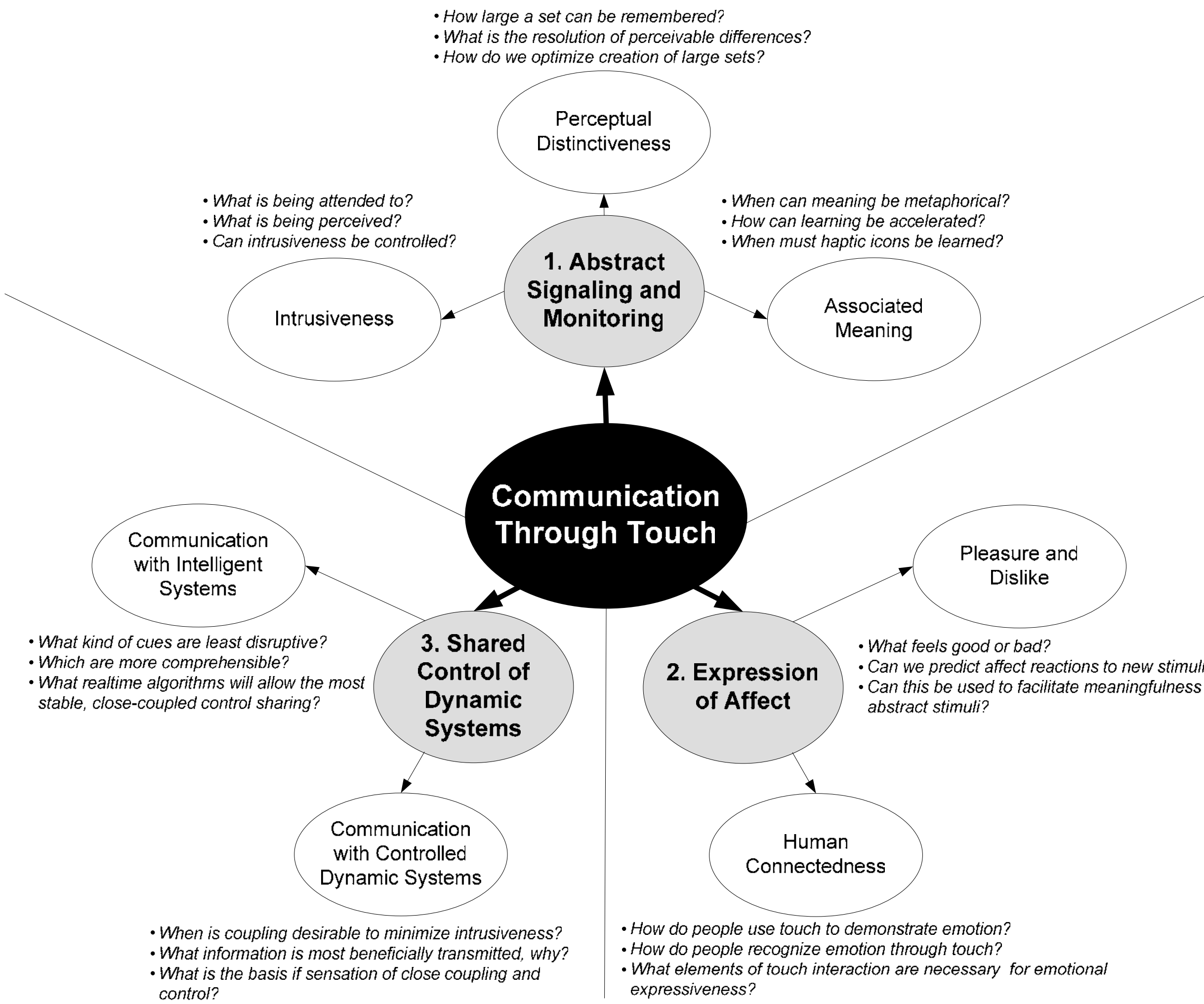

Figure 1: Three core areas of our group's research interests.

