# Simple Haptics

## SKETCHING PERSPECTIVES FOR THE DESIGN OF HAPTIC INTERACTIONS

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**Sketching Perspectives for the Design of Haptic Interactions**

Camille Moussette
http://www.simplehaptics.se

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# ABSTRACT


Historically, haptics—all different aspects of the sense of touch and its study—has developed around very technical and scientific inquiries. Despite considerable haptic research advances and the obviousness of haptics in everyday life, this modality remains mostly foreign and unfamiliar to designers. The guiding motif of this research relates to a desire to reverse the situation and have designers designing *for* and *with* the haptic sense, for human use and looking beyond technical advances. Consequently, this thesis aims to nurture the development of haptics from a designerly perspective, leading to a new field of activities labeled *haptic interaction design*. It advances that haptic attributes and characteristics are increasingly part of the qualities that make up the interactions and the experiences we have with objects and the interfaces that surround us, and that these considerations can and ought to be knowingly and explicitly designed by designers.

The book encompasses an annotated *research through design* exploration of the developing field of haptic interaction design, building on a considerable account of self-initiated individual design activities and empirical-style group activities with others. This extensive investigation of designing haptic interactions leads to the Simple Haptics proposition, an approach to ease the discovery and appropriation of haptics by designers. Simple Haptics consists in a simplistic, rustic approach to the design of haptic interactions, and advocates an effervescence of direct perceptual experiences in lieu of technical reverence. Simple Haptics boils down to three main traits: 1) a reliance on sketching in hardware to engage with haptics; 2) a fondness for basic, uncomplicated, and accessible tools and materials for the design of haptic interactions; and 3) a strong focus on experiential and directly experiencable perceptual qualities of haptics.

Ultimately, this thesis offers contributions related to the design of haptic interactions. The main knowledge contribution relates to the *massification* of haptics, i.e. the intentional realization and appropriation of haptics—with its dimensions and qualities—as a non-visual interaction design material. Methodologically, this work suggests a mixed longitudinal approach to haptics in a form of a well-grounded interplay between personal inquiries and external perspectives. The book also presents design contributions as ways to practically, physically and tangibly access, realize and explore haptic interactions. Globally these contributions help make haptics concrete, graspable, sensible and approachable for designers. The hope is to inspire design researchers, students and practitioners to discover and value haptics as a core component of any interaction design activities.

# PREFACE

The journey to bring this thesis to completion has been a very exciting and eventful adventure. I am in the fortunate position of being the first graduating doctoral student of Umeå Institute of Design (UID) at Umeå University. Such a position comes with its inevitable share of opportunities and challenges. While it was somewhat demanding to act as a guinea-pig for establishing many of the institutional procedures and requirements of doctoral education in design here at UID, it also meant I was given unparalleled freedom and ample resources to develop my research activities. I am truly thankful for the level of trust, confidence and support I received from the institution, and particular from the head of department Tapio Alakörkkö.

Certainly, completing this thesis was an arduous exercise, but it was also a very rewarding experience for me as a researcher, as a designer, and as an individual. It got me thinking about design and research in ways I could have never imagined. Over the past five years, I have had the opportunity to meet and work with a team of absolutely amazing and clever people willing to share their knowledge and enthusiasm with me. My supervisor, Daniel Fällman, has been exceptional in helping me navigate and make the most of this doctoral adventure. His advices and suggestions have always been sound and enlightening. I am very grateful for his continued support, particularly during the last few months reviewing my drafts during the summer break, or late at night on short notice.

A great many people have contributed in one way or another to the completion of this work. Besides the students and staff of Umeå Institute of Design, there are a few key individuals that I would like to thank for their contribution and inspiration: Mike Stott, Niklas Andersson and Erik Stolterman for their very inspiring perspectives on interaction design and its education; Antti Pirhonen and Jonas Löwgren who have provided valuable feedback at different stages of my Ph.D; and Karon MacLean and Vincent Lévesque for inviting me to participate at UBC and openly sharing their expertise of haptics. I would also like to give Bill Buxton special thanks. His role as my secondary supervisor has impacted my work tremendously. It is because of him that I was able to collaborate with Microsoft Research during my studies. His intellectual and practical understanding of design and everything that surrounds the field still baffles me. I am grateful he shared some of his wisdom with me.

My extended visits at Microsoft Research have been very rewarding and instructive, many thanks to Richard Banks, Asta Roseway, Desney Tan and Dan Morris who acted as tutors and mentors. The writing stage of this thesis has been particularly productive thank to Barthold Vonen, who generously offered his house in Dale (Norway) for over six weeks. I also have to mention my colleagues Tara Mullaney and Gareth Paterson who kindly proofread this thesis, thanks!

Above all, this doctoral journey would not have been possible without the support of my dear parents. The few thousand kilometers separating Umeå from Montreal did not refrain them to provide moral support and encouragement throughout these years. Finally, my deepest gratitude goes to the other Camille, my life partner, who has been so patient and supportive during this Ph.D. adventure. My doctoral journey is now complete; let's go hiking in the mountains again!

# CONTENTS

# PART 0
# INTRODUCTION

For over a decade, I have been intrigued, captivated and engulfed in the idea of using the sense of touch to design man-machine interfaces. My formal training in Industrial Design gave me a variety of skills and tools to develop functional, usable and aesthetically pleasing products or systems. However, when once confronted with the touch modality during a particular project, my design knowledge and tools felt very deficient, or simply inadequate. Why could I comfortably design in the visual universe after just a few years of training, but could not in the haptic realm? Was it me, my tools, my education or the design tradition that made me seemingly inept at designing haptics? Why did I not have a design base for leveraging our touch sense and its rich capabilities?

The work presented in this thesis is the final installment of five years of research and doctoral studies at the Umeå Institute of Design in northern Sweden trying to answer these important questions. The research activities have been carried out in an industrial design school using a designerly approach. Such contextual information is helpful to frame the nature of the work; its direction, perspective, purpose, and contribution.

My work investigates a nascent field at the confluence of the Interaction Design and Haptics domains. Although the work is strongly tied to haptics and naturally builds on a myriad of other disciplines like neuroscience, psychology and Human-Computer Interaction (HCI), just to name a few, it is ultimately framed as a research endeavor in the field of *Interaction Design*. It is the discipline that I am most familiar with, and the one that has been nurturing my activities for the past decade.

What is *Interaction Design* exactly? The Interaction Design Association (IxDA) states the following (IxDA, 2012):

> *Interaction Design* (IxD) defines the structure and behavior of interactive systems. Interaction Designers strive to create meaningful relationships between people and the products and services that they use, from computers to mobile devices to appliances and beyond.

Bill Verplank offers a broader and more elegant definition, in my view (Verplank, 2000).

# INTERACTION DESIGN


Figure 1: Verplank's depiction of Interaction Design, reprinted from Verplank (2000), with permission of the author.

*Interaction Design* is design for human use. It involves answering three questions:

**How do you do?**
What sort of ways do you affect the world:
poke it, manipulate it, sit on it?

**How do you feel?**
What do you sense of the world and what are the
sensory qualities that shape media?

**How do you know?**
What are the ways that you learn and plan
(or perhaps, how we want you to think)?

Due to its multidisciplinary nature, there are many more perspectives and definitions of what constitutes interaction design. Often the word *digital* is tied to interaction design, but in my view *digital* is just a subset of technologies for and through which we ought to interact and design. Consequently, many argue that interaction design is the natural evolution of industrial design (Bürdek, 2005, p. 403): as tools and materials of the 21st century are invariably becoming digital or computationally-enabled, so should our ensuing design practice and skills. For the remainder of this thesis, I will adopt Verkplank's rendition of interaction design. Its specificity around sensing, knowing and learning, and affecting the world resonates with my own views, my professional experience, and the nature of this research work. The label "for human use" puts forward a human and humane perspective of design, in the same way Henry Dreyfus proposed in his book *Designing for People* (Dreyfuss, 2003).

# STRUCTURE

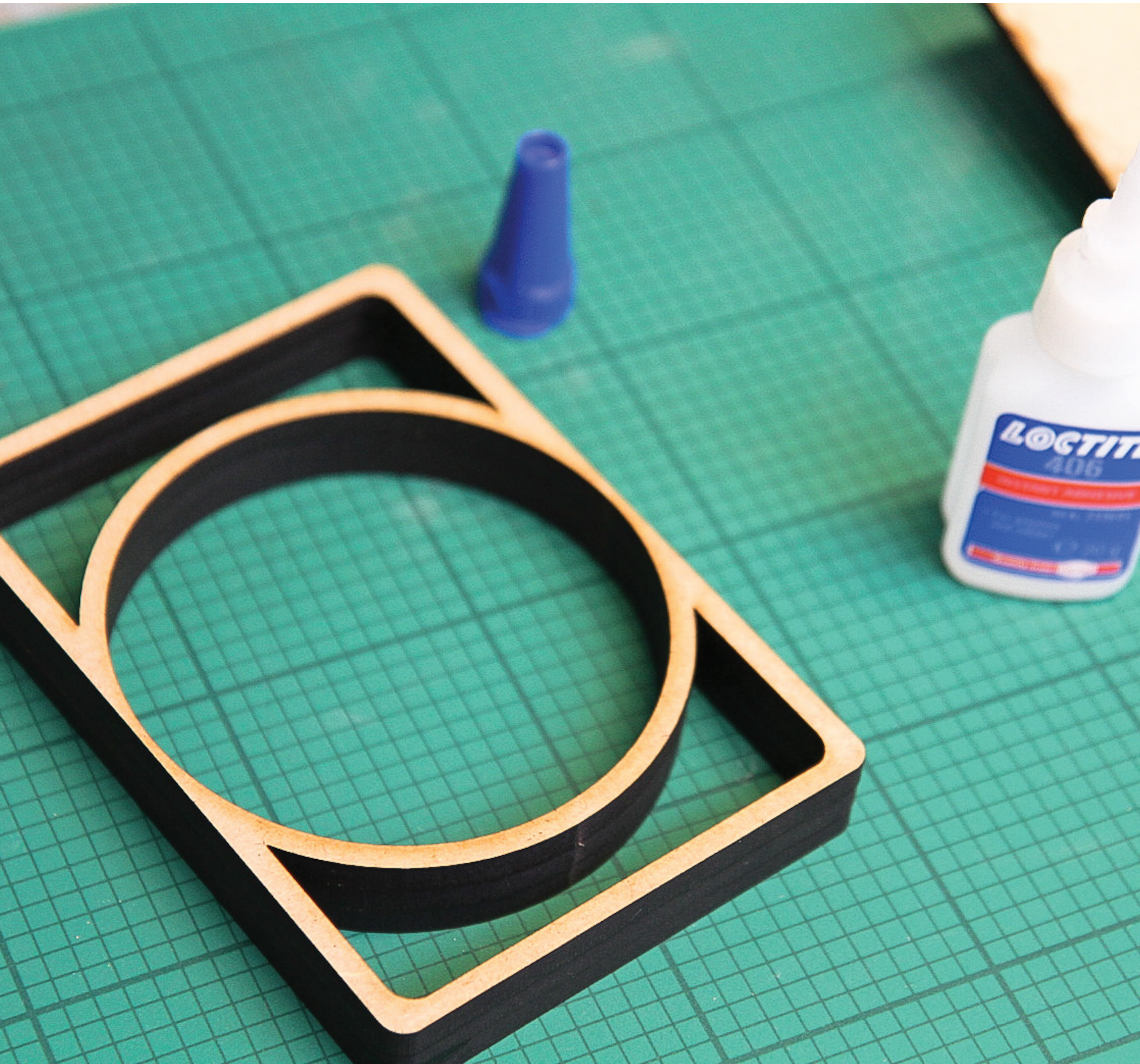
This thesis investigates how designers venture into haptics, and how they can ultimately refine their design repertoire of haptic interfaces. The thesis is divided into 3 parts: **Foundations, Activities, and A Way Forward.**

**Part 1: Foundations** starts with a contextualization and methodological presentation in chapter 1.1, and then introduces key considerations and particularities of the human haptic sense in chapter 1.2. The following chapter 1.3 explores design expertise, and more precisely how design representations, activities of prototyping and sketching support design knowledge development. Chapter 1.3 also includes with a review and discussion of the terms *prototypes, models, sketches, prototypes and mock-ups* to fully expose the bases underpinning much of this work.

**Part 2: Activities** reveals my empirical research inquiries, and the activities I have undertaken at the confluence of design and haptics. The discussion starts by exposing a general timeline of my activities, and some of my general research questions and hypotheses. The details and outcomes of a multimodal study are then presented in chapter 2.1. Chapter 2.2 and 2.3 put forward research through design activities realized in collaboration with Microsoft Research, first involving the examination of *making and sketching in hardware* for haptic knowledge generation, and second with the exploration of haptic feedback concepts for Kinect (or similar gestural interaction systems). Chapter 2.4 summarizes activities and insights from a series of workshops I conducted with students in the haptic design space.

**Part 3: A Way Forward** contains a thorough discussion of the nascent design space of *haptic interaction design*. It examines the current state of affairs of this new field before exposing the crucial research contributions of my work. More specifically, chapter 3.1 investigates the current state of haptic interaction design using four assessment points: interest and motivation towards this new field; the availability of materials; the availability of tools; and finally, skills and knowledge to support haptic interaction. Chapter 3.2 addresses the all-important contributions of my work. The contributions are divided into three categories: knowledge contributions, methodological contributions, and impact my work has had or is expected to have on research and practice. Chapter 3.3 titled *Perspectives* involves framing the work of this thesis in today's design and haptic worlds. It specifically discusses what makes haptic interaction design different than haptic research, how haptic interaction design relates to the contemporary design research agenda, and ultimately why the work of this thesis is relevant to the greater design realm.

# PART 1
# FOUNDATIONS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# PART 1 / FOUNDATIONS

At its core, this thesis embodies a personal course of actions in haptic interaction design, an emerging field at the junction of the haptics and design domains. It aims to demystify and comprehend activities of design *for* and *with* the haptic sense. Despite being a personal odyssey, this work recognizes and builds from already existing knowledge in both domains. Part 1 of this book is an examination of the various foundational pieces that make up the haptic interaction design puzzle.

**The first chapter**, called tactics, exposes the background, context and motivation underlying my work, and positions it in the interaction design field. It also exposes methodological considerations associated with the nature of my inquiry. The chapter presents my research through design method and how my work emanates from haptic desiderata. Overall it divulges my role as an explorer venturing in the new haptic interaction design expanse that lies straight ahead.

**The second chapter** offers a highly condensed introduction to haptics. It revisits the origins of the discipline, and looks at how its historical development can be divided into two major tracks: a body-centric approach and a techno-centric one. Those two tracks illustrate fairly adequately how haptics has been researched and developed up to this day. Additionally, this chapter highlights crucial aspects of what exactly makes haptics: the details of the human skin, its receptors, the neural mechanisms, and the basic technical considerations underlying the realization of haptic interfaces. Far from constituting a thorough review of the domain of haptics, this succinct presentation is useful to ground the coming discussions of part 2 and 3.

**In the third chapter,** a similar foundational examination is realized for design, and more precisely for one aspect of design expertness: how design representations, activities of prototyping and sketching support design knowledge development generally and specially in the field of interaction design. The terms prototypes, models, sketches, prototypes and mockups are dissected and discussed, as various communities of practice make different use of the terms. A deeper examination of prototyping versus sketching allows us to discern important aspects that make these activities so crucial for design, and consequently for this investigation also.

Overall, this first part exposes that this work builds on the shoulders of giants within the design and the haptics disciplines. These foundations allow me to properly frame and plan, as an explorer, my discovery journey into the new haptic interaction design field. However incomplete this preparation might be, it is still a valid beginning to start navigating a previously uncharted swamp.

# CHAPTER 1.1 TACTICS

## 1.1.1 PURPOSES AND FRAMING

The guiding motif —the leitmotiv— of the development of this thesis emanates from a desire to design *for* and *with* the human haptic sense. It recognizes that the human haptic modality is often underdeveloped and undervalued in most design disciplines and particularly in interaction design activities.

Physical attributes and tangible manifestations are traditionally scrutinized and assessed for their visual and functional qualities, primarily. They are often regarded as static qualities, fixed in time and unchangeable; consequences of material selection and transformation processes. Increasingly, these assumptions need to be revisited. The arrival of dynamic materials, and the increased capability to define or alter macroscopic attributes of many materials, turns material stability on its head. More importantly, advances in neuroscience and psychophysics are increasingly capable of elucidating haptic perception, and pinpointing the processes that make us capable of perceiving, making sense and acting on and in the world.

This thesis posits that haptic qualities, attributes and characteristics can and ought to be knowingly and explicitly designed by designers to some extent. It advances that these haptic considerations are progressively part of the qualities that make up the interactions and the experiences we have with objects and the interfaces that surround us.

Recognizing that the haptic modality deserves the full attention of designers is only a first step. The question remains: how do we get there? This thesis offers an answer in that regard. The work exposed in this book is an annotated design exploration of the developing field of haptic interaction design. It builds on a considerable research through design account, and the experience of others, to investigate the characteristics, qualities and dimensions that make up this new field. This thesis not only lays bare this new haptic interaction design field, it actually proposes a method, a program to be more general, to ease its discovery for designers. The Simple Haptics scheme is proposed as a fitting approach for designers to successfully venture into haptics, and ultimately evolve a design repertoire for designing haptic interfaces and haptic experiences.

## 1.1.2 TERMS AND AUDIENCE

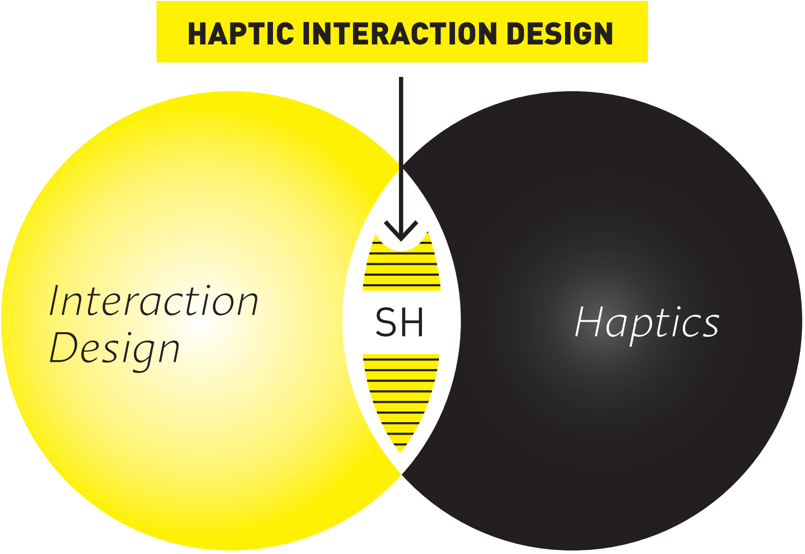



Figure 2: Simple Haptics (SH) is a proposition to evolve the nascent field of Haptic Interaction Design.

Throughout this book, three similar terms are mentioned and referred to: Haptics, Haptic Interaction Design (haptic IxD or HID) and Simple Haptics (SH). They are heavily related and connected but they are not interchangeable. To ease the unfolding of this work, it is crucial to clearly establish what each term refers to.

*Haptics*. As will be seen in the next chapter, this term refers to the domain or field of inquiry that encompasses all different aspects of the sense of touch and its study.

*Haptic interaction design*. This term refers to a new field of study extending the interaction design discipline to include haptic considerations. Haptic interaction design encompasses all haptic aspects and qualities that are deemed relevant, important or necessary in interaction design activities.

It relates to the human haptic sense, the same way graphic design relates to visual communication and presentation. As shown in Figure 2, haptic interaction design corresponds to the overlapping area between the disciplines of haptics and interaction design.

*Simple Haptics*. This term refers to a particular approach to haptic interaction design —the proposition developed in this book— where haptic interfaces and systems are purposely investigated, designed and built using uncomplicated and accessible technology and tools. The approach advocates sketching with haptics to best learn, understand and seize the full potential of this new modality. Explorative and experiential qualities take precedence over technical accomplishments. This approach aims to support the discovery, familiarization and appropriation of haptics by designers.

This research work is elaborated first and foremost for a design research audience. Interaction design research is the dominating perspective in which this work took place, and it is only natural that its results resonate primarily with this field. My activities draw from (and are) designerly ways of working with haptics. The outcomes and contributions should be useful to design researchers for intellectually and practically approaching the design of haptic interactions. Interaction design students and practitioners should also benefit from this work, as it provides guidance and annotated techniques to discover haptics from an interaction design perspective, using common tools and approaches. Furthermore, this work hopes to expand the contemporary haptic research field with a new and refreshing approach to haptics: design. From the work and contributions exposed in this book, haptic researchers ought to learn about design; its processes, benefits and limitations, and overall that design enterprises can yield distinctive insights and results for advancing the state of haptics.

### 1.1.3 DESIGN RESEARCH

Design, the profession with its skills and purposeful activities, has been taught in school for over 90 years. It is fairly recently however, during the last 40 years or so, that design has been included in the higher academic spheres. Doctoral programs in design are in their infancy worldwide, and despite a definite growth, their purpose is still not clearly articulated (Margolin & Justice, 2010).

There are naturally many views on how design and research should come together to advance the profession, the discipline, and its impacts on society at large. The numerous and different professional and scholarly traditions in design and research do not weave together easily. Despite obvious friction points and divergences, the design research field as a whole is steadily growing, maturing, and gaining recognition in today's society. This doctorate is a living example of such enterprise.

The scholarly examinations on the nature, relevance, and benefits of design research are plentiful. From the initial postulate of Simon's *Sciences of the Artificial* (Simon, 1997) to Rittel's *The Reasoning of Designers* (Rittel, 1987), scholars and practitioners have recognized the need to view design differently from scientific studies or artistic endeavors. More recently, Nelson and Stolterman's book *The Design Way* (Nelson & Stolterman, 2003) offers a thorough perspective on the activities, processes and claims of design that amount to a rendering of design as a particular type of inquiry. It positions design (and design research) as a unique but fully capable and valid way of understanding and engaging with the world. Design is presented as a compound inquiry between the *real*, the *true* and the *ideal*, with an emphasis on impacting the (real) world.

Nelson and Stolterman's voice resonates with a growing community of design scholars (Buchanan, 2001; Cross, 2007; Friedman, 2003; Lawson & Dorst, 2009) arguing strongly for:

> a) A refined study, rationale and comprehension of design – the discipline, the activity, its education and thinking – in continuation of Rittel's and Schön's seminal works (Rittel, 1987; Schön, 1983, 1990).
>
> b) A larger promotion, recognition, acceptance of design in other fields and domains.

The discipline of Interaction Design has been a strong vector for design research advances during the last two decades (Rogers, 2004; Stolterman, 2008). With strong ties to Human-Computer Interaction (HCI), interaction design has sustained a continuous stream of rigorous examinations on the role and contribution of design at the confluence of people and technology with researchers pondering the characteristics and values brought forward in/with design.

Fallman has repeatedly advocated a more explicit design-oriented agenda in HCI (Fallman, 2003), and has proposed a structured model, the triangle of design practice, design studies and design exploration (see Figure 3), to understand and to some degree be able to predict various kinds of interaction design research activities and situations, each with their own tradition, perspectives, and measures of success (Fallman, 2008). The true richness and perhaps unique character of interaction design research, according to Fallman, lies in the researcher's abilities to roam, explore or travel the various paths and dimensions between the these activity areas (Fallman, 2008).

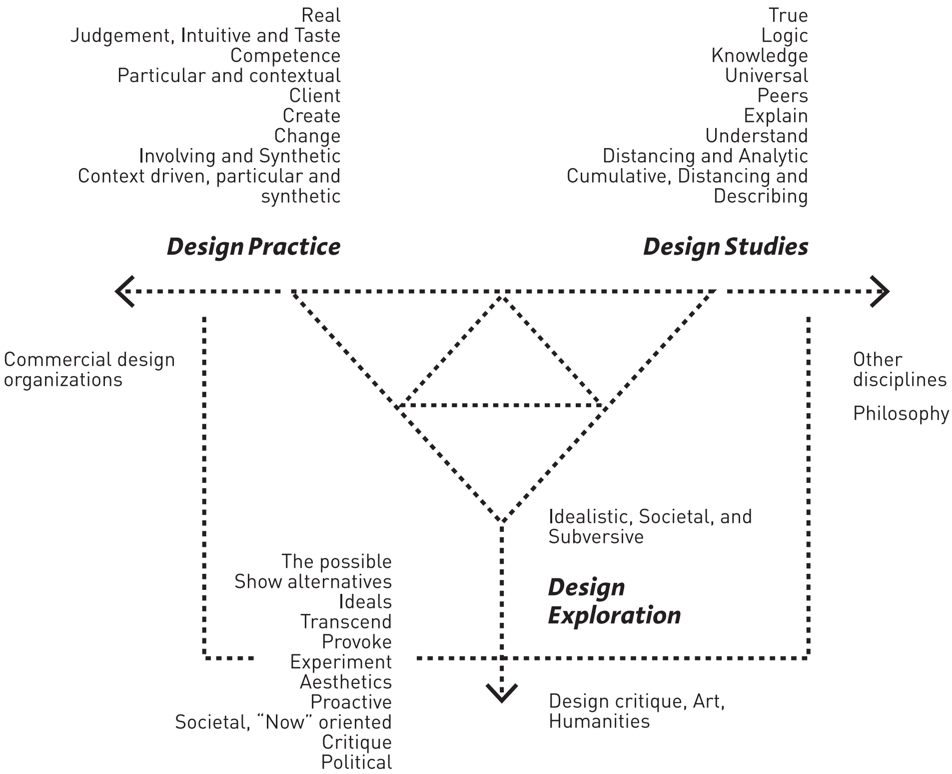



Figure 3: Fallman's model of Interaction Design Research, adapted from Fallman (2008).

Zimmerman et al., as well as several other authors in the field (Buxton, 2007; Löwgren & Stolterman, 2004; Moggridge, 2007), have been investigating how a designerly approach can be of great value to HCI and interaction design projects. They show that by engaging in *Research through Design* (RtD), the designing researcher tends to tackle and relate research issues differently than a non-designing researcher (Zimmerman, Forlizzi, & Evenson, 2007). A 'research through design approach' gives researchers the opportunity to reframe problems more freely and work towards the right thing using designerly skills and tools. The outcomes generally come as rich, grounded and impactful contributions either in the form of concrete design artifacts or through conceptual insights. More recently, Gaver has been arguing for research through design contributions articulated around the form of annotated portfolio, justifying that such work is particularly fitting with the core abilities and skills of designers (W. Gaver, 2012).

## 1.1.4 RESEARCH THROUGH DESIGN FOR DESIGN

Retrospectively, most of my work can be framed as a combination of Frayling's terms: *research through design for design* (Frayling, 1993). My research activities reported on in this book explore and aim to expand design activities involving the haptic sense, thus the *for design* label. The work aims to advance design knowledge and contribute a vivid design perspective on haptics. Ultimately, I hope other designers and design researchers will recognize haptic design or haptics at large as worthwhile design considerations.

I also qualify my work as research *through design* due to a strong pragmatic and designerly approach. Two factors played a role in adopting, almost instinctively, such a methodological approach: first, my education and experience as an industrial and interaction designer, and second, the fact that my doctoral studies were anchored in a design research group that in turn was part of a design school.  With so much design in and around me, it seemed natural and appropriate to use the tools, techniques, and methods of design to tackle my research questions. Such an approach for doctoral research is not entirely new (Avila, 2012; Broms, 2011; Trotto, 2011) and is inscribed in the larger quest of advancing design as a proper and fully respectable discipline.

## 1.1.5 HAPTIC DESIDERATA

In trying to expose my design methodology, I find it valuable to relate my activities to the notion of *desiderata* proposed by Nelson and Stolterman (2003). Desiderata capture an integrative and call-for-change approach that sits above common strategies for intentional change. This deep inclination for change, the motivation to react and  act, the refusing to accept the status quo emanate from *desires*, and those desires can be derived from three perspectives. Nelson and Stolterman state: "What we *want* can be seen as our aesthetics. What we believe *ought to be* relates to our ethics. What *is* corresponds to reason." (Nelson & Stolterman, 2003, p. 135). The notion of desiderata unites the three perspectives into something that is bigger than the sum of its parts. Desiderata are essentially "about what we intend the world to be". The notion is defined as what "make design possible and necessary"(Nelson & Stolterman, 2003, p. 151), by recognizing and intentionally aligning human capacity and human achievement.

The notion of desiderata stands in contrast to other approaches to intentional change, in particular, analytical and design pattern strategies. Analytical approaches consist of the dissection and breaking down of a problem, and finding the right solution to that problem. The caveat is that such enterprises often lead to analysis paralysis. The ever-increasing influx of new information commands more analysis, and in turn inhibits change at the source of the inquiry. Design pattern strategies involve applying known and ready-made solutions to new problems. This type of approach often prescribes actions and courses of action without a deep understanding of the problem at hand. Such an approach can easily obliterate the richness and detail that makes every design situation unique (and of value).

Desiderata are a designer's way to skim over the many intricate subtleties of design, and uphold an intellectual, ideal and practical heading towards intentional change. In my case, the notion of desiderata resonates with my interest in researching the meeting point of design and haptics. My motivation resides mostly on the level of that-which-is-desired, and the field of haptic interaction design seems so complex and intricate that only a desideratum appears possible and justifiable. Any other approach or stratagem appears insufficient and reductionist.

In the end, my haptic desideratum is best described as a blurry, intentional, almost ideological, examination that seeks to realign technical development with human capabilities, particularly around our touch sense. I see the work presented in this book as means to expose and dissect my haptic desiderata for the interaction design discipline.

To better frame my research work, its goals and aims, and the claims that will be made, I find it suitable to first state what my work is *not* about. Although my research deals with human perception in many ways, this work is not primarily aimed to advance or contribute to our accumulated understanding of human perception and the psychophysical processes underlying our action/perception in and with the world. Design, as a discipline, is relatively ill-equipped to directly contribute to such an understanding in a style recognized by those scientific disciplines. Investigations of the human perception and somatosensory system reveal extremely complex processes, many of which that are not fully understood to this date. The latest research in sensory neuroscience and developmental psychology is advancing our knowledge of the human haptic sense, but a vast area beyond our comprehension still exists to this date. Despite such knowledge frontiers, there is a growing body of knowledge that designers can tap into, explore, and comprehend to venture sensibly and thoughtfully into the area of haptics. With this work, the intention has been to distill some of the most valuable aspects and to make at least parts of this haptic knowledge more accessible to designers. In particular, chapter 1.2 deals with and exposes such haptic foundations.

Equally, I have had no intention of providing study-driven quantitative data to support novel haptic interfaces or to seek to justify an advantage versus non-haptic interface alternatives. My interest pertains to a greater exposure of haptics to designers, stimulating them to discover and embrace the sense of touch in a larger context. In this, the aim has not been to seek or to evaluate any resulting design concepts and proposals, such as; is a particular haptic interface concept more interesting than another graphical user interface based interface proposal? The answer to such a question would depend on a plethora of different considerations and variables. The validity and appropriateness of a said haptic interface for a particular project is beyond the scope of this thesis. Rather, the overall perspective of this study has been intentionally biased from the start, with a strong inclination towards haptics. Accordingly, I find it important to state that measuring any direct functional, emotional and experiential advantages from haptic interfaces over any other means of human-computer interaction is outside the scope of this research; it has not been the main purpose of the study.

What this work does encapsulate however, is a recognition that haptics is one of the new frontiers in interaction design and a suggestion that designers should be able to positively contribute to this nascent field of research and design. It is suggested that discovering and embracing haptics may unlock a considerable new world of possibilities and considerations within interaction design. By approaching haptics from a design stance, we will inherently yield insights that are different from what other scientific or cognitive approaches would bring forward. The haptic community itself, which is mostly quite technical into its nature, has already acknowledge such a need (see MacLean & Hayward, 2008). Their hope is that design can provide fresh, human-centered as well as opportunistic perspectives that complement and contribute to the more traditional scientific and engineering approaches usually applied within haptics (Hayward & Maclean, 2007; MacLean & Hayward, 2008).

## 1.1.6 REFLECTIVE ENGAGEMENT AND EMPIRICAL GROUNDING

From an epistemological standpoint, my doctoral study activities build on research methodologies and approaches that have become common to design research. These activities consist of a combination of *empirical* and *explorative* work. My empirical research consists of a mix of self-realized activities and educational workshops, both documented extensively (see Moussette, 2012; Moussette & Banks, 2011; Moussette & Fallman, 2009). The explorative work, for the most part realized in a first-person perspective, i.e. with myself as the designer, has affinity with artistic research. The interplay between empirical and explorative design work has been important for the research process and is key for understanding the scope and purpose of this work. While the research directions pursued, the tools used and the generated outcomes that ensued, are clearly charged with subjectivity and reflective measures, the many workshops realized with students and researchers constitute complementary empirical grounding that is detached and external to me at least in some respects.

This pool of observational data and qualitative feedback from participants has been beneficial for shaping and advancing my research. However, I have opted not to dissect this data with extensive analytical procedures for a number of different reasons. From my perspective, the main merit of this pool of empirical data is that, first, the artifacts, documentation, and feedback are real, they happened in this world; i.e. they constitute pragmatic evidences of my design research process and were not specifically *designed* for data analysis per se; second, as such, this experimental data has more reflective richness than analytical and prescriptive capabilities. I have consequently favored richness and openness in terms of new rounds of engagement and additional interventions, rather than dissecting in great details a limited dataset using only a few variables.

To some extent, readers acquainted with the social sciences' traditions, might be tempted to compare the efforts in this book with *Participatory Action Research* (Wadsworth, 1998). While there clearly is some overlap between the approaches, this work was neither originally planned nor has it been conducted as a participatory action research study. For sure, I sought to engage with my subject of study as much as possible and I wanted to see what would limit, hinder, and fuel haptic design with my participants (who were for the most design students or practicing designers). I coordinated activities with them, offering new tools and alternatives, noting their advancement and impression, and regularly adapting my interventions. However, unlike a textbook-style participatory action research study, the activities reported on in this book generally lack qualities such as *multiparty engagement, communal problem solving, and organizational change* that often characterize action research (Järvinen, 2007). My main concerns and engagements were primarily derived from egocentric design actions and considerations, with a motive for discovery and direct engagement. I would consider my research as immersive, appreciative, and oriented toward gaining knowledge by continued and prolonged exposure more than anything else. Such considerations overlap with characteristics from Action Research, User-Centered Design, and Participatory Design, but ultimately my research is markedly more self-centred and individualistic. Above all, it candidly tries to resolve the integration of theory and practice in the design of haptic interactions, with a conscious intention of continuous learning.

## 1.1.7 FROM EXPLORER TO CARTOGRAPHER

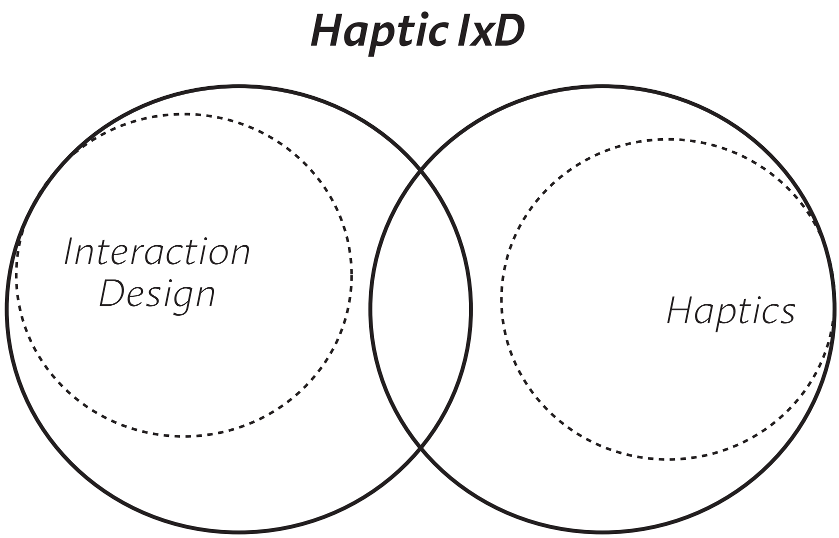



Figure 4: Haptic interaction design resulting from the overlap of the fields of interaction design and haptics research.

Initially, I set out to explore the meeting point of design and haptics without well-defined goals or flawless research hypotheses. My main objective was to develop a certain familiarity with the topic and let my own discovery process guide any further actions. This endeavor might seem unstructured for a doctoral research project, but the underlying activities were not void of structure. On the contrary, they were imbued with a strong *designerly commitment*, *preparedness* and *consideration*, very much like a new design project. The analogy of an explorer is quite appropriate and revealing in understanding this process. Schön talks about being in 'the swamp' (Schön, 1990) and my initial goal was exactly that – to find and explore that haptic design swamp.

In the same way that one does not go out to sea unprepared to discover a new continent, I initiated my journey with a rich mixture of routine design actions and engagements, careful documentation, and a readiness for adaptation. Early on in the process, I immersed myself into designing haptic interface concepts very quickly to get insight into and start to comprehend some of the problems and challenges at hand. I chose and carried out activities, constraints and situations that felt constructive towards my general quest to bridge design and haptics. I made and built things frequently to relate my thoughts to real and experienceable sensations. Adopting such a first-person perspective was insightful, but also constituted an inherently self-reliant perspective.

To expand my inquiries and in order to try to discover less self-biased perspectives, I then conducted activities together with other researchers, designers, and students in different constellations to seek to capture their experiences and impressions. In addition, I also sought to engage actively with research, design, and haptics in and around a variety of different contexts and perspectives. To this extent, within the realms of this study I was able to work within Microsoft Research twice, which considerably expanded my horizons on academic research, haptics, as well as on industry practices not only relating to haptics design but to interaction design in general. As the months and years passed by, the haptic design swamp I set out to discover inexorably grew with better-defined areas but also gained newer blurry expanses. As the study went along, I constantly made sure to document my journey and progress extensively, very much like an explorer's travel diary, capturing both banal and extraordinary facts, anecdotes, and other information on its way towards a far off unknown destination.

When looking back, from one perspective, my research journey seems unstructured and fairly messy. From another perspective however, it nevertheless seems like a proper way to approach the purpose of the study. I initially set out to explore the meeting point of two very different domains (interaction design and haptics). During five years, I explored this new territory, following some already-made paths, but also finding unmapped grounds and defining new routes. The journey has been full of tentative, exploratory, and idea-testing design actions that allowed me to acquire new knowledge, new skills, and constantly adjust my perspective. Little by little, I corrected my a priori assumptions, developed new tentative hypotheses, and invariably gained a finer-grained and clearer understanding of both the territory as well as how to navigate it. This discovery journey is unique in the same way a design project is the ultimate particular (Nelson & Stolterman, 2003): a particular situation in a particular context with a unique set of constraints.

At this point it is of course important to acknowledge that this discovery journey constitutes in itself only a partial or incomplete research contribution. Is it essential to put this journey in perspective and try to extract further knowledge from a retrospective and/or meta perspective. This thesis allows me the opportunity to develop a reflective meta-perspective of my design research activities to date. In this, I am able to step out of my role as an explorer and instead assume one of a cartographer. This allows, or even requires, that I distill and articulate knowledge beyond my mere whereabouts and findings. I can look back and reflect on the activities I realized previously, with a different take and renewed perspectives. Adopting a positive stance on the hermeneutic circle notion, my goal is now to turn my privileged knowledge into new presuppositions and discernments that I (or others) can consider in further inquiries towards a new design practice. To relate to the cartographer analogy, I am inclined to draw a map knowing it is inherently personal and incomplete. However imperfect this map might be, it is still a new aid to navigate a previously uncharted swamp.

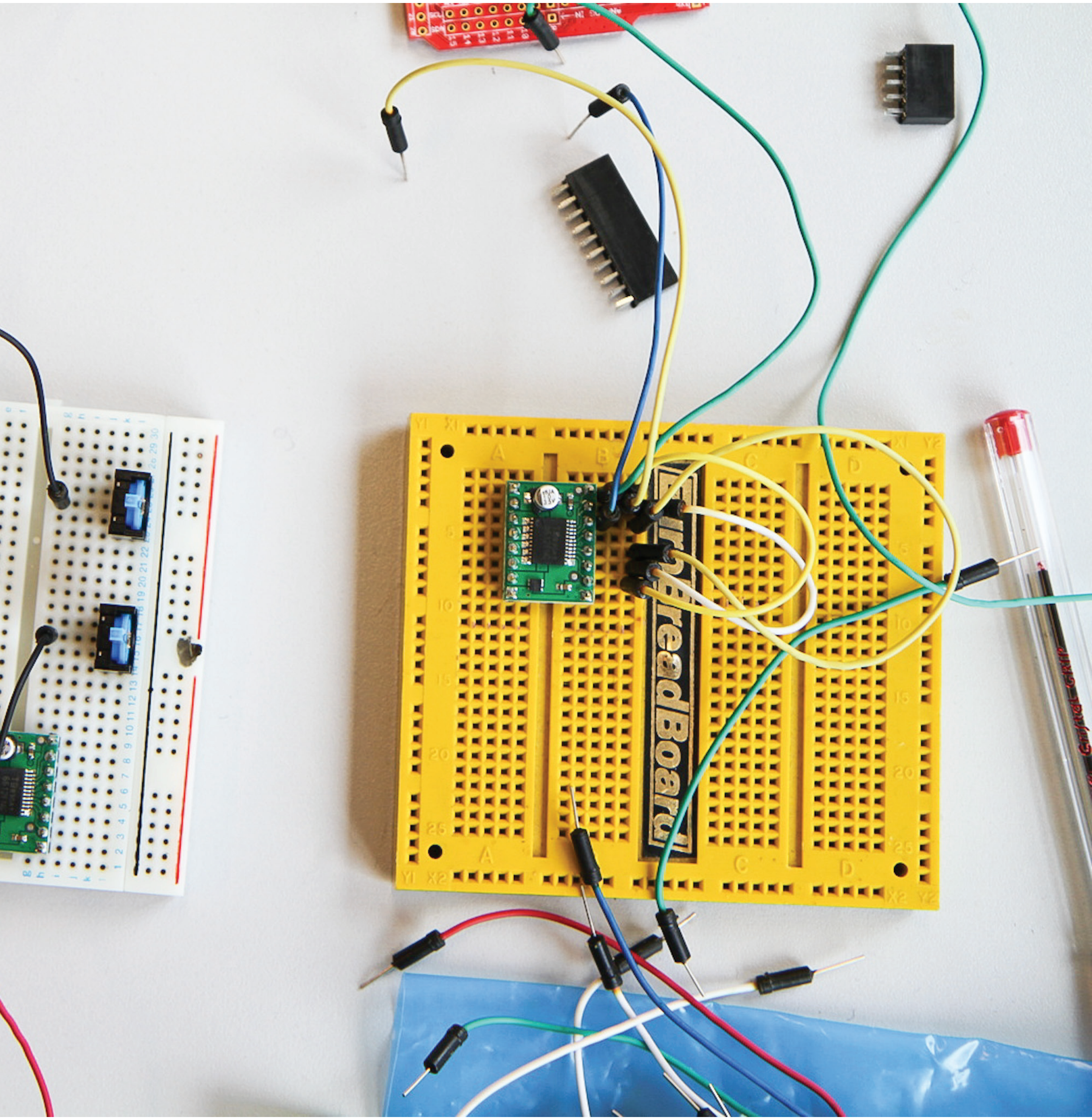
### 1.1.8 AN EMERGING HAPTIC INTERACTION DESIGN MAP

This thesis is my map of the world at the confluence of design and haptics. In my conceptual map, the two domains, continents or landmasses naturally stand out, far apart of each other. My methodological approach has been to demystify as much as possible of each of these two landmasses, and identify where the two are or should be connecting or overlapping. My explorations tackle both practical technical activities as well as intellectual inquiries. Probably the best feature of the map is that it incorporates a final analysis or meta-perspective on all my activities. It aims to link and connect, in retrospect, various theoretical perspectives with practical explorations. The ultimate goal is to provide a map that is rich in content but still intelligible and legible enough for other designers and researchers to discover this new world, and in their turn, further explore and expand the boundaries of this new territory.

## 1.1.9 CONCLUSION

In many ways, the research work presented in this thesis can be said to transpire the current state of design research: it is vibrant and diverse; in quest of its identity; and still young but maturing. This work builds on the shoulders of giants within the design discipline, but these are nevertheless relatively young giants. To the general public, and even to design practitioners and the general academic community, the field of design research is nascent and emerging.

Advancing design, its methods and its processes as a fully legitimate and commendable style of inquiry in its own right is quite an undertaking. It calls for internal measures of rigor and clarity while seeking relevance and respect from other, often well-established, disciplines.  Ultimately, it seems unlikely that design and design research will come to solve all the world's problems, but it is my hope that the work presented in this thesis will demonstrate that its methods and activities provide a quite powerful alternative to other kinds of inquiry in comprehending and engaging with some of today's new, messy, and complex challenges.



# CHAPTER 1.2 HAPTIC FOUNDATIONS

## INTRODUCTION

As discussed in the previous chapter, the main ambition of this thesis is to explore the meeting point of haptics and interaction design. Initially the two domains might seem very disparate, but on closer inspection, we will find that they are similar in more ways than they appear.

The objective of this chapter is to survey and aggregate previous research into basic human haptic capabilities, leading towards the formulation and accumulation of what we might call *haptic foundations*. This chapter is in part a literature review and in part a collage of bits and pieces of haptic knowledge collected from various scientific disciplines outside of the design field. While it is of course practically impossible to gather and report all relevant material, it is important to note that this compilation has in itself evolved from the pragmatic and active design research stance that permeates this work. From the start, the intention has been to home in and identify fundamental haptic knowledge that could eventually inform or otherwise be of practical relevance to haptic interaction design endeavors.

In the first section of the chapter, we will look at the origin of haptics and expose two lines of interest that have led to the development of the field. The second section examines various haptic capabilities and characteristics in detail, revealing some key qualities that are unique to our touch sense. It covers sensorimotor learning processes, physiology of the skin, sense priming, and other signal/response mechanisms. The third and last section discusses the characterization of haptic systems in order to estimate and relate their performances.

## 1.2.1 WHAT IS HAPTICS?

**Haptics is to touch, as optics is to sight.**

[Will Provancher, eduhaptics.org]

The term haptic was first proposed by German philosopher and psychologist Max Dessoir, as an attempt to encompass all different aspects of the sense of touch and its study (Grünwald, 2008, p. 22). The term has lasted to this day in both singular and plural forms, where its plural form *haptics* denotes the domain or the field of inquiry and the singular *haptic* can be understood as an adjective, referring or pertaining to the sense of touch. Consequently, haptic communication relates to touch-based (nonverbal) forms of interaction between humans, and haptic technology as technology that interfaces with a user through the sense of touch (Kern, 2009).

As the term haptics thus refers to a field of inquiry involving various disciplines, the answer to the question of what haptics means or 'is' depends greatly on to whom you ask the question or to which domain those you ask pertain.

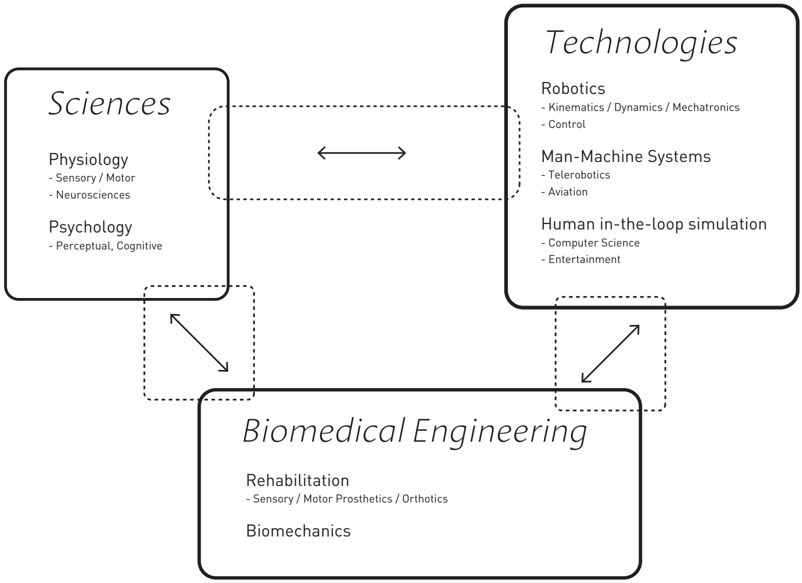



Figure 5: Elements of haptics, adapted from Colgate & Adelstein (2012).

However, in the contemporary understanding and use of the term haptics, two major perspectives can be distinguished:

- The first, which we can call the *human-centric approach*, is based on perception and cognition, whereas

- the second, the *techno-centric approach*, relates to technological systems used to create and modulate stimuli on the human sense of touch.

These two lines of interest have their own origin and set of considerations. Yet, a thorough study of haptics would ultimately involve a multi-disciplinary and all-encompassing course of action. To ease the discussion and revisit historical milestones of the development of haptics, it seems appropriate to first present the two perspectives as totally separate tracks, fully aware that the two angles are, and have in fact always been, much closer and almost intertwined.

## FROM THE INSIDE OUT: THE HUMAN-CENTRIC APPROACH

In the human-centric approach, haptics relates to internal processes used by individuals to understand, comprehend, and interact with the environment. The perspective is body-based, investigating human perception processes and actions, looking outwards to the world from the inside. The American psychologist J.J. Gibson defines a haptic system as "the sensibility of the individual to the world adjacent to his body by use of his body" (Gibson, 1983). Gibson stresses that haptic perception is mostly an active exploration related to body movement and intentional engagement with the world.

At the most basic level, haptics thus relates to our notion of reality and consciousness, however, philosophers and scientists have debated for centuries over the nature of our *body plus mind* entity and on the notion of meaning in its purest form. How can we know about the world and what are the processes that make us capable of interacting with it? When it comes to human experience, what is inherently associated with our senses and what is derived, abstract knowledge?

There are of course tremendous challenges in trying to demystify and understand the many physiological elements and psychological processes associated with haptics. Even if one adopts various posits of phenomenology and distributed cognition, it still remains difficult to fully comprehend the various processes underlying phenomena such as tacit knowledge and mindfulness of action.

What we can say however is that our haptic sense does contribute to our human perception capabilities along with our other senses such as vision and audition, but most importantly the haptic sense is the principal constituent of our sensorimotor capabilities. Haptics encapsulates *perception* and *action* like no other sense. The haptic modality is thus a very rich and complex bidirectional interface between us, as body-mind entities, and the world.

The study of haptics from a body-based perspective has been historically driven by the fields of anatomy, physiology, developmental and experimental psychology, and more recently by neuroscience. Since Weber's studies of the tactile senses in the first half of the 19th century (Weber, Ross, & Murray, (1834) 1996), our understanding of the human sense of touch has evolved tremendously. Science now knows which mechanoreceptors populate our body and skin, their individual sensitivity and characteristics, and how they connect to our brain. For instance, the complex anatomical pathways between our fingertip and our brain is fairly well understood by scientists in different disciplines (Goldstein, Humphreys, Shiffrar, & Yost, 2004; Grünwald, 2008), yet many of the operating and integrative processes of haptics still evade us to this date.

Considering this chapter's goal of developing *haptic foundations*, it seems valuable at this point to briefly present and discuss some of the historical accounts that have contributed to the current level of knowledge within the human-centric approach of haptics.

The investigation of our touch sense has its roots in the discipline of psychology and more specifically in its experimental specialization. By combining anatomical and perceptual considerations with practical measurements, experimental psychology paved the way to a greater understanding of human perception at large. More than a century ago, scientists like Gustav Theodor Fechner, Charles Sanders Peirce, and Max Dessoir developed methods and experimental guidelines to investigate human perception in a rigorous manner (Bicchi, Buss, Ernst, & Peer, 2008; Grünwald, 2008). Concepts such as *just noticeable difference* (JND) and *perception blindness* are some of the best examples of this period. Extensive clinical studies with varying sources of stimuli helped establish many sensing abilities of the human body and skin. Some of this work eventually gave rise to the discipline of psychophysics as 'the scientific study of the relation between stimulus and sensation' (Gescheider, 1997). It could be said that the first wave of research in haptics focused on *pure* (as isolated, almost clinical) perception and predominantly on static touch.

