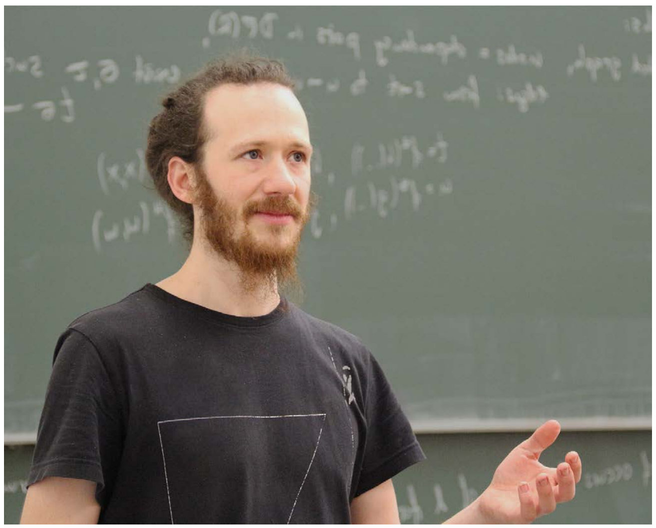
SIGCHI Outstanding Dissertation Award: Shaping Material Experiences



Paul Strohmeier

Human Centred Computing
University of Copenhagen
Copenhagen, Denmark

and

Saarland University
Saarland Informatics Campus
Saarbrücken, Germany

strohmeier@cs.uni-saarland.de

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Abstract

When interacting with materials, we infer many of their properties through tactile stimuli. These stimuli are caused by our manual interaction with the material, they are therefore closely coupled to our actions. Similarly, if we are subjected to a vibrotactile stimulus with a frequency directly coupled to our actions, we do not experience vibration – instead we experience this as a material property. My thesis explores this phenomenon of 'material experience' in three parts. Part I contributes two novel devices, a flexible phone which provides haptic feedback as it is being deformed, and a system which can track a finger and simultaniously provide haptic feedback. Part II investigates how vibration is perceived, when coupled to motion: what are the effects of varying feedback parameters and what are the effects of different types of motion? Part III reflects and contextualizes the findings presented in the previous sections. In this extended abstract I briefly outline the most important aspects of my thesis and questions I've left unanswered, while also reflecting on the writing process.

CCS Concepts

•Human-centered computing → Human computer interaction (HCI); *Haptic devices;* User studies;

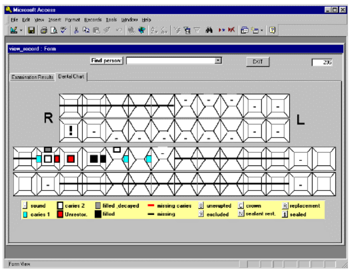

Figure 1: Symbolic information available to the dentist – the world is rearranged so a dentist has access to the state of the patients teeth.

Figure 2: A tool for embodied exploration – using it, the dentists body is extended so that the dentist can experience the state of the patients teeth.

Why this thesis topic?

At the time of writing my thesis, I had a range of rather eclectic papers to work with. I had published papers on flexible displays [20], robotics [3] and telerobotics [14], novel devices [17], eTextiles [15], and haptic perception [16]. Initial drafts of my thesis tried to force all this work into a single narrative, which never quite worked out; the drafts felt like enumerations of projects rather than a piece of cohesive work. Finally, as my self imposed deadline moved closer, my perspective changed and I thought about it less as a writing exercise, summarizing my work so far, but instead as an opportunity to discuss things I cared about, outside of the constraints we impose upon ourselves when submitting papers to traditional HCI venues.

I had long been fascinated by the idea of perception as an activity, exploring the link between perception and action. This had been an implicit motivation to a large part of my work. I decided that this thesis could be an opportunity to make much of this implicit motivation explicit; an opportunity to discuss issues which so far only existed in between the lines of my writing. Once I made this decision, it was easy to chose which work to include in my thesis: the papers which helped me highlight what I find fascinating about perception, how perception is an active process, and how this might be leveraged for HCI.

What is a material experience?

