# Towards Transparency in Pervasive Information Display: Possibilities for Attentionally-Managed Tactile Signals

Karon E. MacLean[1]

## Abstract

*When combined with realtime knowledge of user context and goals, haptic feedback can contribute to the need for transparent, appropriately salient information display in information-rich pervasive environments. Designed with respect for human perceptual and attentional limits, it can serve as a "background" communication channel by freeing visual resources, and being naturally suitable for low-attention processing. In this paper, we describe opportunities, tools and research results in support of such functionality – including user-centred stimulus design mechanisms minimizing attentional load while optimizing cognitive resources, and emerging indications of approach scalability and best learning practices.*

## 1. Introduction

Users can be overwhelmed by the glut of data available in pervasively augmented environments, where we tend to multitask in the presence of many and uncoordinated information sources. When networked information can be screened or triaged for relevance to a user's current tasks, goals and physical situation, there arises an opportunity to optimize the user's attentional resources by managing display channel and signal salience according to importance and context. The haptic sense, comprising taction (perceived via the skin) and proprioception (body forces and motions), has special properties which make it a promising candidate for this. We use it in the physical world to collect information in intuitive, transparent ways, both independently and in co-operation with other senses; yet it is underutilized in contemporary computer interfaces. Handheld devices provide opportunities for haptic display – delivered for example as tactor waveforms, by a vibrating screen and felt through a stylus, or by the motion of a force-feedback knob.

*Haptic icons* are brief tangible stimuli with associated meanings, composed by varying the control parameters of a given haptic display: e.g. for vibrotactile voice coils and piezos, these have included vibratory frequency, amplitude, duration, waveform and rhythm, combined in various ways. To be viable, users must be able to quickly learn associations and remember them over time. Emerging results from our group and others suggest that this is a feasible goal [1, 4, 8, 14, 15, 17], but underscore the need for careful design. Application creators require mechanisms to ensure that sets of *stimuli* (underlying haptic sensations, independent of meaning) are perceptually distinguishable and to control their salience. We further require means of choosing meaning-stimulus matches to create learnable icons; and finally, in a longer view it is important to be aware of the scheme's ultimate scalability.

In the following, we suggest possible roles for haptic signalling in pervasive computing environments, then summarize recent developments towards several technical challenges.

---

[1] Dept. of Computer Science, University of British Columbia, Vancouver, B.C., Canada. Email: *maclean@cs.ubc.ca*

## 2. Haptic Icons in Pervasive Environments

Haptic feedback can play a variety of possible roles in environments where networked, context-dependent information is continually available, and visual attention is not. We focus here on envisioning the contributions of information-loaded, icon-like communication; other interesting roles, such as force-feedback workspace constraints or literal haptic rendering of visualized information, are beyond our scope. We require as a starting point a haptic display in contact with the skin, with the hand being the most sensitive.

***Events and User-To-User Communication:*** Signals transmitted by the system to the user vary in overall criticality and relevance to the user's current task. Event notification, or user monitoring of ongoing status, can be transmitted by specific haptic feedback which is salience-adjusted according to the need for urgent user attention as well as likely interest level based on context. Likewise, asynchronous *inter-user communication* varies and can be treated in the same way – for example, with a specific icon being associated with a close co-worker [2], and signal salience adjusted for context-determined criticality of a given incoming communication. Dedicated, task-specific inter-user communication can also be set up using a protocol (e.g. in collaborative turn-taking [3], sports team-member awareness, or medical service team needs).

***Control Identity:*** Multipurpose control/displays located in vehicle cockpits, on mobile handheld devices and throughout homes, workplaces and public spaces, have replaced manual controls of the past in response to embedded computing and function proliferation; but their multiple functions and often modal (state-dependent) interfaces can be disorienting and hard to use. Even when graced with a spacious graphic display (e.g. on a high-end car dashboard) the user's vision is often occupied elsewhere, and any screen can get cluttered. Haptic icons can indicate information like current interface mode, available functions and most-common command gestures, allowing users to navigate such spaces more automatically and we hope ultimately, without visual input [4, 7].

***Content or Service Identity:*** In a similar way, the identity or contents of data or available services encountered or searched in augmented environments via a handheld device (e.g. large-screen shared displays, laptops or wireless handhelds, RFID or barcode-tagged objects and locations [11]) can be indicated with haptic icons [9]. Haptics can also offer augmentation of both handheld [7] and large display workspace navigation and browsing.

***Media Browsing:*** Video and audio data which has been annotated using automatic [10] or manual logging or combination thereof requires an interface to make use of the annotation layer; other complex data-visualization environments have similar challenges with more relevant data than can be displayed visually. Browsing either a linear stream [13] or in a 2D or 3D projected space with either a fixed or handheld device is an opportunity for informative haptic annotations.