1.2 Paper Overview

In the remainder of this paper, we will discuss each of these research areas, grounded by specific recent examples from our group's research and starting with a short introduction to our research group. We will then collect our insights and relate them to key ongoing challenges.

Throughout the paper, we make use of a series of usage scenarios to illustrate how simple (albeit tricky to design) synthetic haptic feedback embedded in our everyday interactions can restore the lost physical connection with our environment. Some of these ideas are near fruition, while others may never occur as we envision them. Regardless, we hope that their specificity will help to demonstrate that the potential breadth and richness of the haptic modality is greater than it might first seem. The series of scenarios are put in context here as we follow a young professional parent on a 3-day business road trip.

> *Tamara is a salesperson who is often on the road. She spends a large part of her day in the car, commuting from one client to another, often from one city to the next. We catch Tamara as she as she kisses her husband and young son goodbye and embarks on a road trip that takes her to her clients in the sales region she is responsible for.*

2. Philosophy

Both the example problems and the choice of research style and methods used to approach them are specifically illustrative of the Sensory Perception and Interaction Research Group (SPIN) in UBC's Computer Science Department. The vision that motivates our choices is of inexpensive, robust and power-efficient physical interfaces that are ubiquitously embedded in our environment wherever we interact with computation – mobile devices, buildings, clothing and cars.

Countering the general trend in this field, the devices used in the research examples mentioned below must be simple because of their intended environment. The techniques used to design applications *with* them must therefore be all the more sophisticated: creating powerful yet intuitive interfaces without recourse to technical complexity is perhaps the greatest interface challenge there is. Our technology (Figure 2) ranges from off-the-shelf (an iFeel mouse proved an application concept with commodity hardware [13]), to adapted components (voice coil vibrotactors [29]), to simple custom interfaces (integrated knobs, sliders and turntables), to complex novel devices (e.g. a piezo skin-stretch tactor in a handheld format [19].

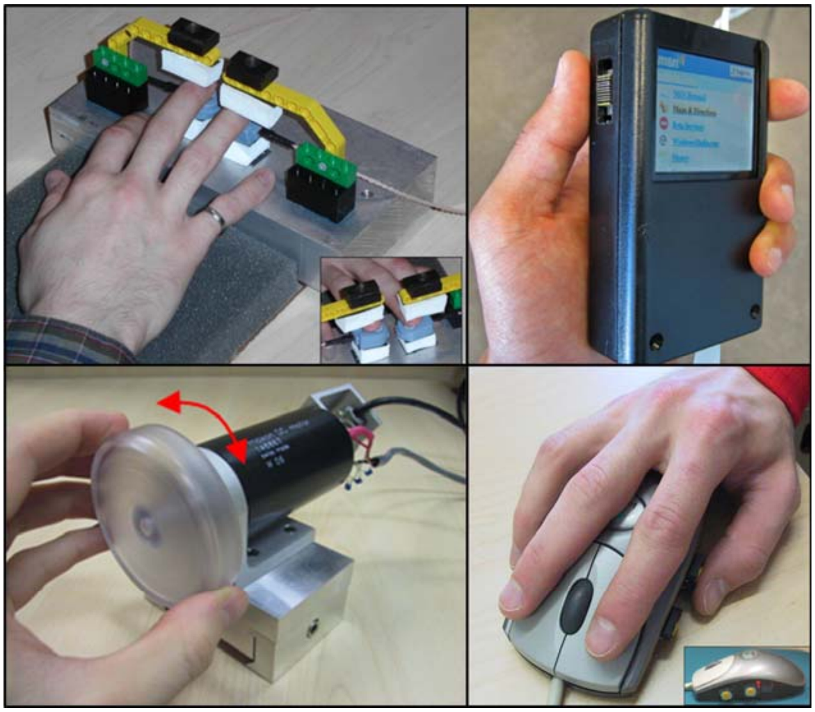

Figure 2: Some devices used in the research discussed here.

Our path is multidisciplinary, integrating methods in psychophysics and application interaction design with advances in device engineering, and demanding a substantial investment in tools and methods. As shown in Figure 3, the process cycles between application prototyping, evaluation and basic psychological study, with transitions driven by observation of the psychological knowledge gaps that are confounding success, and then again by progress in resolving them.