Anything we touch has physical, material properties. A full bucket of water might be wet and cold. A sheet might be crisp and smooth. In my thesis, I refer to these aspects of experiencing a material – wet, cold, crisp, smooth – as *material experience*. Surprisingly, many such material experiences can be provided to users through vibrations. These include textures, friction, compliance, counterforce, heaviness and other, more nuanced experiences. Instances of such artificial material experiences have previously been reported in the literature with primary focus on textures and compliance [12, 7, 4]. In my thesis, I highlight that many of these experiences share a common mechanism.

What problem am I addressing?

I am curious about ways of presenting information. This curiosity was piqued by I telerobot I built. This telerobot was intended to convey touch – when one of the touch sensors on the robot was touched, the remote user felt a vibration on their body [14]. Needless to say, this did not work very well. While users understood that the vibration was a representation of touch, the experience always remained abstract and symbolic. This was disappointing – I did not want to design haptic feedback which was a symbolic representation of something else. While I have never cared much for realism, I wanted to design something more direct, which would be experienced as the thing itself and not as a proxy.

I stumbled upon this distinction between symbolic and more 'direct' representations again, in a discussion by Don Ihde [5] on how people and technologies relate to eachother. He speaks of relations of mediation, where technology acts as an intermediary between the human and the world. Ihde distinguishes between two types of technological mediation: One is symbolic or *hermeneutic mediation*. Here the world is reconfigured to provide the user with access to information (See also Figure 1). Examples might include a thermometer with a numerical representation of the temperature outside. The other is *embodied mediation*. Here the technology reconfigures or extends the user, enabling them to experience things which otherwise would be beyond their perceptual horizon (See Figure 2). The canonical example of this is a blind person exploring the world with a cane. Lovely examples from within haptics research are devices which amplify forces in a "quasi transparent" manner [11]. These devices, for example, allow users to experience surface tension, as an insect would.

Figure 3: Magnetips consists of (a) a magnetometer array to track a magnet on the fingernail, and (b) a coil to provide haptic feedback to it. These can be used simultaneously and integrated with mobile devices (c,d) to enable interactions in the space around the watch (e) [9]. I also used the Magnetips system for providing vibrotactile feedback to an Implanted magnet [19].

A core question of my thesis is then: *How must (haptic) information be presented for embodied mediation to occur?* The examples I mention all have high realism, however, I do not believe that embodied mediation requires realism. What then is required for providing embodied mediation of information? In addition to the more tangible outcomes of my research, my thesis also provides steps towards a theoretical understanding of what embodied mediation means.

Summary of Included Papers

The papers chosen dissect haptic perception bottom up. The thesis starts out by observing what we are able to perceive. Using *Magnetips* (Figure 3) to stimulate the outside of the skin [9], as well as provide in-vivo stimulation through an implanted magnet [19], I mapped out how changes in frequency influence the experienced strength of a vibrotactile stimulus. This work links the existing body of literature in psychophysics [21] to applied research on novel devices within HCI.

I then present *ReFlex* [17], a flexible smartphone which generates vibrotactile signals based on how it is bent. It is here where I first observed that under certain conditions, vibration does not feel like vibration, but instead is experienced as a material property of the device one is interacting with (Figure 4). I slightly broaden the methodological scope, by no longer simply observing if signals are perceived. Instead, my co-authors and I measured task completion times with varying haptic conditions. Interestingly participants reported strong subjective effects of the haptic feedback, which were largely not reflected in our measurements. With this paper, I introduce the concept of *material experience*. The discrepancy between measured effects and self-reported experiences was important in future methodology choices.

The third paper of the thesis – *Generating Haptic Textures* [18] – investigates these subjective experiences in more detail. As it was the experience I was primarily interested in, I decided that I would from now on solely rely on self-reported data. I build a sliding device, which could produce similarly motion-coupled vibrations as ReFlex did. This time, participants did not have a specific task, but could instead freely explore the sensations. I systematically varied the granularity, amplitude, and timbre of the vibration, and – using a standard magnitude estimation procedure – established how strongly user experienced various material properties, when moving the device. This third paper demonstrates that the material experience which emerges from such motion-coupled vibration, can be parameterized. This paper also highlights that the timbre, or waveform, of the individual pulses should be given special attention.