During the 20th century, an expanding experimental psychology community coupled with various technical advances allowed new kinds of inquiries that were directed toward more complex human perception phenomenon such as active touch, where action and perception are intrinsically coupled. As the name states, *active touch* involves motor action *in* and *for* perception, where movement will yield new stimuli and enrich perception and motor action is constantly modulated by sensorial cues. As an example, the work of Lederman & Klandsky about *explorative procedures* clearly highlights the notion of active touch (Lederman & Klatzky, 1987).

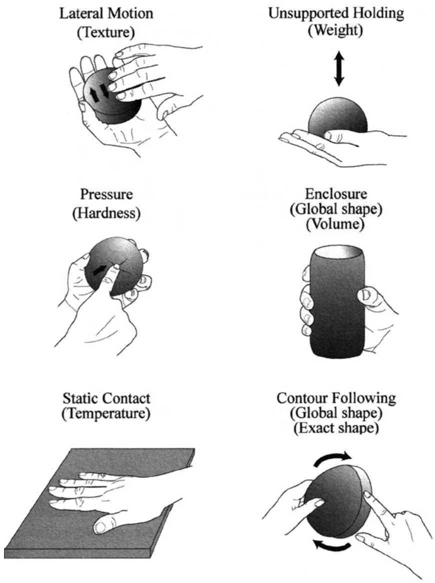



Figure 6: Exploratory procedures (EPs) and the associated qualities being explored, adapted from Lederman & Klatzky (1987).

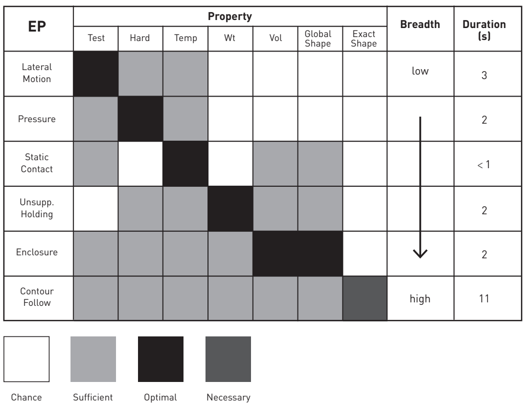



Figure 7: Costs and benefits from exploratory procedures (EPs), adapted from Jones & Lederman (2006, p. 78).

The very tight coupling between action and perception invariably brings forward notions of intention, control, memory, and causality. Active touch and more generally sensorimotor skills are highly complex processes that researchers have been persistently exploring over the last few decades. Cognitive psychologists and neuroscientists now have a refined picture of the development of our sensorimotor mechanisms (Piaget, 1999). For example, it is now possible to explain some very delicate and fine-grained neuropsychological principles of dexterous manipulation in humans such as how we modulate grip force in order to grasp and move objects safely and reliably (Johansson & Flanagan, 2009). In section 1.2.5 below, some of these mechanisms will be examined in greater detail.

From this perspective on haptics, we can distinguish a 'second wave' of human-centric haptic research that goes beyond just the characterization of sensorial input. Here, the investigations tackle *active touch*, where dynamic and bidirectional couplings give rise to complex sensorimotor skills. Researchers have ventured into understanding complex action-perception mechanisms in relation to human activities (such as walking and grasping), and most importantly how we, as a species, come to develop and learn such important capabilities and skills.

Science's understanding of haptic perception has thus come quite a long way in the last hundred years or so. The intricate physiological details of our body and skin have to a large extent been revealed and explained and in today's research laboratories, the interplay of action and perception can be investigated deep down at the neurological level with impressive accuracy. Naturally, we collectively know much more about haptics than we did a century ago, but as noted above, many human touch-based processes still evade human understanding, especially if we explore the multimodal nature of human perception.

## FROM THE OUTSIDE IN: THE TECHNO-CENTRIC APPROACH

As for the second distinguishable approach to understanding haptics, the argument is that approaching it from a technical standpoint in fact reveals some important insights that to some extent are as rich and relevant as those that stem from the human-centric perspective. The label *technical* should in this circumstance be understood in a larger sense, as an environmental term. If we see the human skin as our interface between the body and the environment, that environment is the area with which this perspective is mostly concerned.

For thousands and thousands of years, this environment—i.e. our world—has been mostly natural and has tended to change very slowly. Our species, our body, and our intellectual and bodily capabilities have developed over the millennia in relation to and in harmony with this environment. As Gibson explains, from an ecological perspective of perception, the variants and invariants in our environment are crucial (Gibson, 1986, p. 14):

> *'The environment normally manifests some things that persist and some that do not, some features that are invariant and some that are variant. A wholly invariant environment, unchanging in all parts and motionless, would be completely rigid and obviously would no longer be an environment. In fact, there would be neither animal nor plants. At the other extreme, an environment that was changing in all parts and was wholly variant, consisting only of swirling clouds of matter, would also not be an environment. In both extreme cases there would be space, time, matter, and energy, but there would be no habitat.*
>
> *The fact of an environment that is mainly rigid but partly nonrigid, mainly motionless but partly movable, a world that is both changeless in many respects and changeable in others but is neither dead at one extreme nor chaotic at the other, is of great importance for our inquiry.'*

However, with the advent of the industrial revolution and subsequent advances in our society however, our environment is increasingly becoming more man-made and technically constructed, i.e. more artificial. To tie back to Gibson, we can define much more of what the variants and invariants of our environment are. This is where the technical label of this section ties back to the environment: our artificial man-made environment and its constituents come to result in new possibilities and problems for us as humans (Simon, 1997). Any new system, tool or device disrupts our environmental priors, proposes new ones, and consequently provides equal opportunity to enhance or hinder human activities. As we will see, during the 20th century, various technical advances tended to coincide with the development of haptic technology and as a result, many of these pursuits have shaped our current understanding of haptics. To further reveal some aspects of this interplay, a short historical excursion seems necessary at this stage.

## MECHANIZATION OF TOOLS AND INTERFACES

Prior to the industrial revolution, i.e. before 1750-1850 depending on where and what delimits this period, we can say, somewhat simplified, that most tools were under full human control. The human operator of a piece of equipment was usually providing both the forces of power and control needed to operate it. Because of this, using and mastering a tool typically meant full mechanical and sensorial engagement with the tool. Feedback from the tool to the human user was direct, immediate, and visceral in nature.

However, with the advent of new power sources during the industrial revolution, different kinds of tools and apparatus evolved that had separate power and controls mechanisms. Through decades of technical refinement, these new technologies' power and actuating systems became more powerful and precise, while at the same time their control mechanisms became increasingly disconnected and abstracted away from the human user. While this on the one hand liberated workers and operators from exhausting labor and typically harmful working conditions, it on the other hand, broke the loop between action and perception, between means and ends. In this new era, engaging with a tool provided very limited or no direct, experienceable feedback.

The canonical example of this development is the airplane cockpit. Up to the 1930s, a pilot could feel the airplane's aerodynamics through the control stick due to the direct mechanical coupling between various parts of the aircraft. As servomotors were put into place to drive larger and more complex aircraft during WWII, pilots lost the direct mechanical feedback of their aircraft's aerodynamics. This lack of feedback was however quickly identified as a serious problem and hordes of engineers started working on ways of bringing back some feedback into the control stick of airplanes for a safer and more experiential flying experience.

With hindsight, we see that the need to build satisfactory electromechanical feedback systems led engineers and scientists to refine the development of sensors, actuators, and control mechanisms. Such endeavors were also part of a larger attention being paid to ergonomics, i.e. how do you design equipment and devices that fit human capabilities and human cognitive abilities? The result was an interesting synergy between the two fields, where new sensor technology provided better tools to probe and measure human activity, and consequently, better knowledge of human perception mechanisms contributed in turn to superior human-machine systems.

Figure 8: Hardiman from General Electric in 1965 was the first serious attempt to build a powered exoskeleton ("GE Report: The Story Behind the Real 'Iron Man' Suit," n.d.).

The early days of robotics and human force augmentation systems show devices and apparatuses that are often very scary (see figure 8). Among other things, this illustrates that planning to actuate and generate forces directly back to people can be harmful or even lethal if not done right. Initial efforts to build dexterous robotic hands and powered exoskeleton, for instance, felt short in many ways as synthetizing human perception and generate high-quality haptic stimuli turned out to be much more complex and subtle than initially thought.

During the 1970s, computation power was limited and control mechanisms consisted of mostly analog electronics. Building systems with real-time output, so-called *rendering*, be it visual or haptic, was very challenging. During the 1980s and the early 90s, rapid computational advances began to allow for faster processing and more complex algorithms to be applied. Teleoperation, virtual reality, and biomechanics became hot topics of research and development and the growing interest in these fields in turn resulted in the establishment of a nascent field of inquiry called *haptics*. While the devices and projects realized during those years where very limited in their haptic capabilities and often restricted to research laboratories, they nevertheless established some of the best practices and guidelines that still stand to this day (Kern, 2009), including the 1000Hz rendering loop requirement, proxy-based rendering god-object, and so on.

## COMMERCIALLY AVAILABLE HAPTIC HARDWARE

Academic haptic research initiated in the 1980s resulted in the area's first commercial enterprises, including Immersion and Sensable, which in turn started offering haptic hardware devices and platforms to a wider audience. This represented an important milestone for the development of the field of haptics. Now scientists could investigate haptics without having to build elaborate, very costly, and advanced technical apparatus from scratch. This lead to an expansion of haptic research endeavors, both in the nature and the quantity of projects concerned with haptics one way or the other. Despite remaining relatively pricey, commercial haptic hardware began to, first, provide a viable fast track solution for those seeking to engage with haptics, and second, in doing so it began to establish a common ground and shared reference point across different labs and scientists.

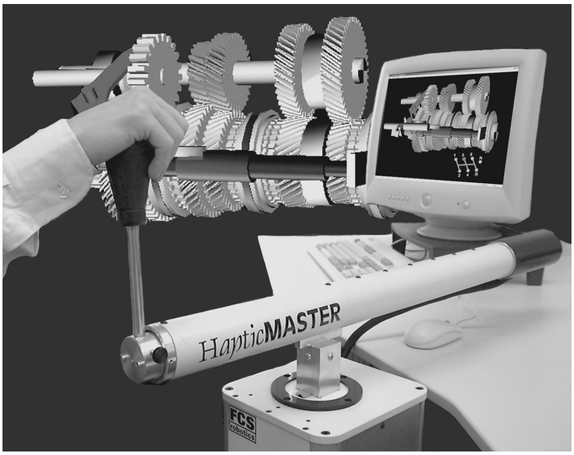



Figure 9: HapticMaster device, from Moog-FCS. Reprint from Thurfjell, McLaughlin, Mattsson, & Lammertse (2002), with permission of Emerald Group Publishing Limited.

Figure 10 (left): Phantom Omni haptic interface, from Sensable Inc.
Figure 11 (right): Novint Falcon 3D Touch device, from Novint Technologies, Inc.

### HAPTICS TODAY

How does the field of haptics fare today? Despite great advances in the way we understand human capabilities and the way we build, actuate, and modulate our man-made environment, haptics still presents more questions than answers. What becomes clear from interpreting the double lineages presented above is that one particular approach cannot develop fully without the other. Haptics requires both human-centric and techno-centric considerations to be coherent and relevant. Great haptic technology is useless if humans cannot comprehend or relate to it, let alone even touch it. For that reason, the biggest challenge of haptics to this date is one of accessibility and democratization.

## 1.2.2 HAPTIC CAPABILITIES

If we are to design haptic interfaces, for or with which human capabilities are we designing? As everyday humans, we are experts in practically exploiting and using our own haptic capabilities. We function, operate and engage with very little friction, in-the-moment reflection or questioning, yet we seem particularly inept at exteriorizing and communicating our haptic-based actions. How do we go about these subconscious and conscious processes to feel and act in this world? This section will attempt to examine some of the fundamental characteristics of the haptic modality in us as humans. What follows is a succinct review of the haptic knowledge puzzle to better comprehend, embrace and eventually design in concert with our basic haptic capabilities.

***Human senses***

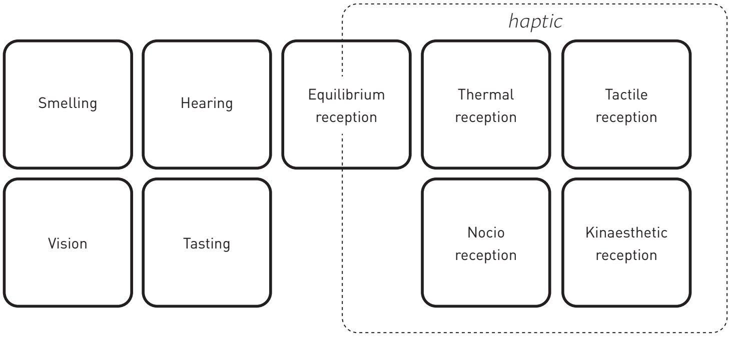



Figure 12: The elements constituting haptics, adapted from Kern (2009).

We often tend to refer to the human haptic sense, or modality, as one entity. In reality however, it actually comprises a variety of different sensorial channels. It is commonly accepted that the haptic sense encompasses thermoceptive, nociceptive, kinaesthetic, and tactile perception (Kern, 2009).

Thermoception or thermoreception is the sense by which our body perceives temperature – above or below body temperature– and is comprise of two main types of receptors in humans: ones that detect heat and others that detect cold. Nociception, also referred as nocireception, relates to the encoding and processing of noxious stimuli (actual or potential tissue damaging events). It relies on nociceptors (pain receptors) that can detect mechanical, thermal or chemical changes above a set threshold. Nociceptive signals can produce autonomic responses like reflexes and other unconscious actions.

Kinaesthetics describes the perception of one's own body motions, through actuatory and sensory capabilities of muscles and joints. It leverages proprioception– one's own conscious and unconscious perception of the forces, torques, movements, relative positions and angles of neighboring parts of the body. Tactition or tactile reception encompasses mechanical interactions with the skin. Tactile perception necessitates direct contact and/ or relative motion between the skin and the objects of interest.

## DISSECTING THE ACTION AND PERCEPTION LOOP

What we have seen above suggests that human perception involves extremely complex processes, including many layers and interaction mechanisms that are not well understood by even the latest neuroscience. Yet, despite some areas of uncertainty, decades of medical and scientific development provide strong evidence about the inner workings of perceptual-motor interaction and the development of our sensorimotor skills.

The human hand, for instance, is probably the finest example of our sensorimotor skill development. One human hand has roughly 30 degrees of freedom, thousands of receptors, and can provide extremely strong and precise control without conscious guidance. Consider bimanual actions, with arm and whole-body movement in an ever-changing environment, and the control mechanisms implied are of mesmerizing complexity. Yet, most humans have no problems using their hands in their day-to-day activities. These capabilities are not innate and dexterous manipulation takes years to refine, for instance precision grasp requires approximately eight years to develop (Johansson & Flanagan, 2009).

Exploring how infants develop their sensorimotor skills reveals valuable information for haptic interaction design. The theory of Piaget offers various stages of this development, including a particular sensorimotor stage and six sub-stages characterizing the development of new skills:

- Reflexes (0-1 month)
- Primary Circular Reactions (1-4 months)
- Secondary Circular Reactions (4-8 months)
- Coordination of Reactions (8-12 months)
- Tertiary Circular Reactions (12-18 months)
- Early Representational Thought (18-24 months)

For a more detailed presentation of each sub-stage, see Piaget (1999). In summary, the process of identifying and relating unknown stimuli into useful perceptual motor skills evolves from continuous interaction with the world. Repeated actions, with variations, different contexts or varying objects, allow the child not only to construct knowledge about the objects themselves but also how to interact with them. Over the years, a child assembles a very rich repertoire of action-perception couplings, and as these couplings are continuously reinforced and solidified, they form the basic assumptions for making sense and engaging with the world.

On a similar note, Johansson & Flanagan suggest that sensorimotor learning consists mostly of 3 phases (Johansson & Flanagan, 2009): first, the exploratory phase, where one discovers basic mapping rules, relating motor and sensory signals by exploring uncontrolled movement; second, a phase where control starts to emerge and performance improves; and third, the refinement phase, where performances gradually improve.

Additionally, Rosenbaum's book titled *Human Motor Control* provides a rich resource of sensorimotor knowledge (Rosenbaum, 2009). From it we can summarize that: sequencing and timing are crucial notions for successful motor control; human actions are from predictive models, from motor memory (neural plasticity) and personal experience; every movement tends to reflect the combined use of feedforward and feedback. Additionally, Rosenbaum points out that "in a negative feedback loop, discrepancies between desired and obtained results tend to promote error reduction. In a positive feedback loop, discrepancies tend to promote error enhancement." (Rosenbaum, 2009, p. 40). Overall, this volume brings out that learning by doing and learning by practising are essential to develop our perceptual-motor skills.

The work of Wing, Patrick, & Flanagan explores dexterous manipulation in great lengths (Wing, Patrick, & Flanagan, 1996). It exposes dexterous manipulation as sensorimotor mechanisms taking place on two time scales: 1) anticipatory parameter control derived from past experiences that preshape our action/perception, and 2) cognitive/contextual and multisensorial inputs to monitor and adjust motor control.

In conclusion, the action perception loop mechanisms and sensorimotor skills can be summarized in three large processes: a) the reliance on predictive models (past experience, motor memory) to shape initial action and feedforward perceptual cues, b) multimodal feedback is constantly monitored for mismatches, and leads to corrective measures and sensorimotor memory updates, and c) learning of perceptual-motor skills is mostly dependent on repetition and appropriate feedback.

## THE HUMAN SKIN

The skin is a very complex anatomical structure that literally is our interface to the world. The skin is also the principal organ of our haptic sense, as it contains the majority of our mechanoreceptors and free nerve endings. It is where the world gets 'encoded' into neural signals. In a way, its elements and their characteristics determine much of our haptic sense's capabilities.

The presentation of the skin in this section is obviously rather succinct, and any medical encyclopedia can provide it in far richer detail than the space allotted here. However, the main points that this section seeks to highlight pertain to the mechanoreceptors and their different characteristics. Their respective attributes are naturally of interest if we are to create and generate stimuli that we intend to be perceivable and recognizable.

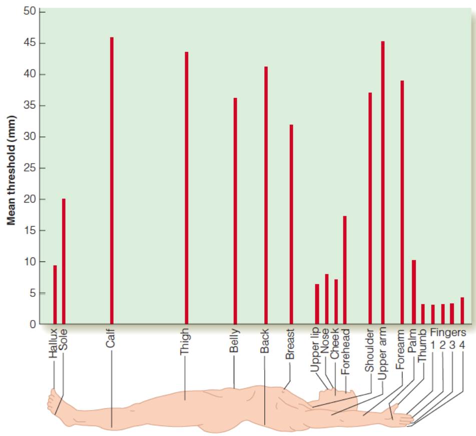
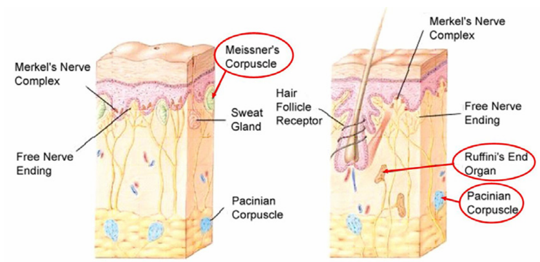



Figure 13: Varying sensitivity across body sites, reprint from (Goldstein, 2009), with permission of Wadsworth, Cengage Learning.




| Receptor | Receptor Type | Field Diameter | Frequency Range | Sensed Parameter |
|---|---|---|---|---|
| Merkel Disks | SAI | 3-4 mm | DC-30 Hz | Local skin curvature |
| Ruffini Endings | SAII | >10 mm | DC-15 Hz | Directional skin stretch |
| Meissner Corpuscles | FAI | 3-4 mm | 10-60 Hz | Skin stretch |
| Pacinian Corpuscles | FAII | >20 mm | 50-1000 Hz | Unlocalized vibration |

Figure 14: The human skin and characteristics of its mechanoreceptors, adapted from (Bark, 2004).

Figure 14 presents our four mechanoreceptors and their corresponding attributes. When interpreting the table, we can see that the mechanoreceptors respond to two major types of stimulation: skin stretch and vibration. Much of contact and protrusion forces, their orientation and amplitude, are recognized through skin stretch. Curvature, edge and bump sensing is mostly detected via local stretching and compression mechanisms, not via physical perpendicular movement as one might think (see Hayward, 2008, for greater details).

Vibration is the second stimulation that our skin is sensitive to. The Pacinian corpuscles allow for very fast response to vibration, and the sensitivity ranges from 50 to about 1000 Hz, with a peak around 250 Hz. It is worth nothing however that their sensitivity will decrease over time if continuously stimulated.

Beside the four mechanoreceptors, the skin hosts numerous nerve endings that provide thermal sensitivity and some proprioception sensing. In addition, hair follicle receptors provide supplementary signals related to movement near or in direct contact with the skin.

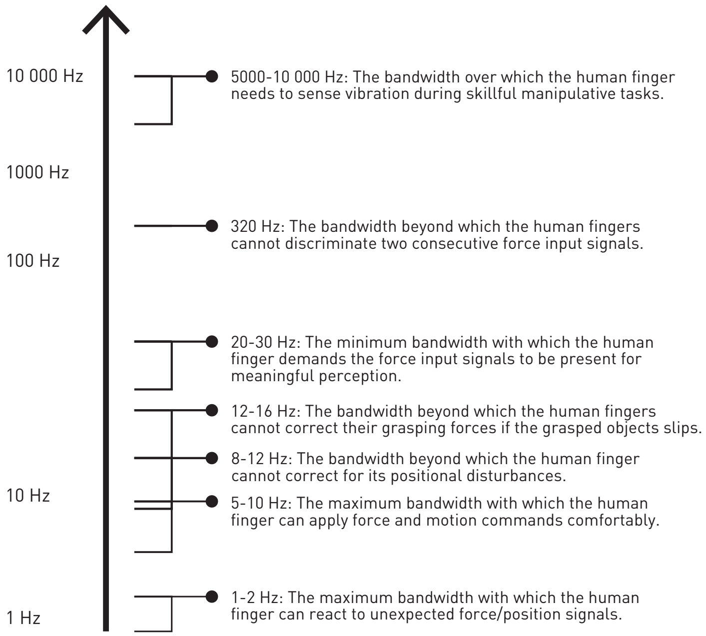



Figure 15: Human finger sensitivity bandwidth, adapted from Burdea (1996).

## HAPTICS COMPARED TO THE OTHER SENSES

Each of our five senses is unique. Each sense relies on different organs and physiological elements to function. For instance, hearing and vision are relatively separate both physically and functionally from other structures and mechanisms within the body, whereas haptics involve a variety of sensors spatially distributed throughout the body and highly integrated with motor mechanisms. In such, it makes studying haptics relatively more difficult. The following section pinpoints how the haptic sense fares compared to other senses. The goal is to identify its core strengths and weaknesses, in order to eventually leverage those when designing haptic interfaces.

Knowledge about human senses is often derived from situations or conditions in which particular perceptual capacities are impaired or simply missing. The adaptive capacity of our human perceptual mechanisms allows us to notice capabilities not present or usually not easily identifiable in normally functioning systems. As an example, we have learnt extensively about haptics based on how non-seeing individuals develop enhanced haptic capabilities.

Touch is the first sense to develop in humans and may be the last to fade. The haptic sense is also extremely fast and sensitive. Neuroscience has established that the haptic sense can perceive two stimuli just 5 ms apart, which is for instance about 20 times faster than vision. The haptic sense can also discern a displacement as small as 0.2 microns in length on the fingertips (M. Jones & Marsden, 2006).

A first and quite obvious limitation of haptics lies in its range: only near or direct contact with the human body yields perceptual haptic data. Anything beyond physical reach, in practice about a meter, is inaccessible and unperceivable to the touch sense. And even within reach, there are some additional limitations. Investigations into things like raised maps and patterns for non-seeing individuals, going back to Braille or even before, has led us to recognize major difficulties for recognizing the context or overview of a particular feature or scene of interest (Jansson, 2005). As opposed to vision, where one always gets contextual information almost instantaneously, haptic stimuli are limited to the contact area or surface when experiencing it only through touch. Scanning procedures are possible to some degree, but integration over space still remains very challenging cognitively and relatively slow.

Another interesting aspect of touch is that our neural system seems to be arranged in such a way that stimuli-response processes are generally faster with tactile perceptions than with visual cues. For instance, a tactile cue (stimuli) can result in finger movement (response) in about 100 ms, where a visual cue yields a motor response in approximately 200ms (Johansson & Flanagan, 2009). Such speed advantage is not terribly surprising though, if we consider the tight interplay between perception and motor action involved in everyday physical movement and skillful manipulation of tools and apparatus.

As already mentioned, vision is particularly apt at providing a very rich and wide spectrum of information. Due to the parallax nature of our vision system, we are capable of deducting the shape, size, and position of elements in our field of view. The various visual cues tell us a great deal about the environment around us and the possibilities for human engagement in it. A particular area where our vision system falls short though is material qualities, especially when it comes to friction. Although we can recognize visual attributes of objects and recall conditions of past encounters, it is our haptic sense that mostly drives our ability to grasp and engage with objects, where predictions of frictional conditions are based of previous haptic experiences. Grip and grasp actions are heavily modulated based on tactile cues, to achieve a perfect balance between required mechanical forces and comfort. Johansson & Flanagan identified that our grip forces in dexterous manipulation are continuously adjusted with a particular safety factor of close to 1.5, so we do not drop things or loose control unexpectedly (Johansson & Flanagan, 2009).

Another aspect worth considering is that the human body is forward-oriented but very symmetric in its left-right division. Although most humans have a predominant hand where motor-control is more developed, most of the basic haptic mappings are easily transferable between hands. For example, when interacting with an unknown object with a non-standard size-weight ratio, the haptic sense requires just a few attempts to achieve proper control or satisfactory handling. Once learned, this new mapping instance is directly applicable to the other hand.

## A COLLECTION OF CUES

Our previous analysis showed, without much surprise, that each of our senses differs in its working mechanisms and capabilities. Although it is important to recognize these differences, much of the amazing abilities of our human perceptual system are found when the senses work in concert. The complementarity and integration of the sensorial signals in the human body gives us a very robust, precise, and always adapting perceptual system.

The following discussion puts forward perceptual mechanisms mostly from the perspective of psychophysics and neuroscience. It is knowingly a physiology-oriented, below-the-skin inquiry.

Some approaches to understanding human perception, for instance within phenomenology, have started to stress that the human body and its brain, limbs, nerve and sensorial systems, etc., all work together to make perception an active process, i.e. that the human body is not just passively bombarded with stimuli but on the contrary actively seeks to position itself so that some stimuli are easier to catch while some then fade into the background. When someone talks to us, for instance, we tend to turn our head slightly to better hear what they are saying. However, while not denoting the important active role of the whole human in perception, for the purposes of this chapter it also makes sense to look at perception from an inner-body sensorial perspective.

From this perspective then, at any given point in time, our perceptual system is bombarded with thousands of stimuli, and somehow our body and mind entity is able to cope with it. Our conscious effort or actions might attend to particular channels and stimuli, but real world events have repercussions across many modalities in general. A ball landing on our hand is not only perceivable through our haptic sense: vision provides cues of increasing proximity and eventual contact, while audition will pick up the characteristic contact sound of the impact. Our perceptual processes have evolved in recognizing and leveraging this multimodal richness.

At its base, the haptic sense builds on a collection of tactile and kinaesthetic signals. The human sensory system filters and integrates these signals to lead to conscious and unconscious chains of events. The integrative processes are very complex and show definite cross-talk and sense-specific alignment (Goldstein et al., 2004). Cross-modality integrations are at the base of space and time constructs. How exactly these integration and mediation processes happen remains an ongoing question. However, what most neuroscientists agree is that such perception processes are feeding on a myriad of cues, and that radical signals or outliers are easily ignored. The process is more of a purgative nature than that of a constructive one. Nakayama labels it "Fast Dumb Mechanisms in a World Rich in Information" (Nakayama, 2008, p. 754).

In light of these observations, the haptic sense can be understood as an aggregation of small consistent and coherent cues coming from tactile and kinaesthetic sources. It is easy to see that additional cues from other senses can reinforce and strengthen haptic perception, as long as they are consistent and relevant with what the perceptual system expects. The question then becomes what is consistent and relevant for these perceptual mechanisms? Answering these questions opens a whole new world of inquiry relating to neuropsychology and neuroscience, but unfortunately these considerations are outside the scope of this thesis. For further investigation of general perception, refer to Goldstein et al. (2004).

## HAPTIC ILLUSIONS

An illusion is a distortion of the senses, a misinterpretation of a true sensation. As the human brain organizes and interprets stimuli, particular conditions can result in a percept that departs from the nature of the stimulus source. The beauty of illusions is that they can be experienced even as we are fully aware of their functioning. As perception takes over human reasoning, these forms of deception or trickery also allow us to explore some of the inner workings of our senses.

Although most popular illusions are of visual nature, illusions on other senses do exist, including the touch sense. The investigation of haptic and tactile illusions has a medical origin. Amputees often report pain and sensation originating in non-present, so-called phantom limbs. Hayward's survey of tactile illusions presents the most extensive analysis of haptic illusions to date (Hayward, 2008a). It details over twenty different tactile illusions, their underlying principles, and how one might go about building apparatuses to experience a subset of them.

| Name | Demonstrability | Stability | Analogs |
|---|---|---|---|
| Diplesthesia | Household | Not robust | Debatable |
| Funneling | Setup | Robust | Debatable |
| Cutaneous rabbit | Setup | Robust | Debatable |
| Size constancy failure | Household | Robust | Visual |
| Blackboard and parchment-skin | Household & setup | Robust | Cross modal |
| Weight-size and weight-X | Household | Robust | Cross modal |
| Numerosity of taps from beeps | Setup | Robust | Cross modal |
| Numerosity of flashes from taps | Setup | Robust | Cross modal |
| Change numbness | Setup | Robust | Auditory and Visual |
| Temporal ordering | Setup | Robust | Auditory and Visual |
| Pseudo-haptic effects | Any computer | Moderate | Cross modal |
| Comb | Household & hardware | Robust | Tactile specific |
| Tactile lens | Specialized device | Robust | Tactile specific |
| Fishbone | Household & hardware | Robust | Tactile specific |
| Curved plate | Household & hardware | Robust | Tactile specific |
| Tactile barber pole | Hardware | Robust | Visual analog |
| Müller-Lyer et alia | Household & hardware | Moderate | Visual analogs |
| Kinaesthetic effects | Household | Robust | Visual analogs |
| Force by acceleration asymmetry | Setup | Robust | Tactile specific |
| Distral attribution | Household | Robust | Visual and auditory |
| Rolling ball | Setup | Robust | Auditory |
| Tactile Motion after-effect | Setup | Moderate | Visual and auditory |
| Weight after-effet | Household | Robust | Visual and auditory |
| Shape after-effect | Household | Robust | Visual |
| Texture force fields | Setup | Robust | Haptic specific |
| Corner smoothing | Setup | Robust | Haptic specific |
| Bump/holes | Hardware | Robust | Haptic specific |

Figure 16: Names of tactile illusions and their demonstrability, adapted from (Hayward, 2008a)

As Hayward explains, these haptic illusions are not only a source of amusement; they represent unique opportunities for research and practical outcomes. In the same way that cinematography and computer display technology heavily leverage the power of optical illusions, Hayward suggests that a refined understanding of haptic illusions could give way to new and particularly effective haptic interfaces. The lateral-stretching interfaces that evolved from his investigation of the comb illusion are very conclusive and inspiring.

## 1.2.3 HAPTIC SYSTEMS AND CHARACTERIZATION

The third and last section of this chapter attempts to dissect haptic interfaces from a functional and technical perspective. The intention is to reveal how a tool or technical apparatus attains the label of being a 'haptic interface'. The discussion will help us identify characteristics of haptic systems, as well as various metrics to estimate and relate their performances.

### DIRECT VERSUS TOOL-MEDIATED INTERACTION

Our haptic interactions with the world take place in only two ways, by direct contact or through using tools. With direct contact, the haptic cues inform us directly about the object's qualities and its characteristics. In the case of tool-mediated haptic interaction, the haptic cues obtainable by the perceiver are an intricate mix of the qualities of both the object and the tool.

For example, grasping an apple with a bare hand will directly reveal information about the apple's shape, weight, volume, texture, compliance, and many others qualities. In this, there is a unique and unequivocal transformation taking place. As our understanding of the direct cues comes from a lifetime of continuous use and learning, the 'sensation space' tends to be very rich and diverse.

Alternatively, one can use a tool like a stick or a knife to explore the apple. The use of the tool results in two distinct transformations: the first at the object-tool contact point (T1), and the second at the tool-hand interface (T2). In a purely static mode, T1 is simply inaccessible to the perceiver. Fortunately, the perceiver has the ability to dynamically engage with the tool and as the tool moves, T1 changes and those variations are accessible to the perceiver via T2. There is evidence that the brain can invert T2 and ultimately access T1 (Hayward, 2008b) . This possibility comes from our experience at perceiving similar sensations when the same tool is used against the same object but using different grip configurations. Hayward calls this the *grip-related perceptual constancy effect*. T2 is then considered known and invertible. As for T1, the problem consists in recovering the properties of the object in relation to the properties of the tool. Here again, due to our long acquaintance of tools and their inherent properties with different objects, we have come to develop a *tool-related perceptual constancy effect*. The tool's dependencies can then be extracted from T1, and the properties of the object per se are finally revealed.

This process of compounded transformations and inversion might seem elaborate to describe in words, but its realization in real-life is totally unconscious. Our mastery of tool-mediated interaction is also extremely refined. In most situations, the tool naturally becomes an extension of the body and disappears from attention.

In comparison to direct touch, tool-mediated haptic interaction offers a sensation space that is naturally narrower and more restricted and the tool in itself imposes physical and mechanical constraints. The result is a far more limited subset of haptic cues reaching the perceiver. Although this realization might sound negative, it in fact directly reduces the otherwise almost infinite space of possibilities as well as the complexity when developing haptic interfaces.

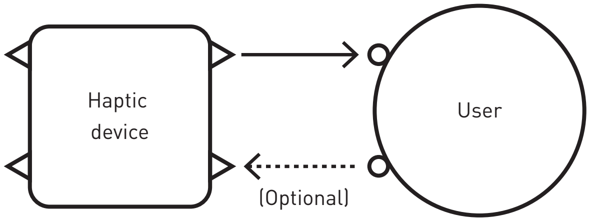



Figure 17: Simplest schema of a haptic system, adapted from Kern (2009).

How can a haptic system be explained or modeled? The simplest haptic system consists of a haptic device transmitting haptic information to a user. Examples of simple passive haptic interfaces are embossed printing on currency bills and the subtly raised markers that exist on the F and J keys of almost all modern computer keyboards. The *passive* label denotes that these systems transmit haptic information solely by their shape.

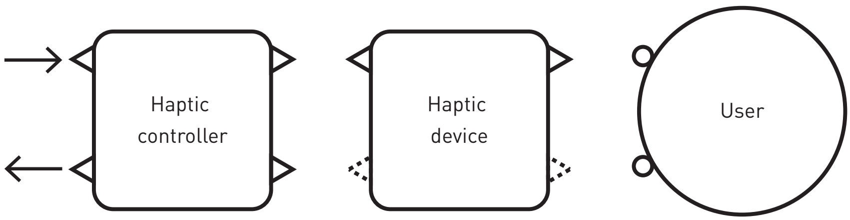



Figure 18: Schematic components of a haptic system, adapted from Kern (2009).

However, more common so-called *active haptic systems* usually also involve an input or feedback channel and a haptic controller. The controller allows for modulation of the haptic output signal, most often based on monitoring of the input and feedback channel. The label *active* in this particular sense denotes that the system uses an external energy source to convey haptic information to the user. A classic example of an active haptic system is a force feedback steering wheel operating as a game controller. Here, the interface actuates the steering in particular ways (by vibration and directional force) in real time based on whatever actions take place in the computer game.

As easily imaginable, the technical realization of the active haptic devices and controllers can vary from the very simple to the very complex. While it is not possible to venture deep into very technical considerations here, there are plenty of books that offer guidance and best practices on these issues (see for instance Burdea, 1996; Kern, 2009). However, four main classes of possible haptic system architectures, as discussed by Kern (2009), are worth considering: open-loop or closed-loop admittance controlled systems, and open-loop or closed-loop impedance controlled systems.

Admittance controlled systems generate a position change (or lock) as haptic feedback and get a force reaction from the user as input source. The Moog-FCS HapticMaster (figure 9) and Haption's Virtuose systems are examples of close-loop admittance systems that can generate stiffness up to 100N. Open-loop admittance systems like a dynamic braille reader (or other tactile displays) do not track the quality or completeness of the actuation.

Impedance systems generate a force as output and measure a position as input. Open-loop systems, like the Novint's Falcon and Sensable's Omni devices, are the most common haptic controllers available today and provide adequate haptic feedback for both textures and hard mechanics. Closed-loop impedance systems, like the delta series from ForceDimensions, use force readings at the grip to dynamically compensate for the mechanics and inertia of the device.

## JEX'S FOUR CRITICAL TESTS FOR CONTROL-FEEL SIMULATORS OR *MANIPULANDA*

One of the main challenges in building haptic interfaces and one that is central to the work being discussed in this thesis resides in attaining what I term as *the right feeling*. This is first and foremost a designerly goal. As a goal, it is knowingly quite vague and naturally depends on a plethora of considerations, but it is the role of the designer to work out and craft the details of the interaction that come together to provide the user with just the right feeling.

For many other actors in the field of haptics, naturalistic interactions are the ideal measures by which haptic interfaces are evaluated. For instance, a simulated hard stop should feel as hard as a natural contact event in real-life. In line with this ideal, following the development of servomotor actuated airplane control, Jex's *Manipulanda* offers four tests to evaluate the quality of haptic interfaces (Jex, 1988) :

- With all other simulated forces set to zero, when the mass or inertia of the simulated hand control is set to zero, it should feel like a stick of balsa wood (i.e. have negligible lag, friction, jitter, or forces) up to the highest frequency that a finger grip can impose, or about 7Hz
- When pushed against simulated hard stops, the hand control should stop abruptly, with no sponginess, and it should not creep as force continues to be applied
- When set for pure Coulomb friction (i.e. within a non-centering hysteresis loop), the hand control should remain in place, without creep, sponginess or jitter, even when repeatedly tapped
- When set to simulate a mechanical centering "detent" and moved rapidly across a detent, the force reversal should be crisp and give a realistic "clunk" with no perceptible lag or sponginess

Jex also concluded that to keep mental workload low, any simulation artifact must be less than about one-fourth of the effective operator response delay. These guidelines are insightful in many ways, but their mechanical heritage is clearly visible.

## 1.2.4 CONCLUSION

As we conclude this primer on haptics, it is important to restate that this chapter only captures a fraction of the haptics knowledge currently available. Despite its conciseness, it has served us well. It exposed fundamental issues about haptic perception, detailed how haptics has developed as a field of scientific inquiry, and presented bits and pieces of haptic knowledge and haptic technology that, taken together, helps us get a better sense of what haptics is.

What ultimately emerges from this review is that all these scientific results and descriptions of haptics are very useful, but are not in and by themselves sufficient to develop "the right feeling" we crave for as designers. No amount of technical prowess or neuroscience will guide us directly towards designing pleasant, enjoyable and purposeful haptic interactions. For attaining this goal, we have to first ask ourselves what is the right feeling that we want?

# CHAPTER 1.3 REPRESENTATIONS, PROTOTYPING, AND SKETCHING

**There can be no design activity without representations**

(Goldschmidt & Porter, 2004)

## INTRODUCTION

Design representations and their making span a large spectrum of goals, needs, activities, and mediums. Their nature and characteristics vary immensely between inquiries, projects, and communities of practice. Nevertheless, the realization of design representations is perhaps the unique and overarching activity that unites the many design disciplines today. This chapter aims to provide a common ground for our understanding of the central vocabulary associated with design representations. Over the years, different communities have come to develop their particular understandings and expectations with regard to the terms and jargon associated with design. In some cases, the designations tend to be used interchangeably and adapted freely. In other cases, uses of the terms convey very specific and widely agreed-upon meaning. As design tools and processes evolve, so does our understanding and use of these words.

In the first section below, the concept of design *representations* itself is examined. Here, some of the main strands of design theory underpinning the subject are uncovered. Some of the latest scholarly investigations on the subject are reviewed in the hope of learning more about their role and usefulness in design. The second section uncovers and discusses the origin of some common terms in design lingo, such as *prototypes*, *mock-ups*, *models* and *sketches*, after which I look into and contrast how some other western languages use analogous or contrasting terms with similar connotations. The third section below focuses on how different disciplines and communities seem to have adopted particular terms and interpretations. In this, special attention is paid to how the interaction design discipline has embraced these terms, and what uses and interpretations prevail and are commonly ratified to this day. The chapter ends with a more distinct focus of the key terms *prototyping* and *sketching*, that both are activities which are very tightly associated in practice in the realization of design representations, and as such are key terms for understanding the work presented in this thesis. This chapter's discussion is then concluded by a more structured comparison between the two notions, highlighting their similarities and differences.

As the attentive reader soon realizes, this chapter intentionally leaves out the perspective of haptics in relation to the above-mentioned design representation terms. The reason for this is that since the bond between haptics and sketching is so central to this thesis, this issue deserves a more comprehensive discussion, which is carried out in part 3, later on in this book.

## 1.3.1 DESIGN REPRESENTATIONS

This sub-chapter asks the question: what are design representations? Such a broad question is obviously not easily answered. Any examination of representation, in its most basic level of inquiry, pervades a large number of domains, including philosophy, cognitive sciences, neuroscience, arts, and technology fields. In order to articulate a meaningful discourse around this topic, it is necessary to restate the primary goal of this thesis: to help advance design activities at the junction of interaction design and haptics. It is within the realms of this perspective that we seek to scrutinize the nature and notions of representations. Consequently, the examination below will have to overlook many fascinating questions of ontology, epistemology, semiotics, and knowledge science. This is not primarily due to a lack of interest on the part of the author, but rather for the sake of brevity and clarity.

### INTERNAL AND EXTERNAL REPRESENTATIONS

Very generally speaking representations can be loosely classified in two types: *internal* and *external* (Brereton, 2004; Hutchins, 1989). Internal representations pertain to the thinking processes of the individual, i.e. ways of understanding, perceiving the world, and describing ideas and concepts.

External representations are physical elements of the material world, external to the human body entity. As easily recognizable, the two types are related: the human intellect does not exist in a transcendental and ethereal space. Common sense tells us that human experience evolves in large measure from reflective and transformative interactions with the (real) world, but how this is happening is still argued back and forth in many fields.Consequently, our understanding of representation constitutes an insatiable source of philosophical and epistemological questionings.

With the goals and aims of this thesis in mind, our interest lies in the use of external representations to support and advance design knowledge, design thinking, and design activities in general. Such concern builds from numerous traditions, both practical and theoretical, acknowledging the richness and indispensability of materiality in the larger human experience. An explicit account of this can be found in the writings of distributed cognition, where human knowledge and cognition can be said to arise from coordination between internal and external representations (Hutchins, 1995).

Since phenomenology is basically "the study of structures of consciousness as experienced from the first-person point of view" (Smith, 2011), the value of external representations stands as an implicit assertion for all phenomenological traditions since Husserl. Some philosophers, like Kuhn and Latour, go even further by claiming that human knowledge is indissociable from the social milieu from which it arises; made of things and people (Goldman, 2010). Nowadays, it is largely admitted that external representations are sources of embodied knowledge and information, and are an essential part of the lived human experience.

As we acknowledge the importance of external representations, what can be said about them in relation to design? The edited volume from Goldschmidt and Porter offers a first scholarly investigation of the nature and roles of design representations (Goldschmidt & Porter, 2004). One of the first observations relates to the fact that external representations have a dichotomy of roles. These representations are proxies, stands-in or stimulations of an abstract construct or ideal; they depict it, point or refer to it. These representations are as well objects of their own, with unique qualities and existence, separate in a way from the thing or idea they represent. For example, a drawing of a chair aims to depict the idea of a particular chair, with distinct aesthetic and functional qualities. The drawing is not itself a chair, but it leads directly to the envisioning of *that possible* chair. The stimulation and proxy notions are at work in this situation. On the other side, the drawing – i.e. the graphic representation on the paper – exists in its own right and holds qualities independent of the chair construct. The drawing is the result of human actions, and is imbued with various considerations. One can look at the drawing and appreciate (or not) the skills of its creator. The ambivalence of roles is challenging, especially as the representation leaves the realm of its creator. The intellectual, creative links that led to its creation are invariable lost, and the only manifestation left is the artifact itself.

Brereton (2004) explores various types of design representations in light of design education and among other things compares various dichotomies of representations: internal versus external, transient versus durable, self-generated versus ready-made, and abstract versus concrete. Her work looks at design engineering activities using different representational frames and she examines the roles of hardware in mediating design negotiations and design learning outcomes. In conclusion, Brereton notes that learning in design seems to arise primarily between abstract and material representations, where representations act as amplifying devices or processes to support understanding and action, and that the process of design always seems to benefit from applying a variety of representations, especially with constructed and tangible non-pictorial representations.

## 1.3.2 PROTOTYPES, MOCK-UPS, MODELS AND SKETCHES?

### ORIGIN, GENERAL TRAITS, AND EXAMPLES

One step towards understanding the materialization of ideas and artifact building in design resides in looking at the origin, key interpretations, and some general traits commonly associated with the most common terms. This inquiry focuses on four main denominations of the English language, namely: *prototypes, mock-ups, models,* and *sketches.* There are of course some other terms in existence that convey similar or related meaning, such as props, probes and dummies, but their contemporary usage is less common and have accordingly been for the most part ignored in this work. Some of them will however appear in the discussion below, whenever relevant.

The point of departure for this dissection starts by looking at the origin and definitions found in a modern English dictionary (Merriam-Webster, n.d.)

## MODEL (NOUN)

Origin: middle French **modelle**, from Old Italian **modello**, from Vulgar Latin ***modellus**, from Latin **modulus** small measure, from **modus**
First known use: **1575**
**1:** a usually small copy of something
**2:** a particular type or version of a product (such as a car or computer)
**3:** a set of ideas and numbers that describe the past, present, or future state of something (such as an economy or a business)
**4 a:** something or someone that is a very good example *of* something
**b:** something or someone that deserves to be copied by others
**5:** someone who is paid to wear clothing, jewelry, etc., in photographs, fashion shows, etc., so that people will see and want to buy what is being worn
**6:** someone whose image is painted, photographed, etc., by an artist

According to this definition, the term model is not only a noun but also a verb (i.e. to plan or form after a pattern, to produce a representation or simulation of) as well as an adjective (i.e. serving as or capable of serving as a pattern, being a usually miniature representation of something). In this, we can discern two main interpretations that seems particularly relevant to our inquiry. The first is related to a version, copy, or representation of something, either in exact or reduced scale. The second interpretation refers to *model* as a set of ideas, abstractions, and processes that synthetize a system or an activity. Here, fidelity seems relevant to the first interpretation, whereas abstraction is key to the second signification.

## SKETCH (NOUN)

Origin: Dutch **schets**, from Italian **schizzo**, literally, splash, from **schizzare** to splash, of imitative origin
First known use: **1668**
**1 a:** a rough drawing representing the chief features of an object or scene and often made as a preliminary study
**b:** a tentative draft (as for a literary work)
**2:** a brief description (as of a person) or outline
**3: a :** a short literary composition somewhat resembling the short story and the essay but intentionally slight in treatment, discursive in style, and familiar in tone
**b :** a short instrumental composition usually for piano
**c :** a slight theatrical piece having a single scene; especially : a comic variety act

Here, as with the term model, sketch is not only a noun but also a verb: "to make a sketch, rough draft, or outline of". Attributes and qualities like *rough, preliminary, tentative draft, intentionally slight in treatment*, and *discursive* are key factors for understanding the essence of *sketches*.

## PROTOTYPE

Origin: French, from Greek **prōtotypon**, from neuter of **prōtotypos** archetypal, from **prōt- + typos** type
First known use: **1552**
**1:** an original model on which something is patterned: archetype
**2:** an individual that exhibits the essential features of a later type
**3:** a standard or typical example
**4:** a first full-scale and usually functional form of a new type or design of a construction (as an airplane)

Although not officially recognized in this definition, the term prototype is very commonly used as a verb (to prototype or prototyping: the fabrication of prototypes) in the lingo of the design disciplines. Semantically, *prototypes* are proto instances, i.e. "... just those members of a category that most reflect the redundancy structure of the category as a whole." (Rosch, 1978). For our purposes, it is worth nothing the reference to *full-scale*, *containing the essential features*, and *functional* qualities related to the term.

## MOCK-UP

First known use: **1920**
**1:** a full-sized structural model built to scale chiefly for study, testing, or display
**2:** a working sample (as of a magazine) for reviewing format, layout, or content

The term mock-up is most commonly used in design and manufacturing activities. Mock-ups are models, typically in the scale of 1:1, used for demonstration purposes, design evaluation, teaching, and as presentation aids. Mock-ups are often quite similar in appearance and form to the intended in final design or system, but typically non-working or non-functional depictions of the real thing, similar to the role of theatrical props. The continuum between a mock-up and a prototype is not entirely clear, and the difference often stems more from how it is used rather than what it is. For instance, a mock-up can turn into a prototype if it provides some part of the functionality of the intended future device or system. In print design and some other design disciplines, the term and practice around mock-ups are used more or less interchangeably with what other design disciplines may call early or low-fidelity prototypes.

As a contrast, the French language has partly different terminology in this area that is worth addressing. Here, we find for instance *maquette*, which is a small scale model, used primarily to visualize, appreciate, and test shapes and ideas without incurring the cost and effort of producing a full scale product; *esquisse*, the initial form of an artistic project, an undeveloped beginning; *croquis*, a quick sketch, a rapid outline; and *ébauche*, a first preliminary underpainting, for instance quick sketch for an oil painting. The word *prototype* also has a much more restrictive connotation in French. In French, a prototype is understood as a quasi-exact and the last test model that is made before initiating mass production of a product.

During my French-speaking industrial design education in Canada however, the term most commonly used for design realizations was maquette. Even at a scale of 1:1, most realizations were maquettes, i.e. incomplete functionally or brought to life through abridged processes or various short cuts. The term prototype was however seldom used, and clearly not as widely used as in English.

In concluding this overview of the origin and definitions, we can recognize major resemblances between the terms of model, prototype, sketch, and mock-up, but also some noticeable differences where each term in its own way tries to capture a particular set of important attributes of the realization of a design representation.

From this examination, we see that it is often inappropriate to dissociate an artifact's attributes from the context and situation of its inception. Rather, it makes sense to look in more detail into how different disciplines and communities of practice come to relate to and use the four terms in their practices.

## 1.3.3 COMMUNITIES OF PRACTICE

All scientific disciplines, as well as most human activities, work with representations of some sort. The term *model*, for instance, pervade all scientific endeavors. The second section of this chapter will be look at a subset of all creative design disciplines that have been found to be of importance and relevant to this work: *architecture*, many variants of *design, game development*, and *human-computer interaction*. The chapter explores how the different disciplines have developed an affinity to particular terms and how they have come to prefer certain interpretations. While this compilation of examples is not complete, they have been developed and complied from reading academic and professional publications and from interviewing and discussing the topic directly with professionals, educators, and students active in those fields. As such, it should provide a fairly balanced and grounded account of how the different fields tend to relate to and rely on different kinds of design representations.