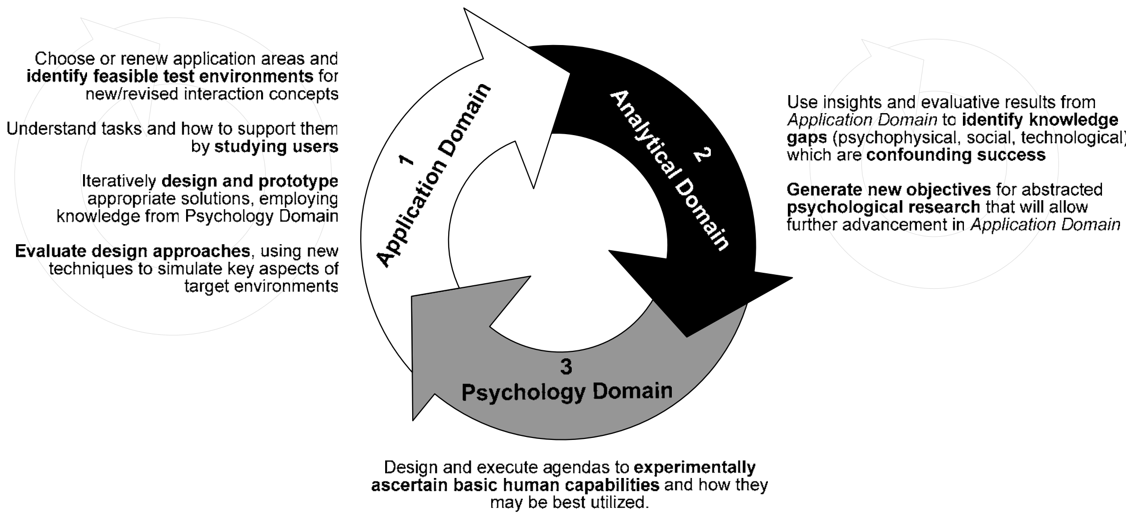

Figure 3: Iterative process cycle driving our group's research approach.

3. Signaling and Monitoring

Today's combination of "always-on" connection devices and feature bloat bombard users with visual and audio information. Touch may be well suited to help alleviate the cognitive overload, because it is underutilized in computer interfaces yet we have a rich experience in the physical world of using haptics to collect information in intuitive, transparent ways [14, 17]. However, we do not yet have heuristics or common expectations for how such information should be transmitted in digital interfaces. Moreover, to augment interfaces haptically without making the overload even worse requires understanding the role of attention (and its saturation) in multimodal perception.

Haptic feedback is also how we can make small digital transactions physical, confirmed, known; e.g. [16]. In the real world, we know a door latch has engaged when it clicks. The computer doesn't usually help us out in this way, and when it does, it's generally with a sound [11] which, while effective, is intrusive in many situations.

Both of these roles can be assigned to a construct which we define as "*haptic icons*": short, synthetic, abstract haptic signals (either tactile or kinesthetic force feedback) that convey information such as event notification, identity, content or state [3, 20]. This effectively represents a synthetic haptic language, which can be viewed as a new dialect of the collective haptic language which we already share. In creating this new dialect, we start with our social and experiential norms for manipulating tangible objects and interpreting physical feedback. Wellestablished metaphors for touch can drive new models for association and bring intuitive meaning and affordances that relate to haptic icons.

However, our new language will go beyond the old one because much of the information it will transmit is abstract, and not easily related to obvious metaphors. A key focus of our research is to derive the methodology by which we make this transition. In this section, we first frame the problems presented by the design of haptic icons, then consider haptic messaging as it relates to attention.

3.1 Haptic Icons

In order to be effective, haptic icons must be meaningful and easily distinguished. They also need to be short, easy for a user to process, and must transmit a message reliably and consistently. They must not be ignorable when conveying urgent and important information. Like graphical icons, haptic icons must either be universal (generally recognized by different people in different situations) or easily learned and compatible across applications.