I conducted the final study – *Pulse Trains* [16] – for two reasons: I felt that a number of different haptic experiences were in fact variations of the same concept and that the difference between them was merely what type of action was performed by the person experiencing them. I also wanted to clearly separate tactile and kinesthetic feedback. To do this I built yet another system for providing vibrations to people. This time, the user would move a wand, or pointing device, through the air and depending on condition, different types of movement would result in vibrotactile feedback coupled to the speed of movement. To me this paper is the key piece of work in my thesis. It demonstrates that many haptic experiences which are assumed to be kinesthetic can be created through tactile cues. It suggests that we can provide sensations such as force, friction, weight or inertia purely through tactile feedback. It demonstrates, again, that users perceive vibration coupled to motion as a material property of the object they are interacting with.

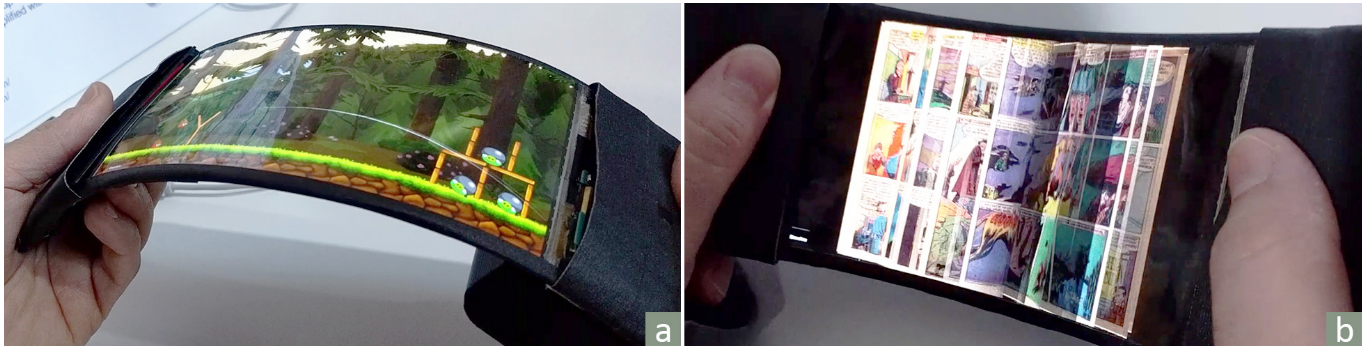

Figure 4: ReFlex is a flexible smartphone which can sense its own deformation and provide high-resolution haptic feedback [17]. Two types of mapping between input method and feedback type lead to material experiences: (a) Vibrotactile impulses are provided to the user relative to the change in strain of the device. This changes the experienced material of the device, here, providing an additional experience of elasticity. (b) Impulses are presented at a constant rate, relative to how strongly the device is bent. As they are synchronous with the pages flipping, they are experienced as a material property of the virtual book.

Methods

There is a conflict between how strongly the result of an experiment can generalize and how well it describes the subjective experience of any one individual. The methods I chose intentionally span this spectrum. While the traditional magnitude estimation studies, and the task performance studies performed in the evaluation of *Magnetips* [9, 19] and *Reflex* [17] should generalize well, they are not particularly informative as to the experience that users have. The magnitude estimation study performed in *Generating Haptic Textures* [18] still aims to be generalizeable, while revealing something about the underlying experience. Finally, for *Pulse Trains* [16] I consciously chose a method not aimed at generalization, but instead at understanding what the users perceived, the temporal structure of the experience. This was done by asking users to introspect on their own experience. Personally, I find the results from *Pulse Trains* [16] to be the strongest part of the empirical work.

Form

I assume that it is likely that people reading my thesis might have already read some of my work, so I did not want to force them to re-read anything. I decided that I wanted the content of my publications included verbatim, so readers can skip sections, knowing that there is nothing they are missing. However, I often feel the original manuscripts does not fully convey what I intend to say. For example, the language I use to speak of experiences changed and matured over time, and the focus of the individual papers often is different from the focus of my thesis. Rather than updating the manuscripts, including them verbatim in the thesis also has another pragmatic aspect: I want changes and additions to the original manuscript to be easy to spot, so I could point them out to others, or others can refer to them to me, for facilitating discussion.