In architecture, *model* seems to be the most common term, often used with a qualifier or descriptor: engineering model, exhibition model, construction model, scale model, etc. Not surprisingly, this discipline has a strong necessity to develop abstract representations at reduced scale, to showcase certain details while omitting others depending on the intention of the model. The terms *plans* and *drawings* denote particular type of deliverables on paper (traditionally) that are handed out to building contractors. *Renderings* are refined, detailed and often highly polished visual depictions, usually in full colors and commonly used to "sell" the project to clients, the public and other stakeholders. *Renderings* and *plans* often integrate elements of the environment (surrounding buildings, details of the landscape) and human figures for better contextualization. *Sketches* and *renderings* are commonly used during the development of architectural ideas, along with samples of materials. *Program* is a term often used to describe a set of broad objectives, and how human movement and use is related to the building or space. The usage of *program* is usually limited to internal discussion between tutors, students and architects.

In the game development field, prototypes are often understood as proof of concepts for new gameplay ideas, game scenario and usability inquiries. Prototyping takes place generally in the pre-production phase, and aims to explore and establish reference points during game design. Most representations are of digital nature (code), but storyboards, drawn schematics and diagrams, pen and paper sketches of visual elements are common too. A game developer I interviewed explains: "the difference between a *mock-up* and a *prototype* for me would be that a prototype makes use of real aspects you want to test, whereas a mock-up is an abstraction of what you want to test". Other terms are used to relate to particular types of inquiries: *tech spike* denotes an investigation of whether one specific technology satisfies a set of said requirements; *vertical slice* designates a single portion of a game with all elements resolved and elaborated; and *probe* implies testing procedures to gather feedback from users. Game development borrows many terms and denominations from software engineering practices: alpha, beta, open/closed beta, golden-master, development cycles, crunch, etc.

The field of Human Computer Interaction (HCI) has a long tradition of inquiry into our interactions with built artifacts. Over the last few decades, researchers developed numerous *models* depicting our cognitive capabilities and processes. Those models are not physical in any way; they are generally sets of rules, methods, diagrams and metaphors trying to grasp how humans can best interact with computers. *Prototypes* range from faked user interfaces using paper or video, to fully functional implementations (computer code) running on off-the shelf devices. *Sketches* and *mock-ups* are rarely used in this discipline. Guiding *principles* are popular outcomes of HCI research as in Wickens et al. (Wickens, Lee, Liu, & Gordon-Becker, 2003). Usage of *prototypes* relates heavily to software development cycle characterization, with a strong emphasis on the iterative process: design, test, analyze the results and repeat. Different kinds of *prototypes* are realized depending on the nature of the inquiries: concept prototypes, feasibility prototypes, horizontal and vertical prototypes (Nielsen, 1993), etc. Fidelity is a common differentiator in *prototypes* for this discipline: low fidelity for rapid and rough inquiries (Rudd, Stern, & Isensee, 1996), high fidelity for refined understanding and investigation. This separation is not without critics (Buxton, 2007; Lim, Stolterman, & Tenenberg, 2008; Moussette, 2010). On the whole, human computer interaction mostly uses *model*-informed *prototypes* to engage with users through evaluation experiments.

The field of industrial design makes uses of a diverse set of terms. Evans & Pei lists 32 compound denominations around the terms of *sketches*, *drawings, models* and *prototypes* (Evans & Pei, 2010). Such composite denomination is very common and often states the activity leading or associated with the representation: appearance model, sketch model, functional model, engineering prototype, etc. The traditional process of industrial design involves representations in sync with the design process itself: exploration via *sketches*, framing problems and opportunities using *drawings* and *mock-ups*, refinements and synthesis via *models* and *prototypes*. The communication qualities of *models* are crucial to present design work. The representations are predominantly developed for visual appreciation and evaluation, as functional qualities are rarely exposed in design models. Final prototypes are usually realized in close collaboration with engineers.

The field of interaction design uses a very varied set of terms. It builds naturally on terms and usage from the field of human computer interaction, but also includes terms with a noted focus on creative, explorative and non-committal endeavors. Critical *artifacts* (Bowen, 2009), *placebos* (Dunne & Raby, 2001), cultural *probes* (B. Gaver, Dunne, & Pacenti, 1999) and technology *probes* (Hutchinson et al., 2003) are built artifacts to provoke or initiate a discussion, or to define a problem-space. Often the qualities of the built artifact are secondary to its engagement and revealing values. The terms often put together a function and a medium: functional storyboard, paper prototyping, experience prototyping, sketching in hardware and so on. Overall, the terms prototypes, models, sketches and mock-ups are used inconsistently in interaction design. They generally represent any mix of hardware and software elements quickly put together to test or communicate a design idea.

## ANALYSIS

Reviewing some key interpretations and commonly ratified terms from five different but related disciplines helps us see a relatively large discrepancy in the use and valuation of words like prototypes, sketches, and models. Some disciplines have developed, in response to new challenges and a shifting practice, a refined and almost strict vocabulary to characterize and discuss renditions or physical instances crucial to the discipline's activities.

On the other hand, other disciplines such as interaction design, have adopted an open and very inclusive approach to various ways of making and valuing design representations. This open attitude has led to a rich palette of new approaches and denominations, but at the cost of diluted comprehension and indecisive common understanding of these terms. As an example, there is currently no clear consensus on what constitutes (or what does not constitute) a prototype or model in interaction design.

The end result is that although the members of a discipline or community share some kind of loose, generally agreed upon notion of what a prototype or a model is, we nevertheless tend to use the words *models, sketches, prototypes* and *mock-ups* inconsistently and interchangeably. This is not least true in the field of interaction design. The view that this work advises and suggests is that greater caution and some thinking about these issues should be applied so that we as a community can discuss and refer to our design activities in a much more stringent, refined, and unequivocal manner. To that extent, part 3 of this thesis will suggest and motivate the use of some particular design representation terms that seem well suited for discussing contemporary interaction design practice, especially when branching towards haptics.

The relationship between sketching and prototyping will be of primary concern throughout this thesis. Hence, the following sections of this chapter will discuss their current roles in interaction design in more detail.

## 1.3.4 PROTOTYPING

In interaction design and fields of research and development related to it, such as human-computer interaction, prototyping plays and has always played a central role. In one particular view, prototyping can be understood as the production and use of material representations. Most design disciplines have always had a strong affinity with prototypes and it is often through and with prototypes that designers develop and communicate what *ought-to-be*. As presented earlier, however, different communities of practice – even those belonging to the same discipline or sub-community within this discipline – may have divergent views of what constitutes a prototype and what constitutes activities of prototyping. Often the prototypes themselves, i.e. the objects or materials outcomes, take center stage when we elaborate about prototyping in interaction design. We tend to discuss extensively on the attributes and qualities of the objects and how well or not they attain or speak to various technical or theoretical ideals or objectives.

In the following discussion, I want to deliberately place attention upon the *activity of prototyping*, more than to the realizations or the prototypes. Like many others (Buchenau & Suri, 2000; Buxton, 2007; Schrage, 2006), I believe that the practice of prototyping is far richer than the prototypes in and of themselves. Like any tools, what counts the most– in my view – is how we use them, not how they are made.

## FROM PROTOTYPES TO PROTOTYPING AND BEYOND

There is already a substantial body of knowledge about prototypes and practices of prototyping in the design and technology domains. Most of it resides in professional experience and everyday tacit knowledge of design practice. During the last decade or so, academics have increasingly started to scrutinize these activities and their work is now bearing fruit. For example, the 'ID cards' collection from Loughborough University compiles and exposes 32 different design manifestations for product design and industrial design, each with their own usage scenario and unique design concern (Evans & Pei, 2010).

In reviewing the current state of the art literature on this topic, three academic publications related to interaction design stand out in their capacity to comprehend the way designers engage in prototyping activities. Below, each of them are briefly presented and their key contributions are highlighted.

In *The Anatomy of Prototypes* by Lim, Stolterman & Tenenberg (2008), the authors present a general frame of reference to relate and understand fundamental characteristics of prototypes (Lim et al., 2008), which proposes the following:

> ***Fundamental prototyping principle:***
> Prototyping is an activity with the purpose of creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole.
>
> ***Economic principle of prototyping:***
> The best prototype is one that, in the simplest and the most efficient way, makes the possibilities and limitations of a design idea visible and measurable.
>
> ***Anatomy of prototypes:***
> Prototypes are filters that traverse a design space and are manifestations of design ideas that concretize and externalize conceptual ideas.

What emerges from this is that the activity of prototyping is about traversing and filtering a design space and about the creation of partial manifestations. Prototyping activities allow designers to shift through alternatives, evaluate them, and see opportunities for new ones. This process offers explorative and analytical values. Prototyping also relates to the manifestation of ideas into tangible and concrete mediums with which others can interact. Furthermore, prototypes are incomplete realizations as they invariably capture only a subset of qualities, characteristics, or dimensions of the full idea or concept being explored. The designer has full control over which dimensions are to be considered or not, and how the prototype can ultimately be used to inform the design inquiry.

In *What do Prototypes Prototype?*, Houde & Hill (1997) proposed a related model that focuses on the purpose and aim of the realizations rather then incidental attributes (Houde & Hill, 1997).

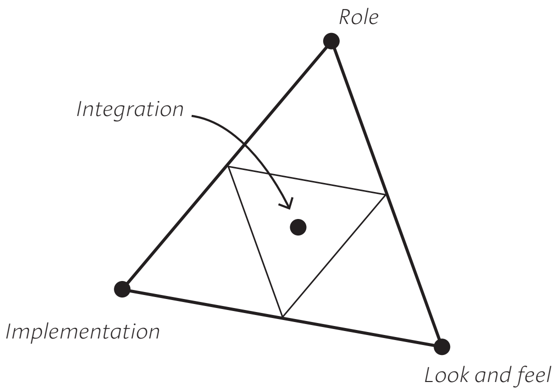



Figure 19: Dimensions of prototypes, adapted from Houde & Hill (1997).

Their model offers three main poles, *role, implementation*, and *look and feel*, each representing a dimension or a set of design questions under consideration. The role dimension pertains to the function of the artifact in the user's life. The look and feel dimension relates to the sensory qualities of the artifact when in use, while the implementation dimension tackles the practical and technical challenges required for the artifact to be realized. A fourth dimension, entitled *integration*, is also added to capture instances when the three other dimensions come together into the same prototype.

The perspective of Houde & Hill is a reminder that prototypes are representations that designers can engage with in order to explore different questions for a host of different purposes. Prototyping is not only about building new artifacts; it is also about how one uses those artifacts to ask questions and tackle and inform design activities at large.

In *Experience Prototyping*, Buchenau and Suri advocate for a form of prototyping that focuses on the resulting experience more than the qualities of artifacts that help deliver that experience (Buchenau & Suri, 2000). As new products and services increasingly get more complex and start to pervade all domains of life, it becomes more important for designers to explore and try to define integrated and holistic experiences rather than working out physical and technical attributes of individual artifacts. Experience prototypes "emphasize the experiential aspect of whatever representations are needed to successfully (re)live or convey an experience with a product, space or system" (Buchenau & Suri, 2000, p. 1). Their perspective does not necessarily discard the value of 'traditional' prototyping, of creating representations, but rather operates to shift the objective to a higher level and calls for a broader view of prototyping, where any activity is commendable as long it builds towards the right experience.

The common thread that emerges from all three contributions reviewed above is the idea that prototyping is a design activity primarily related to the crafting of particular renditions in order to inform or support a design process. The prototype, the device or the thing in itself, is *just* a means to an end – a tool, or a vehicle, to support an inquiry. The value of the prototype is much larger than the thing itself, the atoms, bits or combinations of the two that make it up. The essential issue posed by the authors pertains to how a prototype is put to use by the designer. As argued by Buxton, design is not only about *getting the design right*, but as much about *getting the right design* (Buxton, 2007). The true value of prototyping lies in its ability to move the design inquiry forward.

We will conclude this discussion about prototyping by introducing two unusual perspectives that were proposed by Schrage during a workshop on prototyping (Valentine et al., 2010). The first perspective suggests that *prototyping is a form of value exchange*. The designers, via their prototypes, aim to trade and exchange values with the world and their users. The prototypes embed certain qualities and characteristic, where the users (or the world, depending on the nature of the prototypes and the purpose) will resonate and respond to these proposals in various ways, that in turn will provide and offer usage, comments, and feedback to the designer via the prototypes. Prototyping can thus be seen as the trading of information and value between parties, i.e. a collaborative effort of giving and receiving. In such an enterprise, great care is needed to anticipate, frame, balance, and adjust the activity so the exchange is mutually beneficial and gratifying.

The second perspective frames *prototyping as a form of serious play* where the rules of design are momentarily relaxed to allow for the emergence of new possibilities (Schrage, 1999, 2000). Under this altered reality, designers have the opportunity to explore in depth different aspects of the design project that are usually not open for consideration. The rules of the game are to be broken or forgotten for a moment, in the hope that new and enlightening questions and considerations will surface.

## 1.3.5 SKETCHING

Sketching is an inevitable stepping-stone in our quest to explore design representations. For this third part, we will focus explicitly on dissecting the notion of sketching from a design theory perspective. What exactly is sketching, what is its role in design work, and why is it relevant to design?

### HISTORY

The historical origin of sketching captures some important qualities worth exposing. It dates back to the late fifteenth century in Europe and relates to the advent of the printing press. Historically, artists, designers, monks, and scientists typically realized their drawings on handmade paper, which was expensive and in limited supply. The rapid development of the printing press generated a strong demand for paper, which pushed the development of water-powered paper mills and their widespread adoption. The increased production capacity led to affordable and readily available high-quality paper to the masses. As the cost of the medium –the paper substrate – became insignificant in relation to the overall enterprise of painting, artists and designers could then afford the realization of study drawings, experiments, and explorations on paper without substantial pre-planning. The innovative spirit of the Renaissance coupled with cheap paper support allowed artists and tinkers to use hand drawn representations as a new thinking substrate. These study drawings were interestingly called *pensieri* during this period, meaning "thoughts" in contemporary Italian (Goldschmidt, 2003). They are today known in English as *sketches*.

In section 1.3.5 the term *sketch* and its interpretations is explored in greater detail, however, focus is placed upon the design theory aspects of sketching, i.e. the activity more than the visual artifacts generated.

## SKETCHING IS MORE THAN DRAWING

While sketching involves drawing, sketching is different from drawing in the conventional sense. Drawing skills relate to the capacity of graphic production as a strategy for communication and reasoning. Skills in drawing can be seen as analogous to linguistic skills, i.e. mastering a particular language does not automatically make you an outstanding orator or writer. An exceptional ability to draw accurately and precisely makes a great illustrator, but many brilliant and acclaimed painters, artists, architects, and designers cannot draw well. Representational skills have different aims and purposes and this is where sketching differs from drawing.

Unlike illustration, sketching involves representational skills working towards inventive and creative purposes. As previously mentioned in conjunction with prototyping, sketching can be framed as a form of play, where the rules of drawing have been momentarily relaxed. As the sketcher engages in more experimental drawings, new mediums or uncertain representational activities, inference of meaning and sense making are derived from other sources than the symbolic representations. The sketcher can see or read more information than what is visually depicted. These added meanings or unexpected interpretations directly feed back into the drawing activities, invariably altering the sketcher's actions and understanding of the situation. Goldschmidt calls this phenomenon the backtalk of sketches (Goldschmidt, 2003). Schön discusses the same process under knowing-in-action and literally writes that "a designer sees, moves and sees again" (D. A. Schon & Wiggins, 1992, p. 135). Sketching is, to put it concisely, a constant evolving sense-making dialog between the sketcher and the sketch, between the human and the medium.

Past researchers have examined *sketching* in great length and details. Goldschmidt's (1991) *The Dialectics of Sketching* dissects the process of sketching from cognitivist and learning perspectives. Schön has written seminal contributions related to sketching and representational skills, analyzing the activities of architecture students and tutors. As an example, his 1992 article titled *Designing as Reflective conversation with the Materials of a Design Situation* (Schön, 1992) resonates with much of the work in this thesis. Buxton (2007), Löwgren (2007a, 2007b), Fällman (2003) and Fallman & Moussette (2011) have all argued that sketching extends to the realm of interaction design and designing with technology and is thus not confined to visual representation.

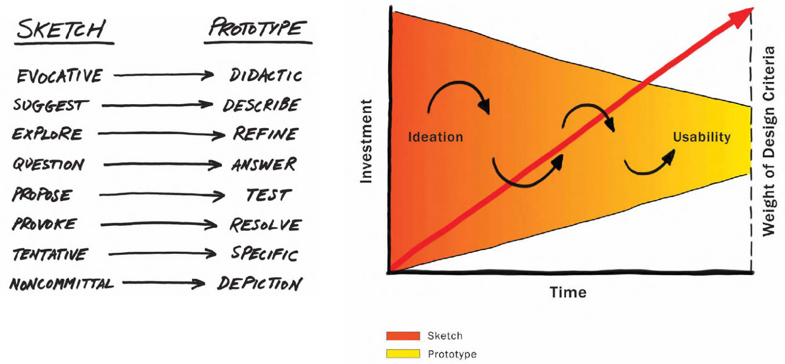



Figure 20: The continuum from sketches to prototypes, reprinted from Buxton (2007) with permission of Elsevier.

## TRANSACTION COST

One crucial characteristic of sketches lies in their 'affordability'. An increased cost of realization, in effort or resources, impede on their own existence and impact. Coase's notion of transaction cost is central to sketching (see Buxton, 2012a). Truly explorative and reconstructive moves are only possible if they are cheap or affordable. The notion of cost here extends beyond its financial definition. It encapsulates the different barriers towards realization: availability of the materials or other resources, skills needed, time constraints, motivation, etc. Sketching requires the right mix of conditions, both in practical terms but also at the human level.

Sketching invariably implies a multiplicity of sketches, in order to truly cultivate the emergence of fresh ideas and unexpected representations. One sketch yields a very limited perspective. The multiplicity criterion is also difficult to achieve if the cost or commitment is high for each exploration.

## SELF-REALIZED DISPLAYS

Sketching involves self-realized fuzzy representations. Designers and other creative professionals are known to gather and surround themselves with inspirational imagery, samples and references materials. Goldschmidt argues that sketches have an added benefit over these ready-made visual elements. Consulting *self-realized displays* like sketches are cognitively more economical than seeking useful information in other *displays* (Goldschmidt, 2003). Designers have some form of control on the representation, and can therefore better steer its usefulness. Both Goldschmidt and Schön recognize that sketching is particularly good at allowing reconstructive moves in design, better than just simple combinatory constructs.

Sketching is also a great modulator of problem space. Sketching can expand the problem space as it allows for the emergence of new unintended representations and interpretations. It nourishes new considerations and new assertions that can be acted upon immediately, or in the next generation of representations. On the other hand, sketching can also reduce a design space with its capacity to acquire new meaning as the sketches talk back. Designers gather new evidences and perspectives to refine their rationale of a particular version or solution track. These new insights help converge towards a more comprehensive design story.

In relation to the previous section about prototyping, the activity of sketching can be seen as a particular instance of prototyping, where the artist or designer uses a particular medium (drawing material, pen and paper) in a particular way to advance its understanding, comprehension and mastery. Therefore, we could tentatively develop a long reinterpretation of sketching as activities of *rapid prototyping using incomplete and partial hand drawn representations on paper to generate new ideas and alternatives*. This characterization of sketching as a form of prototyping may seems a bit curious at first, but I believe it has some value.

## 1.3.6 CONCLUSION

The design disciplines have long embrace the value of prototyping and sketching, regardless of the labels or denominations used. From my perspective, the line separating sketches and prototypes is very blurry. The main, and possibly the only, distinction can be found in the *radiation pattern* each encompasses.

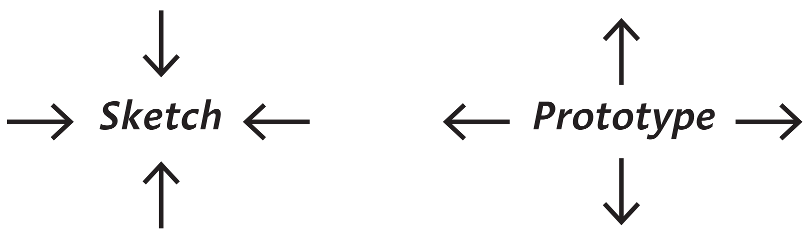



Figure 21: Sketches contribute back to its creator, prototypes radiate outward to the others and the world.

Here *radiation pattern* denotes attributes along the lines of focus, impact or force vector. Let me explain: a sketch is an approach or excuse to primarily inform its creator; the work conducted is egocentric, reflective, self-driven, self-regulated, and ultimately most useful to its creator. The impact and work vectors are directed at the author and initiator of the sketch. In the case of a prototype, the work is realized by the author or creator, but its impact is outside his immediate sphere. The prototype is used to communicate something, reach or affect others (colleagues, clients, participants, the general public) in a particular way.  The prototype is an instance that is meant to travel and impact the world somehow. That impact can be shaped, carved and prepared, but once it leaves the creator's nest or bubble, viewers might adopt and perceive it in very different ways.

As we close this chapter on design representations, prototypes and sketches, part 1 also comes to an end. This first part of this thesis consisted of an overall positioning and contextualization for this work. It established the necessary foundations of design research, design representations and haptics, paving the way so we can now properly use these tools to venture into real, practical and sensible activities of designing haptics.

# PART 2
# ACTIVITIES

# PART 2 / ACTIVITIES

In the first part of this book, the key pieces that make up the haptic design landscape have been introduced and discussed. By scrutinizing their origins and potential, and framing their role in this book's inquiries, this new landscape is inevitably starting to reveal itself, becoming more approachable and comprehensible. While not everything is clear yet, the conditions are suitable enough to take my work to the next phase, that of *designing* haptics.

The second part of this thesis, titled *Activities*, presents the bulk of the haptic design activities that constitute the core part of this work. Design work, in this circumstance, means a number of practical, creative, construction-oriented, and making-related design research activities in the area of haptic interaction design, i.e. activities which previously have been discussed as *research through design for design*. The coming chapters will thus present a number of selected first-person experiences of the author of this work, engulfing designing haptics, under partly different conditions and within different environments, as a design researcher. These direct first-person experiences; the documentation in the form of notes and chronicles that remain; and the feedback that has been gathered from other participants throughout these processes all constitute essential elements of this research work. This is because, first, they come together to expose the practical work that has to be accomplished in designing and developing haptic interfaces. As with any design project, this design work must be analyzed, dissected, and valued in relation to its original design mandate.

Second, the documentation that remains from these activities is more than project descriptions; they are stories and narratives of a journey into haptic design, enriched with comments and impressions of the author's experiences using a direct first-person perspective. In many instances, I explicitly comment and reflect on my own work, sharing my impression of what I did, why this was done, and try to detail how a particular haptic stimulus felt. It is one way of inviting the reader into some kind of disembodied haptic experience. Short of having the reader holding a haptic device and trying it out, it is the best that can be achieved within the limits of academic text and the book format. The activities presented are hopefully rich and nuanced enough so that one can get a feeling of the particular design situation and the experiences that took place during these activities.

This second part of the book is divided into four chapters, each one dissecting a significant practical, real-world activity of my research. Chapter 2.1 presents an early workshop activity, the so-called eNTERFACE workshop, which was the author's first real encounter with haptic research and as such became a prototype study for the whole work. This experience proved crucial in my understanding of haptics and left a strong desire to approach and explore haptic design differently. Chapter 2.2 gives an account of the first of two internships at Microsoft Research, where I was able to act on my new design-led ideal of haptic design and put it to the test via a series of hardware sketches. It is through this work that my research started to materialize and where it gradually became more articulated and coherent. Chapter 2.3 introduces the second Microsoft Research internship, where the role and potential of haptics was specifically scrutinized in relation to an existing interaction platform, the Microsoft Kinect system. Chapter 2.4 summarizes the activities, the lessons learnt, and the insights gained from a series of five workshops that were conducted over a two-year-period with different groups of students, professional designers, and professionals from other domains. These workshops were carried out in an empirical vein, i.e. to intentionally share the author's haptic design work with others and to actively seek out feedback, reaction, and further inspiration, that in turn could feed back into my design work. Such a collective testing ground has allowed me to significantly refine my ideas of what haptic interaction design is and can be.

Hence, the design research journey described in this part builds on a diverse set of experiences and concrete realizations. It has been full of tentative, exploratory, and idea-testing design activities, allowing me to acquire new knowledge, new skills, and constantly readjust my course of action. Little by little, the process has come to correct my assumptions, develop new ones, and I have invariably come to gain a clearer understanding of the haptic interaction design territory and how to best navigate it.

- 5 YEARS
- 65 CONFERENCES / EVENTS
- 197 DAYS OF TEACHING
- 9 PAPERS / ARTICLES
- 2 INTERNSHIPS + 2 DC + 4 SV
- 72 BOOKS + 275 GB

# CHAPTER 2.1 THE PROTOTYPE STUDY

## 2.1.1 AN ADVENTURE IN MULTIMODAL INTERFACES

My first serious introduction to haptic research took place in the summer of 2008 when I participated in the eNTERFACE summer workshop on multimodal interfaces (D'Alessandro, 2008). This is an annual four-week-long research gathering that allows doctoral students and senior researchers to meet, work, and advance multimodal research. During the workshop, I joined two established researchers from psychophysics and one other Ph.D. student in audio synthesis. Our team decided to work on a non-visual multimodal project. The structure of the workshop meant that we had only four weeks to plan our research, develop the multimodal interface, run a study with participants, and write a preliminary research report. Details of our work, the multimodal interface we worked with, the study, the results, and subsequent analysis were presented in a separate publication (Murphy, Moussette, Verron, & Guastavino, 2012).

This initial encounter with haptic and multimodal research was both revealing and disconcerting. While exposure to new research methodologies, procedures, tools and best practices were gained; I also realized that my initial understanding of haptics was rather naive and tainted. Looking back, this experience played a pivotal role in my research work and my discovery of the haptic interaction design space.

Below, a number of reflections of this workshop are presented, each focusing on an important aspect or quality of haptics and haptic interaction design that have turned out to be important or otherwise guiding in my work. In providing these descriptions and reflections, the focus is not necessarily so much on the actual study that was completed and its findings, but more on the author's role in the process, on the development of the haptic interface itself, and on some of the activities that took place behind the scene. The reflection will expose a certain number of challenges and issues that emerged from this first real encounter with haptics and multimodal research. Some of the issues below may be considered novice *faux pas* on the part of the author, yet is believed that the reflection also reveals some more complex challenges that are inherent to the design of multimodal interfaces. In subsequent chapters, we will partially return and refer to these friction points or initial misconceptions that have guided my research activities.

### 2.1.2 FRAMING AN UNCOMMON INTERFACE

The realm of multimodal interaction research is vast and multifaceted. Framing a worthy research question and consequently finding my role and my relevance to the project seemed daunting at first. Out of the fifty or so participants in the workshop, I was the only one with a design background. Initially, I felt insecure about my ability to contribute to the workshop's agenda, as I was joining this research summer school with limited knowledge of the field and its current research frontiers. Despite my initial anxiety of my ability to contribute, I was nevertheless quite enthusiastic to having the chance of discovering a new community and plunging into this new territory.

The workshop participants were divided into groups. My group consisted of myself, Emma Murphy, Charles Verron, and Catherine Guastavino.

During the first few days, we faced the difficult task of framing a relevant and interesting research question or hypothesis from which to work. As a pragmatic solution, the group decided to examine our collective expertise and see how we could best leverage our own abilities to come up with a research question that would be fitting and realistic. My three collaborators were mostly knowledgeable in the auditory domain, while I contributed skills and knowledge in interaction design. All four of the group's members had at least passing familiarity with haptics and haptic interfaces, but none of us were expert in the field. After some discussion, we came to the conclusion that developing a research project involving a multimodal interface that had no visual component at all was uncommon and consequently of interest. This is because typically, most haptic interfaces also have a visual component, e.g. where vision and touch work in parallel to create a rich set of stimuli, for instance used in surgical tele-operations, augmented virtual environments, and so on. We speculated that it would be interesting to work on a purer haptic interface, leveraging only touch and audition, totally deprived of visual cues or representations. Our initial hypothesis was that haptic feedback, along with auditory cues, might be valuable for conveying navigational and structural cues when the visual modality might not be available or suitable.

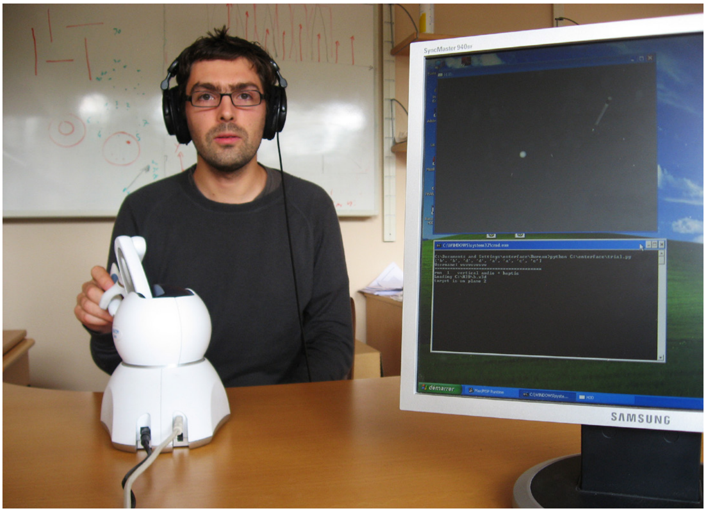



Figure 22: Multimodal interface with audio-haptic feedback, the visual environment was only used for developing and controlling the experiment.

## 2.1.3 INTERFACE DESIGN VERSUS EXPERIMENT DESIGN

Once our research question was sufficiently precise and formulated, we started designing the audio-haptic interface. What we had at our disposal was one haptic controller, a Phantom Omni device (see figure 22), and a selection of standard desktop computers. Initially, we struggled for quite some time to get the haptic controller working with various software packages and in the end only one haptic rendering library proved to work reliably with the device. Our selection of tools and approaches were thus directly constrained by our technical abilities with certain pieces of software or hardware. While this might perhaps not be described as an ideal situation to start out from, it was however the only way we could obtain a working haptic interface considering our tight schedule and the lack of external support.

As a result of what we had available, the final development platform for the project consisted of the Phantom Omni controller device coupled with various software components. This specific haptic controller uses a stylus-type grip, offers six degrees of freedom, and provides a workspace area of 160 W x 120 H x 70 D (mm). The haptic scene and effects that we made available through the device were designed and controlled using H3D, which is an open source haptic graphic engine ("H3D - Open Source Haptics," n.d.). The auditory component of the interface was developed in Max/MSP using the Spatialisateur plugin (IRCAM) for binaural sound rendering over headphones.

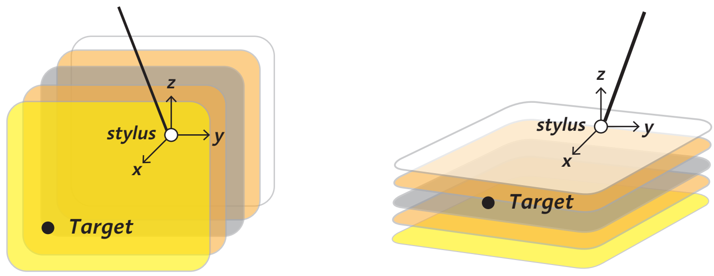



Figure 23: Structure of 3D planes in both vertical and horizontal orientations with target located randomly on one of the planes.

Up to this point, which was now more than a week into the four-week-long workshop, our interface concepts and realization ideas only existed in our heads. However, with some of the hardware and software issues resolved, we were finally able to test our interface ideas with actual haptic feedback.

The main concept we developed was a haptic interface that consisted of virtual planes that were linked to spatialized audio and haptic cues, which aided navigation and target-finding tasks. The target finding task involved finding a virtual target located at a random location on one of the planes as shown in figure 23. In order to find the target the user had to navigate through the planes and identify which one contained the target. A virtual bowed sound was played when the target and the stylus of the haptic device were located on the same plane (horizontal or vertical, according to the configuration). By identifying the position of the virtual sound source, the listener could navigate on the plane and locate the target.

After numerous trial sessions of self-evaluation and haptic explorations, we opted for five equally spaced parallel planes, oriented either horizontally or vertically. The five virtual planes were arranged into a stack-like configuration that matched reasonably well with the physical constraints and working volume of the haptic device (Figure 23). Overall, we spent about four days refining the audio and haptic feedback of the interface, fiddling with and fine-tuning the many variables and configuration options. Due to time constraints, we did not explore many major variations and alternatives to the stacked-planes interface idea. We tested the audio and haptic feedback ourselves frequently during the process and most of the features and characteristics of the interface were rather quickly agreed upon in the group, based on our own informal tests and on discussions between two or three of us. Typically, to avoid visual feedback when programming, we would close our eyes or try to look away from the monitor when trying out the interface.

To speed up the development process, most of the work on the audio feedback side of the interface was developed on a separate computer, which no haptic controller present. We did test the integration of the audio and haptic qualities rather frequently however, to ensure that the fusion worked correctly and that the interface felt responsive and had minimal latency.

In addition to designing and implementing the details of the interface, we put a large amount of work into developing the tools and procedures to run an experiment with external participants. Designing the actual experiment turned out to command a quite different set of considerations than those required in developing the interface. For conducting an experiment using the interface, the configuration settings needed to be able to be changed on the fly and randomized adequately and the participants' actions must be captured and saved for analysis later. Additionally, some kind of control mechanisms for running the experiment must be made available to the experimenter to, for instance start and stop the study as needed, and the experimenter must also have some means of knowing whether or not the experiment session is running properly and the system is recording data. While these requirements hardly push the frontiers of computer science, they nevertheless represented some of the biggest challenges we faced during this workshop. The knowledge and skills involved in capturing interaction events and in tracking concurrent processes in a modern operating system proved to be rather far from my expertise in interaction design. Yet, in spite of inexperience in the area and not in line with the best practices of data acquisition, we managed to patch together various scripts to be able to monitor the haptic controller and collect all the needed data for the study.

To sum up, most of our time and effort during this study was spent figuring out how to build a system capable of capturing experimental data and on managing the specific routines we were to apply in the study. Only a small amount of time was directed towards the actual design of the interface and on thinking about and trying out its haptic qualities. Ultimately, partly because of the haste in getting things to work, we came to rely on rather basic geometric shapes and standard haptic effects that came bundled with the H3D software package, i.e. not really gauging alternatives and moving beyond default configurations. The integration of the audio layer required slightly more thinking, planning, and coding from my colleagues, but still required nowhere near the amount of work we collectively dedicated to the planning, conducting, and recording of the experimental study. Hence, my initial expectations of what it meant to design a new multimodal interface was only minimally met and clearly became a background concern when designing and realizing the experimental study.

## 2.1.4 PROGRAMMING A NORMALIZED AND DISCONNECTED HAPTIC WORLD

Prior to the workshop, my experience of using haptic controllers like the Phantom Omni was rather limited. I had some understanding of using haptic controllers for CAD and other design activities in the past, but I had for instance never actually programmed haptic feedback. Thus, before the workshop started I was slightly nervous with regard to my skills and capabilities, anticipating that all other attendees would be knowledgeable or have expert skills in all aspects of haptics and its many underlying technical aspects. At the actual workshop, it however turned out that the collaborators in my group were novices too in the area. After a short group meeting, we decided that I would take the lead for the haptic programming, since I expressed a strong interest in the topic. This felt daunting at first, but eventually turned out to be a fairly easy task to accomplish. Once the initial hassles of installation and debugging cleared, I was able to fairly quickly, within only a matter of hours, build a virtual 3D environment with haptic features using ready-made APIs and programming libraries.

Although we were able to quickly setup virtual scenes with various haptic effects, we had some difficulties understanding how various forces and position data related to real world values.

For instance, within H3D, our haptic engine, most of the variables required normalized values. Static and dynamic friction values range from 0 to 1, position values from -1 to +1, and so on. As an example, the H3D documentation provides the following description for the stiffness property of a haptic surface: "The stiffness of the surface. Should be a value between 0 and 1 where 1 is the maximum stiffness the haptics device can handle." ("H3D API documentation," n.d.) However, the general specifications from Sensable Inc. for the Phantom Omni unit only provides the lower limit of its stiffness capability ("Phantom Omni," n.d.):

**Stiffness**

X axis > 7.3 lbs / in (1.26 N / mm)
Y axis > 13.4 lbs / in (2.31 N / mm)
Z axis > 5.9 lbs / in (1.02 N / mm)

The result is that the maximum stiffness (value of 1) can be rendered very differently across devices and even depending on the particular direction of the movement. This directional disparity is not compensated by H3D at the software level and it becomes rather mesmerizing to consider that for instance a cube object assigned a uniform surface stiffness will be rendered two times stiffer in one particular axis.

While the approach of using normalized values might be beneficial or natural from a programming perspective and for multi-device compatibility, it turned out to be fairly problematic for us, especially during analysis of participant data. Throughout the development and completion of the study, we recorded position data that we knew were normalized. This data was generally coherent and consistent with the user's movement. At one point in our analysis, it became necessary to transform our normalized values to real-world distances in order for us to be able to discuss spatialization of the audio cues. It is only at this point we started to realize that all of our readings were based on a default calibration matrix in H3D, applicable to all Phantom Omni units. Additionally, the haptic library we used relies exclusively on the values provided by the controller, which had only been calibrated at the factory. The calibration issues made us wary about our capacity to actually be able to relate and discuss real world measurements and references based on our normalized data. In this, the documentation for the software library provided little help and kept referring to the controller's specifications for technical capabilities. It became surprisingly difficult to clarify and with some kind of confidence establish the link between the normalized data used in the software and the absolute physical position of the controller in use.

Eventually, we found that we were in fact unable to clearly and transparently establish a direct relation between our recorded participant data and real world units or measurements, as we had opted not to run a full calibration routine of our Phantom Omni unit before the tests began and relied fully on the self-initialization test routine of the manufacturer.

With hindsight, we should of course have known better and for instance verified the accuracy of the readings against the real-world measurements of the controller's stylus position. Although this did not prevent us from finalizing our study and recognizing some meaningful interaction patterns, it did hinder our capacity to refine the data analysis.

In conclusion, the haptic library software required us to work with normalized values for specifying haptic features and managing the haptic controller. This approach provided an initial ease of use, got us quickly on the road, and greatly simplified the haptics rendering processes, but in doing so it also blinded us to the complex link between the virtual world and the physical world; both of which we were dealing with. We took for granted that for instance, a value of 10 registered in the software was the result of a 10 mm displacement in the real world, and we did not bother checking the reliability and accuracy of our recorded data in absolute terms. As a consequence, we have had to live with the limitation that our experimental data from this study is only usable in relative terms.

## 2.1.5 HARDWARE HARD IS RELATIVE

While conducting this study, a specific quality or characteristic of haptics became increasingly apparent, the stiffness of the haptic controller. As I was programming the haptic rendering effects, I noticed that the stiffness, i.e. the material hardness setting in the haptic library, did not feel truly hard at all when experienced via the haptic controller. Quite the contrary, there was a large discrepancy in terms of hardness between the virtual representation and the felt sensation. This became even more obvious when we tweaked the haptic settings in trying to obtain a solid-like contact. Event at the highest stiffness setting, a virtual surface or object felt only resistive or springy at best, not stiff or hard. We started to associate this sensation to *mushy hard*, i.e. offering some kind of distinguishable resistance to movement but in practice unable to effectively stop or block user movements. These 'use sensations', which are expected to be stiff and hard but in practice turn out not to be, stand in stark contrast to the hard contacts and collisions that are actually frequently experienced by anyone using the controller, i.e. when one is docking the stylus or when one reaches the physical limits of the workspace. The docking procedure in particular leads to very solid and firm *clunk*, which locks the stylus and prevents any movement. Those sensations work as reminders of what hardness in terms of haptic feedback really is: unequivocal physical constraints that overcome a human desire to act.

Some of the problems associated with haptic controllers' *imperfect stiffness* have been documented (Burdea, 1996; Kern, 2009; Salisbury, Brock, Massie, Swarup, & Zilles, 1995), and in the case of the Phantom Omni these can be directly linked to its hardware, more precisely to its open-loop impedance model where actuators generate forces based on the wanted or unwanted position of the end-proxy. With such hardware, the device can only generate a limited amount of push-back or repulsion against the user's hand. It is also worth noticing that the Phantom Omni device we used is generally considered a low-cost unit (even at €3000), where one of its limitations is its capabilities with regard to exertable force (~3 N). In contrast, more expensive, high-end devices are capable of producing considerable more force; a full order of magnitude higher. The Phantom Premium 1.5 High Force device, for instance, is able to generate a force of 38 N.

Being a designer venturing into haptics, my expectations of haptic qualities were based firmly in real-world experiences, where hard feels and is hard. Whether you knock on wood, click a computer mouse button, or walk head first into a glass door, there is a sudden, physical full stop. Our workshop's haptic controller could not match this and delivered a sensation of hardness that was significantly different. While a more capable and costly unit could have fared better with my real-world expectations, the discrepancy between *physical hard*, as found in the physical world, and *simulated hard*, as offered by a large family of haptic devices, appeared troublesome to me as it drastically dissolves the notion of hardness and our common understanding of *solidity, rigidity,* and *stiffness.*

In the haptics domain, no actuation technology can reproduce the full gamut of material qualities and real interaction forces (Burdea, 1996; Kern, 2009). Regardless of technological implementation, different haptic controllers have different kinds of capabilities to generate haptic sensations. Specific configurations might excel for a particular condition or for generating a specific sensation, but such apparatuses invariably also include limitations or trade offs. Hence, we are far from a general-purpose haptic actuator that is able to match the full range of haptic stimuli we experience on an everyday basis in the real world. As all-encompassing naturalistic recreations of haptic sensations are currently not possible, and might never be, we as designers and researchers in the field of haptics have to deal with artificially generated haptic stimuli that are not equivalent to real-world experiences but are instead pared-down approximations that to some extent only provide hints to their origin in the real world. This poses some interesting questions for our haptic interaction design activities: can we expect to build good haptic interfaces despite this limitation? Consequently, what would be the most useful metrics and aesthetics of such a pared world of haptics? How can we work in this design space with the competing perceptual and experiential frames of reference?

Arguably, the problems associated with *mushy hard* do not primarily lie in the technical challenges involved in producing real-like sensations. The important issue rather pertains to context, i.e. to the particular situation where those stimuli take place and how the process unfolds. This is to say, the fact that a haptic controller cannot accurately reproduce a full stop sensation is not in itself problematical. Problems emerge, however, when one expects a particular sensation but the device does not provide a satisfactory response or stimulus, or when the system provides diverging or inconsistent cues for the particular situation. In the description above, the haptic controller provided two versions of hard: the virtual mushy hard contacts issued from the haptic scene and different physical hard contact coming from the mechanical structure of the unit. Problems arise from one's expectation that the two types of experiences are to be similar, but they are not.

On the other hand, knowing the operational details and technological potential of the specific haptics device used is a double-edge sword. First, it brings a sense of forgiveness to mismatched sensations; recognizing the man-made imperfect contraption and its inherent pitfalls. During the workshop, we frequently voiced comments like "—It's not so bad for what it tries to do" or "—I get it even though it's not perfect". Yet second, it also lays bare and to some extent amplifies the device's weaknesses, inviting one to only see the drawbacks and issues with the device.

## 2.1.6 SCIENTIFIC RESEARCH FOR DESIGNERS

The workshop was an excellent opportunity to rediscover the experimental processes driving scientific enquiries. It was in part a revisit for me, going back to my earlier degree in physics. The scientific method, with its primacy on objectivity, measurability, reliability, and validity, differs in a number of important ways from a traditional design process. As the workshop catered to scientific researchers mostly, it was unsurprising that the established tools and methods of inquiry were primarily of scientific nature. For me, adopting such a non-design perspective was slightly destabilizing, but it turned out to be intellectually stimulating and formative. It provided a practical opportunity to contrast and reflect on the design process in relation to the scientific process.

One of the most rewarding experiences in this respect consisted of having to transform or translate haptic design ideas into scientifically valid research questions. Here, a good design idea is not always a good research question, and vice versa. Defining clear research hypotheses and devising their associated experimental procedures is puzzling, as there are countless details that have to be considered to make the study as unbiased and conclusive as possible. Abiding by this perspective leads to different considerations and priorities, where knowledge generation surpasses any real-life purpose or practical application.

Committing to the realization of a scientific-style experimental study also proved much more demanding than initially expected. Following through with the initial research program forces one to take action and tackle numerous practical problems. The requirements for a successful experimental study are fairly stringent, both in the planning (finding participants, equipment and facility) and in its execution (recording satisfactory data). This pushed me to realize and get deeply involved in activities that I might never have accomplished in my otherwise more design-oriented interaction design research activities. For instance, it meant that I had to program a haptic controller, which led me to discover various limitations of the technology. In addition, working together with more experienced scientific collaborators, I also had the opportunity to refine and expand my knowledge and skills in experiment design and statistical analysis.

More importantly, the immersion into a scientific way of thinking and approaching the world that this workshop provided, gave me an opportunity to think, reflect, and act in paths not commonly taken in my previous design activities. The scientific method, here applied to the design of a haptic system, commands a particular intellectual rigor that is commendable, but it also cultivates an obsessive attention to procedures, details, observation, and reporting.

### 2.1.7 DESIGN FOR RESEARCH?

Previously in this chapter, my experiences of tackling scientific work from the perspective of a designer have been highlighted and discussed. While this did not make me a full-fledged psychophysics scientist, I did pick up a few basic things about experimental research and perhaps more importantly, it made me think more explicitly about and reflect on the relation between a scientific stance and a design stance on haptics, and realize that the knowledge and skills I brought to the table were also useful and valid.

Even though this research gathering was never touted as a design workshop, it became clear that many scientific researchers could actually benefit from learning a few things about design, or at least involve designers in the process. As an example, many of the multimodal interfaces that were put forward by more than 30 participants in the workshop were quite awkward and uncomfortable to use. It was noticeable how little these scientists knew about design, design processes, and how far they were from questions of ergonomics or even a classical user perspective. In general, the human side of things was rather quickly forgotten in the practice of their research inquiry.

These observations led me to think that design could come to benefit scientific inquiries, not necessarily in the fundamental questions being examined, but with the tools, approaches, and processes to evolve experimental activities and in testing these procedures with people. Science might aim to minimize human subjectivity in its research activities, but we gain little from having experiments that are unnecessarily unpleasant, devices that are awkward or painful to use, or situations that are generally unclear, confusing, or embarrassing to people.

Scientists tend to work hard to devise and design experiments that match their research inquiries. The design of experiments, or *experiment design*, consists of devising information-gathering exercises for a particular object of study. This kind of 'design' is mostly addressing procedures, equipment, and notions of variance (Fisher, 1936). When human subjects are involved, experimental design generally tackles legal and ethical considerations. Apart from some higher-level ethical concerns, i.e. that no subject should be harmed during the experiment, more subtle factors such as usability, ergonomics, comfort, and clarity is usually left at the discretion of the experimenter, and as a result, often neglected. In my view, these considerations should play a crucial role in the experiment, as they can affect the results of the study and thus need to be dealt with carefully.

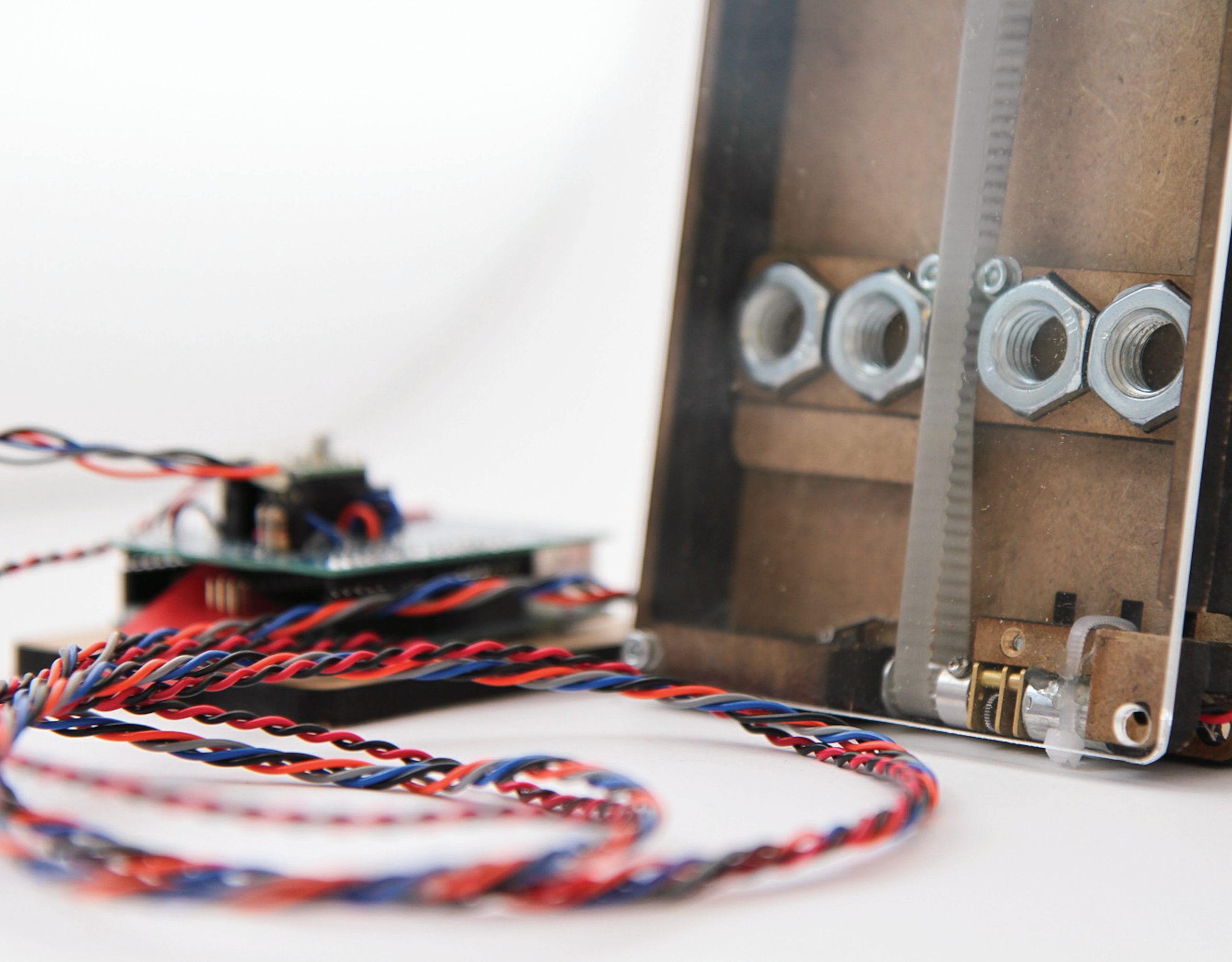
As an illustration of this, we conducted our experiment study during the summer, in France, in a soundproof booth with only a hint of air conditioning. The individual test sessions were over 30 minutes long and it turned out to be quite unpleasant to sit around for such a long time in a hot, enclosed space. All such environmental conditions are of course difficult to account for, but they do affect even in the slightest bit the well-being of the participants, and consequently also influences their performances. There is thus a large design space between what is scientifically advisable – i.e. fulfilling the research objectives – and what is ethical or unethical – i.e. preventing human harm – when devising a new experiment. A countless number of design decisions have to be made and implemented in carrying out such a study: how participants and experimenters engage with the experiment, how elements and things are controlled, used, recorded or manipulated over time, and so on. These issues relate in part to core interaction design problems. Designers are trained to seek out and explore alternative solutions within a given design space with certain restrictions, in order to maximize for instance functional outcome and human satisfaction. In general, researchers are not accustomed to look for these variations within the space of experimentation, and this is where many design disciplines — be it graphical design, industrial design, or interaction design — can help seize the opportunity for improving human-experiment interactions.

## 2.1.8 CONCLUSION

As described above, my participation in the eNTERFACE'08 summer workshop on multimodal interfaces was an intense excursion into scientific research, where I collaborated with three other researchers in a group effort to bring to life a novel non-visual, audio-haptic interface. Our group collectively ideated and designed a novel haptics system and completed an experimental study with more than 20 participants, the results and findings of which have been published elsewhere (Murphy et al., 2012).