## 3. Progress towards Technical Challenges for Usable Haptic Icons

***Perceptual Distinctiveness of Stimulus Set:*** A vocabulary of haptic icons is based on a soundly produced *set* of underlying stimuli. Current commodity haptic display technology – which can be compared historically to a few pixels of monochrome graphic display – constrains this design space. Stimuli are ultimately matched with meanings according to either a semantic (stimulus characteristics suggest meaning), or abstracted approach (more systematic and therefore more scalable, but with open questions about learnability). Either way, we must understand the *structure* by which people perceive and categorize the raw stimuli, and how this changes under workload.

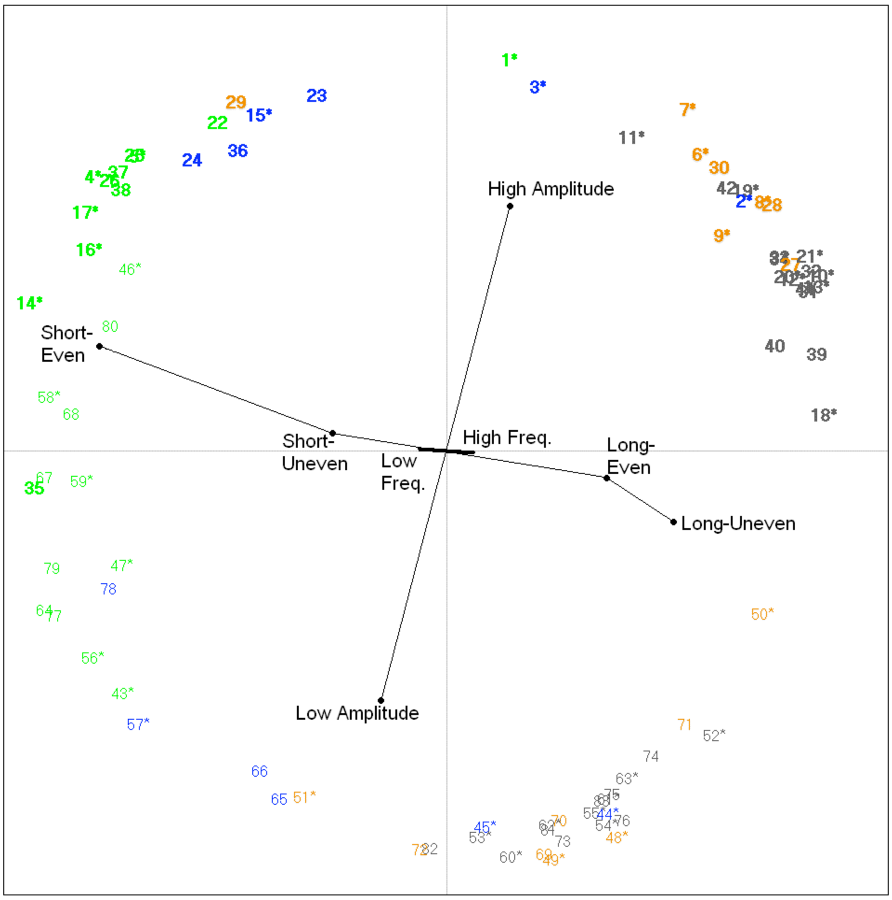

**Figure 1: A 2D MDS perceptual map of a set of 84 user-distinguishable haptic stimuli, varying in rhythm, frequency and amplitude. The map revealed previously unsuspected user categorizations based on rhythm evenness [17].**

We have developed and validated a tool based on Multidimensional Scaling to reveal the perceptual structure of a set of haptic stimuli. MDS provides a map of the perceived similarity of haptic stimuli, based on dissimilarity data obtained by asking subjects to repeatedly sort test stimuli into groups [8, 12]. The MDS algorithm then places the stimuli *relative to one another* in an *n*-dimensional space (e.g. Fig. 1), where an appropriate *n* is revealed by the data. Stimuli close to one another are perceptually similar.

This tool can be used to improve perceptual spacing [8]; if stimuli are not distributed as desired, their control parameters can be adjusted. Having access to this representation of the *user's* organization is invaluable for meaning assignment and predicting learning patterns [7, 16].

***Verifying Performance under Stress:*** Our goal is for users to process haptic icons without explicit effort; haptic signals may be suited to deliberate hiding from conscious attention [5]. Perceptually adjusted, meaning-matched icons that will be used in the presence of distractions therefore need to be further tuned according to the response they elicit in representatively distracting test environments. Some stimuli are *intended* to be intrusive; i.e. constructs whose importance overrides other tasks. We have developed abstracted test environments that capture key elements of the intended use, including workload [3, 6, 15].

***Learning Haptic Icons:*** Current foci are to ascertain (a) whether users can more easily learn semantically or arbitrarily associated haptic icons; and (b) the upper limits on learnable set sizes, given sufficient learning time. For the first, we have found indications that users do employ mnemonics to learn icons, but the same model does not work for everyone and furthermore, users can invent mnemonics themselves that help to learn even arbitrary associations. In a recent surprising result, we found that users were able to recall such arbitrarily chosen meanings for a set of 10 learned icons after a 2-week interval with the same accuracy (87%) as for associations they'd chosen themselves [4]. In terms of scalability, we have recently extended both our MDS methodology and largest distinguishable set size to support a rhythm-based set of 84 elements [16], which in ongoing work we are deploying in a longitudinal study to determine how many stimulus-meaning combinations users can learn.