I implemented two strategies for adding novel content to the previously published material. Each publication is accompanied by reflection chapters. I use these to add additional data, present supplementary studies, and explain how the presented work links together. These reflection chapters are intended to largely stand on their own. As a way of engaging the reader in a type of asynchronous dialogue I additionally use margin-notes to directly comment on the content of the work. I use these margin notes to create additional links between chapters, and sometimes to highlight where I find myself in disagreement with what I once wrote. These margin-notes make it explicit that a PhD thesis has a temporal dimension: the person who starts on their PhD journey is not the same person who puts the finishing touches to their completed dissertation manuscript. The margin notes are then also a playful dialogue between the me that is writing the thesis, and a past me who conducted the research, years before.

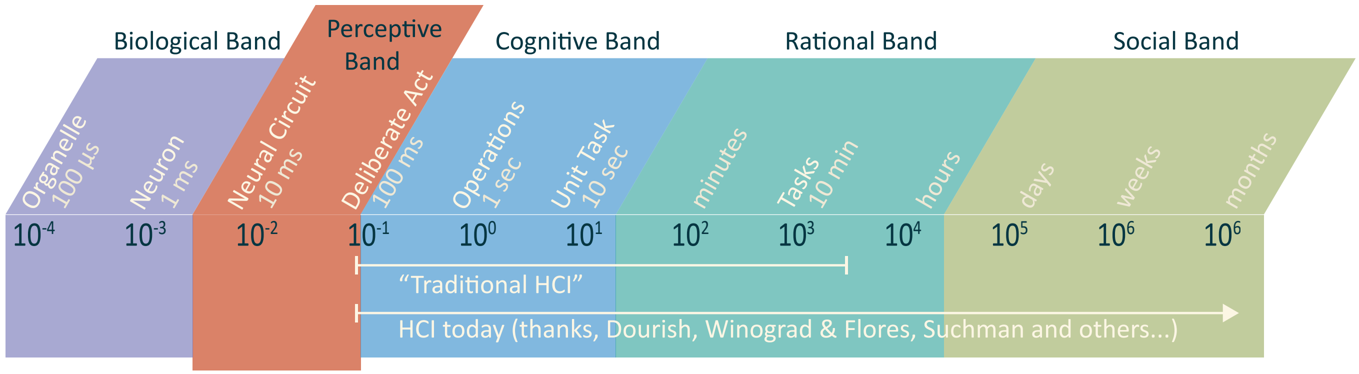

Figure 5: Traditionally, we assume the subject matter of HCI to start with simple deliberate acts, up to basic operations and tasks. More modern interpretations of HCI also include their social context, extending the temporal subject matter of HCI to weeks, months and beyond [8]. For designing novel sensory experiences, HCI must also expand in the other direction, in timeframes below that of deliberate acts, to capture the subtle, preconscious interactions between our fingers and materials. I suggest that when thinking of temporal bands [10] we should consider a *perceptive band* between the biological and cognitive, as it is in these timeframes that perception allows experiences to emerge.

Going Meta: What did I learn?

The bulk of what I learned in conducting my research is not contained in any of the papers, but existed hidden between the lines of writing, in a hidden space between the published manuscripts. This hidden knowledge seemed like the very thing most worth writing about, the thing that people would never find by reading any of the papers on their own. Part III of my thesis is therefore dedicated to synthesizing and contextualizing the results, as well as various unstated assumptions and observations made when conducting the research. While these observations may have been made before, I believe it is worth re-iterating them, as when it comes to the design of novel experiences, it is worth taking them more seriously.

(1) Perception is Active
All we know is change. In a world where nothing changes, we perceive nothing [13]. If there is no change, but we wish to perceive something, we cause change [1]. If one wishes to feel the texture of a material, one reaches out and touches it. To feel more detail of the surface, one might brush ones fingers over the surface. Even if one is only touching the material passively, maybe somebody's jacket brushes against one, one is aware of the counter-force one produced, and how one chose to react to that touch or not. These actions are not incidental to perception, these actions *are* perception.