In this thesis, my experiences from this workshop are treated in a way that go beyond the findings of the particular study we conducted. The workshop was my first real encounter with haptics research and it introduced me to haptics design and programming, experimental research procedures, multidisciplinary tensions, and many other scientific concerns in a way that bears some resemblance to attempting to learn to swim by jumping into a lake. While I did come to learn a lot from the other group members during the workshop, it also made me ponder about the new design space with which we were working. Many aspects or details of the haptics space and how it was being approached by science at work appeared somewhat unsettling: virtual hard was not hard enough; the normalized world of the software gave us headaches for our analysis; and the experimental design work did not involve 'design' as I had known it from before. While the research work we completed was very constructive and valuable, I became increasingly hesitant about embracing these types of haptic activities in my doctoral work. What I saw and experienced at the workshop did not match my vision of haptic interaction design.

In retrospective, the experience of participating in this workshop was essential in shaping my future research activities, i.e. those that are reported on in this book. It provided me with sufficient insights, references, and friction points to envision a different take on the design of haptic interfaces—one that would be more designerly in nature; one that would more fully try to embrace haptics as a new design space; one that would be closer to the materials of haptic interaction design; and one that would focus less on specific technological requirements and meticulous experimental study details and more on activities of sketching and making. In short, one that would be closer to an interaction design perspective and its human-oriented and experience-centered attitude. For me, realizing this was the main take-away from the eNTERFACE'08 summer workshop.



# CHAPTER 2.2 SKETCHING HAPTIC INTERACTIONS

## 2.2.1 INTRODUCTION

The second and third year of my doctoral studies proved pivotal to my research. It marked the start of my collaboration with Microsoft Research, an experience that would invariably sharpen my understanding of different kinds of research practices and activities, inside and outside academia. During this period, my research vision, desires, beliefs, and motives matured and became clearer, intelligible, and as such more discussable with others. With a more coherent understanding of the area of research and of my own abilities and positions within it, it became easier to start to take action towards realizing my own vision of haptic interaction design.

This chapter describes and discusses the activities realized during the first of two visiting researcher internships at Microsoft Research. It exposes the design research work I accomplished there, but also brings forward details of my journey from a meta-perspective. Providing some background information, describing and discussing the context of work, and revealing a few personal struggles are important to discuss here, as they have had considerable impact on the work, the direction it took, and on some specific design research decisions made during this period. The chapter starts with a brief presentation, partly a recapitulation, of my desire to do haptic design differently. The actual work carried out during this internship is described, exposing the program and processes to which I committed. Five tangible demonstrations of different kinds of haptic experiences, which constitute the main outcome of this internship period, are then described in some detail before delving into a more meta-reflective discussion of the experiences of this internship.

## 2.2.2 A DESIRE TO DO HAPTICS DESIGN DIFFERENTLY

The previous chapter detailing my experiences of the eNTERFACE'08 workshop ended with hints of frustration and dissatisfaction regarding the state and conduct of current haptics research. Framed like this it sounds like a rather negative stance, yet in reality I was definitely more optimistic and opportunistic than unenthusiastic at this point. The more acquainted I became with the haptics research field, the more I realized that design thinking in general and interaction design activities in particular were generally absent in most haptics projects. The priorities were elsewhere, apparently—in psychophysics and neuroscience inquiries, in robotics, and in system control advances. While I thought that the lack of design thinking, processes, and skills in haptics was a major problem for the field, it also represented a major opportunity for me and my research to make a contribution and to have real impact. I speculated that to reach mainstream dissemination, acceptance, and relevance to a non-scientific audience, haptics might require design activities and designers' attention—and this might be exactly where my research work ought to have a role to play.

In relation to this, after having attended numerous haptic conferences, workshops, and seminars, it seemed as if haptics research was deeply involved with exploring the extremes, i.e. the limits or frontiers of what is currently known about this modality and the limits of what is technically possible to achieve. More restrained approaches, where haptics might be less extravagant but more ubiquitously present and somehow real, seemed to receive very little consideration. At this time, I started to ponder about questions like: are these problems already solved or are they perhaps not interesting or too mundane? The more I thought about these issues and discussed them with others, the more I started to lean towards answering those questions with a "no": putting haptics in *use* still seemed like a baffling undertaking.

Despite becoming increasingly knowledgeable about haptics, it was however still unclear to me how I, as a designer, could add to this now more familiar yet still untamed modality. It also seemed that the design disciplines were rather ill equipped to work with haptics. This is because designers, in general, are typically not that familiar with the very personal and non-visual haptic sense. In addition, designers do generally have neither the science training that might be required to understand the latest findings and questions being pursued, in for instance neuroscience and biology, nor do they typically have the engineering and programming skills that might be required to operate and further develop existing equipment.

However, as pursued in this work, the term *haptics design* takes a very different meaning. Its immediate challenges, such as programming a force feedback arm, were in fact hiding a much larger issue: how do we work with, discuss, dissect, communicate, and document haptic experiences?

I started to think that while designing haptic stimuli actually requires only a limited amount of familiarity with the world of haptics, some passing skills in programming, and a little electronics, this knowledge was actually missing in design. Thinking more broadly about this issue, I then realized that this unfamiliarity with the world of haptics is not limited to designers but in fact applies to more or less everyone: it seems that we collectively have a very limited capacity to talk about and communicate haptic sensations clearly. While we very clearly recognize different haptic sensations, for instance how particular materials feel when we sweep over them with our hands, we cannot elaborate on the details of this experience in our language. For everyday living and going about our business this is of course not a major problem, but for specifically seeking to design haptic experiences, this lack of vocabulary and shared terminology was itching at me.

After having realized this, I became interested in returning to the basics of haptics: how we haptically experience the everyday world, the richness of touch that we find in materials and in our interactions with others. While simulated and technologically recreated haptics is very complex to get right, *real* or *simple* haptics is on the contrary omnipresent and fills our everyday life. The hypothesis I began formulating at this point in time was that maybe a designerly approach to haptics could be to start to deal with this kind of everyday haptics before even considering venturing into more technologically complicated endeavors in the haptics domain. There would also be a lineage to the design tradition in such an approach, i.e. to develop deep and close understandings and appreciation for the qualities and potential of various kinds of design materials.

According to this view, to create appropriate and human-oriented haptic experiences, designers need to have knowledge about but also the practical skills of mastering haptic qualities and capabilities. My evolving vision of doing haptic design from a design stance thus started to get more and more elaborated. It should be less about simulation and recreation of stimuli and more about arranging and producing collages of haptic qualities already present and readily available in the world. In my developing view, *haptic interaction design* should strive to provide relevant, appropriate, and satisfying haptic stimuli that leverage materials, hardware, and software that are accessible and easy to craft and modify, leave room for design variations, and that aim to focus on purposefulness over technical prowess.

With this vision in mind, I argued that such a positioning of haptic interaction design would indeed depart from mainstream haptics research, but still remain complementary to it and enrich the overall haptic development agenda with a new design-driven approach.

## 2.2.3 MICROSOFT RESEARCH CAMBRIDGE

During my third year of doctoral studies, I had the opportunity to spend time as a visiting researcher intern at Microsoft Research in the Cambridge, United Kingdom. With my vision for haptic interaction design in mind, this opportunity was very exciting for two main reasons. First, I would join a large world-class research organization with some of the brightest researchers out there, and second, I was offered the opportunity to define my research project very freely. The conditions were quintessentially to start investigating my new haptic interaction design vision.

Consequently, during the spring of 2010, I joined the Socio-Digital Systems (SDS) group under the supervision of Richard Banks, Principal Interaction Designer. The SDS group's vision is heavily centered on human considerations and on finding new and alternative approaches to technology, where designers, sociologists, and computer researchers work collaboratively to explore non-traditional computing uses while clinging on to the ideal of the primacy of human values over new technologies. It felt particular fitting to explore the realm of haptic interfaces within the SDS group from a designerly and to some extent even craft-like perspective. To find words and terminology to as appropriately as possible, describe my plans, I opted early on to adopt the term *sketching in hardware* as the main approach that my work would follow, to put emphasis on *making things*, on *experiencing things*, and on the dialogue between making and experiencing as the main sources of haptic design knowledge.

The main objectives of my study were to:

> **1)** develop a minimum of five different haptic interface concepts into experienceable demonstrators, and to
> **2)** evolve an understanding of *sketching in hardware* as a designerly approach to be working in the design of 'simple haptics experiences'

However, in order to structure and thus strengthen my approach, I intentionally and right from the beginning came up with and adopted a set of self-defined rules to which the process would subscribe. These self-inflicted guidelines were to 1) try to build, explore, and refine as much as possible; 2) to attempt to establish a distinguishable conversation with the design material, much like sketching; and 3) to thoroughly document all activities. In addition to these, a number of simple design constraints were also defined. These were that the hardware sketches I proposed:

- Should be handheld, ungrounded, have a fixed shell and size, and be made of one principal material: Medium Density Fiberboard (MDF board)

- Should be made up of simple components and parts (and thus contain no high-end or expensive parts)

- Should be self-experienceable, i.e. should not require an experimenter's intervention or even presence

- Should prioritize the haptic user experience over issues such as implementation feasibility and being directly linked to real-world problems or application

These constraints were in part guided by prior insights and best practices in interaction design, and partly came from guidance from my supervisor and from my new colleagues within Microsoft Research. However, this also provided a first point of friction between my designerly stance and the largely research-based conduct at Microsoft Research. While defining a number of constraints, based rather loosely on my design intuition and on previous experiences more than anything else—their main purpose being to reduce the realm of possibilities and to artificially reduce complex problems into something that is manageable and graspable— this was not common practice at Microsoft Research and caused some initial questions and a few raised eyebrows.

An early critique of this approach was that within the confines I had set up for myself, I would only be able to explore a fraction of the full potential of haptics interaction, a very narrow band on possible haptic design interfaces. I was willingly aware of this limitation however. In fact, my main interest at this point in time was not even in the final interfaces that I would come up with, but more on the design processes underlying the haptic design activities: what were the difficulties, friction points, and strategies I would come up with for dealing with haptics in the way I wanted to treat it? Can we sketch haptic sensations in a manner similar to the way we sketch using visual representations? What fidelity level is appropriate or required to sketch in haptics? How do we go about describing haptic qualities, documenting them, or sharing them with others? The more official project goals of making five demonstrators were hence a very utilitarian incentive—a good excuse—to face these questions head on.

## 2.2.4 A MAKING FRENZY

The visiting research internship at Microsoft Research was planned as one 13-week-long period and those weeks went by very quickly, or so it felt at the time. The first weeks were naturally a bit slow as I had to go through all the practical concerns that one has to go through when moving into a new work place, e.g. getting safety clearance for the workshop, get my workstation up and running and all the tools ready, and so on.

Once the most basic elements were in place, I started the process of being engaged with the design material through making. Playing by my self-imposed rules, I set out with the challenge to myself of building a minimum of *one thing a day*; i.e. one entirely new hardware sketch, one major improvement, or at least one significant change to an existing piece. While this might seem a fairly easy target at first, it actually turned out to be quite demanding, both physically and mentally, to systematically maintain this making rhythm. In addition to the actual making efforts, I also tried to write down my impressions, reflections, and states of mind at the end of each day, in the form of a design journal or diary. This was done with the intention that such a logbook would help me better remember and reflect on my activities as I went along and make it easier to later revisit my work.

Figure 24: All analog hardware sketches, no electronics.

On a typical day, I came to spend about three to four hours rather vigorously making stuff. At times, I spent full afternoons and evenings sitting next to the laser cutter measuring pieces and components, cutting test parts, filing rough cuts by hand, refining parts, and cutting again.

The first hardware sketches I made had no electronic control mechanisms at all (see figure 24). For these, I mostly used foam core, MDF panels, hot glue, and small motors to actuate certain parts or build simple mechanisms. Building working and more intricate mechanisms and structures with actuated elements turned out to be more demanding than I initially had expected. I discovered that it is rather difficult to take shortcuts in the physical domain. Through my initial making undertakings, I soon discovered some simple yet rather useful characteristics or rules of what to expect when designing for haptics: for instance, parts that are loosely connected cannot feel solid no matter how you go about it—solidity and durability cannot be faked.

During this early phase, I divided my time equally between finding and shopping for parts, trying to put bits and pieces together, figuring out electronics circuits, and producing code snippets to control them.

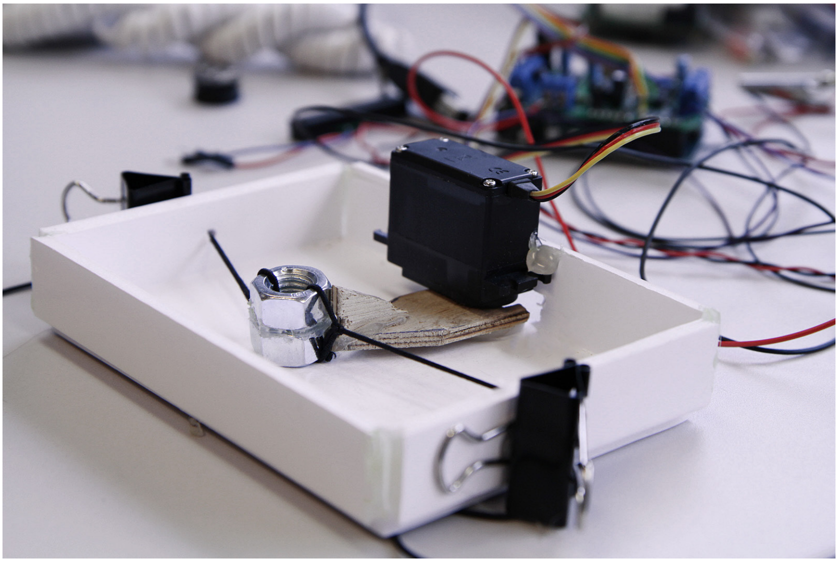


Figure 25: Hardware sketch mixing foam core, hot glue, servo motor, and bungee cord.

The initial plan, which was largely followed, was to start working on an entirely new concept every week. Consequently, by the end of the first month, five parallel but different design tracks were active. From these, I would refine and develop them concurrently as much as I could until the 13-week-period came to an end. Reflecting on the process as a whole, what struck me was the amount of ideas and opportunities that emerged while I was working. It was challenging to maintain a constant focus on building stuff, trying to get things done to some sort of completion, and to finalize a prototype, when new ideas or ideas for subtle variations kept surfacing, some of which could feel just as exciting or relevant to pursue.

## 2.2.5 FIVE HAPTICS SKETCHES

By the end of my first internship at Microsoft Research in Cambridge, I had five tangible and functional haptic sketches, each encompassing a particular haptic interface notion or concept, which I had ideated through my sketching process and kept improving and subtly refining during my 13 weeks. Each of these final sketches is thus the result of many iterations and variations, often on a daily basis. On average, each sketch had undergone six to eight prior versions.

In real-world terms, all five hardware sketches are composed of the same kind of box made out of MDF board. This box is what is picked up and grasped by the user, who—holding it in one hand—experiences a specific haptic sensation through it. The boxes are also tethered to an external control board, while four of the five haptic sketches also include a virtual control interface present on an adjacent laptop, which can be used for adjusting various parameters and offer control/trigger actions. With more time and resources available, most of these external interfaces could have been directly embedded and integrated into the boxes themselves. The fifth sketch, *The Slacker*, was actually implemented as a wholly self-sufficient standalone unit, only requiring external power.

These five haptic sketches, described in detail below, have been published and demoed at the Tangible and Embedded Interaction (TEI) conference in Madeira, Portugal, in 2011 (see Moussette & Banks, 2011) and there is also a supplementary website providing access to all the logbook notes, sources files, photos, and videos of the design process (see http://www.simplehaptics.se/msr1). Below, each of the five haptic sketches are presented one by one, focusing on the way the final sketches feel when you hold them, the ideas that led to their inception, and some remarks and discussion regarding the challenges and obstacles encountered during development.

## THE SLACKER

Figure 26: Loose elements are connected by a string (dental floss).

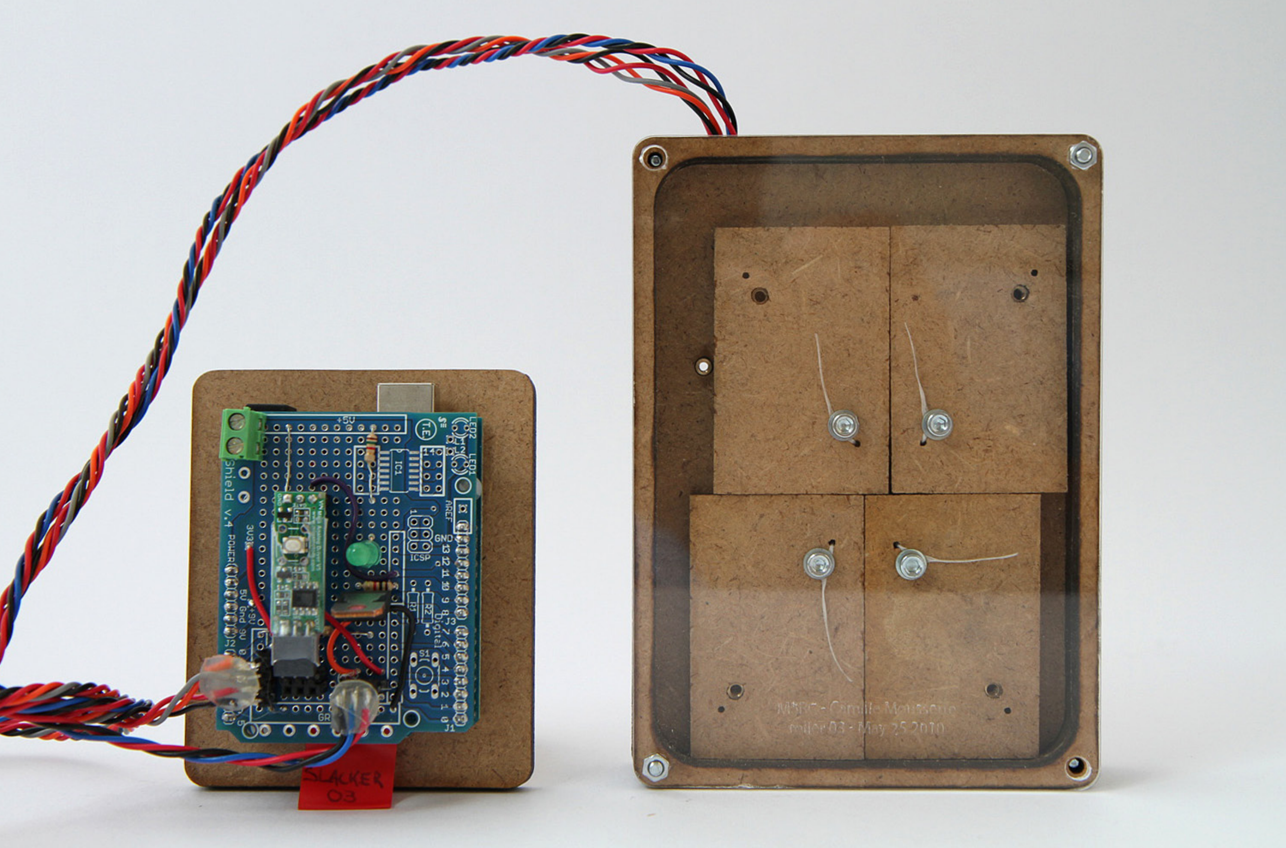



Figure 27: Slacker box connected to its control and actuation unit.

The original idea for 'The Slacker' was to have a device with a fixed and solid shell, but where its inside mass can change so that it feels different, e.g. becoming either loose or solid, shaky or secure, or reactive or inert. The inspiration for this haptics experience comes from various sources, for example from how one can shake an opaque container in order to be able to estimate the amount of liquid inside. Hence, could one by joggling the box come to learn more about it and could the box, by changing its internal 'character', inform or tell the user something?

The principal design challenge for this design was to come up with and evolve a mechanical system that allowed parts inside the box to go from loose to solid. Together with my advisor at Microsoft Research, we identified a *clutch mechanism* as a good descriptor or term to use for the intended interaction. Initial explorations in this field involved the use of electromagnets to constrain and then let go of metal parts. This restraining technique proved a bit too distinct however, as it only allowed either active or non-active states. Having tried this out, I found that in-between states, ideally a continuous scale from loose to solid, would be preferable as this would make the range of potential experiences with the device much more open and richer in nature.

Figure 28: Giraffe toy as inspiration for the clutch mechanism.

During a stroll in downtown Cambridge, at the city market, I stumbled on a small toys vendor offering to sell a number of string-animal figures. On these figures, the pressing of a physical button under the base would make the entire appendages loosen or tighten mechanically (see figure 28). These toys caught my attention and I immediately connected it with my quest to find a suitable clutching mechanism. All said and done, I bought a yellow giraffe from the vendor and used it over the coming days for inspiration.

To comply with the goal of achieving smooth transitions between the box's solid and loose state, the solution ended up being the use of a shape memory alloy actuator, as it matched the needed action for the string mechanism very well: a strong force over a small range of movement. Another advantage was that it works silently, something very uncommon for actuators.

Hence, in the last refinement of the mechanical design for The Slacker (see figure 26), four loose blocks of MDF board are attached with string to the actuators on the back of the unit. In one extreme state, the rest state, the blocks can move around, shake, and collide with each other inside the box. When current flows through the actuators however, the shape memory alloy shrinks, which pulls the strings, which in turn make the blocks lock into position. In this other extreme state, the blocks are fully locked and the whole unit now acts as and feels like a single, solid entity.

Interaction-wise, earlier versions featured a simple button, or responded to a mouse click on its virtual computer interface, that allowed the triggering or release of the mechanism. The final sketch in the iteration however, used an accelerometer inside the box itself to detect certain kinds of user movement (i.e. shaking of the box) which then activated and deactivated the clutch accordingly. There were thus two modes, *shake to solidify* and *shake to release*. While the default configuration was to start with the *shake to solidify* pattern, some users were found, during some informal in-house testing, to find the *shake to release* action more intuitive at first.

## THE SPRINGER

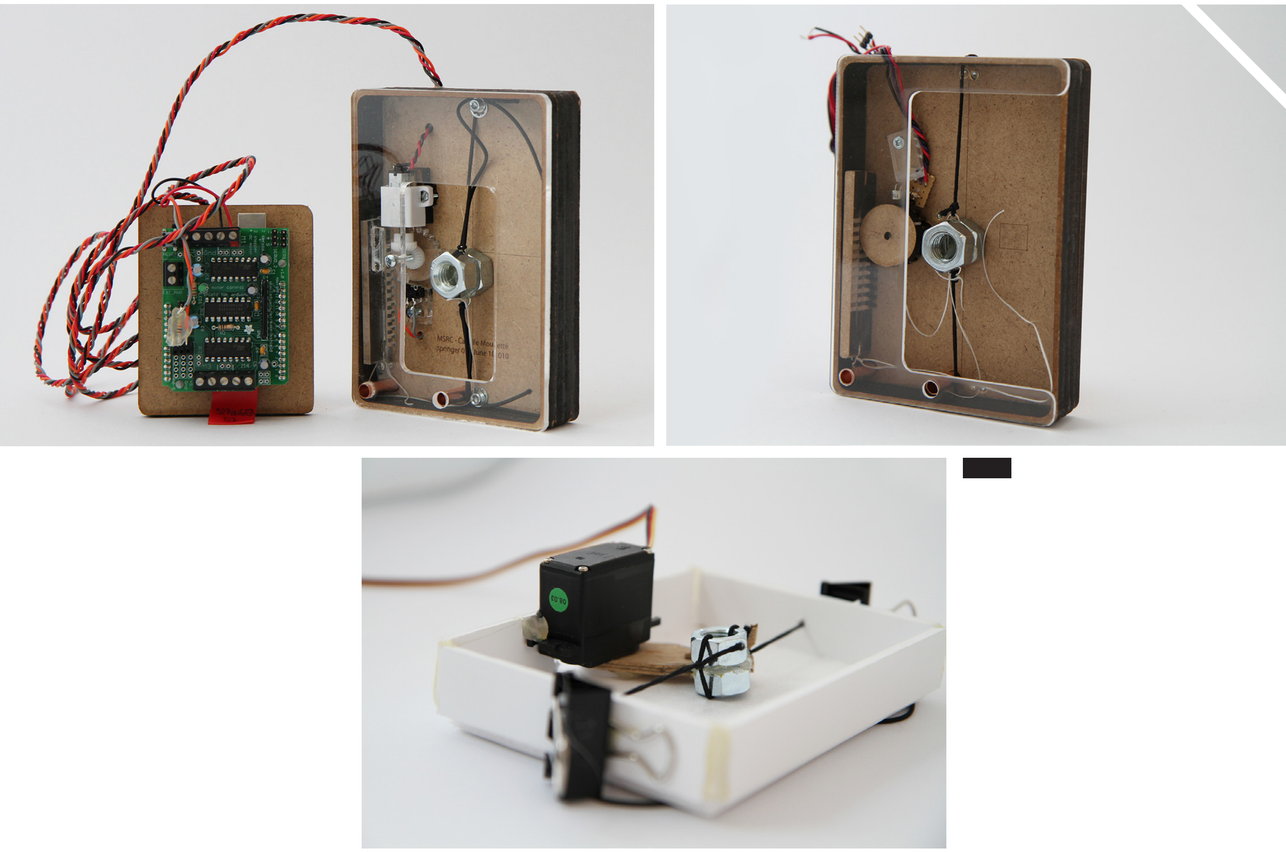


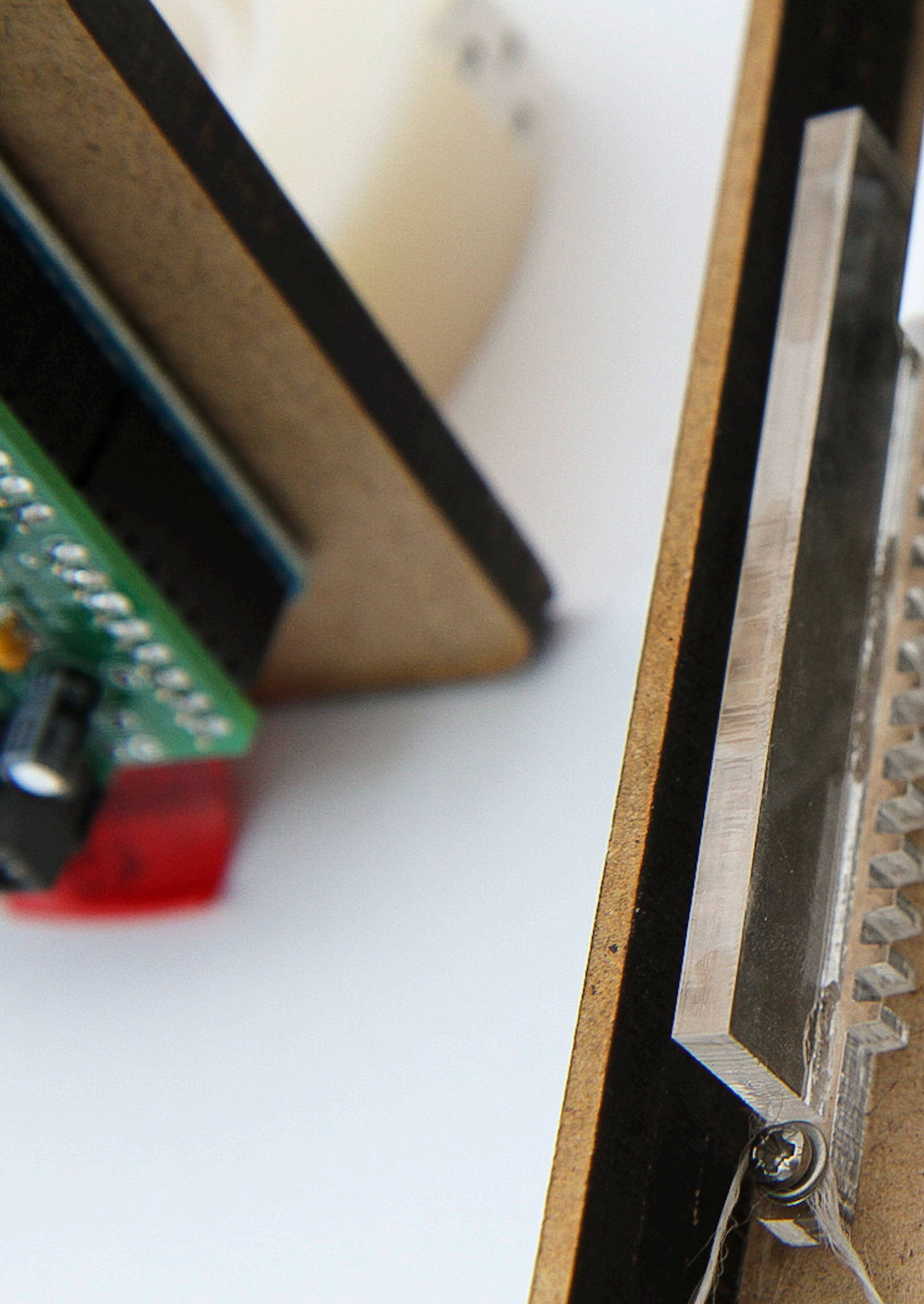
Figure 29: Evolution of the Springer device

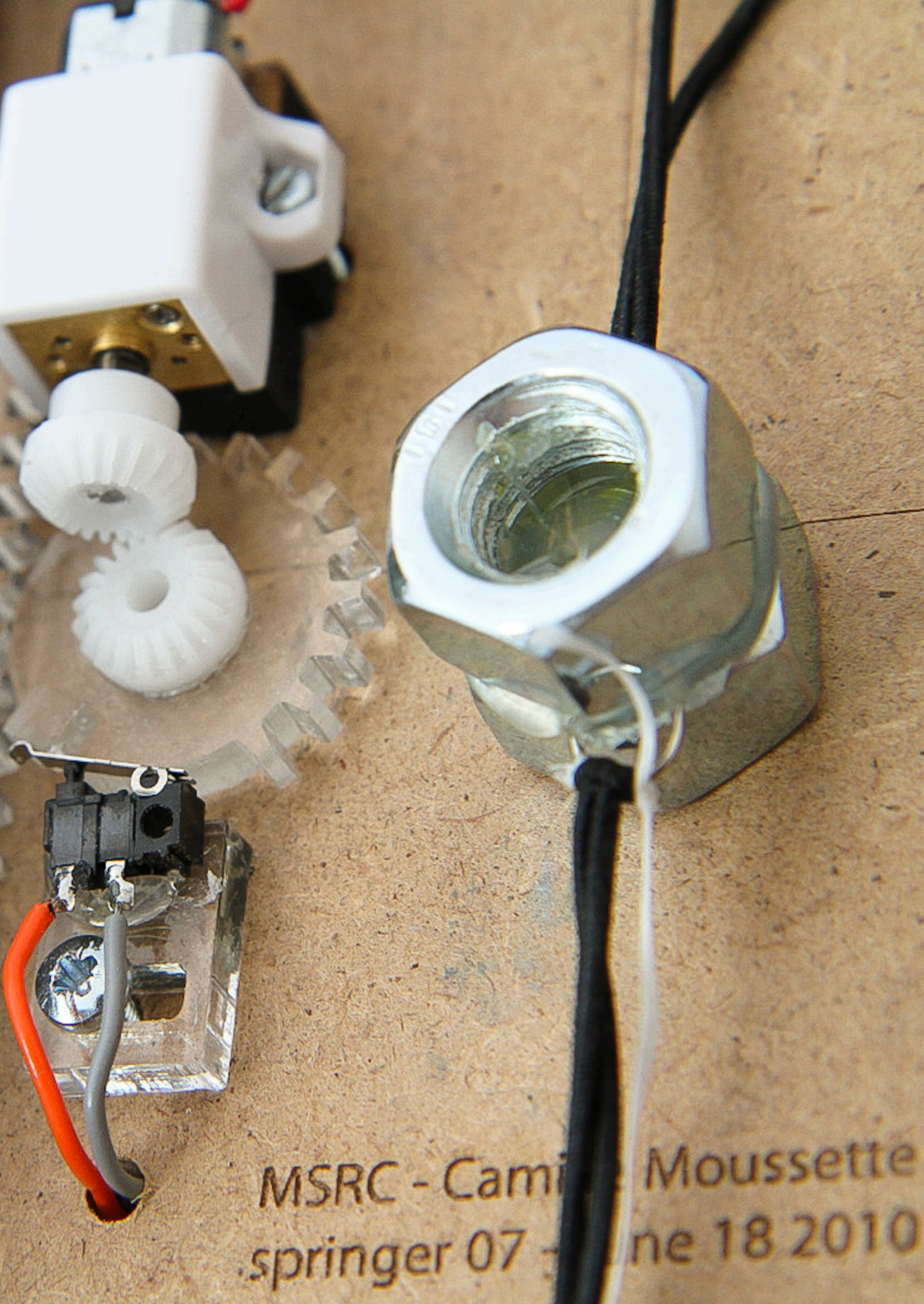
'The Springer' idea partly grew as a reaction against today's overabundance of visual interfaces that often find inspiration in real world physics and for instance assign gravity, bouncing, and springing behavior to certain interface elements. When discussing the concept of reality-based interaction, Jacob (Jacob et al., 2008) refers to such design patterns as "naïve physics". An example of an instance of this interaction pattern can be found when dragging or scrolling an object out of bounds on a desktop computer, where the object 'springs back' into its maximum allowed state.

The idea and goal behind exploring The Springer was to try to reintroduce or rediscover the real physical action behind, or underlying, the naïve physics' visual derivatives. Here, the experienceable haptic stimuli would come from an internal object that is truly mechanically springing back as the user interface element recoils and springs back. The visual and haptic stimuli would be aligned and coherent.

The main challenge that this hardware sketch presented was the realization of an appropriate mechanism for recoiling, hitting, kicking, and letting go of a dead weight attached to elastic cords inside the device. As realized by Yao (Yao & Hayward, 2006), I knew that it would be possible to fake and synthetize such haptic stimuli using a high-end voice-coil actuator and a proper control signal, but for the task at hand this route was far beyond my sketching ideals as well as the constraints I had put up earlier. So, I opted for the genuine implementation of a dead weight being actuated inside the box instead. I tested a few different mechanisms that I found in mechanical design handbooks, but most of them were developed with large metal parts in mind, intended for factory settings and manufacturing plants. My mechanisms however were made of wood and acrylic and had to be scaled down to fit inside a small, handheld box. Finally, a mechanism based on a rack and pinion combined with a partial gear came out as the most successful and functionally reliable version (see figure 29).

There were two main issues that conspired to make this the most demanding to build of all the five sketches: first, finding a configuration compact enough for my target box size, and second, reliably being able to trigger the mechanism. The compactness of the layout was achieved with a set of bevel gears, allowing a small motor to be mounted inside the box and not protruding out of the back of the box as it did in prior variations. Yet, the only small bevel gears I could find were made out of plastic and kept skipping under heavy load. To overcome this, I tried to more firmly secure all the parts, but the unfortunate mix of plastics, wood, and less-than-perfect alignment made the drive mechanism go awry on a frequent basis.




MSRC - Cami Moussette
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The mechanism was set to load—pull or crank the nut—and wait for a release signal to let go. To calibrate the sequence, i.e. knowing when to stop pulling, I tried a few different options, some of which were time-based and other sensor-based. The use of a switch proved the most reliable variation to track the gear's position, thus the recoil position. After further calibration and a few tests, everything ran well and stayed in sync. To celebrate, I invited a colleague to try it and it failed immediately and repeatedly. It turned out that he was holding the device differently than I did and the recoil force became too strong, which resulted in a loading action directly followed by the release. My calibration was off due to the different orientation of the box in relation to the force of gravity. At that point, I decided not to act big on this issue, both because I was running out of time and also because any chance of arriving at a satisfactory solution would have required substantial redevelopment and increased complexity. At this point, rather than grand redesigns, I swallowed my pride and opted for calibrating the sketch with a very tolerant configuration and accepted the limitation of having a restricted orientation in space for proper operation.

The final iteration of this sketch produced a satisfying physical *kick* or *punch*, but the *bounce* was weak, almost unperceivable. A synchronized *springing* visual user interface was presented on an adjacent computer. From informal in-house testing, the *kick* tends to come as a surprise for most users and is clearly recognizable. The bouncing qualities on the other hand, are not as obvious, and a different mechanical solution could probably have expanded on this aspect or quality of the haptic stimuli.

At the end of the day, this haptics sketch was very demanding to produce, consumed a lot of thinking and iteration to get going, and in the end the experienceable results felt a bit weak considering the amount of development that was put into it.

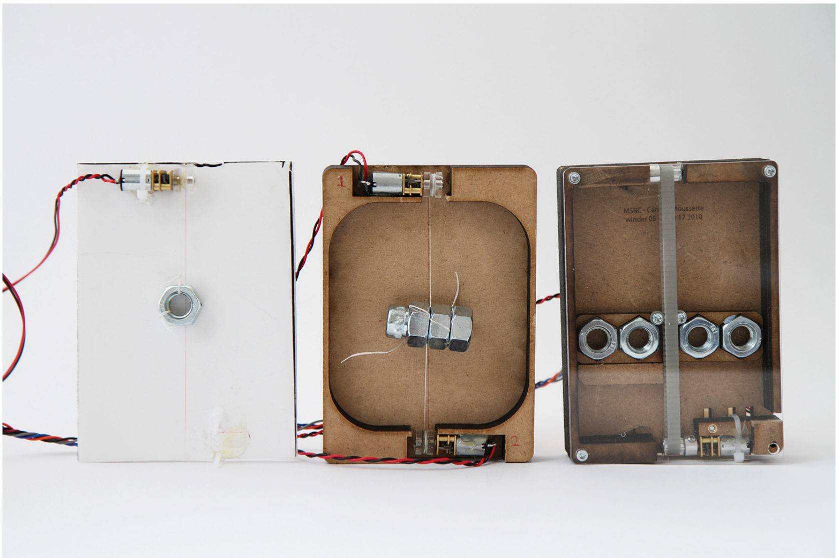


Figure 30: Three iterations of the Winder device.

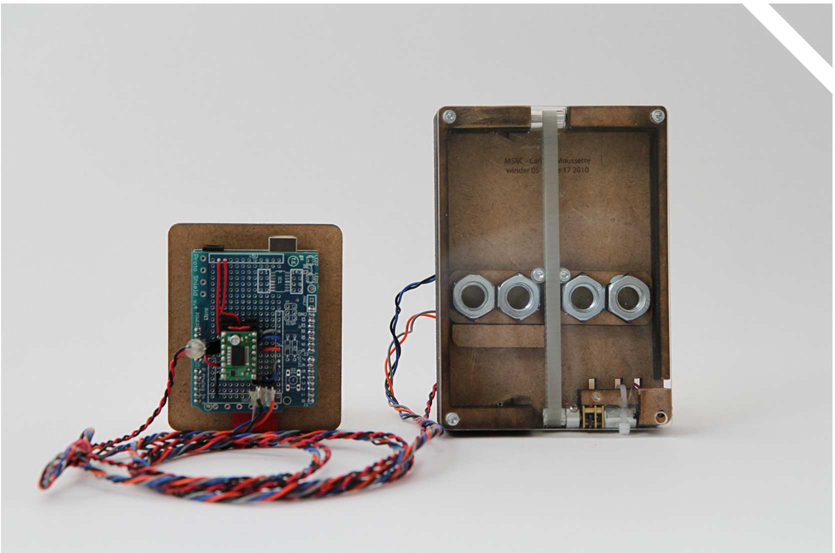


Figure 31: Final iteration of the Winder device.

The Winder started as a desire to move around a weight within the device, where the idea was that the changing of the device's center of mass could be somehow linked to a signifier or a notification. For instance, a top-heavy device could indicate something, a bottom-heavy device something else, and the transition characteristics—i.e. the speed and style of transitioning from bottom to top heavy—allow for interesting interaction design patterns. To achieve this haptics effect while limiting complexity, I early on decided to constraint the movement to just one axis, i.e. the length of the box, as it provides the largest range of movement possible within the box shape used, around 15 cm.

The first variation of this theme featured a dead weight being winched by a small motor. This design turned out to work well when the weight was moved in one direction but not equally well for the reverse direction, despite reducing the friction at the wrap-around points with pulleys. For the next iteration, I added a second motor in order to have adequate pulling action from both directions. When calibrating the two motors to run in sync—one reeling whilst the other is unwinding—I noticed that the tension could be increased quite a lot when the motors run in opposition, actually up to a point where the back plate would bend. Interestingly enough, this tightening, tensioning, and ultimately bending were all perceivable when grasping the device. When holding it, it felt like it was loaded with energy, ready to burst, explode, or suddenly break apart. While the physical parts were in fact literally charged with more energy, I did not expect to be able to actually feel this kind of intricate state so directly. Hence, for a while, my focus turned from transitional movement to a more general exploration of tension, energy, and power in relation to the materiality of the box itself—something not expected initially. Yet, although the tensioning qualities and potentials were interesting, I decided to keep focus and continue to work on the weight movement with new variations.

The final configuration of The Winder involves just one motor, but this time combined with a set of transmission belts and matched pulleys. For simple but somewhat crude self-calibration, two contact switches monitor the extremities of the movement. At power-up, the device measures the actuation time for a complete course, from which the middle position is defined as half of this value. Taking the lid off, it is possible to add and remove steel nuts in the carrier plate to afford trying out different loads.

The Winder, as well as some of the other sketches, uses a common type of miniature-geared motor, which is available off-the-shelf in a range of different gear ratio configurations. This means that changing the motor is a fairly straightforward activity that requires no subsequent changes or other kinds of manipulation to the electronics or the control application. Consequently, design explorations of the effects of different speeds and torque settings can be quickly realized and experienced.

At first, The Winder was controlled using a small joystick (or two for the dual motor configuration). A virtual software control mechanism, using a scrollbar cursor as the mapping for controlling the carriage's movement, was then added to the design. It was compelling to be able to use a computer mouse, a trackpad, or keystrokes on a computer keyboard to move the weight around inside the haptic box. The final instance of The Winder, however, was demonstrated using a scroll wheel of a computer mouse mapped directly onto the weight change.

From the informal in-house testing sessions, we noted that the absolute position of the weight within the device was initially difficult to recognize upon grasping the box. Any changes to the weight's position however, even very slow and subtle ones, were immediately perceived by most users. While this on the one hand speaks about the refinement of our human touch sense, combination of high-frequency vibrations from the motor and transmission system and some audible noise generated might have also come together to support our participants' perception of movement within the box.

## THE SPINNER

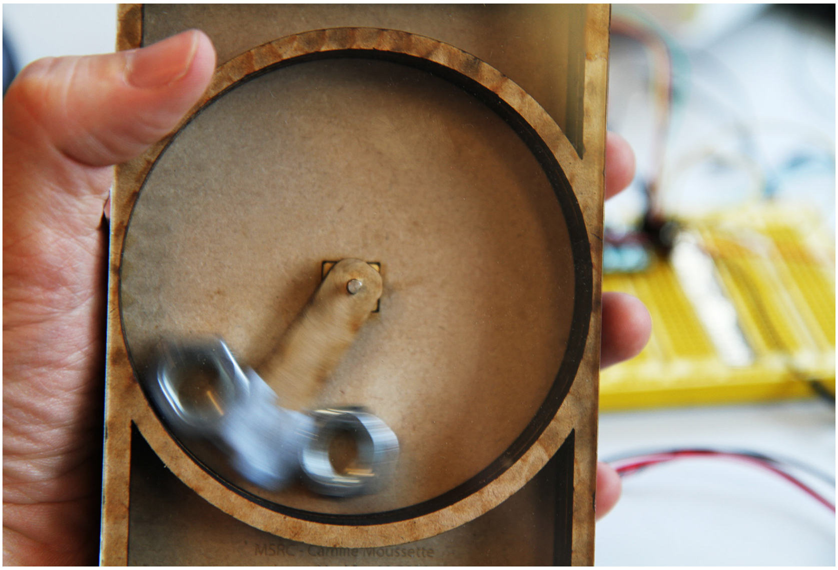


Figure 32: First iteration of the Spinner device.

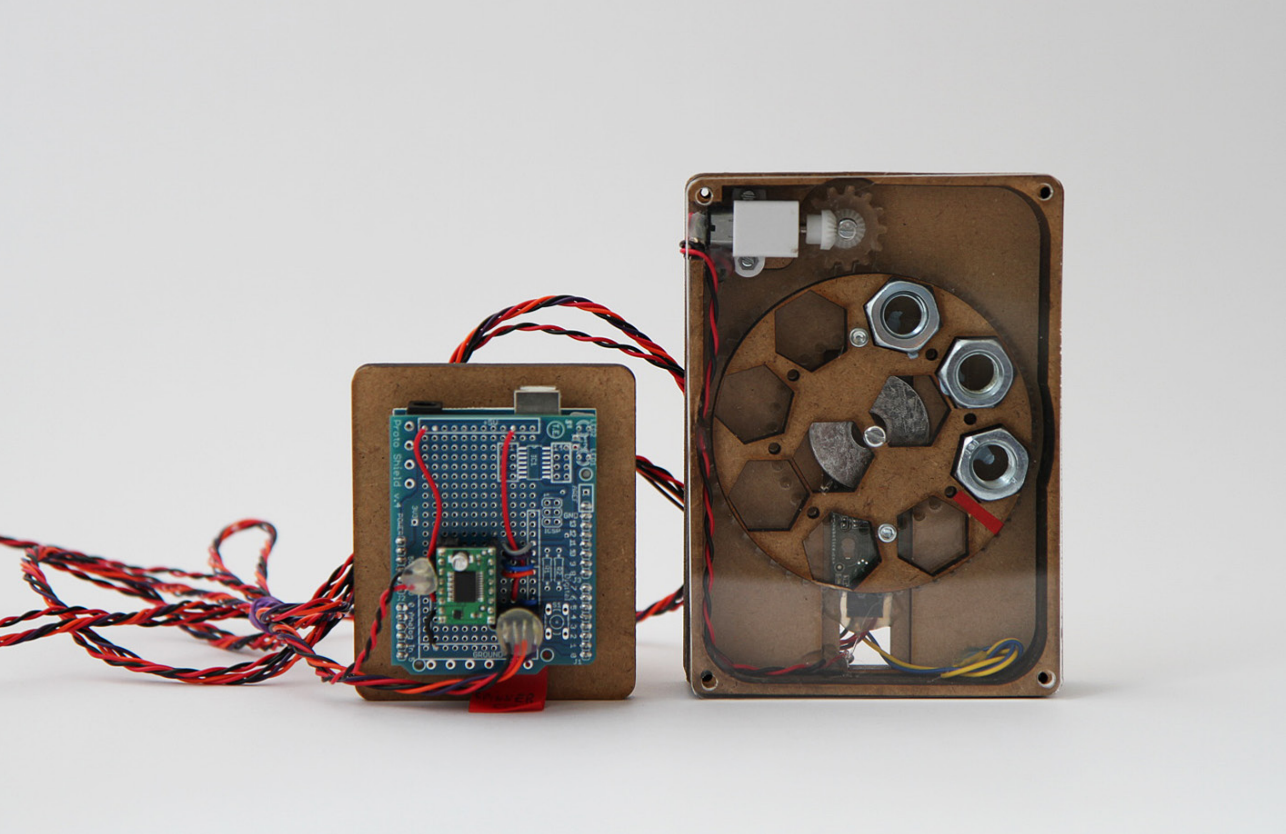


Figure 33: Final iteration of the Spinner device.

The principle behind 'The Spinner' started out as explorations in the area of vibration. What is vibration? While the textbook definition of vibration is periodic movement or oscillation, at what point does a slow vibration lose its 'vibrational quality' and just becomes movement of some other sort? With this in mind, I set out to build a few units where a small-geared motor could drive and rotated an off-centered weight within the box. The same line of motors as previously used in The Winder was used in order to quickly try out different speeds and torque settings. To achieve other kinds of variations, I also experimented with using more or less weight.

My initial impression was that very slow vibration, a few cycles per second or so, felt more like a *wobble* than like vibration. If the box was held vertically, the movement tended to be faster in the down section of the cycle and slower to way up. This is of course due to the force of gravity working in combination with the limited capacity of the small motor to move uniformly under different loads. At slower speeds, the cycle became less constant, to a point where the weight would stop in the lowest position, as the motor would not have enough torque or momentum to effectively be able to move the arm. Realizing this behavior led me to think and start tinkering in the area of positioning and direction control, a bit similar to The Winder sketch but here in a rotational configuration.

The next few sketch iterations were realized to explore such directional capabilities, partially inspired by Hemmert's haptic compass concept (Hemmert, Hamann, Löwe, Zeipelt, & Joost, 2010). In this vein, I built a carrier wheel plate to afford modification to the weight and its distribution, and a sensor was also added to track the absolute position of the carrier wheel. To make the layout compact enough, the design relied on a set of gears. While this configuration allowed for very accurate positioning, the rotation speed was limited. Where I could achieve 20-30 cycles per second in an earlier configuration (see figure 32), the final sketch iteration of The Spinner was limited to maximum rotation speed of about a single cycle per second.

In terms of controlling the unit's behavior, the first iterations used a simple knob to adjust the spinning speed. To manipulate the positioning control, a rotational encoder, free to turn indefinitely in either direction, was used. For later iterations, I added a virtual control interface on the computer, using a compass reference. Here, the weight change in the haptic box would correspond to and change with the mouse cursor's position and movement on the computer screen.