Our group has worked for several years to refine the process of designing haptic icons for specific applications, beginning by satisfying the necessary (but not sufficient) requirement for perceptual distinctiveness [20]. We have demonstrated that users can learn a small set of abstract icons quickly: in one typical result, users learned 7 abstract haptic icons displayed on a vibrotactile mouse in less than 3 min, and retained and use them beneficially over a 3-hour period [5]. We have deployed designed haptic icons in a number of applications and device form factors [1, 4, 22].

Most recently, we have taken these findings into the context of a novel handheld tactile display device evolved from a previous project [18][1]. This project considers how embedded tactile displays can help meet user needs in ways that are not currently met (in terms of intrusiveness and eyes-free operation) by contemporary mobile information interaction practices that make use of visual and auditory feedback alone [19]. Because the sensations the device renders are completely unfamiliar to users, the language for *this* device is truly new. Our initial results elsewhere indicate that this kind of abstract haptic feedback has sufficient expressive and information capacity to provide significant benefit in these contexts, and user feedback confirms a need for quiet, non-intrusive haptic signals in applications such as hand-held mobile devices.

Usage Scenario: Tamara receives an urgent call on her cell phone

> *During an informal chat with some clients she is visiting, Tamara receives a call on her mobile phone, which is on "vibrate" mode. Reaching into her pocket and grasping the*

[1] This work is the result of a tight collaboration with McGill University in Montreal.

phone with her thumb on the small tactile display on its side, she immediately receives a sharp, anxiety-provoking sensation. Two traveling ridges start repeatedly from the two opposite ends of the tactile pad and meet in its center; they accelerate like a heart beating faster and faster. There is definitively something wrong at home! After apologizing to her clients, Tamara answers the phone to find out from the babysitter that her 5-year-old boy, Bobby, has cut himself with a rusted nail. The babysitter is on the way to the hospital and wondering about tetanus shots.

It is easy to imagine Tamara's cell phone displaying other haptic icons to indicate many different conditions and callers. She is able to get details about the urgent message from the phone's tactile display with a quick, discreet motion (slipping her hand into her vest). While the transmitted message must always be clear and concise, in most situations it should not demand Tamara's full attention.

3.2 Designing for Attention

When attention is in short supply, interfaces will eventually become smart enough to know when to intrude; and haptic icons may be a good delivery mechanism for interfaces which aim to manage intrusion. Getting haptic icons to this point requires the ability to test them (as sets) while controlling workload intensity in multimodal task simulations.

We have worked to develop techniques for prototyping realistic contexts of specific test applications, to explore more basic questions such as how cognitive workload is impacted by haptics communication, and whether conscious attention is required to make use of haptic signals. For example, when testing haptic feedback provided as a subtle pushback through an automobile pedal to indicate dangerously close following, we modulated multimodal and cognitive workload in an abstracted driving simulator [8]. We found that for complex tasks, subjects' strategic idiosyncrasies and the absence of real risk in simulated driving made workload particularly challenging to control, directing us towards less direct experiment manipulations. In an application with haptic mediation of an urgency-based turn-taking protocol for distributed collaboration, crafted waveforms 'played' on iFeel mice indicated, by varying signal intrusiveness, the urgency of 'floor' requests without disrupting the group's work flow. This, along with other haptically communicated data, appeared to encourage more equitable control sharing and frequent turnovers among the collaborators [4, 5]. In a more abstracted instance, we used a similar technique to compare several schemes for iconic rendering of ordinal data for their efficiency and robustness under workload [22]. The importance of workload testing was apparent in both cases in the diversity of response patterns that different types of icons elicited as load increased. For turn-taking, some icons needed to be more intrusive than others, whereas for the ordinal renderings, our aim was for uniform salience; workload testing allowed iteration to achieve both of these goals.