What is the implication for HCI? When designing novel experiences, we must first focus on tracking technologies which provide input to a digital technology to the same extent which we focus on the technologies output.

(2) Perception is not a reflection of the world
All we know of the world is created by interaction. We do not directly experience the world, but merely how things in the world interact with each other or with our body. In the case of touch, it is through interaction with our body that stimuli are created which we can perceive. The receptors which are responsible for texture discrimination fire based on the frequency of vibrations they are exposed to [6]. When we move our finger over a material, the structure of our fingertip and the structure of the material interact, causing vibrations. It is our physiological response to these vibrations which leads to a material experience [2]. The material experience is caused by the interaction.

What is the implication for HCI? If we wish to design novel experiences, we need to attend to interactions within the time-frame at which experiences emerge. This means extending what we consider the temporal domain of HCI to the low milliseconds range (see Figure 5).

(3) Experience is more than a Representation of Perception
Experiences are not dictated by perception. This is exemplified by bistable images, such as the Necker cube. While

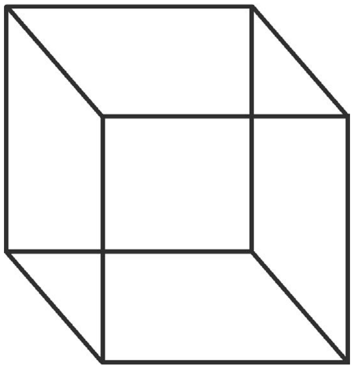

Figure 6: The Necker cube consists of 12 lines, arranged in such a way that we experience a cube. The cube is bistable and can be viewed either from the top or from below.

we always perceive the same 12 lines, nothing which we perceive indicates weather we experience the cube as viewed from the top or from below (Figure 6). Additionally, someone who sees the Necker cube for the first time, might simply experience 12 lines. Clearly, there is an element of cognition, beyond perception, which is involved in the experience. The differences between experiencing 12 lines, a cube from the bottom, and a cube from the top cannot be attributed to changes in what we perceive.

The interviews from *Pulse Trains* highlight that the same is true for the haptic experiences provided using my systems. This means that precise tracking and close temporal coupling are necessary conditions for material experiences to emerge, but not sufficient. The sufficient condition appears to requires a form of involvement from the user. How then do we ensure that a user has a material experience?

This is a question I cannot conclusively answer. However, the final section of my thesis highlights how consistency over time, congruence between mapping and perceptual channel, motor familiarity, and contextualization might play a role. I highlight how this perceived limitation might actually be a powerful tool for evaluating novel experiences, and present a set of statements, which – if contradicted – would lead to further insights in our understanding of perception.

Where am I now and what got me here?

My interest in technology as a field of study was sparked during my undergraduate studies at University College Maastricht, through courses in the Philosophy of Technology as well as Science and Technology Studies. My interest in contemporary philosophy is complimented by strong technical skills, which I was able to develop during my research-based masters at Queen's University, Canada. Under the supervision of Roel Vertegaal I worked on flexible display devices and wearable technologies, designed new sensing solutions or used existing sensors in unexpected ways. As a PhD fellow at the Human Centred Computing group, under the supervision of Kasper Hornbæk, I learned to value methodological rigor and the importance of Theory. My explorations of haptic perception are characterized by a thoughtful and deliberate engagement with different ways of creating knowledge, spanning from quantitative measures to elicitations of introspective experiences. My time as a PhD student is also characterized by numerous collaborations inside and outside of academia, leading to multiple publications co-authored with non-academic hackers, designers, and artists as well as a robotics experiment conducted in zero-g during a parabolic flight.

Currently, I'm part of the HCI lab of Saarbrücken University, working as a postdoctoral researcher with Jürgen Steimle. I'm applying my previous experiences with haptics and eTextiles to epidermal devices. In a previous life, I was an audio-engineer and musician (echoes of that life can still be found online). I lived in Austria, the USA, Belarus, the Netherlands, Canada and Denmark. I now live in Germany with my partner Susanne and our daughter Rosa.

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