## THE SLIDER

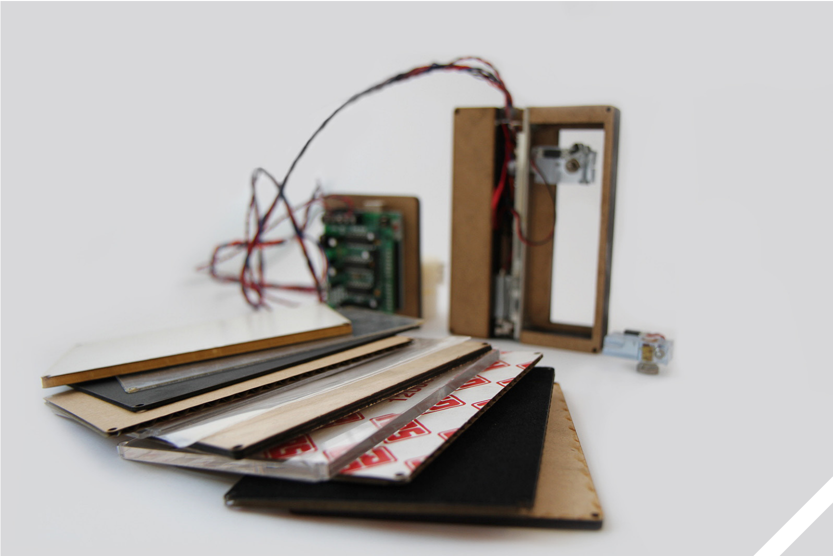
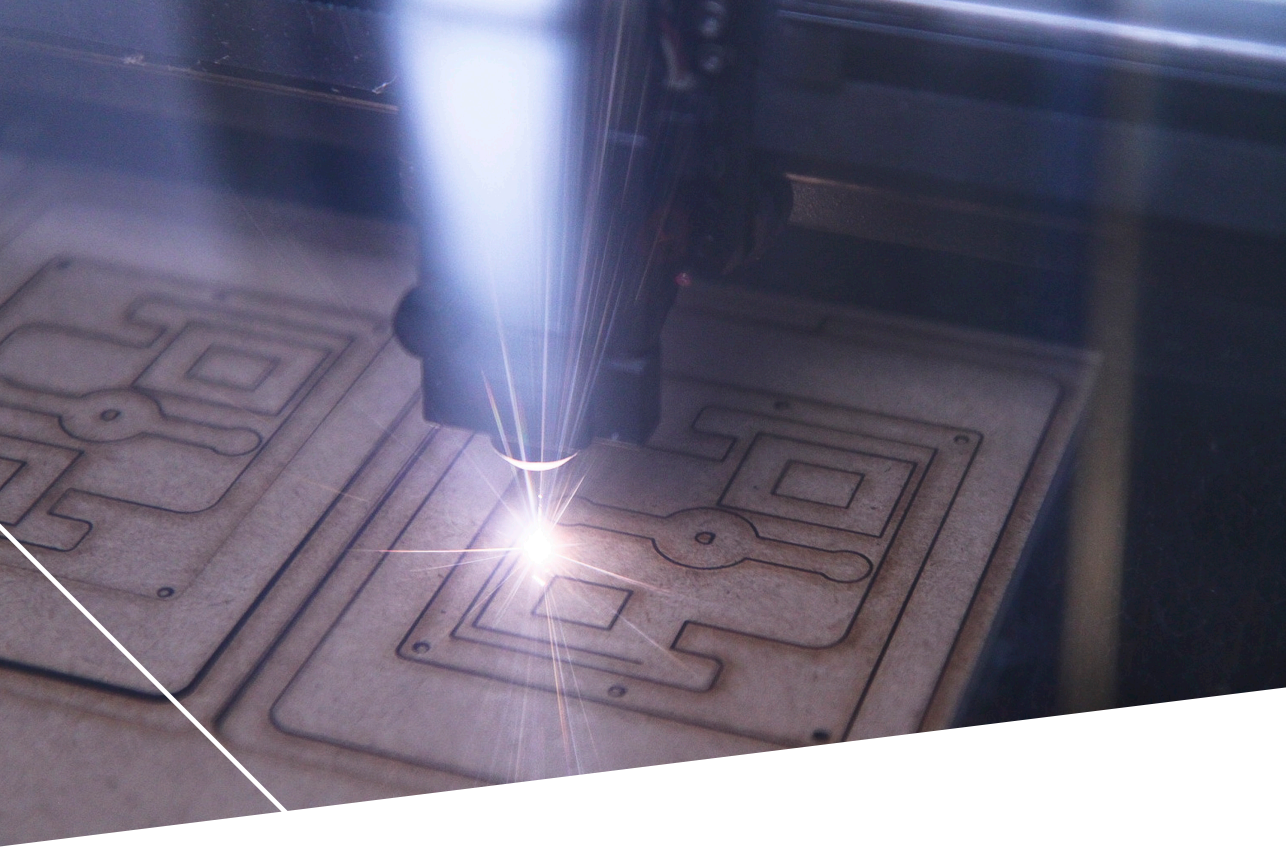
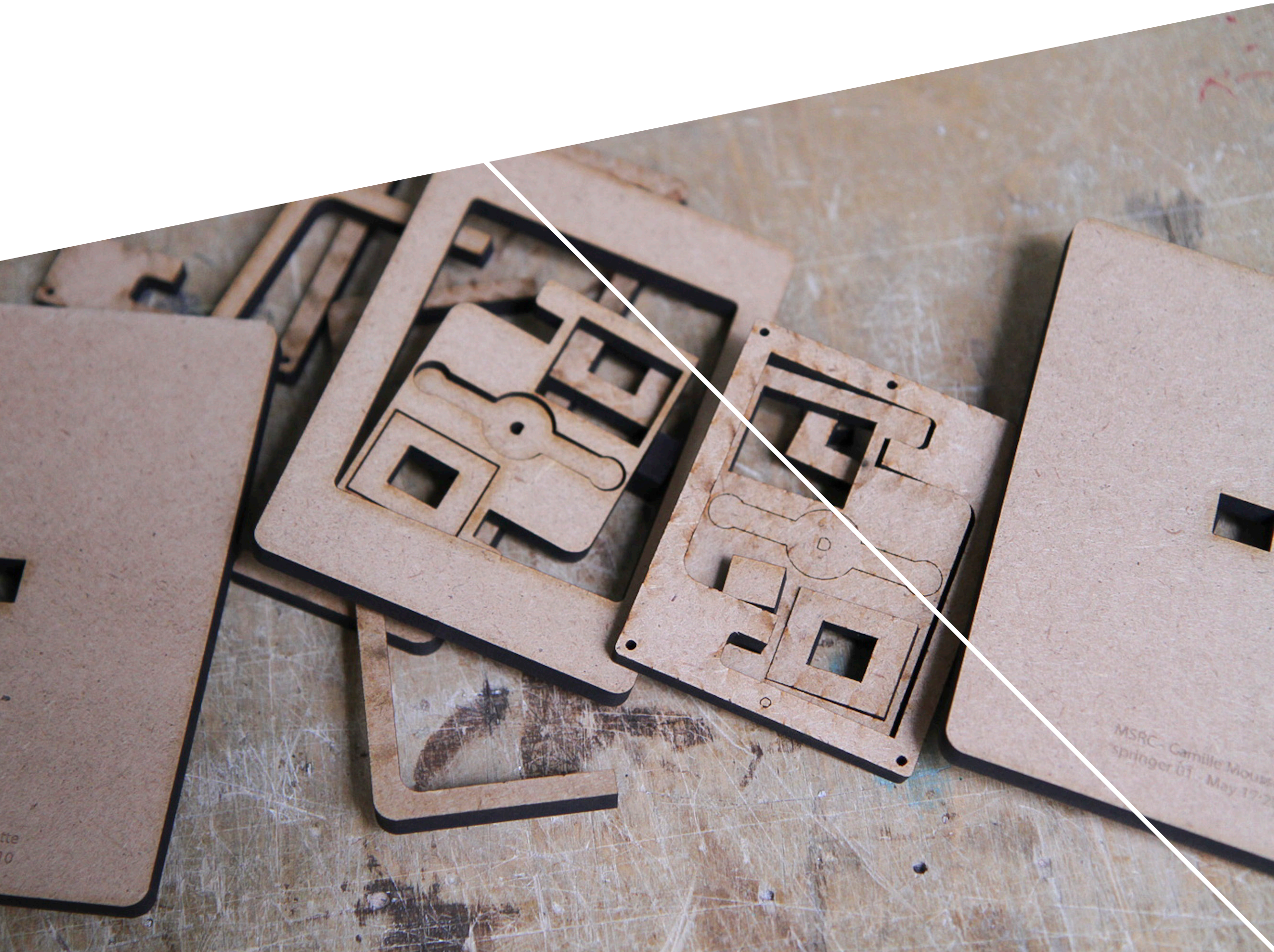


Figure 34: Slider device, with 2 dynamic sources, and the different materials for testing.





# MICROSOFT RESEARCH 1

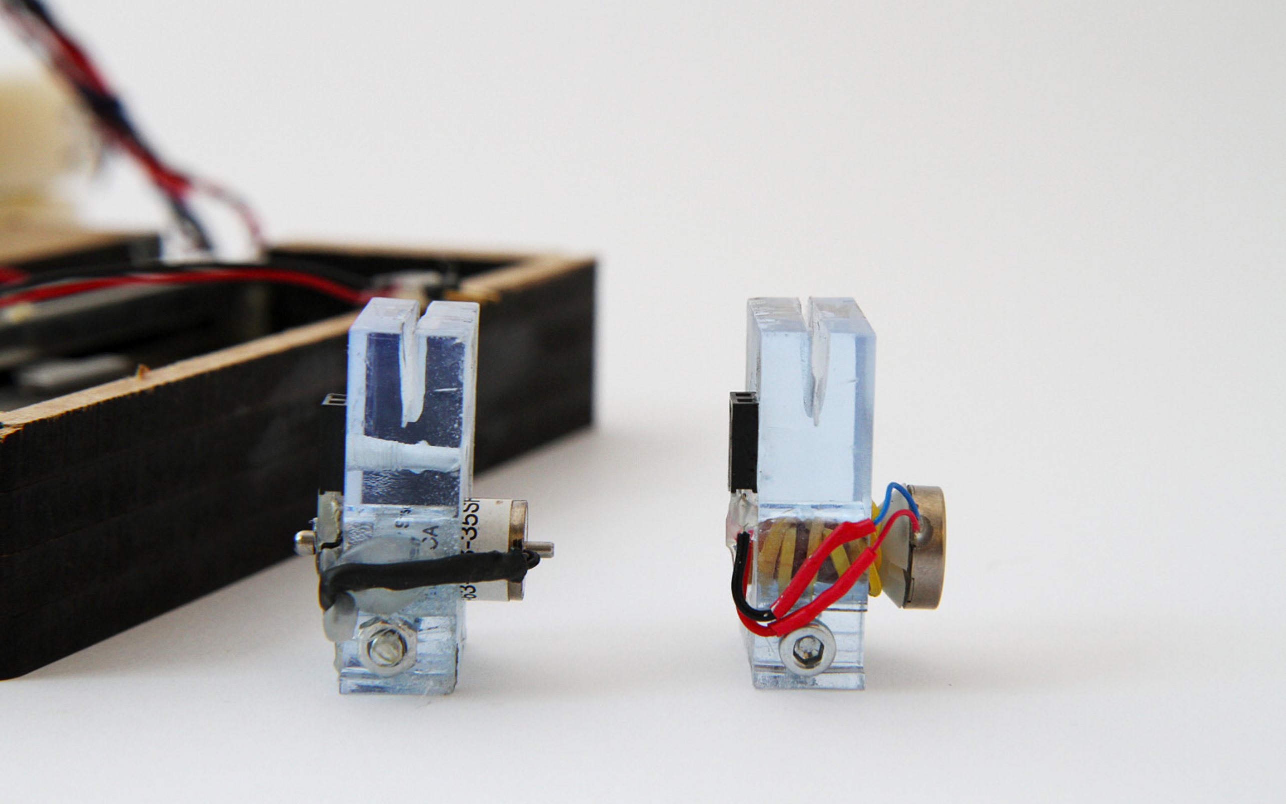


Figure 35: The two different actuators: poking and vibrating.

The concept behind 'The Slider' started as examinations and experiments into the positioning of the haptic actuator: does it matter if the actuation element is at the top or bottom of the device? Would users be able to discern the location of the haptic stimuli within the handheld box? After having worked on this theme, the answer is that it depends on the materials used, the type of actuation used, the mechanical configuration of the box, and the type of grasp with which you hold the box.

The first iteration was simply an empty box with various actuators distributed on the main back plate. Various sequences were then programmed to trigger each of the actuators individually. After having tried out this device, the initial conclusion was that it was actually very hard to perceive the source of the actuation, as the whole box was affected by each actuation. While I continued to explore this track using different actuators—speakers, vibrotactile motors, and voice-coil units—it more or less led to the same conclusion. I then shifted my exploration from the actuators to the mechanical design of the box and started to experiment with different assembly techniques, including gluing, screwing, and taping the back plate. To my surprise, the shift in experience of holding the The Slider was actually quite substantial with the screwed and taped attachment. The stimulation now appeared much more localized and it was possible to recognize, at least loosely, the source of the actuation within the box.

The next installment of The Slider was designed to have a single, moveable actuation source. One motorized audio fader was used to move an actuator carriage equipped with a mini solenoid for knocking and poking actions and another fader featured a vibrotactile motor for vibrations. With this setup, I could for example generate a vibration signal that could move across the length of the box in either a continuous manner or using discreet steps. I developed a virtual control interface on the computer to view, control, and adjust most of the various parameters, including step time, pause time, carrier speed, actuation power, actuation duration, and so on.

For the final iteration of The Slider, I constructed the haptic box so that it was possible to change the back plate, where the actuator is in contact with the shell of the box. This design provided the ability to change the material at the interface between the dynamic source and the user's hand and the interchangeable back plates could be secured in place by tape, blue tack, or by screws. The intention was to let users explore different materials and feel and experience for themselves how the haptic qualities change in relation to different variables.

The Slider series of sketches put forward the idea that not only its haptic qualities per se but also the actual location of a haptic source, and its movement, in relation to for instance a user's hand can be used in a meaningful way to convey information to users.

## 2.2.6 FEEDBACK AND TAKEAWAYS

At the end of the internship period at Microsoft Research in Cambridge, I gave a seminar to the colleagues in my group where a summary of my work was presented and all of the final iterations of the haptic boxes demonstrated. Some of the more down-to-earth design-related takeaways and findings from this study were that:

- ***Assembly technique matters: glued versus screwed.*** Haptics signals of low and high frequencies will propagate differently depending on the mechanical construction of the boxes. Mechanically isolating or separating sections, layers or parts help support or suppress haptic stimuli.

- ***Noise is almost inevitable and always felt***
Mechanical movement most often includes by-product vibration and auditory elements that help our perceptual system to make sense of the haptic stimuli.

- ***Exploit material properties instead of fighting against it***
Metals, plastics and wood have inherent material qualities that should be taken advantage of. Wood is anisotropic for example, the directionality of its grain affects how it compresses and flexes.

- ***Absolute versus relative change, specially for center of mass***
Haptic perception is limited in regard of overview and context. Absolute positioning is often difficult to perceive directly, but relative change is easily recognized.

- ***Hardware sketches are valuable for shared understanding***
Artifacts ease the communication and understanding between peers, by allowing multiple members to share an experience or a particular perspective.

- ***Modularity enhances reuse, mix and match and variations***
Having the possibility to swap modules allows faster development of alternatives, either by reusing already built parts and elements or by mixing unrelated items for interesting results.

The feedback my work received ranged from very supportive to very critical. While the negative side of the feedback shocked me a bit initially, I have found it immensely insightful and revealing having had time to reflect on it. The main point of departure for the negative critique related largely to the basic approach of using sketching in hardware as the primary means to engage with the design space. For many of the researchers attending the presentation, it appeared inappropriate and odd to proceed to tinker, ideate, and build new artifact without first thoroughly researching the playing field and surveying and framing the domain of study. With my approach, how could I possibly know which routes or paths are worth pursuing? In essence, the critique boiled down to: why these five units and not five others?

On the fly, my initial answer was that the process chosen led me to develop these five particular units and that another, similar research process—regardless of whether or not that designing researcher would have been me or not—would quite likely yield different results, potentially very different results. This does not mean, however, that the five paths I came to develop were random. Rather, they have been grounded in the way designers and designing researchers typically ground their work: in a conversation with the design materials and the design situation at hand. The qualities and values of a particular haptic interface idea are impossible to assess without having a representation of the idea to experience; i.e. grasp, touch, and feel. In this spirit, discussing haptic qualities using only words is a bit analogous to reading a menu and trying to establish whether or not something is tasty, or attempting to learn to swim without access to either a lake or a pool. The design research process followed in this project represented the opposite of this; it was all about direct engagement with the design material and about capitalizing on the opportunities and bits of knowledge that emerged from it.

The critical voices at the seminar were not really convinced. They said that a thorough examination of the design space or at least a review of current knowledge and best practices in a relevant area, such as psychophysics, prior to these making efforts, would have helped identify zones or themes worthy of further investigation. While this is a fair point from one perspective, it does not really accept that the goals and aims and the type or character of the knowledge that is produced from different styles of inquiry might be different, but still valuable. I regard the design knowledge that was gained in this project as deep, relevant, and well grounded in relation to, and in some form of concord with, a lot of different areas of research and practice in and around haptics. It is unclear to me if deeper knowledge in psychophysics would have substantially improved the design conversation; what is clear however is that this would have taken a large part of the 13 weeks allotted.

In light of the larger perspective on the work presented in this thesis, this project also constitutes an important milestone in my discovery path into the area of haptics and haptic interaction design. From a perspective from outside of design research 'through design', my activities during these 13 weeks may be difficult to understand and appear as scattered and unstructured. Here, one typically has to look beyond the immediate results or outcomes to appreciate approaches like *research through design* and *sketching in hardware*. The underlying processes are rich, reflective, and insightful, but not always directly applicable to concrete design mandates. Like sketching using pen and paper, the activities of sketching in hardware might not have immediate value for a particular project at hand or for some distinguishable problem in the real world—and as such they might feel like a waste of time and resources. In the long run though, the argument for approaches like these is that they build deep knowledge, skills, awareness, and even connoisseurship of the particular design materials. A good carpenter has to know a great deal about wood and its characteristics and limitations before he sets out to construct a table or a chair. The same is true for haptic interaction design, without properly being acquainted with the design material, great designs will not happen.

In this project, when being involved in building and making stuff on a daily basis, technical and mechanical problems constantly surfaced, many of which are intrinsic to haptic interfaces. In this process, I learnt how built elements work together to produce interesting haptic qualities or effects. By constantly changing and modifying variables which are both physical and virtual—e.g. in the materials, sizing, actuation speed, and strength—I arrived at a better understanding of some key characteristics of what makes a particular haptics interface interesting or not, as well as what is mechanically feasible to build. I gained deeper technical and material knowledge while I was also able to evaluate new ideas quickly and in context. The iteration loops were quick, which allowed me to fail often and fast on many fronts simultaneously. Thus, an interesting character of the design process itself was that it allowed me, and even inspired me, to constantly take risks, as the penalty for failure was so low.

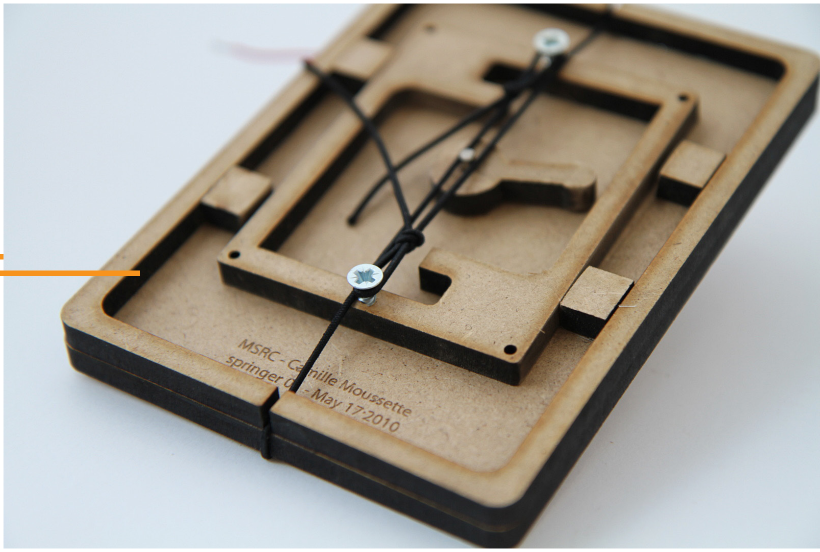


Figure 36: A failed attempt for the Springer device.

## 2.2.7 WORKING STRATEGIES

As stated above, the sketching in hardware approach and the goal of constant making forced me to directly and continuously engage with various aspects of my design material. Yet, how did my conversation with the design material really happen?

From one perspective, most of the 13 weeks of work was a never-ending struggle with some aspect of haptics. This struggle was not only to get things to work as desired but a constant effort to also document and reflect on what I was doing, and in that process somehow frame haptic design. This omnipresent reflection led me to notice that particular tools, approaches, and activities were particularly fitting, more productive or simply made my life as a designing researcher easier. Below, these are collectively framed as *working strategies*. They encompass the ways of working and approaching haptics that made sense to me. They also are some form of early, ongoing analysis and synthesis of my design research work on a level above individual designs. I have opted to expose them here rather than in the chapter dedicated to contributions later on in this book, because the direct context to the work described above helps relate their origins, characteristics, and values. These strategies will come to appear in the third part of the thesis however, but then framed in a larger and retrospective analysis of what is called haptic design expertise.

### DESIGN AT DIFFERENT SCALES

I initially decided to work on hand-sized haptic sketches. This constraint was expected to be quite challenging, as evolving mechanisms that are robust and compact are no easy feat. In order to sidestep a lot of problems, I initially worked at a larger scale, about 2-3 times bigger than my hand-size box template. This larger work canvas made the use of motors, gears, and other mechanical elements much easier to arrange and connect, and work was more pleasant and less cumbersome, and thus significantly faster.

For example, with The Winder concept, I first built a large back plate of about 40 cm x 30 cm and tested the electronics and control software with it. Once I knew that my circuits and code were functioning properly and that the weight was moving as intended, I started scaling down the builds. Finding smaller motors was straightforward, but finding smaller gears, pinions, and pulleys turned out to be more challenging in some cases. On numerous occasions, I had to reconsider a few design decisions and find alternatives that worked well in the smaller form factor. For The Springer, I even reverted to making my own gears and pulleys using a laser cutter machine. That learning and realization experience was more constructive than frustrating for me, as it pushed me to find new suppliers and learn more about mechanical engineering.

Working at an alternate scale also provided me with an opportunity to discover how haptic stimuli vary with scale. For impact signals, scale seems less important, as high frequencies propagate generally across the whole piece. For vibration however, size and amplitude matters more, as a 100 Hz signal with an amplitude of one millimeter is very different than one of one centimeter.

While some haptic sketches have intrinsic qualities embodied in their size—such as The Winder and its movable center of mass—others could scale up or down very well and maintain their haptic attributes. I envision that the blocks in The Slacker, which has four relatively large blocks moving in its cavity, could be much smaller, perhaps even tiny marbles in a tube, and that the haptic clutching it produces would still be interesting.

Overall, using different scales as a strategy to design haptics with was very helpful and a stimulating process. It meant building and constructing comfortably around a set of predefined parts, leveraging resources that would be hard to custom-build at the right size. It meant that I could test numerous setups and mechanisms, knowing that small equivalents were theoretically possible but practically difficult to realize. In addition, it required me to explore and investigate haptic sensation in relation to size. Working at different scales thus made me approach haptic design problems differently; to see hidden possibilities, and discover unexpected solutions.

## INSPIRATION FROM VOCABULARY, KEYWORDS, AND VOCALIZATION

As discussed previously, one of the greatest challenges in designing haptics resides in our ability—or rather our inability—to clearly communicate haptic sensations. While we as humans are extremely sensitive to even very subtle haptic stimuli, when it is time to explain what we feel or experience, our vocabulary is very limited.

During my internship at Microsoft Research in Cambridge, I specifically tried to expand and develop my vocabulary in regards to haptics. I kept looking at new words and terms to try to describe and capture haptic qualities. It is fairly common to use analogies and metaphors to share meaning and experiences with others, and some figures of speech and idioms are quite powerful in their way of conveying a complex haptic experience in a simple, meaningful way. Also, I did the opposite too, picking a keyword or verb and attempted to investigate its haptic implication or signature. For instance, when presenting The Spinner, the question of when a vibration loses its vibrational quality and becomes just slow cyclic movement was introduced. Early on I also collected a list of more than fifty action keywords that denote movement related to haptic stimuli in some form: poke, rub, bump, kick, etc. These were very helpful to communicate haptic qualities verbally, between interlocutors, with or without haptic stimuli to experience.

Besides words and metaphors, vocalization and non-speech sounds have proved advantageous to document and capture haptic qualities. As exposed in chapter 1.2, haptics and audio overlap in the frequency domain. This means that often *sounds can be felt* and *haptics can be heard*, so it is no big surprise that audio works well in documenting haptic sensations. Actually, one of the more interesting routes for communicating haptics might be vocalization of the experience. On countless occasions, I have described a haptic sensation saying something like *sscchiiitttakkk* or *thhhumpppffff*. These sounds are often rich in their qualities, intensity, and timing. Other people can generally recognize those attributes and will respond with their own equivalent or will try to correct it using their own vocalization. While the recording of these vocalizations were unfortunately not part of the documentation of this project, I believe, with hindsight, that they hold a lot of potential as a means for communicating haptics and haptic qualities quickly and accurately among peers.

## DISCARDING THE VISUAL

Many of my haptic sketches were initially realized with transparent acrylic top panels, thus exposing the inner working of the units. This feature was intended to help check and debug the actuation mechanisms without having to constantly open the boxes. However, having the mechanism visible was rather quickly found to be detrimental to the haptic experience in general as the users being exposed to the sketches quickly became overly interested in the functioning of the device more than anything else. The haptic interaction and its qualities were then of secondary interest, at best.

In order to have them focus on the haptic experience, paper covers were added to all sketches. This way, the units all looked the same: wooden boxes with white paper tops. With this setup, people became more curious and spent more time grasping, holding, and experiencing the boxes. As the human perception system is essentially multimodal, discarding the visual reduces the possibility to support haptic sensations with visual cues, the latter being something that we can generally put words to very well. Visual perception acts as a primer for haptics, hinting at possible movement, contact, and stimuli. Discarding the visual also made sure that the focus was on the haptics, if only momentarily. On the other hand, having overly generic boxes might instead cause the user to think of them as being part of an experimental or fully artificial—i.e. non real-world—situation. Despite this, the removal of strong visual cues was a valuable excuse to bring users into a moment of surprise and to use that moment of surprise to focus on haptic qualities.

## REUSE KNOWN MECHANICAL DESIGNS

Newtonian physics is not exactly new and a lot of clever engineers and designers have developed and refined solutions for a great variety of mechanical systems and problems. There are numerous handbooks detailing things like gear configurations, power transmission arrangements, and other nifty mechanisms. During the development of The Springer, I came to a point where I did not know how to build a particular crank and release mechanism. A quick visit to the university library led me to old guidebooks offering hundreds of machine and systems plans going all the way back to the industrial revolution. Almost immediately, three configurations that matched more or less exactly the actuation sequence I was looking for were found. Of the three, the first two I built did not turned out well—using wood did not help as it provide too much friction and these were originally plans for cast-iron machines—but the third mechanism worked beautifully. This particular crank and release mechanism originally developed for forging steel pieces ended up being the mechanical design used for the final instance of The Springer. While forging and haptics are not typically related, that century-old hammering motion proved very useful in my haptic design development.

## ABSTRACTION LEVELS: DESIGNING DESIGN TOOLS VS. DESIGNING HAPTIC SOLUTIONS

The haptic design sketches that resulted from the process described above are intentionally abstract and generic. They represent haptic interfaces ideas that are relatively unrefined and raw, and as such they are not final haptic design solutions per se. A plethora of parameters are changeable and adjustable, for a purpose. The context of use, the exact configuration of the stimulus, and the relevance and appropriateness with a particular project, device or system are for instance left to a hypothetical other designer to define and tweak and further develop. It was a deliberate choice to develop such raw and to-be-tweaked sketches, as this work is primarily targeting designers, engineers, and other professionals—not end-users purchasing a haptic device. These units are building blocks for haptic design, a platform or pattern for designers (including myself) to further discover and embrace haptics in design work.

Unfortunately, framing the work at a tool level—where the exact details are not fixed—makes it sometimes harder to see its full potential. Having the ability to tweak the parameters of the interface means that the experience can appear unrefined and unpolished at times. The interaction is not necessarily optimized and framed for a particular objective or problem in mind. Because I developed them, I know how each of them they can be tweaked, changed, and transformed; their optimal configurations; as well as their limits and weaknesses. For someone picking up these sketches for the first time however, designer or not, these capabilities are initially unknown and need to be discovered. To this end, I worked hard to expose the modifiable qualities of the sketches with for example pre-made configurations, but much more could be done in this area to enhance and speed up the chances of discovery and appreciation by others.

## FLUENCY AND MASTERY OF THE TOOLS: 2.5D MAKING

An insight from this work relates to tools for sketching in hardware. Fluency and mastery of one's tools are crucial for being able to sketch in hardware. However, the best tools for sketching are not necessarily the most advanced ones, but rather the most appropriate ones. As seen in the first part of this thesis, sketching is about creative explorations that go beyond iterative refinements. Here, the transaction cost for each sketch must be low, otherwise sketching as a process is impeded upon and the process becomes something else, such as prototyping.

I came to use a laser cutter machine extensively during the project described in this chapter. The excellent facilities at Microsoft Research offered fancier equipment such as 3D printers and other machines for making prototypes. Even though I am comfortable designing in 3D using CAD software, I ended up favoring the laser cutter as my principal hardware tool. A laser cutter machine allows cutting sheets of material quickly and precisely using a laser beam. Because of the way most laser cutters are constructed, it can only cut in two dimensions at one time, i.e. when you place a sheet of MDF board in the machine, you can cut along the X and Y dimensions, but not the Z dimension.

Even with this limitation, it is of course possible to use layering of the material for building 3D representations, which is a very flexible and forgiving process. It can be described as designing in 2.5D, a label often used in contemporary animation techniques (  enka & Slavík, 2003). Here, you designing a stack of layers in a vector drawing program such as Adobe Illustrator, which is quick and flexible and requires far less commitment than building a full 3D model in a CAD application. Mixing and matching these layers allows one to develop a three-dimensional shape as well as allowing for constant reinterpretations and easy variation of this shape. The operations take place in the physical world and can be executed using a large selection of manual tools or techniques, and the options are also far greater than the list of boolean operators in a CAD application. The stack is a natural modular system and layers can be swapped easily, or reused and repurposed across builds. Also, modifications to the digital source file can be made quickly and sent directly to the machine for new results in just minutes, not hours or days as might be the case with 3D printing and rapid prototyping technologies. This strategy of finding a toolset and work pipeline that was fast and precise, yet flexible and adaptable turned out to be an essential factor in being able to explore many variations and alternatives in a short period of time.

## 2.2.8 CONCLUSION

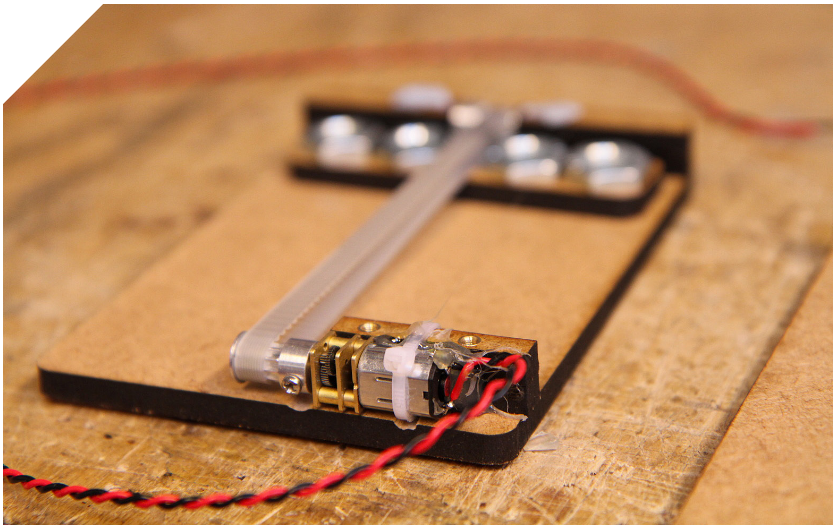


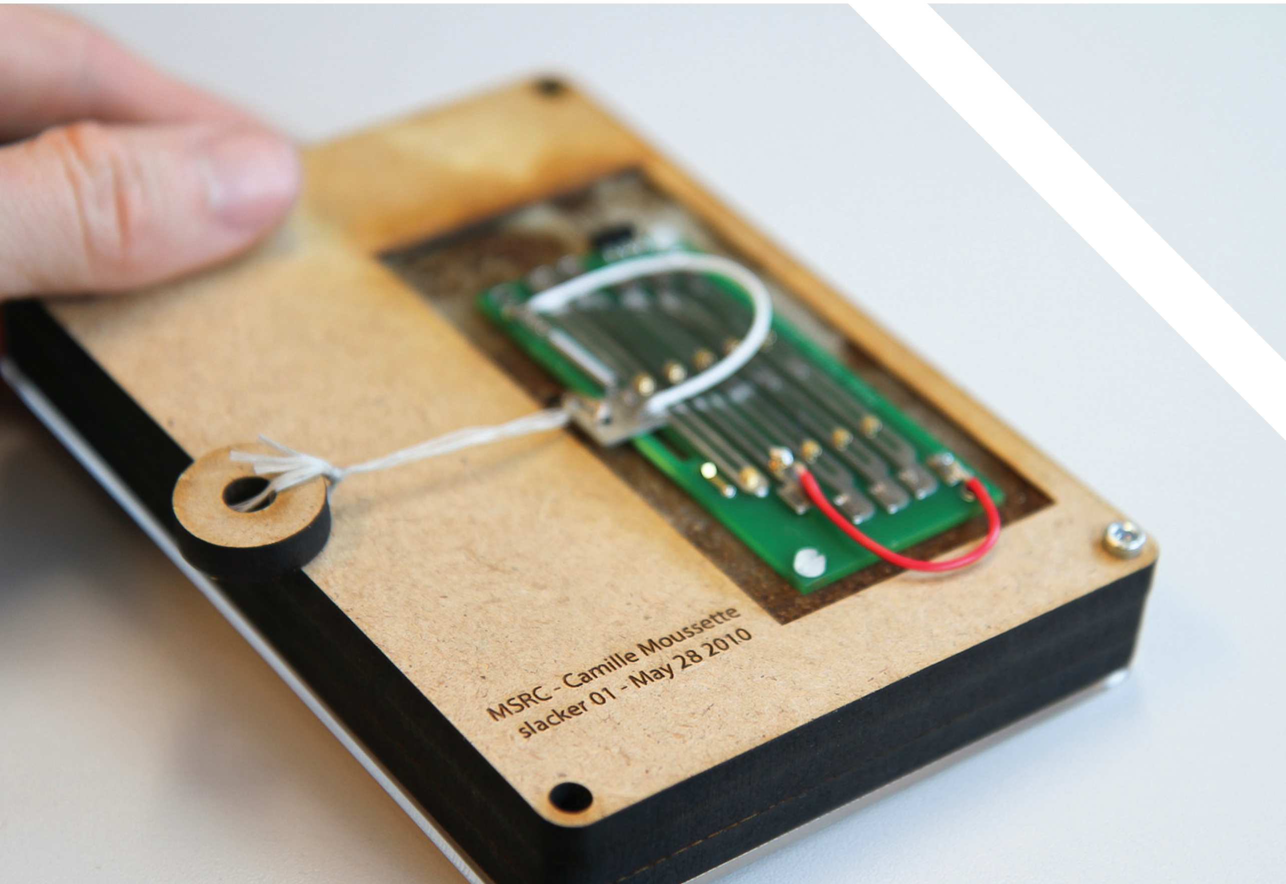
Figure 37: Sketching in hardware, mixing high tech fabrication technique and handmade alterations for the best of both worlds: filed down grooves for improved clearance and tie-wrap/hot glue combo to secure the motor.

To summarize, the internship at Microsoft Research Cambridge came at an appropriate time in my research odyssey. It provided a very inspiring research platform to explore haptic design activities differently: using a designerly approach, getting closer to the material, and using simple mechanisms. Over the 13-week-period, I built over 30 hardware sketches covering five main haptic interface concepts or themes. The outcome of this work surpassed the five haptic interface demos, as lasting impact can also be found in the tacit knowledge I gained through making and designing with the haptic material. In the process, I developed a new affinity towards haptics: how it relates to material considerations and actuation challenges, but also how things feel and how one can talk about how they feel.

The work was ultimately framed as a collection of semi-abstract design tools, not as novel haptic interfaces or design solutions for specific problems. As such, the sketches were built with variability in mind. Several parameters could be changed, tweaked, and fine-tuned in order to achieve different qualities of haptic stimuli and experience.

Looking back, the work conducted during this internship is indeed very different than my previous eNTERFACE'08 workshop experience. The approach, the processes, and the outcomes are closer and more related to what I think of as design. More specifically, exploring haptics using a design perspective has proved beneficial on two main accounts. Firstly, the level of exploration, the change of directions, and the number of unexpected results is far greater than typical haptic research activities. Secondly, I developed a heightened sensitivity to the design materials and mechanisms by having to sketch in hardware and build stuff continuously. This technical expertise goes hand-in-hand with a refined familiarity of haptic perception, as the ability to build quicker also leads to more exposure to haptic stimuli. Having more options to explore, and more opportunities to feel haptics is, in my view, a definite advantage for developing proficiency in the area of haptic design.

On another level, this internship also allowed me to be immersed in a large—if not the largest— research organization in the areas of human-computer interaction and interaction design and also one that is commercial in nature. Apart from receiving insightful guidance on my design and research work, it was exciting to learn about how researchers and research groups deal with large projects, their publication pipelines, their sharing and diffusion of knowledge with other divisions, and their treatment of IPR and legal issues. Although Microsoft Research has strong ties to academia, its organization and research agendas are aligned differently than most university-based research groups of which I had previous experience. For me, it was very inspiring to experience such high levels of energy, passion, and openness within a commercial research organization.


MSRC - Camille Moussette
slacker 01 - May 28 2010

# CHAPTER 2.3 DESIGNING HAPTIC INTERACTIONS FOR KINECT

## 2.3.1 INTRODUCTION

My internship at Microsoft Research in Cambridge was followed six months later by a second research collaboration with the same company, this time at their Redmond campus in the USA. This second visiting researcher internship project set out to explore haptics in relation to Microsoft's newest gestural sensor unit, called Kinect, for the Xbox gaming platform.

My research agenda resided in the realization of haptic design explorations for use with the Kinect sensor or in Kinect-derived interactions. This second wave of haptic explorations at Microsoft Research involved a very different set of constraints and requirements and culminated in a new and different set of perspectives and insights for haptic interaction design.

This chapter exposes in some detail the work I conducted. First, the details of my work looking at haptics for Kinect are presented. Second, the dozen or so haptic sketches I realized during this internship are described, detailing their haptic traits and qualities. Third, some working strategies that have helped come to grip with this work are discussed. Fourth and finally, I conclude with some takeaways and a general remark on the design of multimodal interfaces.

## 2.3.2 KINECT AND HAPTICS


Figure 38: Microsoft Kinect unit, from ("Microsoft Kinect for Windows," n.d.).

My second visiting researcher internship took place during the winter of 2011, just a few weeks after Microsoft had launched its new Kinect device for the Xbox gaming platform. Briefly, Kinect is a motion sensing input device allowing the user to interact with a game using just movements of one's own body, without the need for additional physical controllers. Likewise, "you are the controller" was Microsoft's way of capturing the essence of this novel human-computer interface.

The Kinect system combines a video camera, a depth-sensing camera, and a microphone array, all pieced together with clever software to track the movement of objects and individuals in three dimensions (see figure 38). The tracking abilities of the Kinect are quite extraordinary and stable, especially as compared to other similar systems. It allows for multi-user skeletal tracking in real-time and without any calibration for a work area of a few square meters.

As a side effect of being entirely controller-less, i.e. as the user is not in contact with any physical interactional means, the Kinect is deprived of physical and tangible feedback capabilities. The only feedback channels typically available when using the Xbox gaming platform are vision and audio. In its most typical setting, often a living room, users of the Kinect-equipped Xbox do their thing facing a television set. This use situation is adequate for a number of different interaction scenarios, such as gaming and public installation, but it is somewhat problematic or limiting for other interaction scenarios. For instance, as mentioned by Hespanhol et al., the ubiquitous interaction pattern of *pushing* an object is difficult to transpose to a non-haptic interface (Hespanhol, Tomitsch, Grace, Collins, & Kay, 2012). Pushing implies the presence of a physical barrier of sort. If such barrier is not present, then the pushing action becomes more of a *pointing* action. In general, *movement* and *action* tend to be confounded in spatial gesture tracking systems such as the Kinect.

The work carried out during this second internship set out to explore the possibility of reintroducing haptic feedback into a system like the Kinect and examine under what forms such feedback could enjoyable, valuable, and not overly obtrusive. Early on, I hypothesized that there might be a sweet spot to be found for haptic interaction design where one is actually willing to grasp or wear something in order to improve and enhance the user experience. Maybe such value proposals might be particularly relevant in everyday computing uses where ergonomic and performance criterions are high, or in high-exertion gaming uses where visual feedback is difficult?

### 2.3.3 HAPTIC DESIGN EXPLORATIONS

Methodologically, this second internship was heavily inspired from my prior experience at Microsoft Research in Cambridge, *where sketching in hardware* and *reflection-in-action* underpinned my knowledge creation process. I adopted a starting point and a research direction, but the actual work, which consisted of some successes but also frequent failures, followed the same designerly conversation with the design materials, but now with the Kinect system as its focus.

From the outset, I decided to favor the realization of numerous *haptic sketches* to truly feel and experience haptics with a working Kinect system. It turned out that using a production-level Kinect system (a 'dev kit' in computing lingo) was not an easy feat, at least not for a designer. The development platform for the Kinect system is optimized for software game developers, not interaction design researcher seeking to experiment quickly and with additional, home-brewed hardware. After three weeks and with the help and resources of some clever colleagues, my Kinect development environment was finally up and running and I was ready to start work designing custom haptic controllers and sensors.

The plan was to develop a series of haptic design sketches based on two different form factors: *handheld devices* and *wearable devices*. The handheld configuration would in a way continue the haptic boxes track I had initiated earlier in Cambridge, thought to provide an interesting comparison. The hand-size format also corresponds to a scenario where one would for instance use a small device, such as a smartphone, tablet, or remote control, to regain haptic feedback in a Kinect-like system. The wearable form factor, on the other hand, provided an incentive to explore devices with different body locations and other types of haptic experiences beyond the hand grasp and grip. I speculated that wearing the device might be more appropriate and convenient for high-intensity interaction and for long-term usage scenarios.

The following sections present a selection of the haptic sketches that were developed during the Haptic Kinect project:

## 2.3.4 HANDHELD HAPTIC SKETCHES

My two starting points were thus to focus on 1) devices about the size of a smartphone, or 2) wearable add-ons that could have different shapes. For the smartphone-like devices, I decided to continue the box format made with the laser cutter, something similar to the work I had carried out during my first internship in Cambridge. The process is fairly quick and many different mechanisms can be housed in generic rectangular boxes. It also reinforces that perception of the stimuli generated and the experiences it provides should come first, and that discerning visual cues are minimized.

### PADDLES & TILTING COVERS

One of my first explorations with handheld devices related to directional cues. I tried to envision how a device could convey a basic forward and backward movement and position using haptic stimulus. This cue felt particularly fitting for a spatial gesture system like the Kinect, for collision feedback, e.g. when you have reached or hit a target, or for soliciting and hinting motions, i.e. when the system wants to suggests the user to move into a particular direction. Such directional feedback also directly relates to very basic, embodied image schemas like UP-DOWN, FRONT-BACK, and NEAR-FAR (Lakoff & Johnson, 1980).

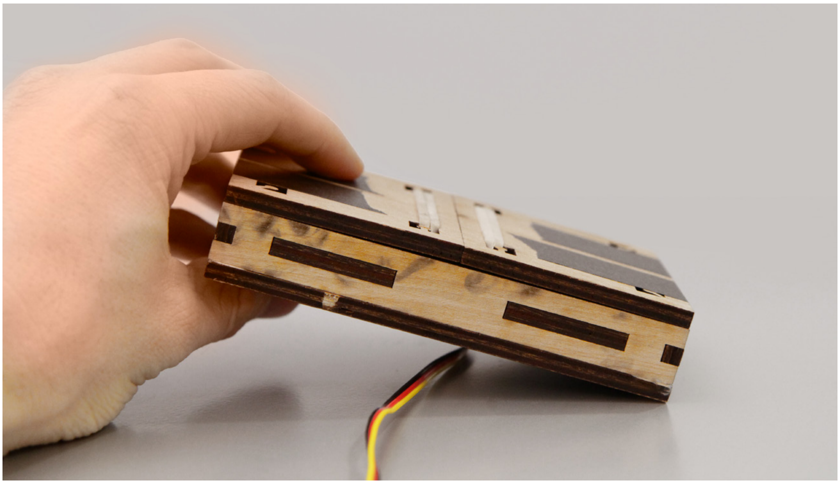


Figure 39: Paddles device.

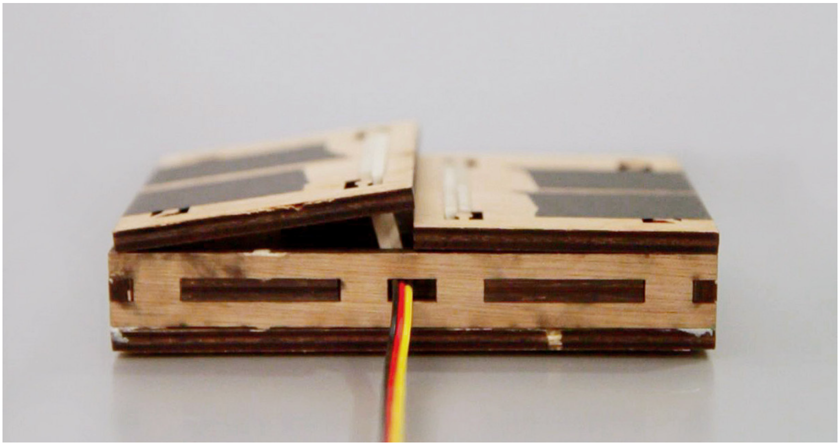


Figure 40: Paddles with one paddle up.

'*Paddles*' is a box with a split top panel. Each half of the top panel can be lifted using small servomotors inside the box (see figures 39 and 40). Depending on type of attachment (at the extremities or at the center), the panels can rise in a convex or concave pattern. The action and movement of the panels is relatively slow and can only runs at a maximum of 2-3 cycles per second. Hence, such stimulus lacks sharpness and preciseness by ordinary haptics standards.
The amplitude of the movement is considerable however, which yields a surprising and almost overwhelming effect, where the range of the panels is actually larger than what you would expect from such a small box, making the experience quite significant.

The sensation you feel when holding the device is a bit like as if your hand or palm would hit a large speed bump on the road. The synchronized movement of the top and bottom panels also offers interesting rendering patterns, as they can either work in concert or independently. The overall character of the box also changes with the shape of the box. It can open or close, or raise all of its extremities, as if it was scared or under stress and tension. In a raised position, the edge of the panel becomes very noticeable, accentuating the actuation. If the grasp force is too strong, the panel will not rise completely, but the noise and force from its mechanisms can still be experienced. The Paddles sketch also has the potential to squeeze or pinch the skin of the user when both panels are actuated in sync. The return movement and the central gap can actually result in a pinch action that is mostly unpleasant.

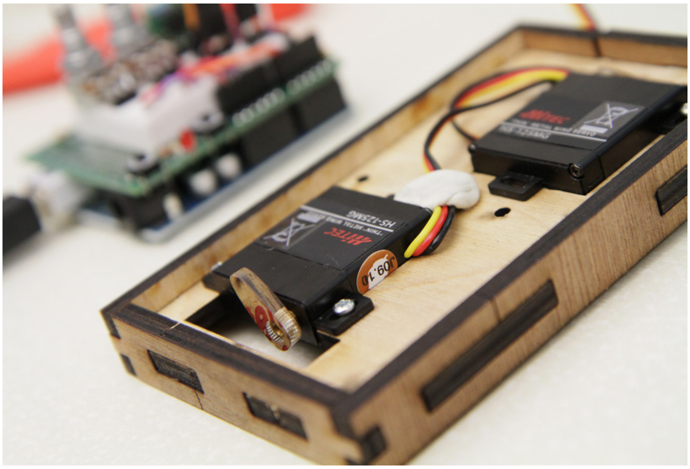


Figure 41: Tilting covers, without the cover, showing the servo motors and cam arm.

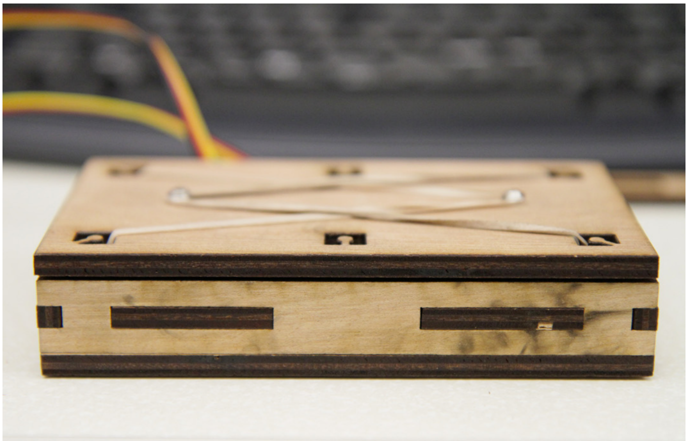


Figure 42: Tilting covers, complete with cover held with elastic bands.

The *Tilting Covers* is a similar exploration, but this time it is the top and bottom panels that are actuated. Servomotors will push the panel's both extremities, resulting in three main patterns: left up, right up, and both up on either the bottom or the top panels (but not concurrently). Since the mechanism that actually moves the panels is held only by rubber bands, the movement is not solely vertical but has some lateral movement or twist to it as well (a bit depending on grip position). This slight extra latitude of movement helps to make the actuation appear a bit more organic, or at least it feels less rigid and mechanical.

The haptic sensation one experiences is very much related to *tilting*, i.e. a recognizable slight inclined actuation, but less pronounced than with the Paddles sketch. The shape change is less drastic and less perceivable as the whole panel moves. As no new hard edge is exposed, the displacement is relative to the rest of box. The range of motion is the same as with the Paddles, but the bigger size of the panel results in a less pronounced angle.

Overall, the Tilting Covers device feels a bit like a box with a rubber balloon inside, a balloon that is inflated to the level where the top panels of the box are starting to give. The panels move outward but not strictly perpendicular. Two concurrent stimulations do not feel exactly the same, as the grip force greatly affects the way the panels come out. The panel actuation of this sketch was less satisfying than with the Paddles. While the actuation is readily perceived, its direction and amplitude are less apparent. The movement is quite subtle and lacks distinctness in its ability for directional cueing.

Figure 43: Tilting covers unit dressed with cloth material.

As with the previous sketch, some pinching side effects were are also found to be present in this unit. To mitigate the problem of getting 'bitten' by the device, I explored various wrapping and clothing material to 'dress' the boxes (see figure 43). It did in fact avoid many of the pinching problems, but also create an altered haptic experience at the material level, i.e. wood and cotton have vastly different haptic qualities.

## STANDARD BOXES, DIFFERENT ACTUATION TECHNOLOGY

A parallel sidetrack of the sketching work during this internship consisted of exploring various kinds of actuation technologies. In this, I was not necessarily interested in the latest technology per se—i.e. the fastest, smallest, latest, etc.—but more in seeing how different actuation technologies led to or contributed to particular haptic qualities. How does a voice-coil motor compare to a vibrotactile motor in the rendering of a simple signal? Can one discern or guess the type of actuator used based solely on perceptual cues? Does a particular kind of haptic quality fit with the Haptic Kinect initiative?

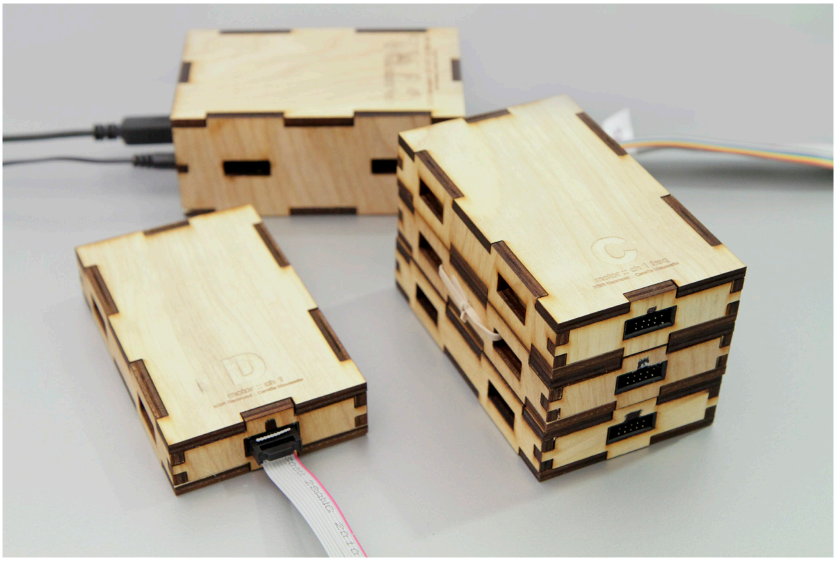


Figure 44: Controller box and various output units.

To compare the various actuators, a series of identical wooden boxes, which housed one actuator per box, was developed. I then developed a master controller box with a standard connector, so that each box could be swapped and changed quickly, without the need to reprogram the electronics (see figure 44).