Usage Scenario: Tamara makes use of a haptically-mediated turn-taking protocol

> *Tamara enters the room for a meeting with several people at her client's company (and several more connected by video link), and immediately notices Karl (the company's technical VP – a person important to not offend, but known for endless monologues). However, she takes hope from her second observation, which is that the room has haptic chairs that help speakers be aware of how urgently others wish to take the floor. Soon, Karl raises a damaging criticism that Tamara can easily address, but doesn't give her an opening. Instead of trying to interrupt verbally, Tamara reaches for one of the buttons on her armrest. Both Tamara's and Karl's chairs emit a firm, brief vibratory burst, indicating that a new and urgent request has entered the queue. Every 20 seconds or so thereafter, Tamara and Karl are reminded of the urgent request by a brief (but different) haptic vibration through their respective chairs. After about a minute, Karl pauses in mid-harangue, then looks down at his chair, mildly surprised. He looks around again, and this time Tamara is able to catch his eye. He raises an eyebrow, quizzically, and Tamara quickly takes the floor. Karl pushes a release button on his own chair to stop the queue-signal.*
>
> *In the middle of her answer, Tamara gradually notices a mild pulse on her own chair. The signal informs her that someone else wants to talk next, but not urgently. She surveys the faces around her as she speaks, but doesn't notice anything. She wraps up her point a bit more briskly and presses her control-release button. Into the ensuing pause, someone on the video link introduces a different topic.*

The haptic signals that Karl and Tamara feel must be matched to both the task and the users. For Tamara, it provided extra contextual information, without distracting her from her speech. In contrast, the haptic cue that Karl received was so evocative that it demanded his attention. To make these interactions possible, application designers need a solid understanding of how people react to haptic stimulation under cognitive load.

3.3 Summary

In this section we have introduced and defined haptic icons as well as the design challenges that they present. We have illustrated their potential to lighten workload through specific examples, and have argued that we need user-centered and psychologically-grounded design practices as well as flexible tools to make haptic applications that work.

4. Expression of Affect

The manipulation of objects from our environment is a source of both enjoyable and unsatisfying sensations. Most of us feel good when a flying ball slams into our baseball mitt, and have experienced frustration that is amplified by the tearing friction of the jammed paper we are ripping out of a photocopy machine. Touch interactions carry emotional baggage. In this section, we explore different ways of exploiting the expressive channel that touch affords. We begin by examining the relationships between the kinesthetic experiences of touch interactions and the corresponding visceral emotional responses. Then, we address the question of how to improve computer-mediated person-to-person communication through haptics.

4.1 The basis of pleasure with physical objects

We are currently studying the attraction or aversion that individuals feel toward manipulating knobs that exhibit different haptic dynamic properties (e.g. inertia, damping, friction.). In [28], we measured users' emotion valence through both self-reports and biometric measures, while they performed a list-lookup task using a programmed haptic knob. Results suggest that subjects preferred the "feel" of the knob when it tended to help them find the target. However, the experiments also identified a few cases with a clear preference between two knob behaviors (e.g. small viscous friction vs. large viscous friction) even though the preferred one, in this case a small viscous friction knob, did not significantly increase task performance. These preliminary findings support the growing view that interfaces must go beyond meeting simple performance and functionality requirements, and form a pleasurable emotional bond with their users to increase the whole usability experience and in some cases performance.

Usage Scenario: Tamara finds a radio station on her car radio

> *Driving to her hotel, Tamara wants some quiet music to relax after a stressful day. In her previous car, she generally waited for a traffic stop to change radio stations because her fingers could never find the small tuning button. However, Tamara's new car is equipped with a haptic knob on the dashboard that allows her to control the settings of her car radio. As she drives along the highway, she reaches for the large, heavy, metal knob, which reminds her of old-style radio tuners; it feels comfortable and reliable. Turning it, her fingers travel over a series of distinct, textured bumps. Each bump represents a different radio station: a wide bump means good reception, and the texture suggests the type of music. Tamara keeps rotating the knob until she feels a large, smooth bump. She knows it will be classical music that will pour through the car once the commercial ends[2], without ever taking her eyes off the road.*

When combined with the development of flexible design interfaces, an understanding of the user's subjective response to different haptic properties will enable creation of interfaces that work well and feel "good".