## 4. Conclusions

We have outlined the need and some potential roles for informative haptic signalling in pervasive environments, posed in the context of its most accessible, portable and versatile form factor: vibrotactile or miniaturized force feedback in a handheld display. Our high-level goal is to reduce overall user cognitive and sensory load. Exploiting new opportunities for information triage and contextualization delivered by this field in combination with our emerging knowledge of haptic and multimodal processing, we can appropriately manage the intrusiveness and comprehensibility of individual demands on individuals' attention. Achieving this requires a holistic and cognitively driven, user-centred design process.

**Acknowledgements**

Work referenced here was performed with the help of students in UBC's Sensory Perception and Interaction (SPIN) Lab, in particular Andrew Chan, Mario Enriquez and David Ternes.

## 5. References

[1] Brown, L.M., Brewster, S.A., et al., "A First Investigation into the Effectiveness of Tactons," in Proc. of 1st Worldhaptics Conference (WHC '05), pp. 167-176, 2005.

[2] Brown, L.M., Brewster, S.A., et al., "Multidimensional Tactons for Non-Visual Information Presentation in Mobile Devices," in Proc. of 8th Conf. on HCI with Mobile Devices and Services, pp. 231-238, 2006.

[3] Chan, A., MacLean, K.E., et al., "Designing Haptic Icons to Support Collaborative Turn-Taking," To appear in the Int'l J of Human Computer Studies, 2008.

[4] Enriquez, M. and MacLean, K.E., "The Role of Choice in Longitudinal Recall of Meaningful Tactile Signals," in Proc. of IEEE Haptic Symp (HAPTICS '08), pp. 49-56, 2008.

[5] Enriquez, M.J. and MacLean, K.E., "Backward and Common-Onset Masking of Vibrotactile Stimuli," To appear in Brain Research Bulletin (special issue on Robotics and Neuroscience), 2008.

[6] Leung, R., MacLean, K.E., et al., "Evaluation of Haptically Augmented Touchscreen Gui Elements under Cognitive Load," in Proc. of 9th Int'l Conf on Multimodal Interfaces (ICMI '07), pp. 374-381, 2007.

[7] Luk, J., Pasquero, J., et al., "A Role for Haptics in Mobile Interaction: Initial Design Using a Handheld Tactile Display Prototype," in Proc. of ACM CHI, CHI Letters, vol. 8, no. 1, pp. 171-180, 2006.

[8] MacLean, K.E. and Enriquez, M., "Perceptual Design of Haptic Icons," in Proc. of EuroHaptics, 2003.

[9] MacLean, K.E., Snibbe, S.S., et al., "Tagged Handles: Merging Discrete and Continuous Control," in Proc. of ACM CHI, CHI Letters, vol. 2, no. 1, pp. 225-232, 2000.

[10] Morrison, A., Tennent, P., et al., "Using Location, Bearing and Motion Data to Filter Video and System Logs," in Proc. Of Pervasive Computing, vol. 4480, Lecture Notes in CS. Toronto: Springer Berlin, pp. 109-126, 2007.

[11] O'Neill, E., Thompson, P., et al., "Reach out and Touch: Using Nfc and 2d Barcodes for Service Discovery and Interaction with Mobile Devices," in Proc. Of Pervasive Computing, vol. 4480, Lecture Notes in CS. Toronto: Springer Berlin, pp. 19-36, 2007.

[12] Pasquero, J., Luk, J., et al., "Perceptual Analysis of Haptic Icons: An Investigation into the Validity of Cluster Sorted Mds," in Proc. of 14th IEEE Haptic Symposium (HAPTICS '08), pp. 437-444, 2006.

[13] Snibbe, S.S., MacLean, K.E., et al., "Haptic Metaphors for Digital Media," in Proc. of ACM Symp. on User Interface Software & Technology (UIST '01), pp. 199-208, 2001.

[14] Tan, H., Durlach, N., et al., "Information Transmission with a Multifinger Tactual Display," Perception & Psychophysics, vol. 61:6, pp. 993-1008, 1999.

[15] Tang, A., McLachlan, P., et al., "Perceiving Ordinal Data Haptically under Workload," in Proc. of 7th Int'l Conf on Multimodal Interfaces (ICMI '05), pp. 244-251, 2005.

[16] Ternes, D. and MacLean, K.E., "Designing Large Sets of Haptic Icons with Rhythm," in Proc. of submitted to Eurohaptics (notif. Feb '08), 2008.

[17] van Erp, J.B.F. and Spapé, M.M.A., "Distilling the Underlying Dimensions of Tactile Melodies," in Proc. of Eurohaptics, pp. 111-120, 2003.