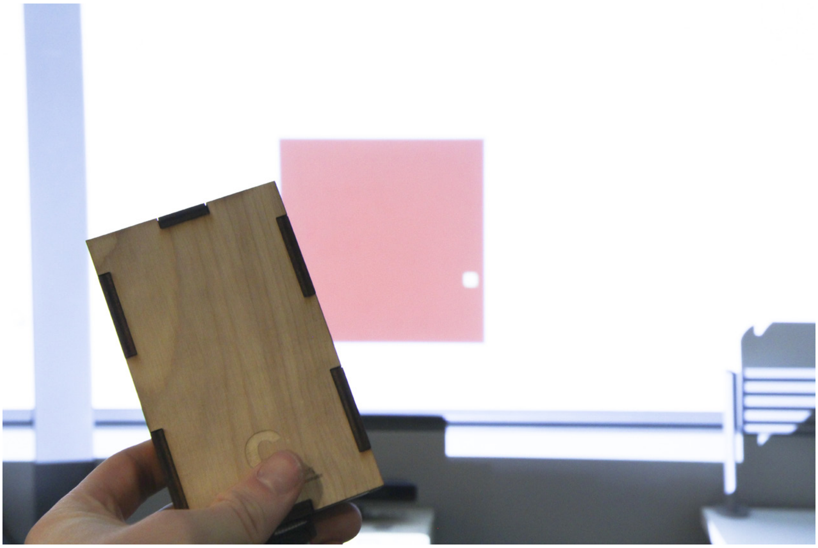


Figure 45: A cube is positioned is 3D space as a target. Entering and exiting the cube triggers a haptic hit.

To experience and compare the variety of haptic hit renderings, I built a simple virtual environment featuring one large single cube positioned in 3D space to act as a target zone. Movement of the box was shown on the screen using a small sphere grey dot (see figure 45). Upon entering or exiting the target zone — penetrating the cube object— a haptic hit was triggered along with the change of color of cube (from green to red). This configuration allowed testing of haptic hits in all three axes easily. Below, I present five of these boxes and detail how they feel when used with the interface described.

This haptic sketch uses a solenoid to strike the inside of the box. If the actuation power is low, the hit can only be perceived on one side panel, the side where the mechanical hit is located, something along the lines of a knock on the door. With an increase in power, the strike is strong enough to propagate throughout the whole box. The signal is then very sharp and energetic and characteristic of a piece of metal hitting a plank of wood. As the power of the strike increases, so does its audible presence as well. There is no perceivable shape change of the box, but the strike resembles a light jolt in the hand of the user, an experience close to the ratchet mechanism found in various hand tools. There is no acceleration or deceleration perceived, just a distinct *TAK*. Any recoil action is barely recognizable, probably due to masking from the initial blow.

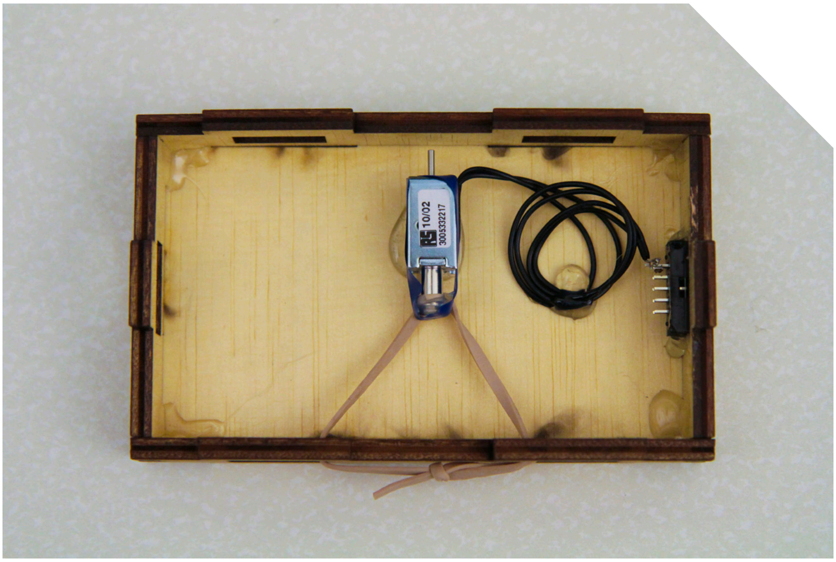


Figure 46: The Knocker.

Using a sound engineer's vocabulary, one could say that the attack and release are short, with very fast decay. It truly feels like a short and sudden square wave impact, an intense mechanical poke. Considering the frequency dynamics from typical impact strikes (Kuchenbecker, 2006; Kuchenbecker, Fiene, & Niemeyer, 2006), we note that the decay is indeed very short, but still does contain some high-frequency components. While we do not directly recognize those high-frequency signals, they are crucial in our perception of contact actions.

## THE VIBRATOR

*The Vibrator* unit uses a vibrotactile motor, which is commonly found in mobile phones. The technology is simple: it consists of a tiny motor with an off-centered weight on its rotating shaft. When the off-centered mass starts spinning we get vibration as a result. This type of actuator requires some spin-up and spin-down time—about 100 ms for each according to the literature (Niwa, Yanagida, Noma, Hosaka, & Kume, 2004)—so its potential for haptic output is definitely not sharp and direct. The ramping is perceivable and thus affects the resolution of haptic stimuli. While the vibration is very clear and recognizable, extended use can result in numbness and reduced sensitivity, as documented in (Luk et al., 2006).

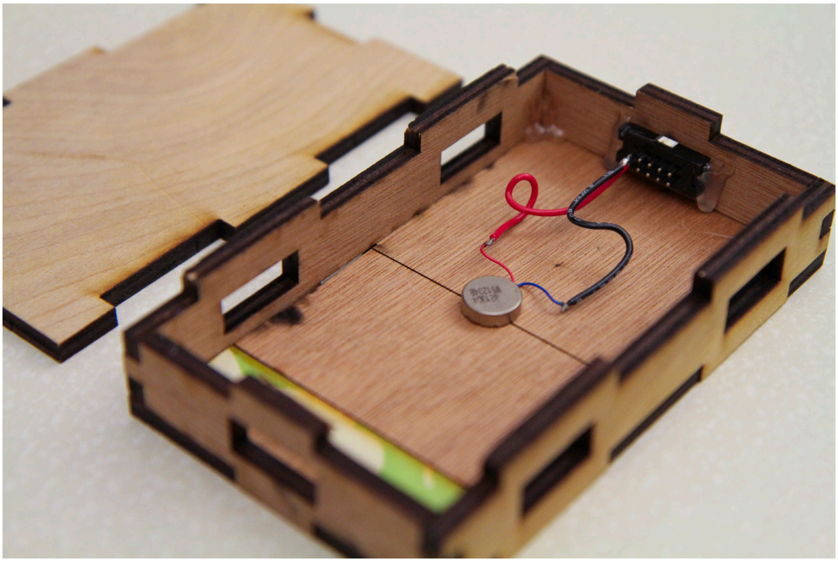


Figure 47: The Vibrator.

Vibration also relates directly to sound, and both are easily modulated across a wide range of frequencies. A vibration at 50 Hz feels very different than one at 300 Hz—50 Hz is numbingly pleasant while 300 Hz is more like intense rubbing. To use the sound engineer's vocabulary again, both the attack and the release are significantly long, with slow or no decay. Vibration, by definition, is cyclic and thus should be sustained or prolonged in time.

Overall, I found the use of vibration to render hits and notches to be problematic. The haptic outputs get scattered and dispersed over time, making it hard to recognize its onset and ending. Vocalized, it could sound like: *ffwWEZZZZZZEeeii*. On the other hand, vibration disperses amazingly well across different materials; it can be perceived independent of the grasp coverage or position, and will conduct through extra layers of materials.

## THE BUZZER

*The Buzzer* haptic sketch operates on a modified small audio speaker. Audio speakers are actually voice-coil actuators that are finely tuned to generate audible signals. The air compression waves result from movement of the speaker cone. By adding a substantial mass to the speaker, it moves more slowly but with greater momentum, thus generating movement perceivable in the haptic domain. Such alteration is deemed the typical 'poor man's haptic actuator'.

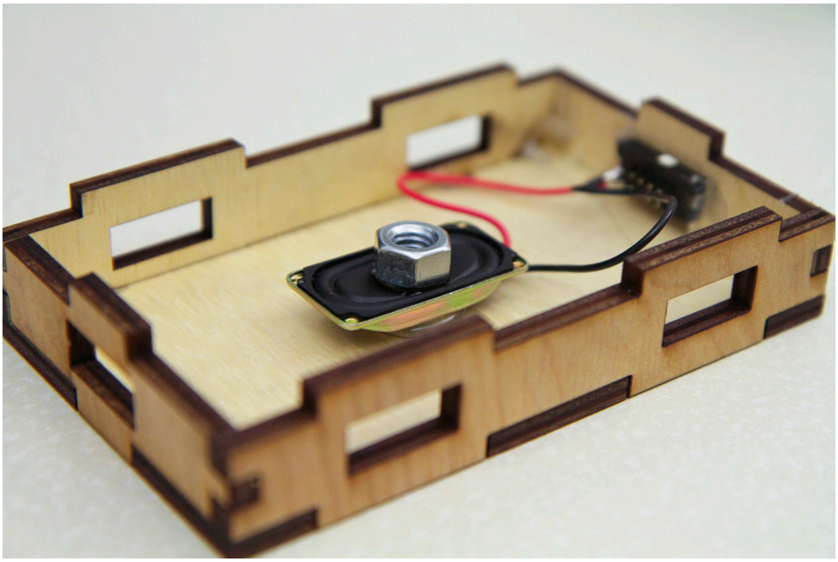


Figure 48: The Buzzer.

From my experiments, I found that the most interesting outcome of this kind of setup is the *buzzing* qualities. In my view, *buzzing* is a particular type of vibration. It is at the inflection point between haptics and audio: a fast vibration that *bleeds* audio. From my testing, I found buzzing to roam in between 400 and 1000 Hz. Also, *humming* is similar to buzzing, but humming may be defined as a more diminished form of buzzing, in intensity or speed.

The main haptic characteristic of The Buzzer is an initial small kick sustained by buzzing. The buzzing occurs during a rather short period of time before the device goes back to its default state. The buzzing sequence really communicates that there is energy going through the actuator, and that it is trying its best to convert it to mechanical movement. It cannot do it completely however and the excess energy then comes out as sound. This is a bit like a miniature microwave oven, where visually nothing happen, but internally stuff is agitated and energized.

## THE THUMPER

*The Thumper* uses a voice-coil actuator, much like the buzzer, but this time the actuator is purposely built to generate haptic stimuli. The actuator is a Haptuator from TactileLabs and can produce up to 3G of acceleration ("Haptuator," n.d.).

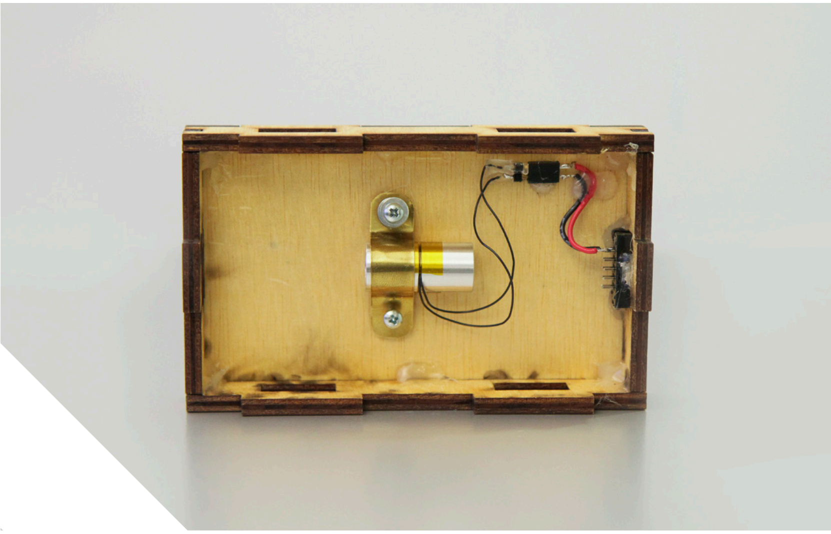


Figure 49: The Thumper.

The Thumper produces the strongest haptic feedback of all units. The actuation is fast, decisive, and has substantial depth. It does not have the percussive quality of The Knocker but still provides a perceivable tug along one axis. I associated the sensation as if somebody would be in handshake position with you and would momentarily pull back 2-3 centimeters. It is a controlled but relatively strong jerking sensation considering the rather small size of the box. The sensation is cleanly haptical—without any audio noise—and can be related to a small thumping piston action.

Using a sound engineer's vocabulary, the attack and release are rapid, but not as fast as The Knocker. The onset and end parts of the haptic sensation are slightly muffled or dampened. The amplitude of the sensation is also an order of magnitude stronger than that of The Buzzer.

## THE COMBO

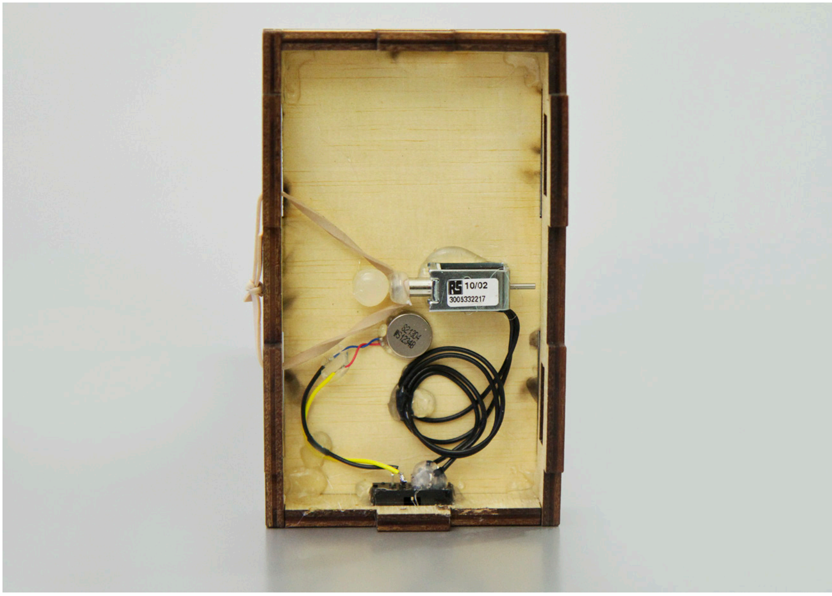


Figure 50: The Combo: Knocker + Vibrator.

The last hardware sketch of the handheld series is a combination of two previous units: The Knocker and The Vibrator. *The Combo* was meant to explore target acquisition procedures in a slightly more delicate manner than just providing a binary state, i.e. on target versus off target. In one configuration, vibration was used as a proximity signal, where within a particular distance of the target, the vibration increases as you move closer to it, and the knock signal was triggered as you reached the target.

I had my hopes up for The Combo, thinking that the additional bandwidth of the signal would provide a richer interaction experience. In practice though, the haptic sensation was not that great. At very slow speeds, it was possible to discern the increasing vibration stimulus, but at more normal speed (such as general gestural action), the vibration signal came too late and ended up being convoluted with the hit stimuli. The problem of the exit route was confusing as well. Upon leaving or going through the virtual target, after the sharp hit, the vibration would pick up strongly and decrease again. Was it due to a new target that was very close or was it just ghosting from the trivial code I had made? To overcome this, I started adding rules to limit the signal to only one particular direction, but border conditions were still confusing. Homing in on target—a succession of forward and reverse around a target—would generate a mixed signal that was hard to comprehend. While I could still see the potential usefulness of rich and complex stimuli sequences, the mapping and link to the interfaces would have to be elaborated much more.

Without much surprise, the perceptual haptic qualities of The Combo sketch are more or less the composite of the individual attributes of The Knocker and The Vibrator. The sum of the two provides clear additional interaction capabilities, but also points out some limitations. For instance, The Vibrator's slow reaction time feels even slower when matched against the sharpness of The Knocker. On its own, The Vibrator is slow, but only relatively so. One becomes used to it too, if it is the only stimulus available. Yet, when having The Knocker as a direct and constant point of reference, it feels very slow. Here, there is not really any room for adaption or acclimatization, it is just plain slow. Ideally, the approaching sequence should be a build up of vibration that ends with a sharp end hit, with minimal reverberation after the collision. In reality, the vibration was still spinning down well after The Knocker hit. The inability to stop the vibration quickly is a technical issue, but in the end it impacts the cleanliness of the haptic sensation and its intelligibility.

The Combo sketch highlighted the fact that combining two simple entities yields interaction design capabilities much more complex than the sum of its parts. There are benefits to this but also trade-offs, and finding an optimal balance is not trivial.

## 2.3.5 WEARABLE HAPTIC SKETCHES

In addition to developing the handheld theme, I speculated that a system like the Kinect would be particularly well suited for haptic feedback systems that went beyond the one-handed grasp configuration. Developing a few wearable hardware sketches seemed appropriate in order to match the strong whole-body interaction model embraced by the Kinect.

As discussed in part 1, wearable systems with strong haptic qualities such as exoskeletons and body-worn haptic devices have been in development for decades. My interest in this area was to focus on much simpler interfaces using basic technologies, except for the Kinect system itself, and explore different contact positions. For simplicity and reuse, I decided to keep the larger hand region as my work canvas. The hand has also received considerable optimization in the tracking algorithms of the Kinect system, so the tracking data is more stable and coherent than for instance the knee joint. Consequently, I restricted my wearable haptic sketches to areas around the hand, from the elbow down to the fingertips. Again, this design constraint was chosen based on intuition and on the grounds of design efficiency, where I sought to find ways to maximizing the number of design explorations in light of the available resources, including time.

The wearable track of sketches was far more crafty and sketchy than the boxes series. I tested numerous configurations of gloves, wristbands, rings, and armbands, all outfitted with various actuators. Below, the glove and wristband sketches are first presented before focusing on what turned out to be the most compelling proposal of the lot, namely an in-between fingers brace configuration.

Most of the wearable haptics sketches were developed using tethered (i.e. wired) electronics, thus subtly limiting and restricting the wearable aspect of the system. While using these cables was an obvious nuisance in a controller-free gestural system, it greatly simplified the technical development of the hardware sketches.

## THE GLOVES

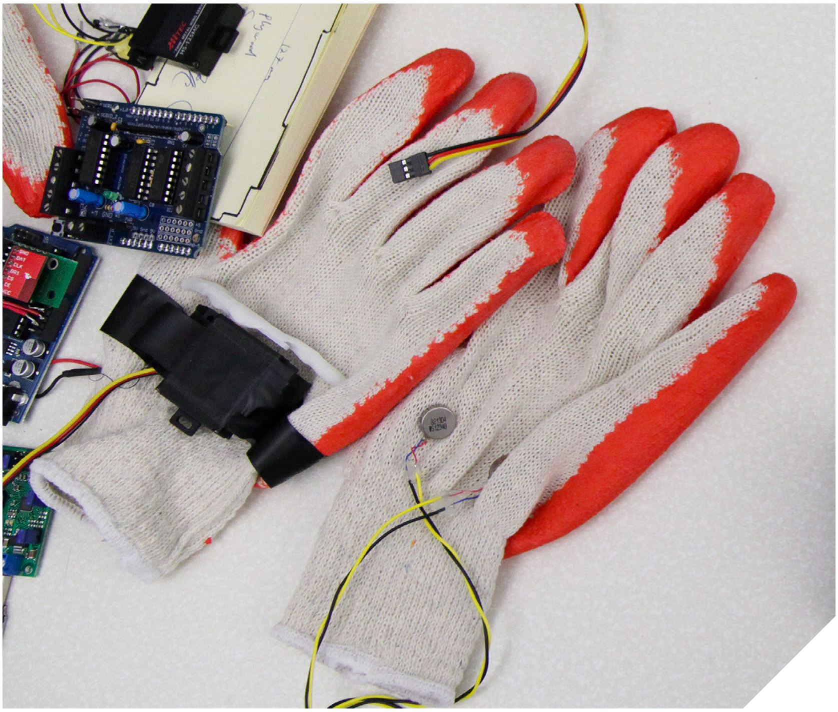


Figure 51: Gloves fitted with actuators.

The series of wearable haptics sketches started with a pair of gloves because they were very easy to obtain and work with. A quick visit to the workshop gave me a whole set of different materials and textures to work it: latex, woven fabric, oven mittens, etc. I started attaching and gluing servos and other actuators to the gloves, on the top of fingers, and on the sides of the hands. For some explorations, I built little extension arms for tapping and poking on different sides of the gloves, a simplified version inspired by the work of Lahtinen around haptices and haptemes (Lahtinen, 2008).

The results were far from interesting however. The haptic sensations were rarely clear and could not be properly localized. In most situations the haptic stimulus was strongest at the point of attachment of the actuator, not where it was poking or touching. The vibration-based sketches were more successfully, but the signal was often weak or altered due to the thickness of the glove and how tightly the glove fit over the hand. The extra material layer in between the actuator and the skin also impeded the haptic stimuli, where it, at best, made it inconsistent. Inserting the actuators inside the glove improved the situation, but rigid wires and connectors in themselves then became sources of haptic stimuli as much as the actual actuators, and any pressure points or uneven pressure distribution would disturb the intended haptic stimuli.

In summary, the glove-based wearable sketches did not produce interesting results at all. The haptic sensations were not consistent, making each sketch capricious. The main value they eventually provided was the realization that quality haptic signals are best experienced in direct contact with the skin and any intermediary material impedes on the haptic stimuli.

## THE WRISTBAND

The wristband series of hardware sketches were produced to quickly explore directional cueing using the natural shape configuration of the arm. The most complete version had four vibrotactile motors glued and sewed on the inside of a sweat wristband. This haptic wristband sketch is partly inspired by work from Oakley, Tan & Matscheko (Matscheko, Ferscha, Riener, & Lehner, 2010), but the resolution in my version is limited to four orientations. The vibrotactile motors (tactors) were located in the top, bottom, left, and right position of the wristband.

The haptic stimuli were clearly perceivable under long (over 200 ms) periods of actuation time. Depending on the actuation power, the sensation was more or less numbing. The main design issue resided in the more or less always alternating orientation of the wrist in space. The up motor, located on one side of the wrist, can point directly to the front, to the side, or upward all depending on the position of the user's arm. This makes it quite difficulty to accurately convey an overall pattern for front and back cueing. A selection of sensors could possibly be used to mitigate this issue, but the design then becomes fairly complex.

Ignoring the small wires, using the wristband was actually very comfortable. The most problematic step resided in the placing of the wearable unit. Great care was needed to have the tactors in good contact with the skin: not too tight, but not too loose either. While this was not a major problem for impromptu experiment-like tryouts, I imagine it might be detrimental in an everyday usage scenario.

## THE IN-BETWEEN FINGER BRACES

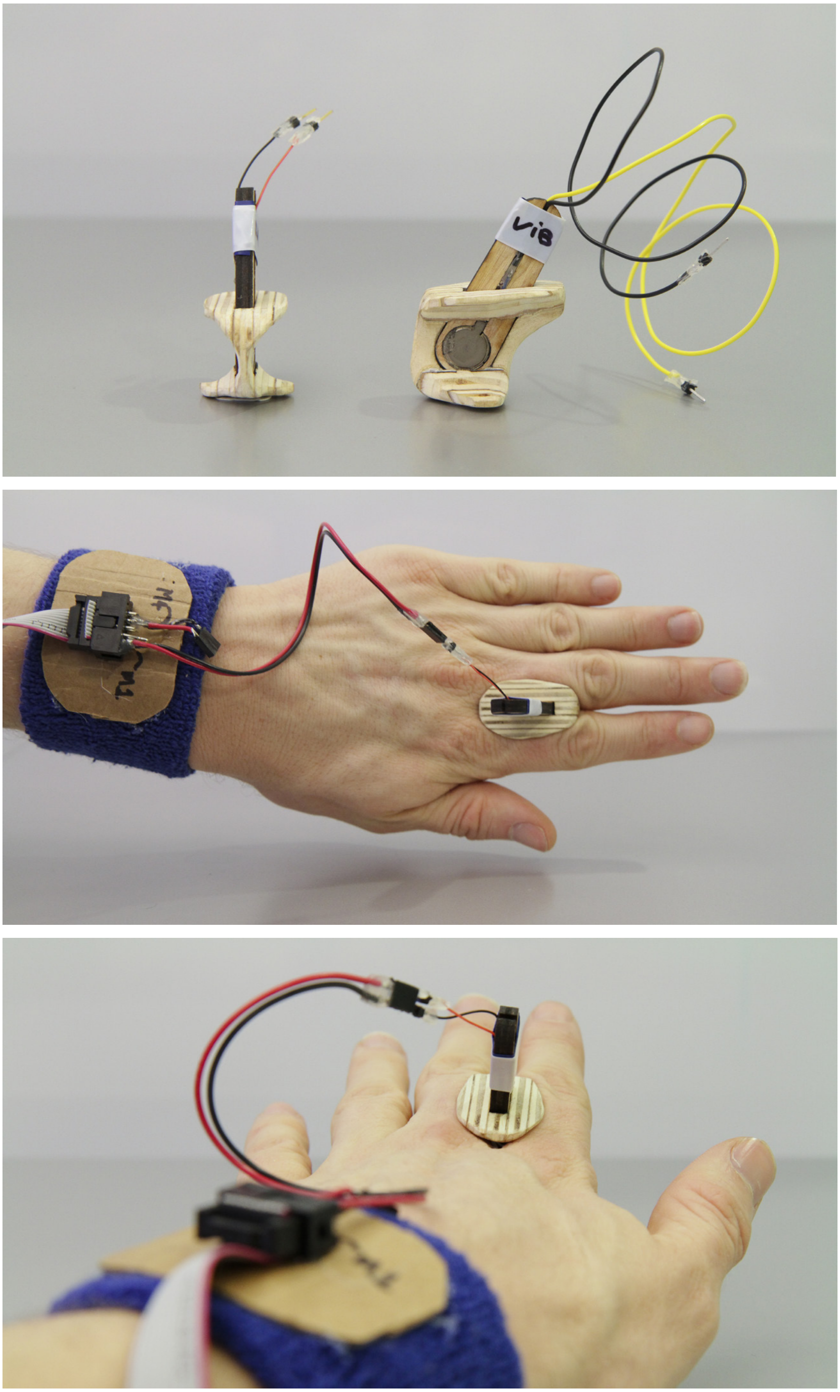


Figure 52: In-between finger haptic module.

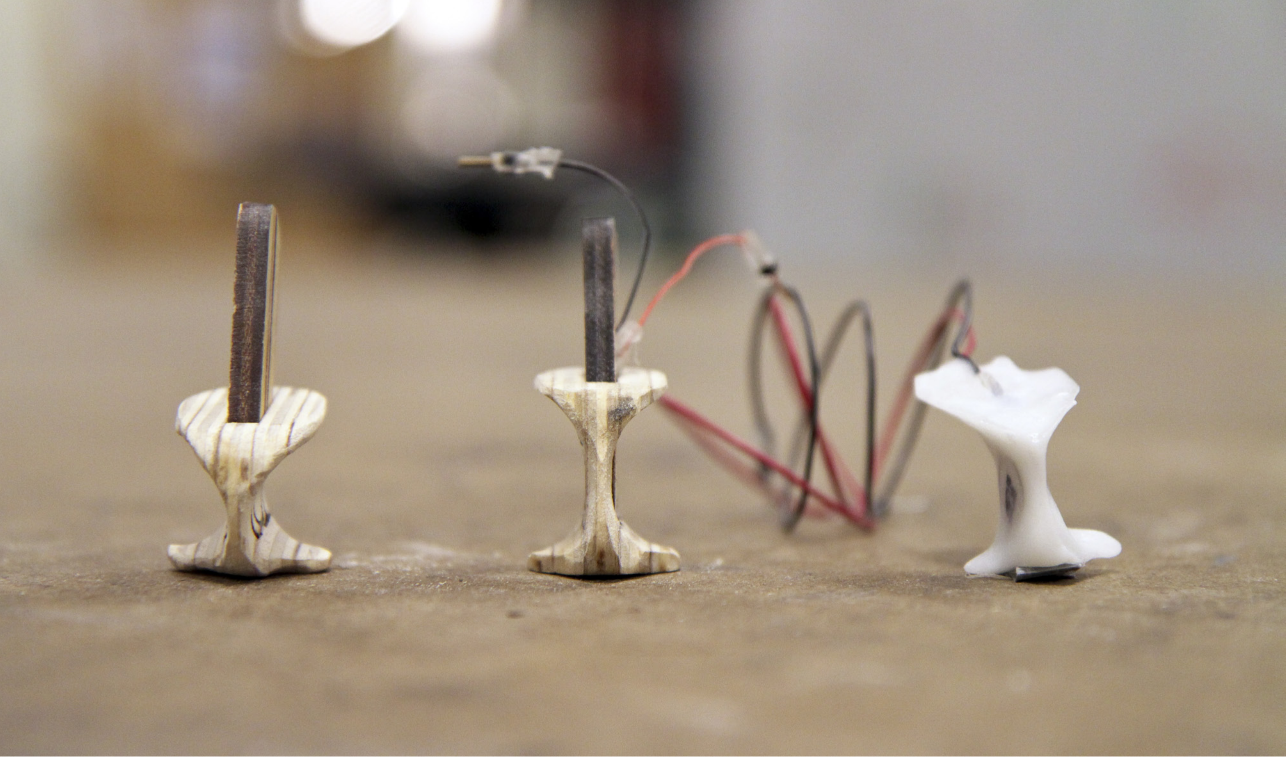


Figure 53: Various models of the braces. At the right, an early variation using Polymorph, an easy-to-shape plastic.

After the interesting, but generally failing attempts with the gloves and wristband, I ventured on to exploring more organic, almost bone-like wearable bracelets and rings. These explorations were realized using a material called Polymorph, which is a low temperature melting plastic that provides enough structural integrity to attach motors and actuators to it.

Among the many sketches produced using this material, one stood out during testing. This unit consisted of a vibrotactile motor encased in plastic to be placed between two fingers. The resulting haptic sensations tickled and titillated, but I was not sure exactly why. It turned out to be a pleasant, subtle but fully unique and unmistakable sensation. Due to its location very near the extremities, the sensation extends to and works well with pointing gestures and actions, to a point where it almost feels as if there is a tool that is extending beyond the fingers of the user.

In order to investigate this rather remarkable haptical sensation further, I build a series of wooden versions where I could take command over and change the actuators more easily. I also developed different sizes so that I could test them with different hand sizes and different finger combinations. Another interesting aspect of the braces is that they did not require the user to actively hold them to stay in place; a fully relaxed hand posture would not result in unintended release of the device.

Eventually, two final braces-style sketches were refined, one with a linear resonator actuator (LRA) and one with a vibrotactile motor. The LRA unit was a voice coil mounted on a tiny flexible structure, a bit like the Haptuator device but smaller. The haptic qualities of this sketch are relatively strong and distinct for its size. The feeling it recalls is that of small mechanical detents. Another reference would be the first generation of the Apple iPod and its mechanical scroll wheel, where the notches are small but unavoidable. The vibrotactile version turned out less enticing, since it becomes very weak in fast configuration mode, where spin-up is directly followed by spin-down without reaching its full speed. The evasive signal this produces cannot match the full interactive refresh rate of the system.

Using the LRA brace with Kinect feels special. The device feels properly balanced, precise, and allows for a very comfortable interaction. It does not require any gripping force or active attention to operate on the part of the user, rather it just sits where it is and almost evades attention. Through the Kinect system, it is able to respond quickly to gestures, as if the tracked space were full of invisible fireflies, resulting in tiny electro mechanic jolts as one browses through this energized cloud.

Yet the system is far from perfect: the in-between braces do not provide satisfactory directional cues and the actuators, both for the LRA and tactor versions, have parts moving in particular directions that are not perceivable, and the haptic stimuli is still binary. Still, the LRA brace just feels right, humane, and a very appropriate addition to the gestural interaction activities that carried out.

## 2.3.6 TAKEAWAYS

Figure 54: Haptic Kinect setup: the Kinect unit on the left (near the wall), a video projector to display the UI, and me gesturing and testing the haptic box on the right.

This second period at Microsoft Research was in many ways different from my first internship, but at its core, the rationale stayed the same: how to go about designing haptics? What the Haptic Kinect work set out to do and to some extent accomplished needs to be recognized as explorative design research activities, not as technological advances. The path was primarily one of discovery and opportunity seeking. The dozen or so devices I have described from this period are knowingly unrefined and crude, but notwithstanding their somewhat primitive nature, they are traces of incessant reflections on the merge of haptics and interaction design.

Returning to my initial hypothesis for Haptic Kinect project, what are the main outcomes and takeaways of this work? Did I end up finding that 'sweet spot' I set out to look for? From the work presented above, I find it difficult to affirm that yes, I uncovered the perfect haptic solution for the Kinect, as this claim would obviously be greatly exaggerated. Nonetheless, my work did successfully identify a few key aspects for considering the role of haptics in a future Kinect system. Out of the whole bag of possibilities, I was able pinpoint some areas and directions likely to be more interesting and feasible than others. For the rest of this chapter, some of these 'hot spots' or considerations worth further exploration are described and discussed. This discussion will ultimately lead to the presentation of my *Z-depth detents* concept; a haptic interface idea that became the most compelling result of this internship.

## LATENCY CONSIDERATION

The principal guideline for haptics is generally 'faster is better' and best practices from haptics research recommend a value of 1000 Hz for the haptic rendering loop, as discussed earlier. Most of my haptic explorations did not match this low latency target for many reasons, i.e. that the Kinect system runs at a maximum of 30 frames per second; some actuators have a low response time; my coding was not optimized; etc. The net result was a number of haptic sketches with varying degrees of latency. What seems particular important however was to fine-tune the apparent (or experienced) latency, not so much the real (measurable) latency value.

At the end of the day, it seemed possible to have engaging haptic experiences despite latency values as high as 150 ms for the haptic channel. Relying on audio and visual cues that are relatively fast (between 5 and 30 ms) reduced the *apparent* latency of the haptic cue to something that felt adequate and acceptable. According to this, the concern of 'faster is better' should perhaps be adapted to 'apparently fast is good enough'.

## DIRECTIONAL CUES ARE DIFFICULT

The Kinect is a whole-body gestural tracking system with previously unheard of capabilities, but it still falls a bit short on recognizing fine-grained hand positions and orientations. In its current state, it does not provide enough resolution to develop interactions based on orientation of the hand, finger positions, or finger gestures. We as humans are very sensitive to those fine details, but the Kinect is not.

During my exploration of directional cues, I constantly bumped into the issue of not knowing the exact orientation of the hand in absolute terms. This proved important, because if one wants to generate stimuli on for instance the right side of the hand, one has to know the orientation of the hand. Without adding inertia measurement unit (IMU) sensors, it seems very difficult to do directional cueing properly. The solution I arrived at was to abandon full directional cueing altogether and instead focus on position data for developing haptic interactions. With this approach, the haptic signal would be triggered by the position of the hand regardless of its orientation. This of course reduces the number of possible interactions, but also results in a system that is more robust, forgiving, and a lot less finicky.

## CHARACTERISTICS OF THE STIMULI

Simply put, designing haptics can be framed as answering three main questions:

**a**) When or at which moment should haptic feedback arise?
**b**) Where should the haptic stimulation meet the human body?
**c**) What is the proper composition of the haptic signal?

In my work, I have found the third item particularly exciting to explore. The composition of the signal, its bandwidth and characteristics, is really up to the designer to define and argue for its appropriateness. My intention was to start simple, with just one bit of information—hit or contact—and explore how far it could be used for various interactions. Technically, the signal might be one bit only, but in its physical and tangible existence over time, it suddenly acquires a wide range of attributes that need to be design with and for. As detailed in section 2.3.4, a simple hit can be experienced in many ways, e.g. as strong, weak, sharp, gentle, etc.

The two mains aspects of the haptic stimuli I concentrated on within the Haptic Kinect project were strength and sharpness. Here, strength denotes a strong or less strong sensation. A powerful haptic stimulus will be very easy to perceive initially, but can become uncomfortable or even indiscernible in repeated form. Extended use requires the right modulation of the strength, i.e. strong enough so the signal is detected, but not too strong so that it creates discomfort over time.

Sharpness of the haptic stimuli relates to how concise the haptic sensation is; a sharp and short stimuli support larger bandwidth over time. Each actuation technology has limitations regarding its capability to physically move in response to a trigger. The controlling signal might be very sharp and precise, but the real world haptic sensation might be slow and mushy. Dealing with sharpness is, however, often more of a hardware issue than a control problem, and understanding how and where a haptics system can be more or less sharp is a very interesting interaction design issue. Harnessing the richness of haptics is largely a tradeoff business, as the temporal resolution of our touch sense is very high, but firing a fast sequence of haptic stimuli is not necessarily useful or pleasant. The haptic stimuli have to be designed, perceived, and assimilated into meaningful sensations, not unlike the intricate relationship between music and sound.

Overall, most of my work during the project tackled rather simple haptic stimuli. In reality, a much larger design space exists for more complex haptic sequences. I had neither the time nor the resources to explore more complex signals, exploiting proximity, direction, response time, and other variables of the interaction. Such compounded and complex signals could very well support new interaction techniques in sync with the Kinect system.

## ABSOLUTE POSITIONING IN 3D SPACE IS CHALLENGING

During the evaluation of my haptic sketches, which consisted of self-testing and informal tryout sessions with colleagues, I became aware of the human difficulty involved in precisely targeting and holding on to a particular position in 3D space, even with the help of visual cues. The interface designers of many Kinect games make frequent use of *dwell time* for selection and confirmation, but this action is quite prone to drifting. For 3D positioning, the visual feedback is effectively 2D (or sometimes in simulated 3D, using some kind of faked perspective or other projection deformation method) while the physical, real space in front of the user is of course actual 3D. This mismatch is well known if many fields like Virtual Reality (VR), tele-operation, and gaming (Burdea, 1996; Stanney, 2002).

We as humans have a heightened sense of the position of our limbs (called proprioception), but only from a body-centric frame of reference. Adapting action and gestures for absolute spatial positioning also requires visual cues. With the Kinect, the visual feedback for movement along the X and Y dimensions is fairly obvious and straightforward. Depending on the display size, it can even correspond to a 1:1 mapping, i.e. if one moves one's right hand 30 cm to the right, one perceives a corresponding visual change on the display. For the depth information, such feedback becomes much less direct, as the visual appreciation of the Z-axis movement on the screen is still in 2D and thus much more dependent on the representational qualities of the visual feedback. This often entails that the mapping of Z-axis movement to visual depth cues becomes arbitrary, heavily distorted, or rely on one or more metaphors that may or may not be shared between the designer and the user.

The limited depth information provided by the visual interface was identified as an opportunity for haptic feedback. The following section presents a suggestion for a solution to rectify this issue that was devised and worked on during my second internship at Microsoft Research.

### 2.3.7 THE Z-DEPTH DETENTS CONCEPT

The Z-depth detents concept aims to support spatial movement in 3D space. It involves conceptually slicing the working space along the z-axis (which here is the space between the user and the Kinect device) at regular intervals. Those virtual markers are used to generate haptic feedback. As one moves towards or away for the Kinect, breaking through the various zones, haptic stimuli are generated. Such haptic depth cues might be compared to the scroll wheel detents on a computer mouse, subtle but always present.

After implementing a first haptics sketch of this interface and being able to try it out, it immediately felt just right. The haptic notches were somehow able to quantify the z-space in front of you rather effectively, allowing an eye-free appreciation and understanding of z-movements and the speed of those movements. On its own, a single notch did not provide that much information, but taken together, as a sequence, the notches conveyed a lot more information. It was suddenly easy to recognize the amplitude, speed of movement, and location along the z-axis.

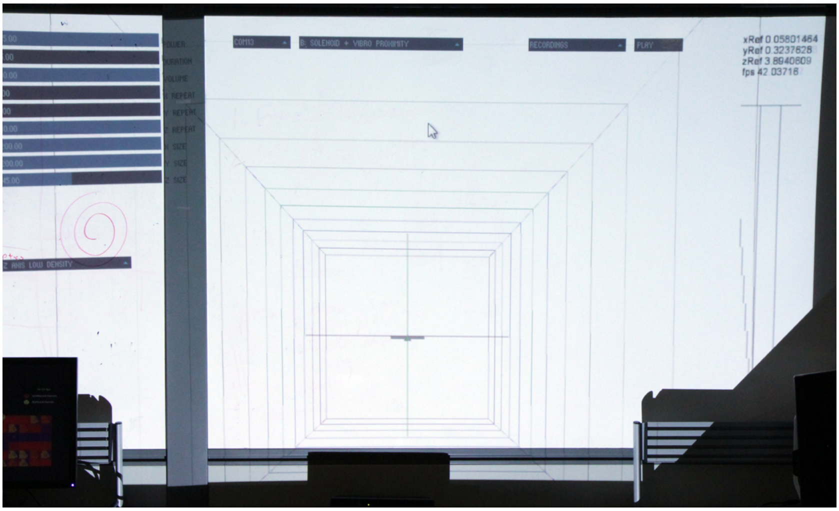


Figure 55: Z-axis slicing with haptic notches.

The Z-haptic scrolling concept was ideated, developed, and tried during the last two weeks of my second internship. This meant I did not have the time then and there to investigate its usefulness with a particular interaction model, a specific task, or any other form of structured test. During the short, informal in-house test sessions I ran with my colleagues at Microsoft Research, everyone appreciated its subtle but unequivocal haptic feedback, especially when combined with The Thumper and the In-between Fingers LRA Brace. Nobody could, however, clearly articulate why it felt so appropriate and likeable, but everyone felt it was somehow well balanced.

## 2.3.8 WORKING STRATEGIES

As in chapter 2.2.7, I will now present and discuss the *working strategies* that surfaced during my work with Haptic Kinect, i.e. the second internship period at Microsoft Research. These working strategies were elaborated during the internship period, and as such, they are not afterthoughts or retrospective reflections. Hence they are principally discussed here and not in the final part of the thesis, although I will return to these strategies in the last part of the thesis for additional discussion. These strategies thus constitute my way of recognizing a few particular problems, approaches, and tentative solutions that came to guide my haptic design explorations.

Right from the start, I knew that I would be working with a Kinect sensor as a key design ingredient throughout the study. Getting one to actually work though proved surprisingly difficult. First, the device was so popular at this time, as it had just been publicly released, that the availability of the modules was very low for weeks, even for employees at Microsoft. Second, actually doing something with the Kinect at that time (which has changed a lot since then, with the arrival of the Kinect for Windows software development kit) required a dedicated Xbox development kit and a suite of corresponding proprietary software. In the end, it took about four weeks of work just to get my Kinect and computer system up and running so I could actually start to work.

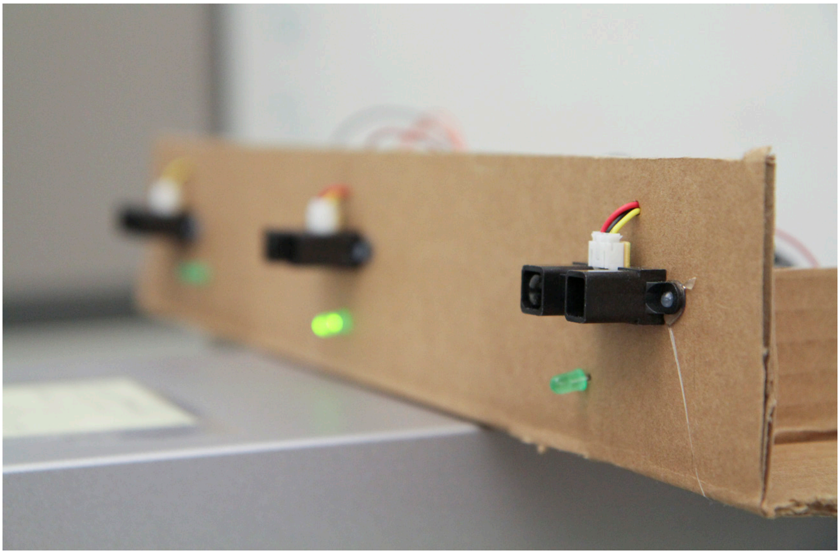


Figure 56: Cardboard stand-in sensing unit.

To mitigate the situation, I started building a simple stand-in rig that would allow me to begin designing haptics sketches even without an up-and-running Kinect system. For this rig, I used a cardboard frame with distance sensors that would generate some data that were similar to the data I was most interested in getting out of the Kinect and Xbox combo setup, i.e. to track the hand's position in space. The simple cardboard prop gave me three zones of distance sensing data, with some crude yet working capabilities to recognize the position of one hand in space.

While the setup was rather clumsy, it provided enough real-time sensing data to drive the haptics interaction experimentations. It only took a half a day to build from scratch but it meant that I could sync haptic stimuli to real gestural movement, not made-up signals and triggers. Even with its extreme crudeness, that stand-in system was vital to my early haptics explorations in this project. When I finally managed to get the full Kinect and Xbox pipeline sorted, I already had code samples and interaction ideas ready for it.

## BUILD FOR INSTANT EXPERIENCE AND COMPARISON

One of the driving forces behind my haptic explorations has been the ability to directly tweak the haptic stimuli. As a designer, I find it crucial to be able to experience multiple alternatives before valuing and choosing one configuration over another. The idiom 'the devil is in the details' is not just a cliché; it is actually particularly relevant for haptic interaction design, as so many factors—personal, contextual, technical, and material—affect one's haptic experiences.

My approach to designing haptics has focused on developing hardware and software platforms in parallel for experimentation, where many settings and parameters are possible to adjust in use. For this purpose, I built a graphical user interface for the Haptic Kinect series of sketches which allows one to manipulate a large set of variables and parameters. Sliders, buttons, and menus expose a complex arrangement of options and settings that all come together to define the overall haptic experience. Additionally, the application has a collection of pre-defined configurations associated with specific haptic stimuli, making it possible to recall and collectively share optimized or just interesting arrangements or particular sensations.

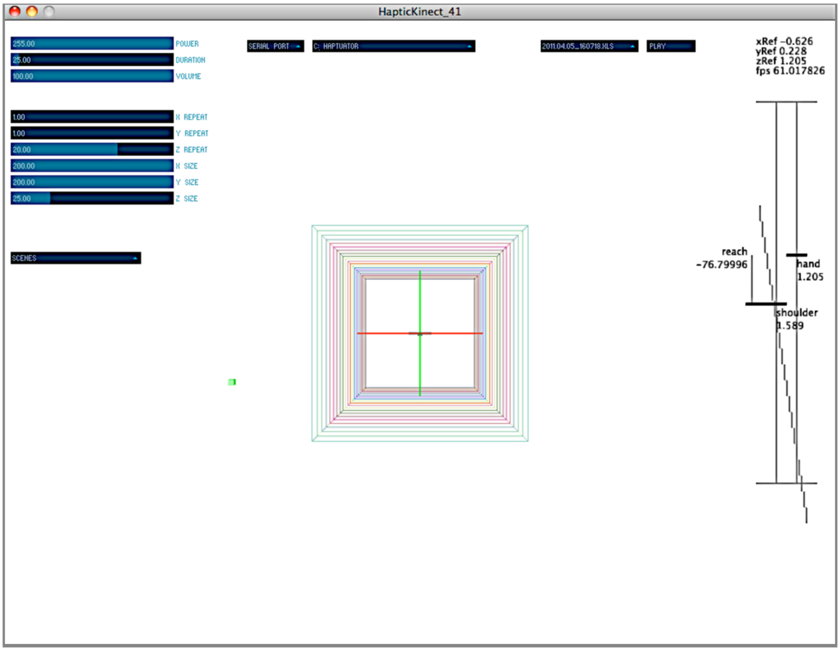



Figure 57: Graphical user interface for Haptic Kinect.

Likewise, it was important for me as a designer to allow this level of variability at *runtime,* and not just as a part of the programming code. Changes in haptics can thus be experienced quickly whilst holding a particular device, leading to a more transparent and understandable haptic design exploration. In the last iteration of the software, I also added the possibility of entering *rendering sequences* to specify the haptic rendering parameters. I came up with a simple text structure to represent a haptic rendering signal (i.e. how to drive the actuator) and scene configurations (i.e. how the 3D space is divided into targets and planes). For example, one part of the rendering phrase was coded as "CH_DIR_POWER_DUR", where entering "1_1_255_100" in the text box would result in: actuation on channel 1, in the forward direction, at full power for 100ms. Such a simple, custom-made text-based entry method made the whole system much quicker and more flexible to tweak for experienced users, including myself.

## A MODULAR SYSTEM WITH COMMON CONNECTORS

My previous experience with the actuated haptic boxes (in the previous Microsoft Research project) had a single controller per output box. For this second internship, I instead decided to opt for a modular system with just one main controller board for most of my output devices. The reasons for this were many: to reduce the number of electronic modules and the associated cost; to maximize the quantity of output devices; and to support hot-swapping of output devices for quick exploration.

The main route I chose for this involved using a common connector to link the controller board (an Arduino board with some additional electronics components) with the haptic units. I established my own standard layout and routing scheme for the signals I needed and wired all my boxes accordingly (see image 58).

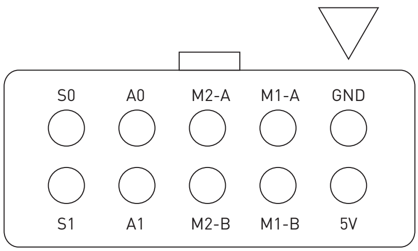



Figure 58: Custom 10-pin connector layout for all output units.

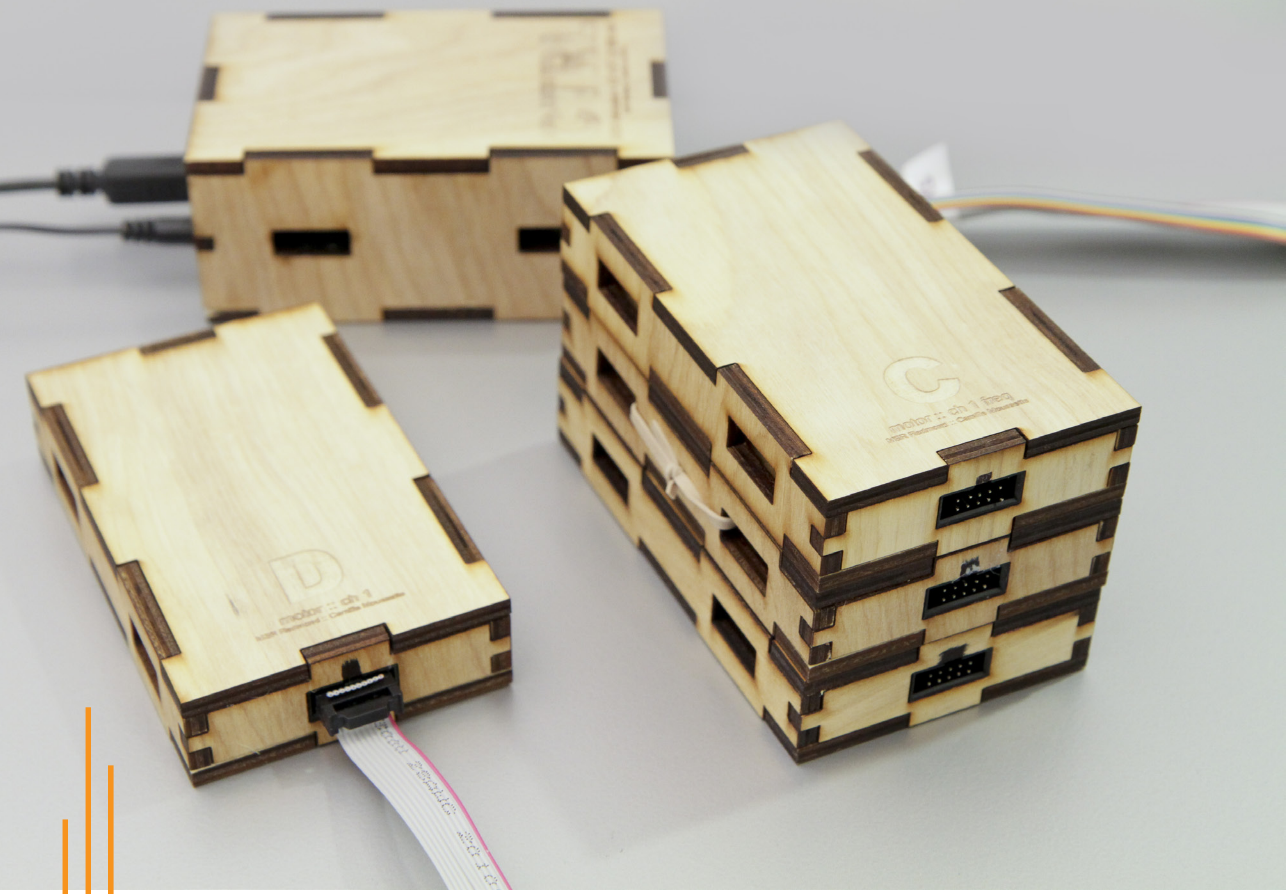



Figure 59: Boxes with modular connector.