[2] We can't do anything about the commercials, unfortunately.

4.2 Human Connectedness

The intrinsic intimacy of the haptic channel seems particularly suited for the communication of emotion from one person to another. In real-life, humans can connect through touch in ways that are not afforded by other sensory modalities. How can we use the subtle and complex human-to-human emotive capabilities of haptic communication in computer-mediated touch interactions? What aspects should be transferred from the real world? Researchers have developed and built devices for computer mediated haptics including novel interactions [9], modeled manipulation of a shared object [2], and have prototyped synthetic versions of face-to-face touch [23]. In our group, we approached the use of haptic devices to communicate emotion between people by studying possible *models* for haptic interaction.

Among other things, we were interested in finding how varying the touch metaphors underlying a shared haptic interaction could influence users' fluency in communicating emotion [25]. In an experiment, members of a dyad were asked to convey a list of emotions, such as *angry* or *delighted*, through a pair of "linked" 1DOF haptic knobs, one for each subject. The dyads were either romantic partners or total strangers. The knobs were linked through a haptic interaction model such that the actions of one individual were experienced haptically by the other. One interaction model embodied a stroking of hands and was sensed through the haptic knobs as two surfaces rubbing against each other whenever the virtual hands were superimposed in space. Another interaction, called *PingPong*, represented the indirect-contact exchange of a ball traveling back and forth between the two subjects and was experienced as hitting a ball and waiting for it to return. Overall, the *Hand Stroke* metaphor created a greater sense of connection, though it was sometimes judged inappropriate (and indeed, markedly unpleasant) between strangers. Computerized haptic interactions, like their real-life counterparts, are indeed capable of connecting people in distinct ways; the desirability and interpretation of this connection is colored by the individuals' relationship.

What mechanisms are required for a completely agent-driven interface to convincingly communicate, and read, a person's emotion through touch alone? We have taken a cue from the physical clues like respiration, purring, ear posture and heartbeat that indicate to us a pet's emotional state (*annoyed*, *contented*). With a real animal, these subtle interactions can powerfully influence our own emotional state. A preliminary Wizard-of-Oz experiment involving subjects interacting with a device exhibiting cat-like behaviors showed that emotional state could be communicated through touch using this animal-like metaphor and a simple display [6].

Usage Scenario: Tamara uses a shared haptic object

> *As Tamara enters her hotel room, she wonders how her son Bobby was feeling at the end of his own rough day. It is too late to call home. So Tamara pulls out of her purse a small pillow covered with fur and with many ear-like appendages, which Bobby has*

dubbed "Creature" and which also happens to be a wireless device. Sitting in bed, she slowly strokes Creature and rubs its ears. Earlier that night, back home, Bobby was doing the same with his own Creature, identical to this one. Tamara's Creature soon warms up and begins to purr softly under her hand. Its ears move slowly, or not at all; its breathing is regular. Tamara is reassured. Bobby did not upset the creature that they share – he was calm when he went to sleep.

This scenario implicitly indicates that the haptic interactions must be matched to the nature of both the social context – i.e. what is appropriate between a mother and her son – and the physical context (e.g. whether the operation is synchronous or asynchronous).

4.3 Summary

An affordance for emotional response and emotion communication need to be explicitly designed into interfaces. By studying the emotional responses elicited by manipulating the feel of knobs, we can learn what makes a knob feel good or bad. We have found that haptic interaction models can impact the communication of emotion between people, and that a simple haptic device modeled on the relationship between humans and their animals is a platform for exploring the essential ingredients of communicating and influencing emotional state using touch.

5. Sharing Control of Dynamic Systems

The previous treatment of haptic icons addressed conditions where there is a clear need for the delivery of brief, discrete messages with specific information content. By contrast, another class of interaction problems requires a user to share control of a dynamic system with a "smart" controller that has access to a different set of information and abilities than the user. As with any tight, continuous collaboration, control sharing requires intimate and responsive bidirectional communication. Because touch is co-located with our motor channel, this kind of job is once again both an opportunity and a challenge for haptic designers: the partnership can potentially be fast and efficient, but poorly designed feedback can easily disrupt the user's intended response.