Adopting such a modular approach required a bit of planning on my part and was at times a bit of an overkill for some of the units I produced, but in the long run this design decision turned out to be very beneficial. It meant that I could just unplug and plug in various output units and they would work directly. Some of the sketches were a bit more special though and I had to make a secondary cable for them, but I could still use the same connector. The software configuration was developed in accordance with the modular connector. Systematically using that connector made the swapping of units very quick, but it also resulted in functional advantages for adapting cable lengths and it also provided a level of failsafe-ness in case of inadvertently tripping on the cable. Finally, it also gave a more polished look to the whole system.

## HAPTICS ONLY FIRST, THEN ADD MODALITIES AS NEEDED AND APPROPRIATE

As previously stated, haptic interaction is multimodal in nature, while the Kinect system in connection with a Microsoft Xbox traditionally uses only audio and visual feedback in its interaction model. My approach to bringing haptics back into Kinect could either try to embrace that multimodality or ignore it and focus solely on the haptics. But if multiple modalities are taken into account, which one tends to get the most attention: haptics supported by audio and visual, or visual supporting haptics?

In this project, I initially chose to explore haptics for Kinect without the help of feedback in other modalities. For example, I started by modeling a virtual wall and established that movement crossing this wall would result in a haptic hit signal, similar to Magnusson & Rassmus-Gröhn (2008). That exploration felt rather awkward however, as if the haptic hit had come too late in the gesture, really far away for where I expected the virtual wall to be. While I knew that the Kinect system was introducing some degree of latency into the system, there was not much I could do about it. Having thought about this problem for a while, I decided to add an audio cue to support the haptic experience, in the form of a simple knock sound. The combination of audio and haptic cues made the whole experience a lot more coherent and well-timed, despite that I did nothing to change the latency issues introduced by the Kinect. Visual feedback was then added too in the form of a projected interface, much like a regular Kinect setup. The visual cues helped to further integrate the haptic auditory cues, which resulted in a well-balanced interface.

The conclusion of this strategy is that haptics on its own is somewhat limited and that everyday haptic experiences tend to span over many senses. Although multimodal cues are richer and more complete, it is nevertheless interesting to explore haptics in its purest form first, before adding cues from other modalities as needed or as deemed appropriate.

## HORIZONTAL EXPLORATION OF ACTUATION TECHNOLOGIES

As presented in chapter 2.3.4 above, I chose to explore how a set of different actuation technologies could render a simple hit signal. The goal of such a wide, 'horizontal' exploration of technologies was not necessarily to seek out every amazing new technical advance, my interest was rather in exploring if some haptic actuators have particular haptic signatures, profiles, or individual ‘characters’, making them directly identifiable and discernable. As haptics is heavily constrained by the progress in actuation technology, it felt appropriate to investigate how each technology is able to shape, support, or invariably taint haptic stimuli.

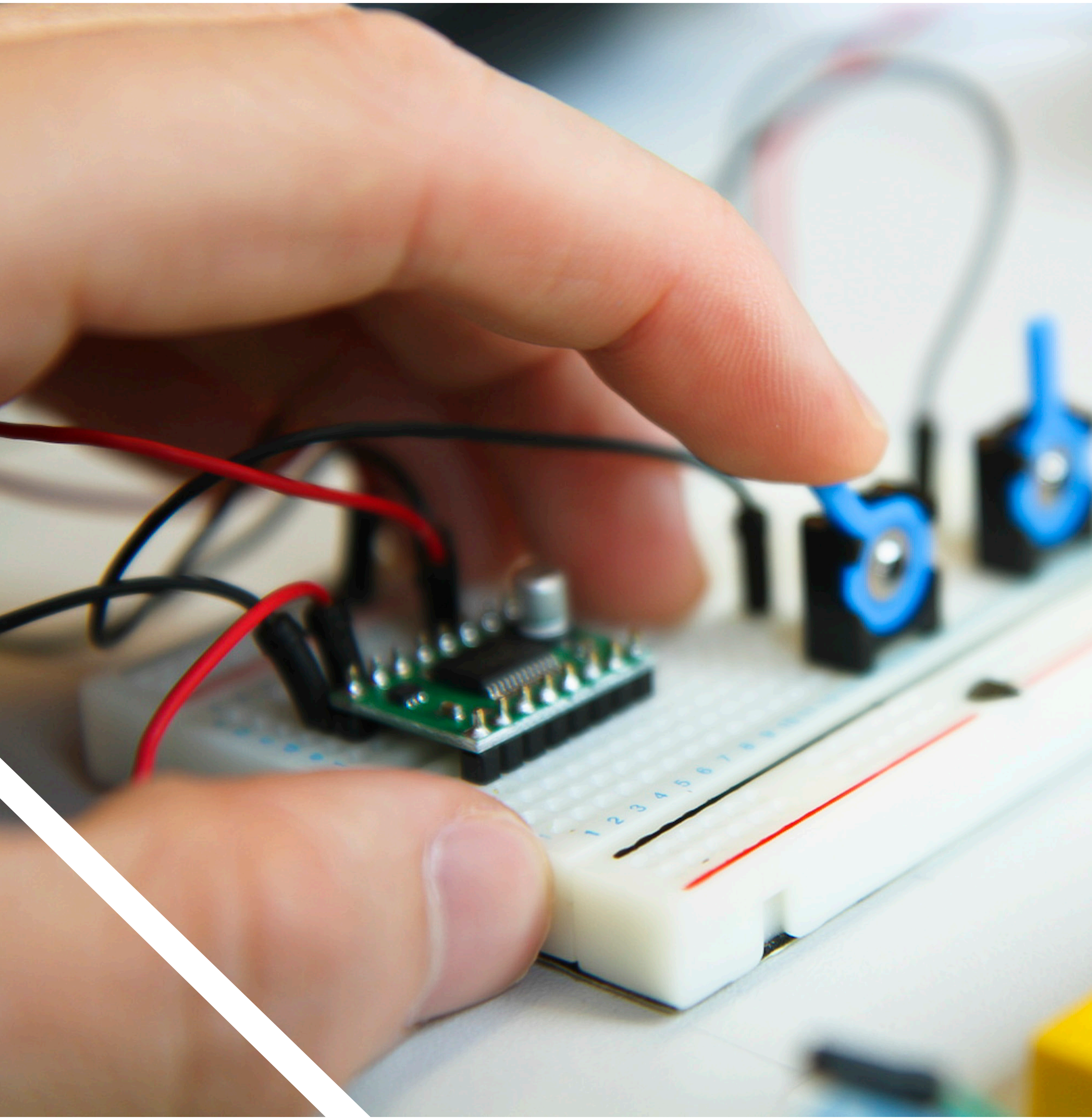
Such a characterization can be related to photo cameras: there are certain major visual qualities and an overall character that can be derived from an image taken with for instance either a polaroid camera; a 35mm film camera; or an early 2000s digital camera. They may all be made to depict the same visual subject, but the results are slightly altered depending on a rich array of subtle differences. The particular characters of each camera can be accounted for by an experienced photographer as well as being used proactively for achieving particular visual results.

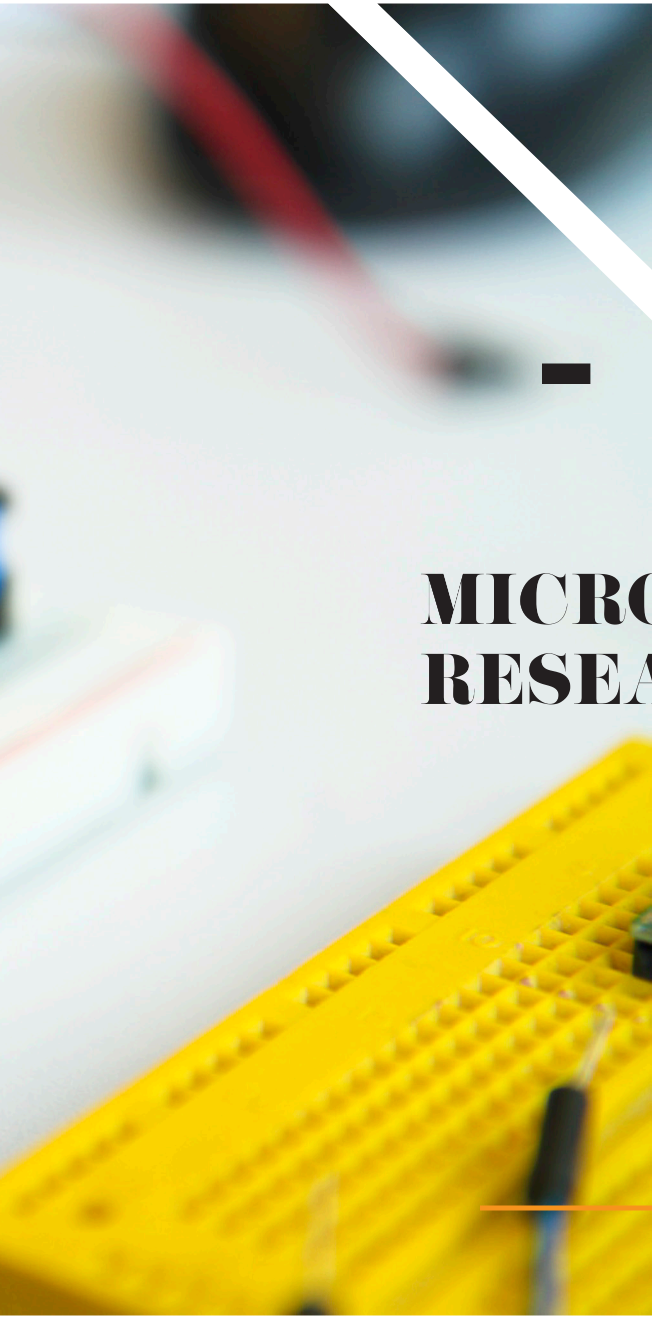
Knowing more about the underlying technology of haptics feedback allows for a more attentive design of haptic interfaces. By learning more about the available technologies in the area, a haptic interaction designer is better able to match particular sought-after haptic experiences with available technical solutions.

## 2.3.9 CONCLUSION

Overall, the work realized during this internship explored how haptic feedback could be used to augment a system like the Kinect, which is currently deprived of physical feedback capabilities. It has been argued that the relevance of haptic feedback is difficult if not impossible to assess without sketching or prototyping such feedback. The intention of building simple haptic interfaces proved quite challenging in the end, as the interfaces had to exist and link with other systems and modalities. My experience of tackling such complex work highlighted the problem that haptic interfaces are generally multimodal in nature. It revived the question: can one develop haptic ideas in isolation of the other modalities? Obviously the answer is no, although starting out with the haptic modality and adding others later instead of vice versa is an interesting approach. The unavoidable challenge thus consists of mitigating the external influences and considerations versus focusing exclusively on haptics. Achieving a fine balance in that quest is very tricky.

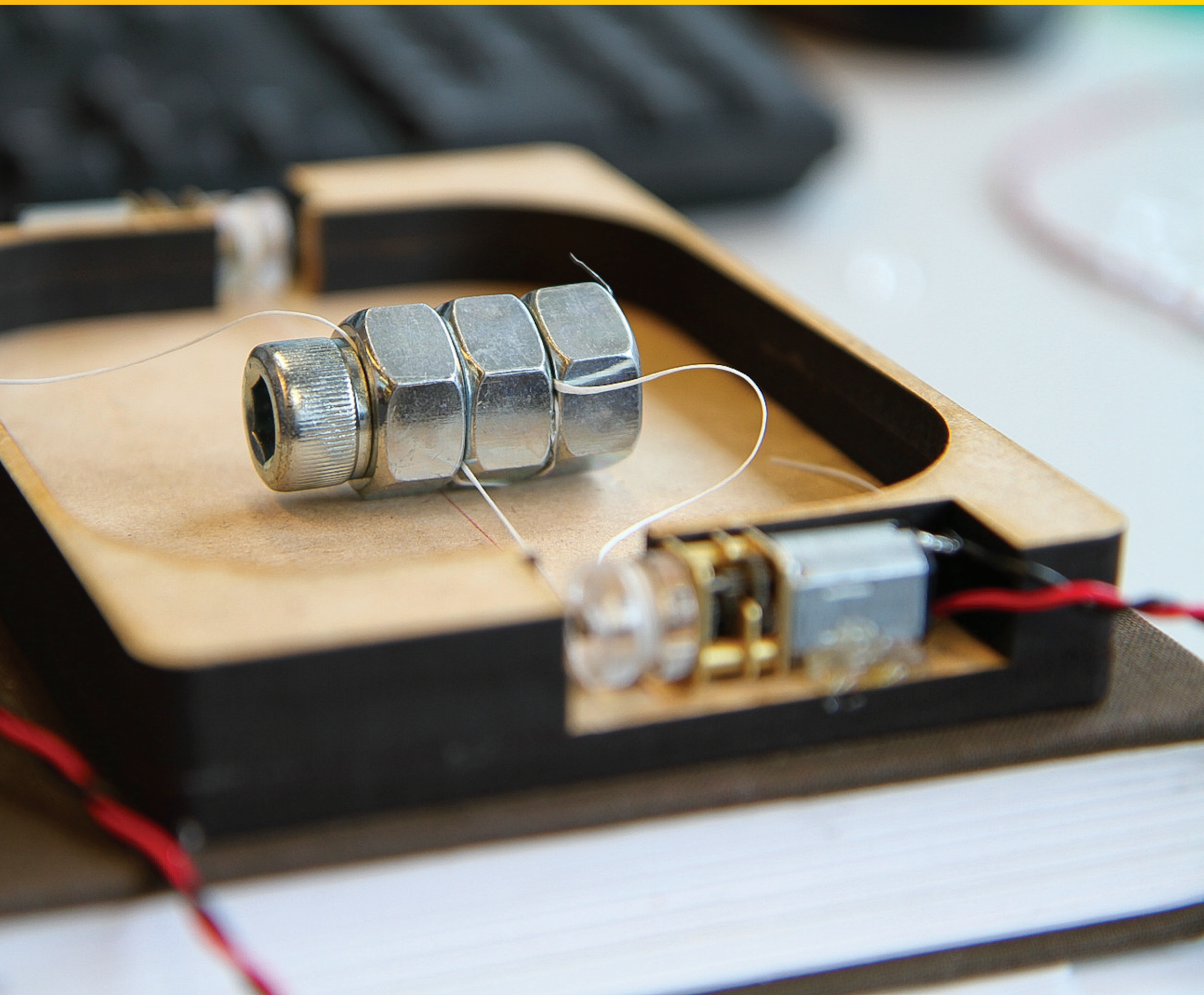
This second internship at Microsoft Research allowed me to explore how my ideals on what haptic interaction design could be fit in a larger ecosystem of modalities. It also gave me an opportunity to directly work with some of the latest technology in human-computer interaction and interaction design and some of the best researchers in the area.





# MICROSOFT RESEARCH 2

*Redmond, WA, USA*



# CHAPTER 2.4 SKETCHING HAPTICS WORKSHOPS

## 2.4.0 INTRODUCTION

Up to this point, my study in the area between interaction design and haptics has been largely self-centered; i.e. how I have confronted the challenges of working with haptics as a designing researcher. To contrast and complement my own experiences and findings, I have also organized a series of educational workshop activities to gain a larger perspective on the area between interaction design and haptics.

There are two main reasons behind this more empirically flavored part of the study. First, I had a general interest in how other designers and students becoming designers as well as professionals and students in other areas such as human-computer interaction and computer science would tackle work for our haptic sense; would it be strikingly different from my own approach? Second, as described earlier, the end users—in search of a better word—of my haptic sketches and the methodologies and my approaches for realizing haptic interaction design are not meant to solve specific day-to-day problems for people or even to be used by consumers directly. Rather, both the haptics sketches and the approaches to quickly arrive at them are primarily intended to be tools for designers—simple artifacts and procedures that designers can learn and use in order to consider and broaden their skills and understanding of the modality of haptics and, hopefully, apply these skills in their own designs. Actually trying the sketches and approaches out with other designers is thus crucial for being able to estimate my work's potential for this purpose.

Hence, over a period of two years, I organized and lead a series of Sketching Haptics Workshops with graduate students in both Sweden and Canada. These students were both interaction design students as well as students in computer science, which I anticipated would provide and highlight different perspectives on my investigation.

Figure 60: An example of a haptic sketch made by a student during the workshop series.

The series of workshops were realized between October 2010 and October 2011. An overview of the workshops conducted is presented in figure 61.

| | Host program, level | Group size | Location |
|---|---|---|---|
| A | Interaction Design, MA level | 9 | Umeå, Sweden |
| B | Computer Science MA level | 16 | Gothenburg, Sweden |
| C | Computer Science MA, PhD and Post-Doc | 9 | Vancouver, Canada |
| D | Interaction Design MA level | 11 | Umeå, Sweden |

Figure 61: Sketching Haptics workshops details.

Workshops A and D took place at Umeå Institute of Design, Umeå University, in Umeå, Sweden. These participants were all Master's level interaction design students and were generally familiar with common design processes as well as sketching and model making activities, but for the most part novices in haptics, programming, and electronics. During the workshops, the students had access to the various workshops and facilities provided by the design school—including wood, metal, and electronics workshops—for realizing their design ideas.

Workshop B took place at Chalmers University in Gothenburg, Sweden, while workshop C was hosted at the University of British Columbia, Vancouver, Canada. These two workshops welcomed groups of students who were far more acquainted with computer science and human-computer interaction, but on the other hand less knowledgeable in design. Both of these workshops also took place in more traditional classroom-like environments, which meant limited access to tools, materials, and equipment for model making and prototyping. It is also worth noting that workshop C had the most heterogeneous mix of participants, ranging from first year Master's students to post doctoral researchers with expertise in haptics research.

## 2.4.1 SCHEDULE AND ACTIVITIES

| | AM | PM |
|---|---|---|
| Day 1 | kick-off presentation + what is haptics + intro to movement, mechanisms and actuation | assignment #1 no technology (cardboard, glue, tape, rubber band, etc.) |
| Day 2 | review of assignments #1 + design process lecture + presentation of various actuators + assignment #2 (3 different scales of actuation) | work on assignment #2 + recap Arduino |
| Day 3 | review of assignment #2 + lecture about motors and actuators with Arduino | rework assignment #1 or #2 with Arduino control |
| Day 4 | assignment #3 (significant challenge) + code/harware clinics | collective literature review/ discussion + work on assignment #3 |
| Day 5 | work on assignment #3 | final presentations, video, documentation and debrief |

Figure 62: A typical schedule of the workshop series.

In structure, the four workshops had similarly laid out programs despite varying time constraints. Workshop A and D ran over the course of 5 days full time; workshop B ran over 3 days almost full time; and workshop C ran for 5 days full time overlapping the weekend (Thursday to Wednesday). Figure 62 presents a schedule used in one of the workshops.

The workshops' schedule had been deliberately developed with a progression in the use of technology in mind, and consisted of three main assignments. Other than the three shared assignments, all four workshops were also composed of lectures, demonstrations, impromptu and short 'clinics' on specific topics, and team tutoring sessions. Participants were strongly encouraged to work in teams of two or three, and change teammates during the week. Various design constraints and small work briefs were defined, but participants were invited to interpret the assignments very openly.

The workshop schedule's first assignment actually involved no technology at all, as the haptic actuation they were asked to work with is entirely human powered and controlled. Here, the use of deception, fakery, or other so-called 'Wizard of Oz'-inspired techniques was advocated.

The second exploration introduced electricity, motors, switches, and other simple building blocks to expand on speed, responsiveness, range, and power.

These new additions were meant to broaden the range of possibilities, but also directly highlighted some common challenges in controllability and durability.

The third and final assignment brought in a microcontroller, sensors, and simple programming using the Arduino platform to begin to explore the link between sensor and actuator, input and output, and complexity. At this stage, the participants were encouraged to build a haptic sketch that could be run and experienced with as little intervention from its creators as possible.

Throughout the workshop, the emphasis was put on felt, experienced sensation and on variability. Figure 63 shows an example of a stand-alone project that directly reacts to the user's action. Here a solenoid and a spring link the two cubes inside. When the user pushes on the pressure sensor (under the thumb), the two blocks are moved away from each other by about 1 cm. Light pressure only triggers the expansion once, while increasing the pressure will repeat the stroking actuation faster and faster.

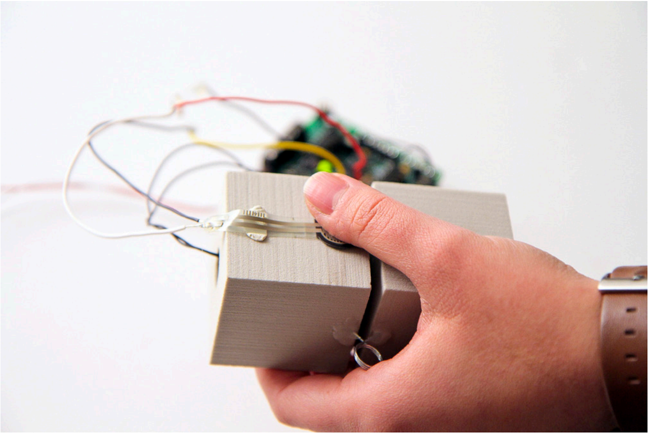


Figure 63: A haptic sketch running in standalone mode, without the intervention of its creator.

## 2.4.2 OUTCOMES

Figure 64 presents a collage of the haptic sketches that resulted from this series of workshops. The various images also reflect, although only partially, some of the tools and processes used by the workshop participant in these sessions. While the remainder of this chapter will focus on the role of these workshops in relation to the work presented in this book, additional information and material, presentation slides, and documentation such as photos and videos from these workshops are available online (see http://www.simplehaptics.se/workshops).

Figure 64: Various hardware sketches made during the workshops.

## 2.4.3 REFLECTING ON THE WORKSHOP SERIES

Apart from the purposes described above, an initial goal of conducting the series of Sketching Haptics Workshops was also to explore the effects of letting the fields of design and haptics clash together during a few intense days, with a strong focus on sketching, engagement, and tangible outcomes. These workshop activities were generally appreciated by both the participants as well as by the hosting educational institutions. Some observations, reflections, and lessons learned are presented below:

### EXHILARATING SIMPLICITY

The Sketching Haptics workshops favored a rough introduction to haptics starting with general construction issues using craft-like materials (such as paper, cardboard, foamcore, hot glue, rubber bands, etc.) and mechanical kits (including LEGO, Meccano, etc.). The priority was for the participants to first get acquainted with the touch sense and to have them start discussing and trying to verbalize different haptic sensations. The realizations, i.e. sketches, they usually come up with at this point are indeed rather trivial and simple, but it is still surprising to see that even simple contraptions and pieced-together rigs can trigger and initiate very rich discussions between the participants.

As motors and other actuators are added to the mix later on, a whole new world of haptic stimuli is opened up to be explored and experienced, such as vibrations, friction, pull and push forces, etc. At the same time, rapidly evolving haptic sketches or embryos of haptic interfaces where physical forces and movement are combined also rapidly increase in complexity, both in terms of construction and in terms of control, which tends to result in a number of miniature wreckages and ruined creations. Quick, non-committal, and explorative constructions are generally not compatible with controlled actuation and repetitive movement.

**GROW, EXPLODE, SHRINK, SCALE,
ROTATE, PULSE, FLICK, REST,
DISAPPEAR, CLUTCH, RELEASE, HOLD,
CAPTURE, PIN, PROMPT, CONFIRM,
REPEAT, STABLE, GLIDE, SLIDE, STOP,
HIT, KICK, CANCEL, EASE IN/OUT, RAMP,
AUGMENT, INCREASE, DECREASE,
AGITATE, SHAKE, TWIST, TRANSFORM,
CYCLE, RICOCHET, FOLLOW, GUIDE,
GRAB, SCREW, IMPLODE, CIRCULATE,
CONSTRAIN, CHANNEL, FORCE, LEAD,
INVITE, SMOOTH, HARD, HARSH, SOLID,
SOFT, COMPLIANT, BOUNCE, SPRING,
BREAK, STOP, COLLIDE, PERMUTE,
ACCELERATE, REACT, BOB**

Figure 65: Actuation keywords used as a starting point for design.

A particular line of exploration that has functioned well as a point of departure for the haptics explorations during these workshops was to ask the participants to start creating interface ideas directly inspired by a number of actuation keywords, such as *shrink, bounce,* and *slide* (figure 65) or from a list of prepositions that involve movement or time, such as *between, around*, and *with*. While these terms can be interpreted quite openly, they often embody visual or auditory references upon which the participants can build.

## HAPTIC QUALITIES VERSUS AVAILABLE RESOURCES

A very basic, but nevertheless important, observation from conducting these workshops is that the selection of available actuators and materials significantly determine what is being built and explored by the participants.

To the first two workshops (A and B), I brought solenoids, vibrotactile motors, and servo-motors to the table as the main building blocks. Among these, vibrotactile stimulus was most commonly used in the projects being developed, probably because vibrotactile motors are among the easiest items to use and control. A few groups used servo motors instead, but those projects had a tendency to be unreliable, chiefly because of difficulties securing the servos properly, and also tended to be difficult to calibrate over multiple runs.

In workshop A, the structure of the vast majority of the hardware sketches being built was made out of wood, as all students from workshop A had quick access to a wood workshop nearby and a plentiful source of free scraps pieces to work with, which meant these students had minimal issues with solidity and stability. In contrast, workshops B and C were conducted with students that had little or no training in design and prototype-construction, and their sketches became unusable or were ruined fairly rapidly.

In the last two workshops in the series, I tried to introduce two other types of haptic actuators (voice-coil and piezo) and their adoption rate too seemed to match their ease of use. For some of the more technically complicated actuators, I prepared some code samples and ready-made wiring connections so the workshop participant could get going more rapidly. Ultimately though, this meant that the students *only* used the actuators that I had pre-simplified and no one tried to venture into uncharted grounds.

Hence, even though the participants were generally very enthusiastic about exploring various kinds of actuators and stimuli, they tended to be drawn to the easy way out and opted not to embark on something they were unsure they could pull it off in the end. Complicated force-feedback mechanisms and kinetic elements seemed outside of the scope of these short workshops.

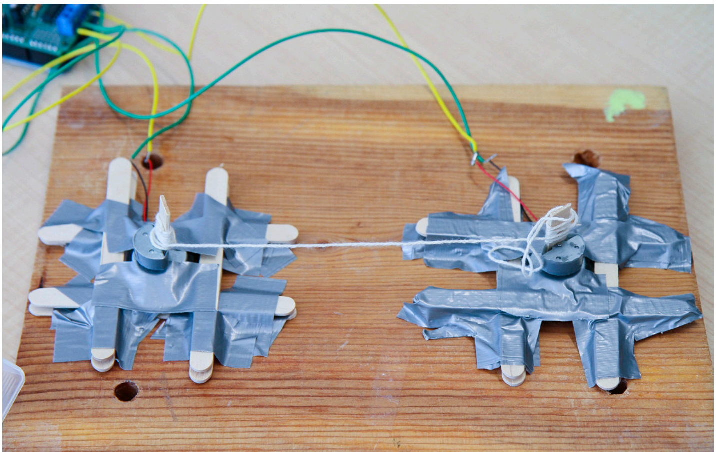


Figure 66: Actuated project without haptic feedback.

The results from the workshops show that design explorations through sketching in haptics are possible. Participants engaged quickly in the topic and found ways to build interesting and clever apparatuses and sketches that embodied a wide range of haptics ideas. After having taken the workshop, participants were able to express details and fairly advanced considerations of their own haptic sensations grounded in their perceived experiences, and they were also able to discuss these sensations with the other participants. Although a very demanding few days, for the participants as well as for me as a workshop organizer, it seems that building haptics to learn haptics has potential as a path towards getting acquainted with and develop a sensitivity of the haptic domain.

This path is not without obstacles however. A particular, and somewhat peculiar, issue actually arose repeatedly in each of the workshops. This had to do with certain groups of participants having a tendency to build actuated projects that in the end did not really have any direct haptic qualities. While the sketch they were working on would be moving, spinning, or doing something else, it would do so without any intelligible action directed towards the human body or skin (as an example, see figure 66). After the debriefing sessions with one of these groups, the participants mentioned that the challenges and perceived pressure involved in just making something working was overwhelming and in worrying about not being the 'failed group', they forgot that the main concern of their apparatus was a direct interface with a human being. The approach for handling this was to bring this concern up and discuss it with all participants rather early on in the workshop, describing the difference between sketching—where it is fine to try but fail—and prototyping and realizing—where it is typically not. Most groups were then relieved of at least some of the pressure they experienced and were able to rectify their activities and focus more on the quality of the haptic output in their sketches.

Another issue discovered in the conduct of these workshops had to do with a potential mismatch between the lengths of these workshops, in relation to the outcome the participants, and to some extent I as an organizer, expected. Despite good planning, a large selection of available materials and tools, rather easy-to-use toolkits, and pre-made simplifications to some actuation technology, it was still challenging for the participants to come up with thought-provoking and mind-blowing new ideas and then also realize them over the course of the relatively short workshops. Typically, the designs they came up with were often variations of known themes.

What made this series of workshops particularly challenging was the strong time constraint imposed on the making endeavors. Generally, the participants had more or less one day (4-6 hours, plus overnight for some) to fully realize a particular assignment or hardware sketch. This strong time limitation was there to try to make sure that the participants were focusing on explorative and non-committal projects so that they could investigate numerous tracks, iterations, or alternatives over the course of a few days. It is possible to speculate that a longer workshop, maybe running over 10 days or so, would provide the time needed for the participants to take their ideas one or two iterations further. Yet, with a longer running time for these workshops, other factors would potentially also come to affect the workshop projects in ways not necessarily desired, including participants starting to worry about finding real-world problems to solve and address, and potentially less dedication from the participants in terms of actual hours spent on their projects per day. These questions relate to larger and more general concerns about the role of sketching and prototyping activities in design. Going from idea to materialization can serve many purposes and goals (Buchenau & Suri, 2000; Buxton, 2007), and it is up to the designer to identify and govern which filters, shortcuts, and perspectives are valuable and worth pursuing or building (Lim, Stolterman, & Tenenberg, 2008). The workshops activities were designed to be an opportunity to learn about haptics, but as they turned out, they were as much lessons in *sketching in hardware* (Holmquist, 2006).

## SKETCHING SKILLS, FROM MODEL MAKING TO PROGRAMMING

The participants coming to these workshops had varying levels of expertise pertaining to model making, prototyping, mechanical engineering, electronics, programming, and haptics. Roughly half of the participants were design students, with considerable exposure and previous experience in creative processes and model making skills. The other half of the participants had a background in human-computer interaction and computer science and they were generally at ease with programming and of working with sensing and control systems. Within these workshops, these two groups were more or less forced to leverage their current expertise and work towards the area more unknown to them. In this way, the computer science students got to learn more about design processes, user-centered methods, and creative explorations. The design students, on the other hand, were able to meet and explore actuation control and psychophysics.

As outlined above, the workshops' structure emphasized a progressive use of technology, starting with no technology at all on the first day, using simple motors and actuators the following day, and then building towards more complete and complex hardware and software systems during the last day. This approach does not aim to satisfy the perceived wisdom that more or advanced technology is better. On the contrary, these activities were purposely structured to veer away, as much as possible, from the overly complex and intricate technology that is often associated with haptic interfaces.

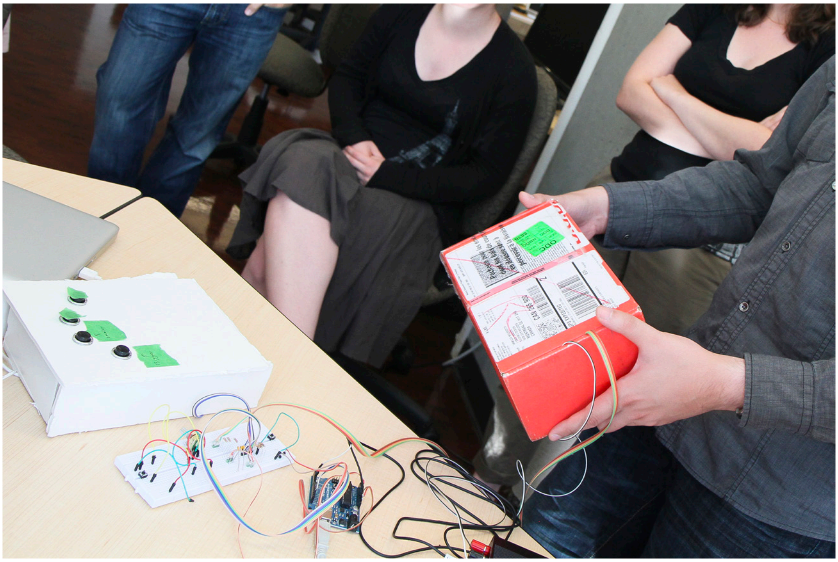


Figure 67: Virtual ball-in-a-box haptic interface built in one day.

Naturally, the two different groups of participants were able to realize different kinds of haptic interfaces based on their skills and interests. For example, one group comprising a post-doc haptics researcher implemented a virtual *ball-in-a-box* haptic interface (see figure 67) within a few hours using a cardboard box, clever embedded electronics, and some programming.

Figure 68: Haptic jewelry responding to proximity of nearby humans.

On the other side of the spectrum of expertise, a design student was able to produce actuated jewelry pieces made from actuators, beads, and felt cloth, which responded to proximity with other human beings (see figure 68). This latter example might be the most representative example of the kinds of sketches the participants came up with—even though this particular example is one of the best exercised. The archetypal sketch is one that integrates simple actuation and responsiveness framed in some relevant context or situation, often based on interests or previous experiences of one or several of the participants in the group.

These two examples are also telling about a final reflection on these workshops. Since the activities are developed around a sketching perspective and in under strong time constraint, there is invariably a trade-off between the quality and the quantity of the sketches that are produced. The participants not only have to design, make and produce some artifacts, but they also have to wisely manage their time and resources. Coping and making do with the available materials, access to tools, and combined expertise from the group's members is integral part of the learning. Knowing when to stop the development of an idea or concept and instead move on to another alternative is part of designing.

Lastly, the Sketching Haptics workshops series aims to support the rediscovery and valuation of *making* activity in today's society. As a long-term result of the industrial revolution, the ability to actually *make* or *craft* things yourself has decreased steadily in value. The axioms of the knowledge economy usually dwarf considerations of practical skills and techniques. Only in recent years have we seen a reappearing, albeit at times somewhat romanticized, interest in craft as a process and as a particular kind of artifact that holds certain specific qualities. As argued in this work, for exploring, understanding, and advancing a field, these making skills are very valuable if not essential, regardless of whether the field is knitting or haptics.

## 2.4.4 CONCLUSION

The Sketching Haptics series of workshops sat out to explore how the fields of haptics and interaction design can come together for educational purposes. The current state of haptic development tends to promote technological refinements over other forms of inquiries. The initial premise behind the workshop series was that designers, with their creativity and user-centered perspective, can also contribute to and drive, alongside roboticists and engineers, the development of new haptic interfaces. While designers might not have the technical know-how to develop new haptic technology per se, they have tool skills, design process skills, a largely humane attitude, and expertise in how people interact with technology. Haptic design activities present numerous challenges for designers and other professionals not familiar with haptics. The exercises and assignments were developed in order to maximize exposure to perceived sensations and circumvent common technological constraints. The overall results from the workshops reveal that quick, creative explorations are possible to achieve in a short period of time, despite a few common obstacles. The various realizations and projects were diverse and inspiring, but most importantly they seem to act as catalysts and platforms for tangibly engaging with new notions, concepts, and technologies, and to be able to relate to, feel and develop a heightened sensitivity for haptics.

In closing, it is my hope that by exposing these workshop endeavors and showing and discussing some of the sketches that came out of them, other design students, practitioners, educators, and haptic researchers may become intrigued and stimulated to initiate comparable activities in their own communities. The field of haptic interaction design is still young and in development. Workshops like these provide a shared opportunity for designers and haptic experts to collectively expand our haptic design toolbox, our vocabulary and library, and help develop the next generation of haptic interfaces that are more humane, valuable, and meaningful to us.

# PART 3
# A WAY FORWARD.

# PART 3 / A WAY FORWARD

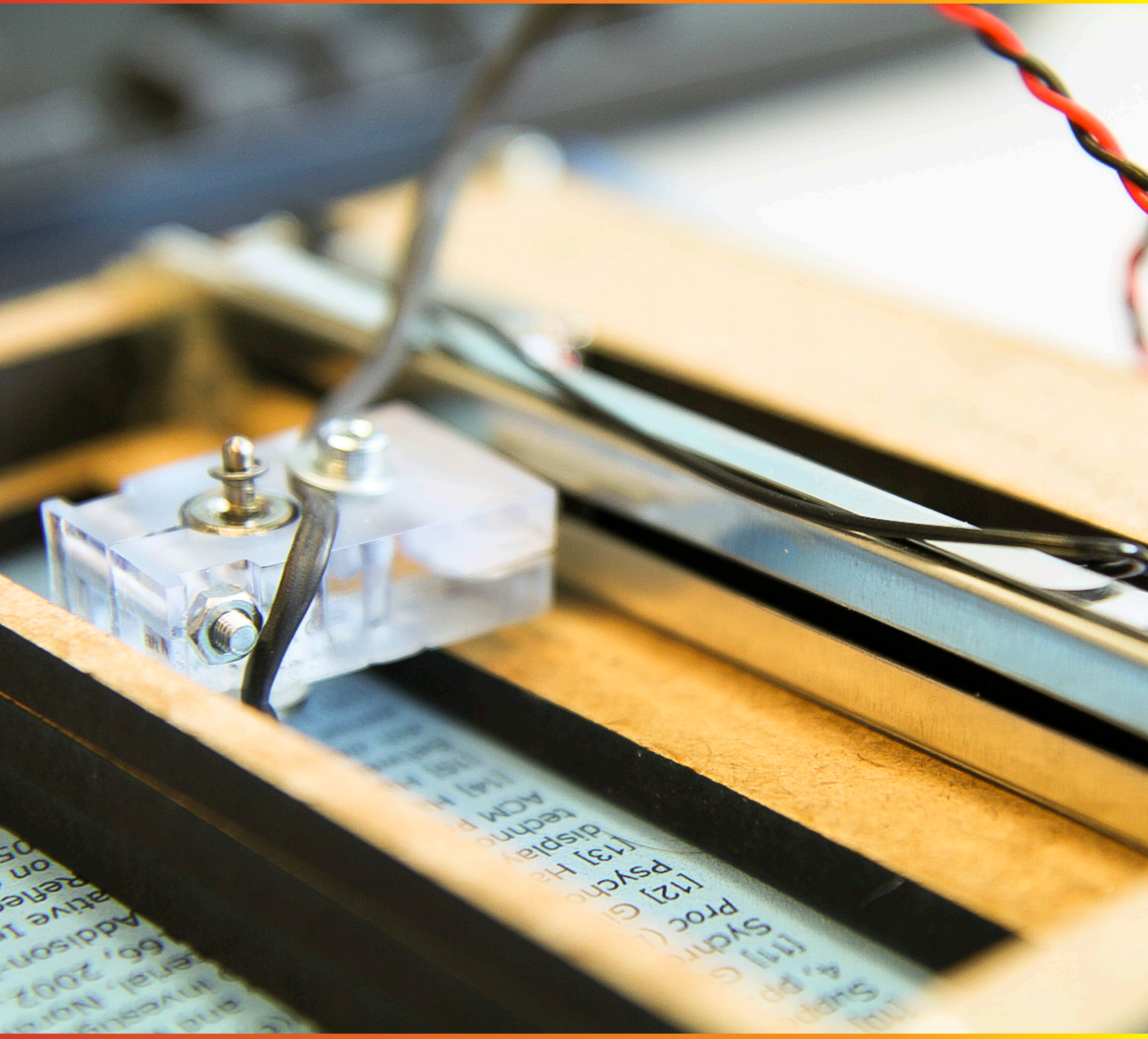
In the first part of this book, the motivation for exploring the meeting point of design and haptics was introduced. Here, the opening outlook was that the two disciplines were expanding and would invariably come to overlap more and more, and that the area of intersection constituted to some extent an entirely new field of investigation, which initially was termed *haptic interaction design*. The nascent field of haptic interaction design constituted the new territory that I, as a design researcher explorer, sat out to scout and discover.

Part 2 of this book exposed the core design research activities that I have engaged in over the course of this doctorate to explore and better understand this new haptic design space; in the form of first-person accounts and reflections on design processes within haptic interaction design, as well as more empirically grounded work pertaining to a variety of problems, contexts, and situations in which designers, design students, and other professionals have been exposed to.

This third and last part of the book concludes my journey into haptic interaction design. For me as an author, it involves leaving the role of an explorer and taking on a partly new role, this time as cartographer. The third part starts with an attempt to elevate the work as a whole into a major finding and outcome, formulated in the form of a proposition: *simple haptics*. This proposition, while tentative, connects the activities reported on in this work, and offers a program to move forward within the design of haptic interactions.

Below, the first chapter of part 3 recapitulates what we have discovered to be the current states of affairs in haptic interaction design. This examination is useful for recognizing the progress that the community as a whole has realized within the haptic interaction design domain up to this point in time, as well as showing that some parts of the map still seems to contain white areas. The second chapter will address a distillation of the contributions of the design research work presented in this book, discussed in terms of knowledge contributions; methodological contributions; impact contributions; and design contributions.

The last chapter is entitled *Perspectives* and attempts to locate my work more broadly in today's increasingly intertwined and complex research, design, and technology landscapes. Here, the evolving field of haptic interaction design is charted and the simple haptics proposition is discussed as a way to approach it. This chapter also contains concluding discussions of what seems to make haptic interaction design different from haptic research, and how they complement rather than oppose one another, as well as an attempt to frame the area of haptic interaction design in relation to contemporary design research agendas. A discussion of some potential future directions of this work concludes the chapter.

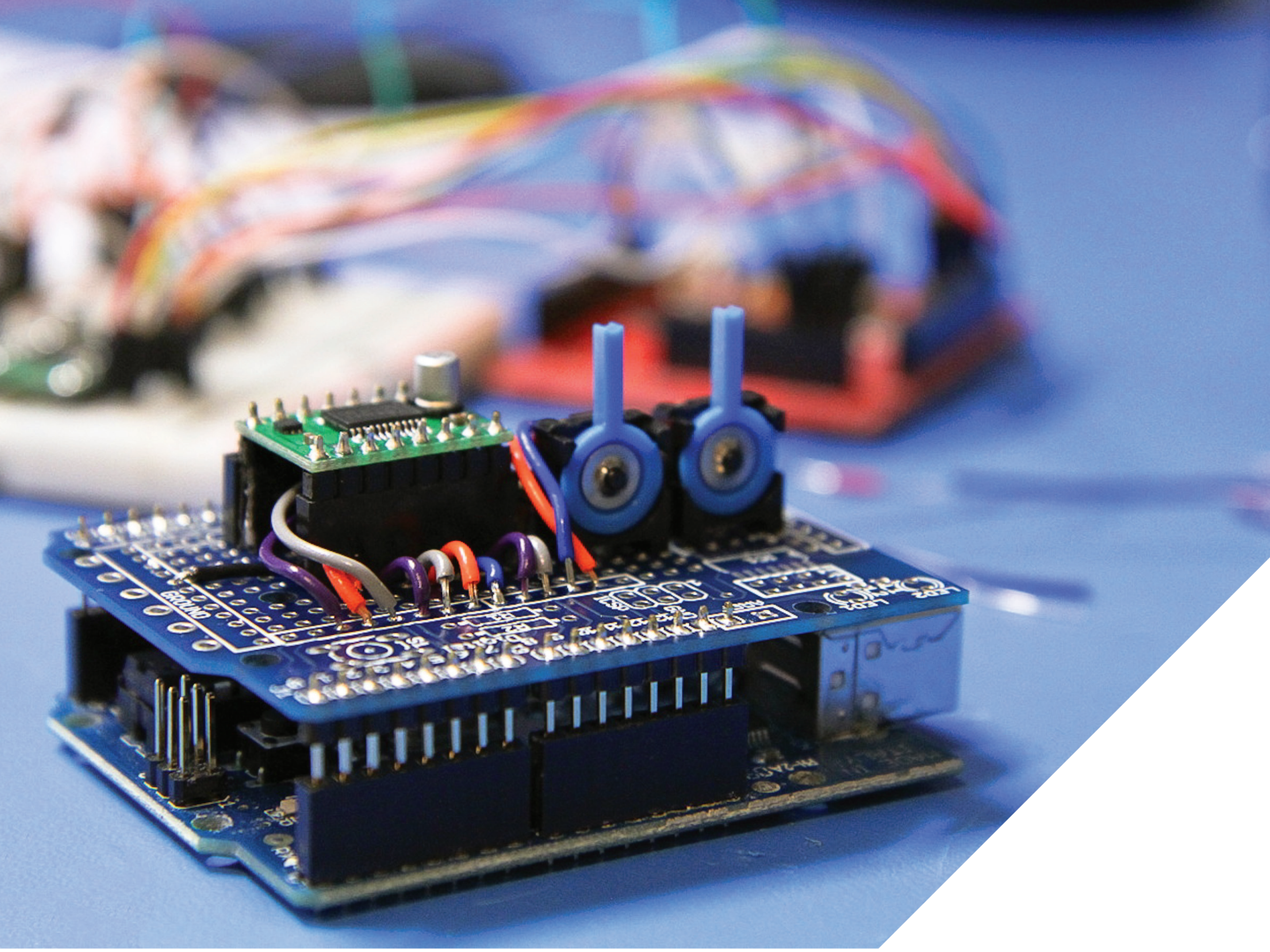


# CHAPTER 3.1 CURRENT STATE OF AFFAIRS

## INTRODUCTION

It is worthwhile at this point of the thesis to pause and try to address the simple yet intricate question: how has haptic interaction design, as a new area of investigation, fared after five years of investigation, exploration, and probing?

This question is particularly fitting to ask at this point, before the more specific discussion of the contributions and findings of this work that will come later in part 3, as it implies a recapitulation of the past and current state of affairs for haptic interaction design. Examining this question involves looking back at the point of departure for this work and recognizing the activities and the progress that have been accomplished since. The question also necessitates looking at the state of other, related communities and requires mapping the numerous kinds of investigations in this work to see if and how they connect. In what follows, four assessment points or conditions related to the current state of affairs in haptic interaction design are brought out, dissected, and discussed. The use of four fundamentals—*interest, materials, tools, and knowledge and skills*—helps ground the discussion and facilitates the identification of inadequacies or opportunities for change. The discussion and assessments below build on my own work but also on that of many others in various design and haptics communities and captures an impression and understanding of the state of haptic interaction design as of the summer of 2012.



## 3.1.1 INTEREST AND MOTIVATION TOWARDS HAPTIC INTERACTION DESIGN

The first point of assessment is to try to gauge the level of interest *in* or *for* haptic interaction design. Is this new field only of interest to me and to a few fellow researchers, or it is of potential importance to a larger group of individuals, communities, and organizations?

Naturally, as stated before, the position maintained in this work is that haptic interaction design should be seen as highly relevant in today's research and practice in design and that it is an upwards trend, poised to become increasingly relevant and important in the years to come. To develop this claim further, we need to return to the initial assertion from chapter 1.1 regarding the expansion and overlap of haptics and interaction design (figure 69) and look for the seeds of haptic interaction design. This analysis uncovers some of the forces and vectors of progress that are supporting the new field of haptic interaction design where the purpose is to demonstrate that the converging forces are in fact considerable and most likely not short-lived. Two emerging trends will be reviewed below; *the healthy and steady growth of haptics* and *the tangible turn in interaction design.*

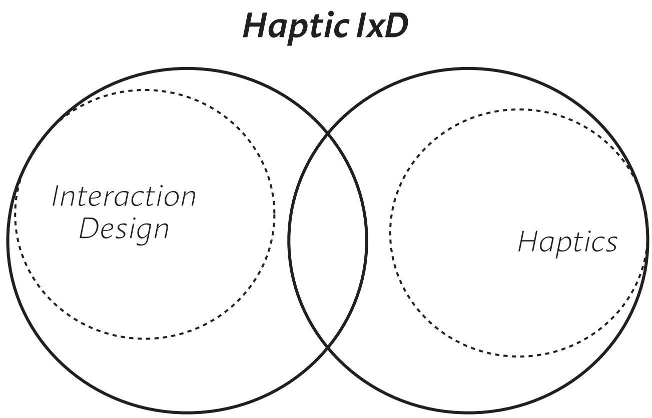



Figure 69: Overlapping area between interaction design and haptics.

## THE HEALTHY AND STEADY GROWTH OF HAPTICS

Chapter 1.2 exposed the origin of haptics research and discussed its history. This community is vibrant and thriving with numerous international conferences and scholarly archival journals. As Klatzky notes, "a quarter-century ago, haptics research was essentially the province of behavioural scientists and neurophysiologists. The entry of engineers into the field transformed it into a truly inter-disciplinary endeavour" ("IEEE Transactions on Haptics 5th anniversary," n.d.). Haptics research is thus expanding in number as well as in breadth. For instance, the number of publications has increased tremendously: from less than around 300 in 1990, to 2000 in the year 2000, and to over 8000 for the year 2010 according to Google Scholar (publications containing the word 'haptic'). This progression is corroborated if we look at publications within the Association for Computing Machinery's (ACM) digital library: from 159 entries in 2000 to 1165 entries in 2010.

As discussed earlier, haptics research has traditionally revolved around the disciplines of psychophysics, robotics, and control systems, and all been carried out under a dominating scientific and analytical perspective or paradigm. Despite a growing community of research and increasing popularity in both academia and business, haptics research has had limited mainstream dissemination. The term has gained recognition and acceptance outside of the research community, but more advanced and elaborate haptics interfaces are still mostly found in research labs or in very small and specialized markets—while mainstream audiences' exposure to the world of haptic technology is largely restricted to the rudimentary and ubiquitous buzzing of mobile phones.

Over the last few years, members of the haptics community have voiced the need for a shift toward accepting and emphasizing more design-driven approaches, as a means for establishing greater relevance and impact of haptics at large. MacLean & Hayward's article *Do It Yourself Haptics: Part II, Interaction Design* from 2008 is the epitome of this call, which seems to have been well received and embraced by the general haptics community. For instance, the 2012 edition of the large Haptics Symposium conference was themed "engaging and connecting with the user" and contained the following description:

> **The Haptics Symposium has long been a central venue for sharing engineering and psychophysical advances related to the human sense of touch, and to advances in our understanding of haptic (touch) perception. 2012 is the year of the user. This conference will feature spotlights on research contributions and methodologies for engaging and useful, usable interactions, applications and design tools. By increasingly engaging our public and industry community, we seek to make our work more available to the outside world.**
> **("Haptics Symposium 2012," 2012)**

As a result, new communities and constellations are forming, such as the *International Workshop on Haptic and Audio Interaction Design (HAID)*, that are coming together to explore and tackle design issues around haptics. The anticipation is that the work presented in this book will be relevant and useful for these new communities.