The process of overlaying forces on a car's steering wheel to support driving is illustrative of the typical challenges of intelligent haptic guidance [10, 27]. First, one must do no damage: integrating haptic feedback with human motor response (as when the user operates the steering wheel) can easily lead to oscillation and instability in the controlled system. The user must remain in charge both actually and in perception, able to override 'suggestions'; and finally, the intelligent system must actually provide helpful information in an actionable format.

Our group has attacked the difficult problem of lateral steering in an under-actuated system by implementing and experimentally comparing three haptic guidance models for a path following driving task on a simulator engine [10]. The most successful guiding algorithm (outperforming the more obvious proportional and potential-field approaches) predicted the desired trajectory, and cued the user to steer towards a point just *ahead* of the vehicle [24]. This approach resulted in better path-following; subjects experienced smaller and fewer guidance forces and they preferred it to the others. Although this experiment task was still a considerable remove from the complex dynamic process and risks of actual driving, these results suggest that haptic guidance superposed on a primary motor channel should be displayed progressively rather than abruptly in order to be both safe and supportive.

Our group has explored similar ideas in a wide range of contexts, including control of streaming media through a virtual dynamic model [26] and longitudinal force feedback in an automobile accelerator pedal [8]. In current work, we are adapting the methods described above to a development platform in which stakes and strategy can be manipulated more effectively, based on training amateurs in the use of a digital music controller.

Usage Scenario: Tamara is driving her car assisted by a Haptically Enabled Driving Support system.

> *Tamara's job requires her to spend long hours on the road, often at night on highways with limited visibility. She is aided by her car's Haptically Enabled Driving Support (HEDS), an intelligent system that knows the car's exact position and proximity to nearby vehicles, and translates this into continuous force feedback to the steering wheel and pedals. As Tamara enters a curve, a subtle force like a light finger touch gradually makes itself felt on the steering wheel, guiding her through the turn. Concurrently, because she is getting too close to the car in front of her, the accelerator pedal becomes "stiffer". Her foot is pushed slightly back and the following gap grows again. Tamara could not describe what the system feels like; she doesn't usually notice it. But she has never wanted to turn it off.*

The haptic system in Tamara's car works well to increase her perceived and actual safety because it is designed to share control. It delivers guidance to Tamara that she can follow and integrate seamlessly into her driving. At the same time, the guidance is delivered in such a way that she can easily choose to override it, making her more accepting of its suggestions.

In this section, we discussed some of the ideas related to haptic guidance; in particular, the dangers of instability in direct feedback, and some promising mechanisms for *usable* guidance delivery. We can maximize user acceptance of shared control systems by leaving the user in control, with the power to either utilize suggestions or override them.

6. Conclusions and Key Challenges

Designing haptic signals to enrich technology interactions requires consideration of the user. This is especially true when the haptics are not implemented as direct renderings of real world forces and textures, but as new interactions designed to convey meaning in new physical ways and support communication. In this paper, we described three primary avenues through which our group is exploring and building a haptic language that can be effectively used for communication: signaling and monitoring, expressive communication and shared control. In each of these three main sections we argued that haptic signals must be constructed with a clear understanding of the task, the user and the intricate affordances of touch. In Section 3, we described how haptic signals must draw appropriate user attention and should be suited for both the delivered message and the user's context. In Section 4, we outlined ways of designing expressive haptic interactions that give rise to intended emotional responses, and are also socially fitting. Finally, in Section 5 we suggested that haptic guidance forces derived from intelligent systems should be displayed smoothly and predictively, in order to safeguard user's sense of control.

The goal of our research is provide the foundations for haptic interactions that are simple, usable and intuitive and that fit within the context of the user's life. Through diversity in our usage scenarios, we hope we have demonstrated here that some common real-life technology-driven problems, particularly a loss of tangibility, can be alleviated by designing for touching, using appropriate tools and representations.

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