In summary, haptics research is still a young, dynamic, and flourishing research field which gathers researchers from many different horizons and disciplines, though so far mostly from traditional science and engineering disciplines. But as haptics research starts to aspire to relate to applications in almost all walks of life—including games and entertainment, rehabilitation and health, art and music, collaboration, skills training, teleoperation, simulation, education, etc.—broader concerns like issues of interaction design and user-centered approaches seem necessary and useful ingredients for the field to further develop and mature.

## THE TANGIBLE TURN IN INTERACTION DESIGN

Just like haptics research, the field of interaction design is a young and thriving discipline. The latter half of part 1 of this thesis painted a quick picture of its current state and some recent developments. The focus here is to specifically examine a recent and growing trend in the field: one that concerns the rise of and return to physicality, what we might address as a *tangible turn* in interaction design.

Traditionally, while not always intended, interaction design has nevertheless been a discipline centered primarily on visual qualities of interfaces, objects, and systems. Looking back, design—as an activity—has long been tightly related to vision and the visual, in a similar way to the role of vision in architecture. The Finnish architect Juhani Pallasmaa uses the term *ocularcentrism* to try to capture this visual paradigm and his book *The Eyes of the Skin* dissects vividly the roots of this contemporary situation (Pallasmaa, 2005). Pallasmaa denotes the limited and constricted nature of human experiences when these are based on *focused* perception often associated with vision. He argues for a return to fuller *unfocused* multimodal experiences of architecture for perceiving and articulating the experiences of being-in-the-world: "The very essence of the lived experience is molded by hapticity and peripheral unfocused vision" (Pallasmaa, 2005, p. 10). While the shift away from vision as the main modality of experiencing our world is voiced in the field of architecture, it equally seems to apply to the many other design disciplines, and perhaps especially to interaction design.

From the early days of personal computers up to today, the most important vector of development has rather unequivocally been about graphics, visual representations, data visualizations, and visual displays. Real-time three-dimensional graphics and video capabilities are commonly found in almost all computational devices, from the largest to the smallest, including watches, miniature audio players, and even in small appliances such as inexpensive keychains. The advances in audio capture, processing, and generation have been significant too, but several orders of magnitude less compared to the advances in graphics rendering capabilities. As for our sense of touch and our bodily involvement in the world of computing, the advances have been limited. Some interesting developments in terms of bodily engagement has occurred over the last ten years or so, mostly in the field of computer gaming, with for instance the Nintendo Wii and Microsoft Kinect platforms, but also with the rise of touch-based input devices such as tablets and larger multi-touch surfaces. Yet, while these systems come to use the human body directly as an input device, they are generally not designed to be able to use the human body also as an output device. Hence, what we might call 'rich' or more elaborate haptic feedback interfaces still remain within the confines of research labs or for very specialized application areas such as tele-operation.

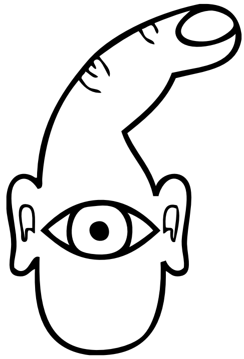


Figure 70: How the computer sees us, reproduced from O'Sullivan & Igoe (2004, p. xix) with permission of Delmar Learning, a part of Cengage Learning, Inc.

In spite of all recent development, interacting with digital technology today—be it with a computer mouse, a graphic tablet, or a multi-touch panel in a home, mobile, or office context—still means exploiting just a tiny fraction of our overall sensorimotor capabilities and touch perception. Comparing O'Sullivan & Igoe's representation of "how the computer sees us" (figure 70, O'Sullivan & Igoe, 2004, p. xix) with a mapping of our motor and sensory homunculus system in our brain (figure 71) shows a major disproportion between the inherent diversity and complexity of our haptic sense and how it has been embraced to this day—or, depending on how you see it, a true potential for much richer experiences.

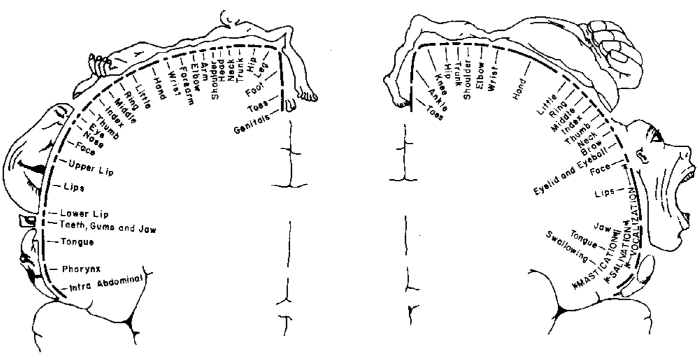



Figure 71: Motor and sensory homunculus showing the repartition of neural resources dedicated to various body parts. Reprinted from Penfield & Boldrey (1937) with permission of Oxford University Press.

The way we act in and with the world is far more diverse and rich than our current interaction models for working with computational systems. Riding a bicycle or playing a musical instrument for instance, is far more bodily engaging, physical, and visceral than editing a text document or browsing the web. Intentionally or not, while digital technologies offer new and incredible possibilities, it limits our physical embodiment and sensorial fulfillment, and tends to makes us, as users, passive in terms of bodily engagement.

As discussed in chapter 1.2, the origin of this sensorial deprivation can be traced back to the industrial revolution. As computing is becoming ever more present and ubiquitous in our professional and personal lives, engineers, artists, designers, and other professionals have tried to develop new practices aimed at realigning technology with human sensorimotor capabilities. These new ventures have formed under various labels, such as physical computing, embodied interaction, tangible user interfaces (TUI), and natural user interaction (NUI). They differ in their focus and speak to partly different communities, but they all advocate a fuller reliance on materiality, physicality, and sensorimotor human capabilities. This push towards physicality and materiality, which here is labeled the *tangible turn*, is interesting because digital technology has grown from a diametrically opposed vision. For many decades, we have longed for faster and smaller computers, for ever-increasing miniaturization, high-level of abstraction, disappearance, and for technology to become ideally unnoticeable, ubiquitous, and almost immaterial (Bürdek, 2005, p. 403; Weiser, 1991). However, as discussed by Bell & Dourish (2007), recent history has shown us that this ubiquitous, invisible future might not have turned out to be the calm, relaxing, and humane state of being envisioned by Weiser; it rather turned out to be quite messy and complex.

The tangible turn thus completes the full circle in regards to technology and physicality, as we now seems to have come to realize that technology propelled by the ideals of faster, smaller, and ultimately invisible might not be as human compatible as we expected. The tangible turn, as a response, seeks to give modern computing an expanded physical presence to better match with human capabilities and understandings.

The research activities described in this book are fully inscribed in the recent push towards more physical and embodied interaction in interaction design. From my perspective, this tangible turn seems not confined to interaction design, as architecture, graphic design, and many other creative disciplines are showing similar tendencies. Over the last decade or so, the resurgence of movements like Do-It-Yourself (DIY) and personal making has brought hardware back to the general public's attention. After having been separated since the early days of the computer revolution in the early 1980s, the boundary between software and hardware is again changing and becoming more difficult to recognize.

Overall, the signs and indicators of a tangible turn in the interaction design disciplines are clear and plentiful, and many sub-communities of human-computer interaction and interaction design have been formed recently to tackle and promote such endeavors, each with their own conferences, workshops, and journals. The exact approaches and considerations might differ across communities, but the common theme is that we cannot continue to consider the digital and material separately. Linking materiality with computation falls directly in line with the haptic considerations dealt with in this book. The human sense of touch is our unique modality to act on and in the world. Understanding and designing with and for that most human of interfaces is thus an untapped source of potential that we are just starting to uncover.

## 3.1.2 AVAILABILITY OF MATERIALS FOR HAPTIC INTERACTION DESIGN

The second point of assessment explores the available *materials* for haptic interaction design, i.e. the real practical substrates, elements, and components that make haptic interactions a reality. Here, one might first think of actuators, sensors, microelectromechanical systems (MEMS), and other nano-scale technologies. One could also think of switches, controllers, joysticks, buttons, and interface elements, where actuation might be more passive, spring-loaded, or just reactive instead of fully motorized. Naturally, 'regular' materials—i.e. materials of the kind that we normally talk about when we say materials in our ordinary language—are also considered, both natural and synthetic, like cloth, fabric, wood, metal, plastics and all the derivatives and composites that ensue. Referring to the analogy of graphic design again, do we have haptic equivalents of paper, canvas, paint, pencil, cathode ray tubes and pixels that make visual representations and interfaces possible?

The haptics research literature extensively covers haptic hardware and technical elements. A succinct introduction is for instance offered by Hayward & MacLean (2007) and numerous other books offer further guidance on the subject (Bicchi et al., 2008; Burdea, 1996; Grünwald, 2008; Kern, 2009). In section 1.2.3 of this book, a summary of these hardware considerations as thought appropriate for haptic interaction design was provided. Among other things, these sources highlight that actuation elements, like sensors, motors and actuators, have been around for quite some time but their use for haptics remains complex and technically challenging. Unlike systems where the human body is used for input, such as the Microsoft Kinect, systems that use the human body as output—*like haptics systems do*—is still very challenging, not least since they are also potentially dangerous. Controlled actuation on a scale that is precise and safe for human interfacing still represents some immense engineering challenges.

Only two decades ago or so, building a haptics interface required a tremendous amount of technical expertise, financial resources, and time. Haptic systems were for the most part custom built and in practice only found in specialized research labs, flight simulators, or mission-critical control systems. Control mechanisms were tricky, costly, bulky, and difficult to use. As digital technologies started to replace analog circuits, it became possible to build desktop size haptic interfaces at a relatively affordable cost (in the €10 000 to €100 000 range). Today, haptic devices are touching on general-level computing devices and peripherals price points. For example, a Sensable Phantom device, the original device similar to the one used in the eNTERFACE'08 workshop, commanded a price of €50 000 in 1990, where as of today a Novint Falcon unit can be purchased for about €120. Individual components like sensors and vibrotactile motors are not only getting cheaper—costing just a few dollars or less and widely available on Internet sites such eBay—they are also being offered in a much larger variety of form factors and capabilities. For instance, the haptic sketches realized in this work at Microsoft Research (described in chapters 2.2 and 2.3) can be priced at around €20-200 each, requiring on average under ten hours of work to build and develop from scratch. Functional realizations at such a low price and in such short amount of time were largely unimaginable fifteen to twenty years ago.

## DYNAMIC AND SELF-ACTUATING MATERIALS

Two vectors of development that have taken place in parallel with the completion of this work seem particularly relevant for the future of haptic interaction design from a material perspective. The first area of development pertains to dynamic materials that seem to offer some intrinsic haptic capabilities, while the second vector relates to traditional material concerns that seem largely undervalued in haptics research.

Recent advances in technology are progressively challenging our assumptions of materials as stable entities to-be-processed or to-be-transformed, and new manufacturing methods and ever-smaller computation are now redefining material science. Sensing and actuation capabilities are being embedded in materials at ever-lower levels or scales. The current state-of-the-art manufacturing processes, for instance, touch on the nano-scale and allow for very fine control of the atomic structure of a material. So, rather than harvesting trees to produce the material 'wood', we now design and build our materials from the ground up at the atomic level. This makes it possible to devise new arrangements of matter and for instance define what is stable and what is not. This means that we can design dynamic capabilities right *into* the material, such as with shape-memory alloys, piezoelectric elements that convert movement to electricity and vice-versa, organic light-emitting materials, and so on.

Some of these new, dynamic, sci fi-like materials are already available at a reasonable price and thus available for consideration in haptic interaction design activities. Shape-memory alloys allow for the construction of very strong actuators that are relatively compact and silent. Interesting for haptic interaction design, they offer organic-like movement that is uncommon in traditional mechanical engineering. Piezoelectric elements, for their part, allow for the direct conversion of physical movement to electrical signal, or the opposite. Piezoelectric modules are very fast actuators that can generate considerable forces. They are increasingly used in mobile devices to actuate the whole device or just individual sections or parts, such as the screen (figure 72). While they remain relatively expensive, brittle, and difficult to work with, their fast and wide bandwidth of movement seems particularly advantageous for haptic interaction design applications.

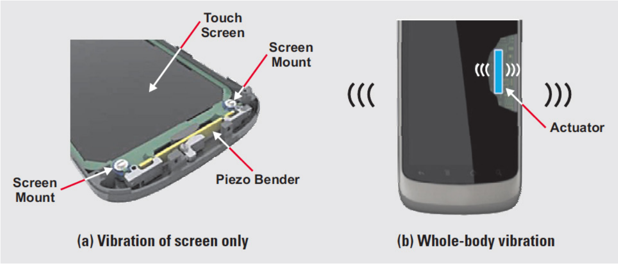



Figure 72: Piezoelectric elements for fast and precise haptic feedback, from (Rao, 2012).

The potential of the new universe of materiality relating to haptic interaction design is both exciting and at the same time a bit scary. It is exciting as we can now design materials and things with amazing and previously unheard of properties and characteristics—but at the same time scary because the results may tamper with our everyday understanding of the world. In this realm of new possibilities, what can or should be dynamic and what can or should remain stable or static? What are the postulates of coherence, continuity, and stability? Do we allow anything to change at anytime or do we keep various fixed bases in the name of proper human interfacing (or sanity)?

At the moment, we are only facing a subset of these questions, as the new dynamic materials that are surfacing are not quite this wild just yet. Today's dynamic materials are often very specialized and limited in their dynamic capabilities. They are in fact more surprising to work with than they are scary, as they slightly distort our conventional knowledge of materiality and in doing so they surprise us and open the door to many new applications and unconventional uses. The perhaps most exciting new dynamic materials are the ones that including actuation or movement coming directly from the material itself, a physicality that in a way ties back to the *tangible turn* discussed previously.

## REDISCOVERY OF TRADITIONAL MATERIALS

The final issue with regard to materials and materiality in relation to haptic interaction design connects with traditional materials. Part 2 of this book presented haptic interaction design activities carried out at Microsoft Research as well as in workshops with students that were realized using less complex and even wholly non-digital design elements. While traditional materials such as wood might lack the strong dynamic capabilities of a piezoelectric element, they nevertheless hold considerable and important haptic qualities and attributes. Common materials, like wood, plastics, and metals, each have particular atomic structures and molecular scale arrangements that impact their macroscopic properties that in turn impact how they feel to one's touch. While an understanding of these properties forms the basis of any approach to haptics design and research, the interest in and expertise of screening and gauging the haptic attributes of common and standard materials seems to be a decreasing concern in traditional haptic research. The work of Kappers and her collaborators however particularly stands out when these matters are concerned (Kappers & Liefers, 2012; Plaisier, Tiest, & Kappers, 2010; Wijntjes, Sato, Hayward, & Kappers, 2009).

From the perspective of haptic interaction design, traditional materials constitute a large untapped pool of haptic resources. They might be undervalued in more technology-related quarters due to their apparent static and low-tech nature, but to develop haptic interaction design further we ought to reconsider and rediscover these materials. For centuries, craftsmen have developed a heightened sensitivity to materials, exploiting and taking advantage of their attributes wisely and carefully. Nowadays, industrial designers typically excel at selecting materials, transforming, and processing them to alter or enhance their characteristics for various purposes. As interaction design is taking a tangible turn, as argued above, we need to explore and better understand what our basic materials can offer for the design of haptic interactions, before we enter the jungle of advanced, hi-tech materials and intricate technical solutions.

In conclusion, the field of haptics has developed in sync with material advances in other areas. From static touch qualities to force-feedback mechanisms, the availability of suitable substrates has always constrained the possibilities *in* and *for* haptic interaction design. The rapid development of technology has given rise to more affordable and reliable hardware that is also considerably smaller and easier to use from a development standpoint. New advances in the material sciences and in nano-technology are on the verge of providing haptic interaction design with a wide range of new dynamic and self-actuating materials that might come to shatter our pre-assumptions of mechanical actuation. As we await these potentially revolutionary building blocks for future haptics design, we might want to look back and revisit our traditional materials. While these materials are common, their qualities and potentials have so far been mostly neglected in haptic interaction design.

### 3.1.3 AVAILABILITY OF TOOLS FOR WORKING WITH HAPTIC INTERACTION DESIGN

This section addresses the current state of haptic interaction design relating to tools. Tools, in the way the term is used here, help researchers and designers to manipulate, shape, and control haptic materials. This definition is knowingly open and encompasses physical devices, procedures, processes, and apparatuses used to achieve a goal. For example, one could either work with a shape-memory alloy wire—the material—and use a simple battery and some cables to electrically actuate the wire, or one could use a microcontroller with other electronic circuitry to actuate the wire, possibly with more control, finesse, and repeatability. A particular tool thus makes certain goals and activities possible and realizable but, in return, often tends to hinder and constrain use. The analogy with graphic design would be using a quill pen or letterpress printing press to come up with a page of a book. Both techniques yield a page, but each has its own set of qualities, advantages, and weaknesses.

As previously discussed, haptic materials can be very elaborate and therefore often require dedicated apparatuses to operate properly. The successful actuation of a motor can depend as much on the capabilities of the motor as on its controller. In many cases, materials and tools are so interrelated than they are bundled together in one technological package. For example, most haptic arm controllers come fully built and ready to use, with matching APIs and supporting software. While complete and seamless technology packages often ease parts of the development, they also hinder variations and deeper explorations of the technology. At times, it might thus be advisable to reconsider, question, and dissect ready-made haptic solutions. Separating the tool from the materials, like building a project from parts (e.g. in the form of unassembled toolkits), might be beneficial too as it will expose other problems but also other possibilities.

As a part of my own interest in how tools relate to haptic interaction design, and as a compliment to my own experience with tools for haptic interaction design, I completed a substantial toolkits review in 2011 [REF]. The review consisted of investigating the capabilities, qualities, and limitations of 30 different electronic toolkits—i.e. most of the available toolkits on the market—that in one way or another offered or claimed to offer support for the design and realization of *hardware sketches*. Most of the toolkits reviewed were not specifically designed to target haptics design work, but they all supported the intricate mix of hardware and software elements that underlie common haptic interaction design realizations. A complete description and discussion of this review would require too much space in this book, so it is made available in the form of a complementary web site (see: http://sketchinginhardware.com).

A few of the conclusions of this review are however worth discussing here, especially with regards to the general examination of tools for the design haptic interactions. First, most of the available toolkits are heavily biased towards input and sensing compared to output and actuation. This makes it particularly challenging to use them to work with haptics, as output has primacy over input. Second, the general value and usefulness of the individual toolkits appear rather relative, or as Buxton notes, "everything is best for something and worst for something else" (Buxton, 2012b). This entails that a particular toolkit that might be very appropriate for a specific endeavor in a particular context will actually be quite unfit for another design activity in a different context. Third, as discussed earlier in this book, many of the challenges involved in sketching haptics using an electronic toolkit do not actually pertain to the electronics side, but rather depend on a number of mechanical considerations. Hence, building something quickly that is also strong and reliable is generally a far more problematic issue than developing the electronics and the code for the same project, regardless of which toolkit is used.

Apart from these toolkits, what can be said about the global situation and major trends in the development of tools in a larger haptic research context? In a larger perspective, haptic tools are progressing rather rapidly. As we have seen, actuators, sensors, and other technology building blocks are getting smaller, cheaper, faster and easier to use everyday. A high-quality general purpose haptic actuator like *The Haptuator* can now be purchased for about €100 and used straightforwardly like an ordinary loudspeaker, rendering custom electronic driver boards superfluous. On the software side, new development platforms like H3D and Chai 3D provide a rich software stack to develop high-quality multimodal (haptics, graphics, and others) applications with relative ease.

Despite great advances and a rather low barrier-to-entry, haptic tools are still characterized by being technology-centered and using them can be daunting for non-specialists, including most designers. The current crop of tools available for carrying out haptics design can still be labeled appropriately as 'engineering tools', as they tend to focus on the functional and technical realizations and not on the resulting haptic experiences. If we seek to specifically tackle interaction design issues, there seems to be a opening for more 'designer-oriented tools' where some of the technical details are abstracted away or at least taken care of behind the scene. However, as established above by examining the existing toolkits on the market, finding the right balance between abstracting away implementation details versus risking locking the user into a specific way of doing something is not an easy undertaking.

In summary, haptic tools have come a rather long way over the last three decades. In the 1980s, haptic hardware and haptic tools were mostly non-existent and projects were custom-built. From the 1990s and onwards, haptic tools, both in hardware and software forms, have made the use of actuators, sensors, and other haptics materials easier. Although current tools still tend to require some degree of technical expertise to configure and operate, and that they, in hiding some of the technical implementation details away from their users, may risk locking them into specific ways of attacking problems. They nevertheless serve to greatly simplify the realization of haptic design projects by providing building blocks and reference models so designers of haptics do not have to build all of their projects from scratch anymore. This means that haptics projects no longer take months or years to realize; it is now feasible to complete projects in weeks or even days, as presented in part 2 of this thesis.

## 3.1.4 AVAILABILITY OF KNOWLEDGE AND SKILLS TO SUPPORT HAPTIC INTERACTION DESIGN

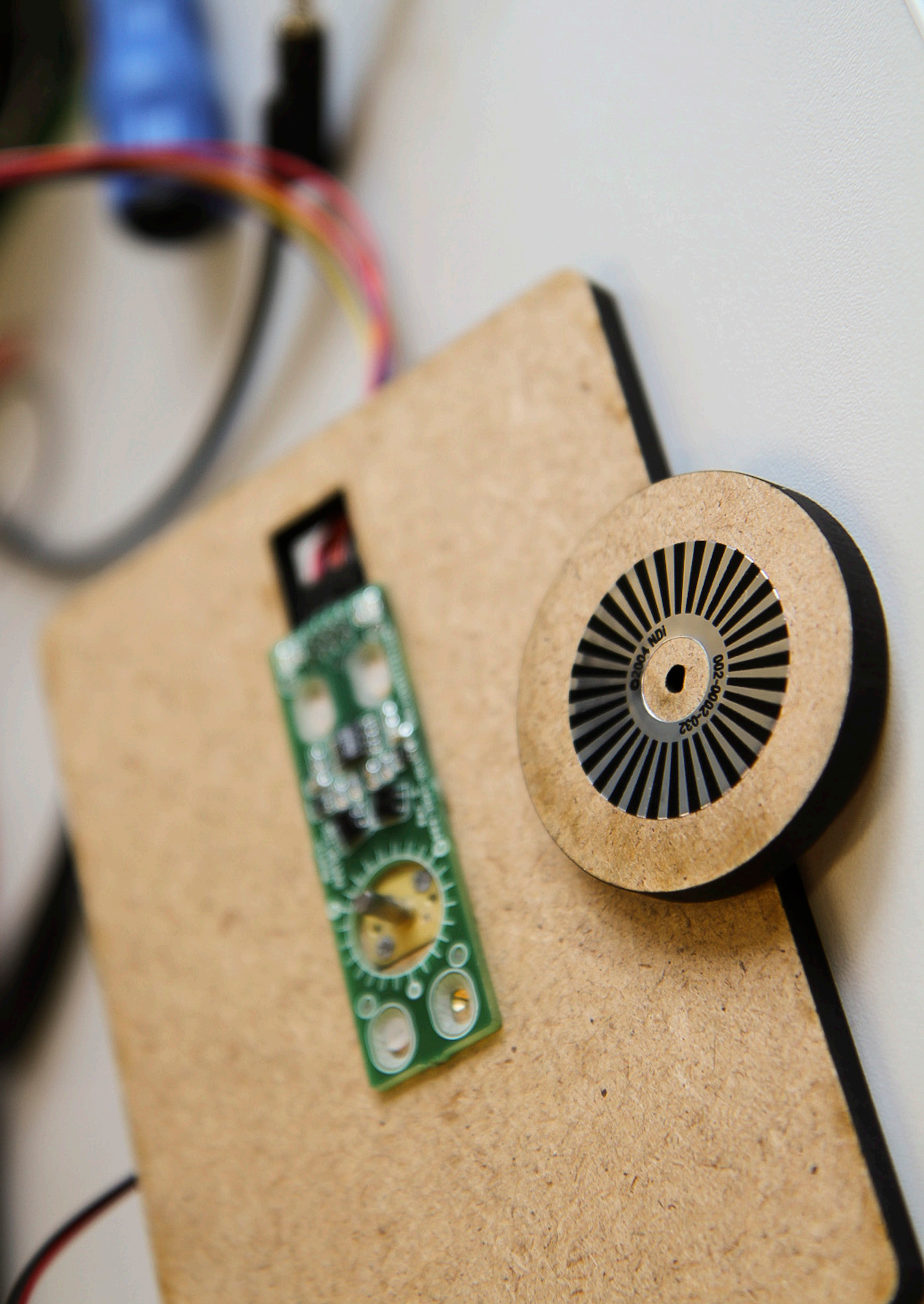
The fourth and final point of this chapter's examination of the current state of haptics interaction design relates to issues of knowledge and skills. Hence, if we have the motivation to further explore haptic interaction design, the materials to build new haptic experiences and the tools with which to build them, what is the current state of skills and knowledge in haptic interaction design?

In the view argued here, the skills and knowledge in haptic interaction design represent the principal weak point of the nascent field of haptic interaction design. MacLean & Hayward note that designing haptic interactions often implies designing for an unfamiliar modality (MacLean & Hayward, 2008). Haptics, as an object of study and inquiry, and as a design material, is unknown to most people, including designers. As humans, we have tremendous tacit knowledge of haptics, but we generally cannot articulate or communicate it clearly. Most designers, having had the principal part of their design training being concerned with the visual qualities, shapes, and attributes, are in that sense also laymen in the field of haptics design.

Based on the work in this thesis, perceiving and identifying haptic details, attributes, and differences comes from direct experience and continued exposure to stimuli. It is thus difficult to start to learn about haptics without experiential exposure to haptics. Designers venturing into haptics must prepare to spend time developing craftsmanship or artisanship to attain the sensitivity in haptics needed to design suitable and humane user experiences—a process which takes time but in turn develops basic design skills in the area.

There are some promising trends in design and related fields that suggest that such a heightened sensitivity for this modality might be within reach. The increased interest in the philosophy of somaesthetics, as championed by Shusterman (Shusterman, 2008), and the general consent about the important role of the body in our sensemaking of the world might help starting a conversation with the haptics modality. However, while Schiphorst's thesis *The Varieties of User Experiences* (Schiphorst, 2009) proposes design strategies based in embodied practices within the somatics and performance fields, it is not clear how such findings directly link to the design of haptic interfaces. While her work mostly advances body-based somatic awareness techniques, a form of self-introspection and personal connoisseurship towards one's own body, the work presented here investigates the other side of this sensorial introspection: its external counterpart, the side that focuses on the material, physical, and tangible elements giving rise to haptic interactions.

In conclusion, many disciplines are currently investigating haptics and continuously expanding our body of explicit knowledge about haptics. However, adopting this knowledge and using it for the design of haptic interactions, and in doing so developing deeper and deeper skills in haptic interaction design is easier said than done. For example, knowing that the response curve of our skin receptors helps in developing optimal haptic stimulations says very little about when, how, and under which circumstances such haptic stimuli can be best used—a design skill. Hence, knowledge about haptics research, and knowledge and skills in the design of haptic interactions are two partly different affairs. The contents of this book will hopefully contribute to the latter, if not also to the first.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# CHAPTER 3.2 CONTRIBUTIONS

**No man's knowledge can go beyond his experience.**
John Locke, Essay Concerning Human Understanding, Book II, Ch. 1, sec. 19

## 3.2.1 SCOPE

Throughout this book, three similar terms have constantly been mentioned and referred to: *haptics* or *haptics research; haptic interaction design;* and *simple haptics*. They are at times heavily related and interconnected, but they are not interchangeable. Before discussing the findings and contributions of this work in more detail, it is crucial at this point to clearly establish what each term entails:

> ***Haptics*** or ***Haptics Research*** refers to the domain or field of inquiry that encompasses all different aspects of the sense of touch and its study (cf. section 1.2.1). Its scope is vast and diverse, from psychophysics experiments to virtual reality applications, with technical constituents ranging from atomic scale actuators to large flight simulators. Haptics research tends to have its foundation in the natural sciences and in engineering, and have traditionally had little to do with the design disciplines.
>
> ***Haptic Interaction Design*** refers to a new field of study, extending the interaction design discipline with haptic considerations. Haptic interaction design encompasses all haptic aspects and qualities that are deemed relevant, important, or necessary in the activities of designing haptic interactions. It relates to the human touch sense in the same way that graphic design relates to vision. Haptic interaction design corresponds to the overlapping area between the disciplines of haptics and interaction design.Its scope is wide, touching on material qualities, touch-based communication, tangible interaction and more, but its focus is on the design of new

haptic interactions and other design-related challenges and opportunities for haptic interactions.

***Simple Haptics*** refers to the particular approach to haptic interaction design that has been developed throughout this book and which will be distilled in detail below. Here, haptic interfaces and systems are purposely investigated, designed, built, tested, and evaluated using simple, uncomplicated, and widely accessible technologies and tools. The approach advocates the activity of *haptics sketching* as the primary means for designers to learn, understand, and further develop their knowledge and skills in relation to haptic interaction design. In these activities, explorative and experiential qualities take precedence over technical accomplishments and meticulous user studies. The simple haptics approach, the primary result of this work, has partly evolved, and has partly been designed to support the discovery and familiarization of haptics by designers.

An aspect worth considering is that haptic interaction design is quite different in purpose compared to more general haptics research. In essence, haptics research aims to encompass investigations for description and inquiries for understanding and predicting behavior, whereas haptic interaction design comprises inquiries for action. Haptic research pertains to a myriad of scientific disciplines, each with their own scientific standards, ways of doing research, and other codes of conduct, whereas haptic interaction design lives mostly under the interaction design umbrella. In the design community, a current lack of knowledge and skills with regard to the modality of haptics has been established. The simple haptics approach is suggested as a particular approach for kick starting and fuelling the field of haptic interaction design.

### 3.2.2 THE SIMPLE HAPTICS PROPOSITION

With the examination of the state of the art in haptic interaction design carried out (chapter 3.1), we are now able to return the question that started this part of the book: how does haptic interaction design fare today? The answer, besides the obvious 'it depends', is subject to the perspective we adopt to assess the inquiry. On a positive note, we can recognize that it fares pretty well, feeding from and capitalizing on a strong current interest in areas such as human-computer interaction and interaction design in taking the design of interactions away from the our computers screens and keyboards into more physical, tangible, and playful realms. It is also gaining visibility and relevance with the introduction and adoption of new tools and materials that live at the border between digital and physical.

On the more negative side however, notwithstanding these trends, we still need to acknowledge that as a more distinct community of practice, haptic interaction design is still emerging and much is still to be developed. First, while the haptic modality is always present in our everyday life, our capacity to design *with* and *for* haptic interactions remains very crude, disconcertingly basic, and elusive. To some extent, we are still in the stone age of haptic interaction design, especially as we compare it with the level of finesse and proficiency interaction designers deal with visual representations. Second, the field of haptic interaction design that is referred to in this work is an abstract or idea-based notion or subset to the larger interaction design movement—very few real interaction designers actually think of themselves as belong to such a community or their activities in this area as haptic interaction design.

Building on this state of affairs, this thesis advances a proposition to nurture and fuel the nascent field of haptic interaction design: the *simple haptics proposition*. Simple haptics consists in a simplistic, rustic approach to the design of haptic interactions. It advocates an effervescence of direct perceptual experiences in lieu of technical reverence and dutiful attention to empirical user studies. Simple haptics boils down to three main traits: 1) a reliance on sketching in hardware to engage with haptics; 2) a fondness for basic, uncomplicated, and accessible tools and materials for the design of haptic interactions; and 3) a strong focus on experiential and directly experiencable perceptual qualities of haptics.

For reasons that will be described below, simple haptics is here by considered as a particularly valuable way to approach the new field of haptic interaction design (see figure 73).

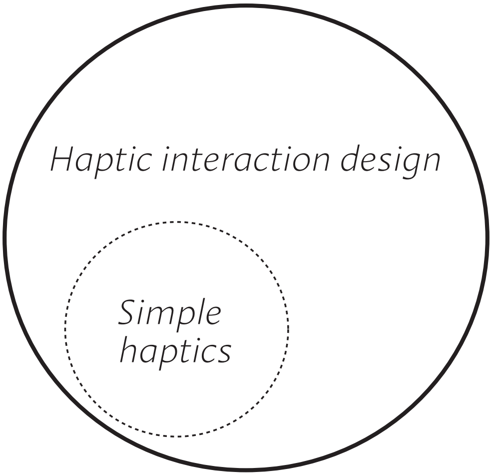



Figure 73: Simple haptics as a particular approach to the field of haptic interaction design.

Simple haptics is this work's response to the growing interest in including design and designers in traditional haptics research. It is also aligned with the notable shift toward physicality, called the tangible turn above, in interaction design and related disciplines. The proposition fits with the desire to discover and embrace new haptic tools and materials. More importantly, simple haptics offers a compelling strategy for designers to become acquainted with haptic interactions. Its focus on direct hands-on engagement assures that designers will develop and build their own design-related knowledge, skills, and experience in relation to haptics and not blindly try to apply the findings of haptic research in design work. Ultimately, simple haptics aims to foster the potential for a future where designers become competent and intelligent creators of new haptic interactions.

Design has a long tradition of using sketching and prototyping to approach, probe, and make sense of the unknown. It is one of the basic ways that we as designers use to come to grip with new problems and situations; it is a basic way in which a designer relates to the world, confronting us with a new reality and somehow summoning us to react or to take action. This intentional destabilization might not always be comfortable, but it yields results, insights, and design knowledge that are unique and sometimes extraordinary. In this way, it is not particularly odd or peculiar to base the proposition of a way forward in haptic interaction design around the activity of sketching. Sketching, after all, is what we do well as designers.

## 3.2.3 CONTRIBUTIONS

The contributions of this work are elaborated first and foremost for an interaction design and a design research audience. Interaction design research is the dominating perspective in which my work took place and it is only natural that its results resonate primarily with this field.

The contributions of this work have been divided into four categories: *knowledge contributions, methodological contributions, impact contributions,* and *design contributions*. Knowledge contributions relate to the understanding of the design of haptic interactions, what it is, and what it entails. These contributions draw from my activities and the work of others to elaborate on the theoretical and practical understandings of designing haptic interactions. The core argument is that my research through design activities have provided access to interaction design related reflections and findings that would have been difficult to attain otherwise.

Methodological contributions expose specific processes, approaches, and strategies that are considered helpful and beneficial for design researchers venturing into the haptics area. These contributions aim to simplify, accelerate, enhance, and drive design activities in the haptic interaction realm. A few of these contributions pinpoint difficult areas of development that require particular attention, but in general, the methodological contributions depict new takes for working with haptic interactions that makes it an exciting, and promising field.

The third type of contributions presented in this chapter relates to impact. This type of contribution looks at the way in which the completion of this thesis has affected, is currently affecting, or ought to have affected people and activities around me. The impact contributions are divided in three poles: impact on industry, impact on education, and impact on other disciplines.

Finally, design contributions are part guidelines, part strategies *in* and *for* design, and part courses of action towards impact. The best way to understand the design contributions is to think of them as the ways and means that have been found favorable to the accomplishment of actual design activities throughout this work.

## 3.2.3 KNOWLEDGE CONTRIBUTIONS

The first kind of contribution that this book offers is about knowledge; knowledge of what differentiates haptic interaction design from haptics, knowledge of what haptic interaction design is all about, and what it entails—its *modus operandi*.

The main knowledge contribution of this work is the realization or *massification* of haptics in design and from this the understanding and discovery of various dimensions that make up the field of haptic interaction design. The discussion that follows dissects this assertion by examining the scope and dimensions of the nascent of field of haptic interaction design. The objective of this section is to capture, from a knowledge perspective, how haptics becomes sensible, approachable, practicable, and more importantly *designable* in the interaction design domain.

### PUBLICATIONS

A direct and rather obvious knowledge contribution relates to academic publications. The format of printed communication (and its digital variant) offers numerous opportunities to share successes, findings, and constructive failures among peers and scholars. More importantly it has provided a fairly robust mechanism to obtain critical feedback on one's ideas. This research project has, apart from this book, also led to the publications of various academic articles, including:

> Murphy, E., Moussette, C., Verron, C. & Guastavino, C. 2012. Supporting Sounds Design and Evaluation of an Audio-Haptic Interface. In Proceedings of HAID'12. Springer. Lund, Sweden.
>
> Moussette, C. 2012. Learn to make, make to learn: Reflections from Sketching Haptics Workshops. In Proceedings of DeSForM 2012: Design and Semantics of Form and Movement, Wellington, New Zealand.
>
> Moussette, C., Kuenen, C. & Israr, A. 2012. Designing Haptics, Studio, In Proceedings of the sixth international conference on Tangible, embedded, and embodied interaction (TEI'12). ACM Press.

Fallman, D. & Moussette, C. 2011. Sketching with stop motion animation, ACM Interactions, Volume XVIII.2, March + April (pp. 57-61), New York, NY: ACM Press.

Moussette, C. & Banks, R. 2011. Designing through making: exploring the simple haptic design space, In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction (TEI '11). ACM Press, New York, NY, USA, 279-282.

Moussette, C. & Dore, F. 2010. Sketching in Hardware and Building Interaction Design: Tools, Toolkits and an Attitude for Interaction Designers, In Proceedings of Design Research Society, Montreal, Canada.

Moussette, C. & Fallman, D. 2009. Designing for Touch: Creating and Building Meaningful Haptic Interfaces, In Proceedings of IASDR 2009, International Association of Societies of Design Research conference, Seoul (Korea), 18-22 October 2009.

## THE MASSIFICATION OF HAPTICS FOR INTERACTION DESIGN

The main knowledge contribution of this book arguably relates to the *massification* of haptics for interaction design. Here, the notion of massification has been inspired by Lund's thesis *Massification of the Intangible*, described as the reverse of demassification and dematerialization which usually permeates design thinking in the digital space (Lund, 2003). Massification, on the other hand, is about transforming the unphysical to the physical: from the ideal to the real, from the theoretical to the pragmatic. Massifying is thus the physical equivalent of visualizing. In some sense, a primary goal of this work has been to massify haptics, i.e. the intentional realization and appropriation of haptics as a non-visual interaction design material. In such, the work of this thesis proposes various ways to make haptics concrete, graspable, sensible, and approachable for designers. It has intentionally aimed to see through the 'obviousness' of everyday haptic interactions and posits that haptic interactions can be intentionally and knowingly designed.

To realize and make haptics available and concrete for interaction design, the notions of *dimensions* and *qualities* of haptics are worth discussing further. Taken together with the sketches, prototypes, and boxes realized during the course of this research project, they create a partly abstract and partly concrete knowledge substrate of haptic interaction design. In this substrate, haptics appears in its most raw form, ready to be further explored and ready to be designed.

The proposition of simple haptics is intentionally articulated towards facilitating the massification of haptics for design purposes. The focus on experiential qualities coincides directly with the desire to unfold the qualities of haptics at large. Additionally, simple haptics accepts that such massification processes, or 'revelations', are not straightforward or evident to articulate. Also, when sketching and exploring one has a certain level of flexibility to examine what that massification entails. Its aim is not to attain the perfect massification, but to treasure a variety of massification attempts.

## DIMENSIONS OF HAPTIC INTERACTION DESIGN

Conceptually, my research position has been to take the mid point between haptics and interaction design and intentionally expand and stretch it through various design research activities. That dissection exercise—if I can call it that—is useful on two accounts. First, it creates a void or an empty zone that needs to be populated. One can create that void and see how it gets filled naturally, without any direct interventions. Alternatively, opening that new space can be an opportunity to pro-actively plant or inject something to fill the void.

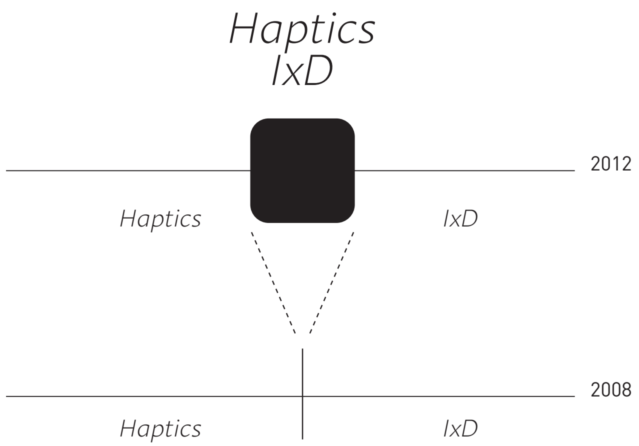



Figure 74: The expansion of the meeting point between haptics and interaction design, creating the new haptic interaction design field.

The zone might be artificially motivated; nevertheless it provides an environment that is both very real and readily available to explore core elements of haptic interaction design. Once that new design space exists, it becomes necessary to characterize it, to see what its main dimensions are and reach towards its boundaries.

Below, four dimensions are presented that should be regarded as depictions of a range of possibilities in haptic interaction design. Each dimension cuts across the rather vast haptic interaction design space and allows the mapping out of instances, projects, and ideas related to haptic interactions. The goal is not to argue that one extremity is better than another, but rather to acknowledge that haptic interactions can and do arise at many points along a particular dimension. The spacing and staggering of points uncovers and reveals the many new angles and realities of the design of haptic interactions. The set of five dimensions that is presented below have all surfaced during the course of my work and have been considered to be particularly revealing and useful in their way to stretch and delimit the whole haptic interaction design space.

## THE TECHNOLOGY DIMENSION

The technology dimension is the most obvious dimension to consider for haptic interaction design. This dimension could perhaps also be labeled as the scale of complexity: from simple to complex. As stated extensively in this thesis, haptics work often includes a form of worship towards technical excellence. To counteract this tendency, my work and the approach of simple haptics have explicitly explored the other extremity, where haptic interaction design is realized with less-technological and simple alternatives and means. Doing so forces one to reconsider the role of technology in haptic interactions, and allows one to explore the wider assumptions of haptics: haptics without power, haptics in everyday situations, haptics with analog components versus digital haptics, and so on. Scrutinizing this technological dimension also exposes less common, less known, or less popular areas associated with haptics. One can see that haptic interaction design can potentially capitalize on these new opportunities.

The following schema (Figure 75) maps a selection of my own haptic sketches and explorations along two technological axes. The first axis, complexity, captures the technical intricacy of the interface. The second axis relates the type of the technology used for realizing haptics, digital or analog.

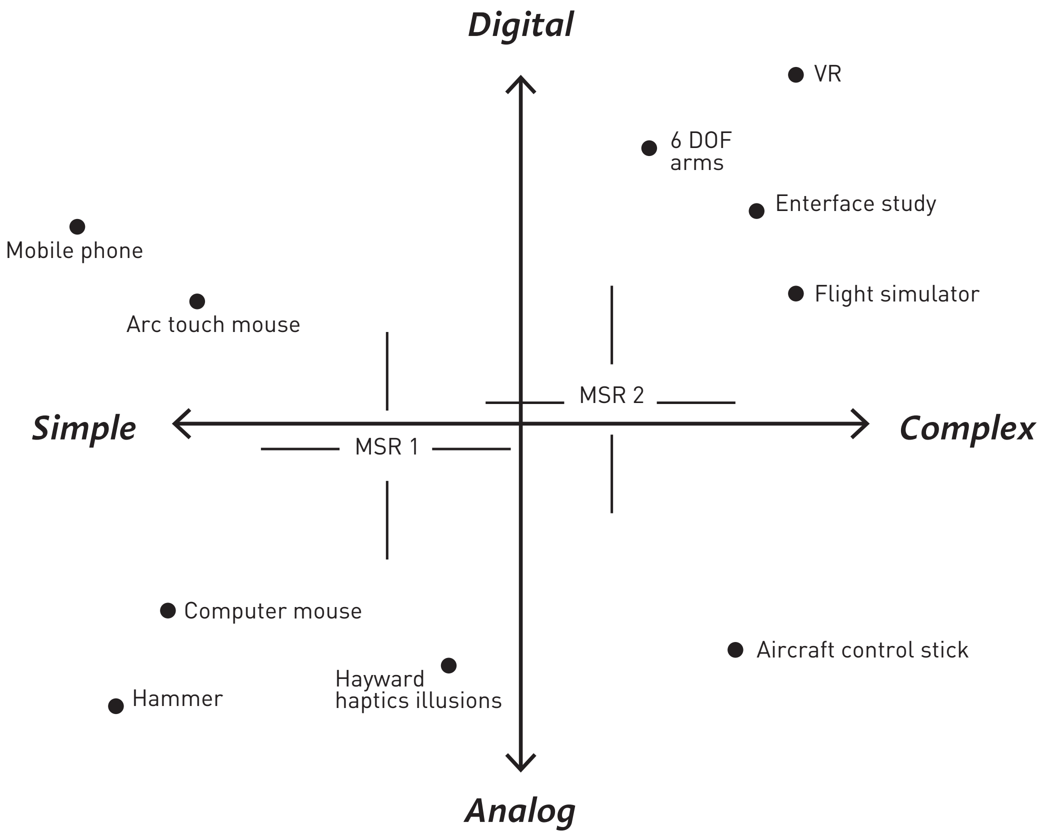



Figure 75: Technology dimension of haptics

Devices in the lower left quadrant are mechanical and as such are generally more static and reactive than fully active. Haptic sketches like The Slider and The Slacker, discussed in part 2, can be positioned in the simple-analog quadrant. The top right quadrant hosts more classical haptic interfaces, generally more technical and fairly complex. A project such as the Haptic Kinect represents the low-end of this zone: the Kinect sensor unit is based on quite elaborate technology (vision tracking, machine learning algorithm, etc.), but the sketches associated with actual haptics feedback contain relatively basic technology. The bottom right quadrant is lightly populated and most items that could be located in this zone tend to date the pre-computer era. A fitting example would be a Second World War era flight stick fitted with mechanically driven feedback for stall warning. In recent years, digital technologies have tended to take over all aspects of such sensing and control systems, and work in this quadrant is becoming increasingly redundant. The top left quadrant presents devices such as mobile phones and game controllers that sport simple haptic capabilities.

## THE BIDIRECTIONALITY OR INPUT/OUTPUT DIMENSION

The haptic sense is our only bidirectional sense: it can perceive as it can act on the world. Haptic interactions, like most other kinds of interactions, can be developed with varying degrees of input and output. For example, a braille reader is an output only device while the Microsoft Kinect is an input only device. Most haptic interfaces have a mix of input and output, as the output signal can be monitored and modulated as necessary. To discuss this, control engineers often talk about *open-loop* and *closed-loop* systems. Open-loop systems assume the instruction, movement, or actuation is realized in the real world, whereas closed-loop systems sense and measure the environment (position, acceleration, etc.) to modulate the control signal in such a way so that the final outcome matches the intended value or model.

During the activities described in this work, input has often been purposely separated from output to ease technical requirements and accelerate the development. This meant that more sketches could be built, but at the cost of having simpler or no sensing capabilities. Varying the balance of input and output capabilities leads to new considerations for the kind of haptic interactions that can be realized. Many successful haptic interfaces involve a tight sensory coupling for perceived control: one particular action has a definitive and clear outcome. For example, actuation of The Winder haptic sketch was linked to the movement of a scroll-wheel on a computer mouse. Scrolling up moved the weight upward in the box. It is up to the designer to explore and define those mappings, and the possibilities grow very rapidly as one starts to consider the context of use, possible mental models, and elements relevant to the interactions.

On the other hand, haptic interfaces do not necessarily need to conform to this tight coupling rule. Many non-interactive (no input) haptic devices are quite interesting in their own rights. For example, the purely mechanical haptic illusions models developed by Hayward are fascinating (Hayward, 2008a). They systematically fool our perceptual system, without having any digital technologies or input channels. The following schema depicts a bi-dimensional conceptual space where haptic interfaces can be located according to their input and output capacity.

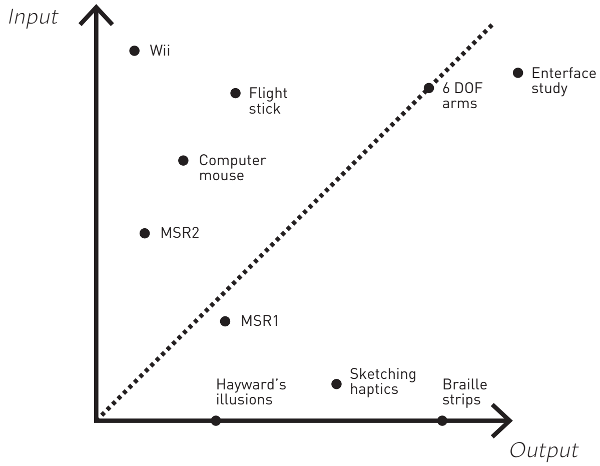



Figure 76: Haptic interfaces mapped according to their input and output capabilities. For example, the Nintendo Wii has numerous input channels (buttons, accelerometer, position tracking) but only one output channel (vibrotactile motor). A braille strip has about 100 actuated output pins, but no input capabilities.

## THE SCALE DIMENSION

In practice, haptic interaction design spans from sub-millimeter actuation (tactile stimuli) to larger gestural movement (like the Haptic Kinect work presented in part 2). Scale can be interpreted as big versus small, but it can also be framed as single versus multiple. Each actuation or stimulation technology has its applicable or effective spatial constraints. Considerations regarding body sites, mobility, and comfort are linked to space and spatial distribution.

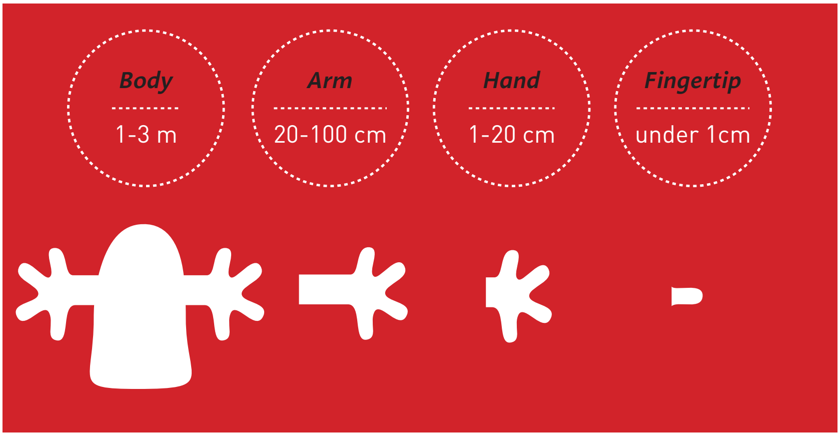



Figure 77: Haptic interfaces range in size from large to miniature

The scale dimension of haptic interactions links to some important considerations about the design of haptic experiences. The first of these considerations relates to the personal character of the haptic modality. Direct skin contact implies a level of intimacy that far surpasses all other modalities. Tactile stimuli and other small scale haptic experiences are exclusively personal, no other party can distinguish or discern it. Larger haptic interactions obviously become more visible and thus public in a different sense. The resulting haptic experiences then typically come to adopt a certain level or aspect of performativity;an aspect that has to be accounted for when designing these interactions. The second consideration is more practical and relates to the ease of construction. Building tiny mechanisms is technically challenging and larger systems, where the actuation or sensing spans over a meter or so, can also be very challenging. Hence, while haptic interactions can be difficult to realize and build at any scale, venturing into projects tackling extremely small or very large haptic systems is particularly demanding and generally requires more time and resources as well as mechanical and electronics skills that typically go beyond that of most interaction designers.

There are countless models and frames of references to develop interaction, primarily coming out of the human-computer interaction field of research. Here, most models from the 1980s and early 1990s tend to focus strongly on the user's cognitive abilities, while more recent models tend to care more for the quality of resulting user experience. In haptics, the main paradigm for the last two decades has been to try to recreate naturalistic stimuli using unnatural systems, virtual reality being a fitting example. Not surprisingly, they generally fail to provide the richness and complexity of real haptic stimuli [REF].

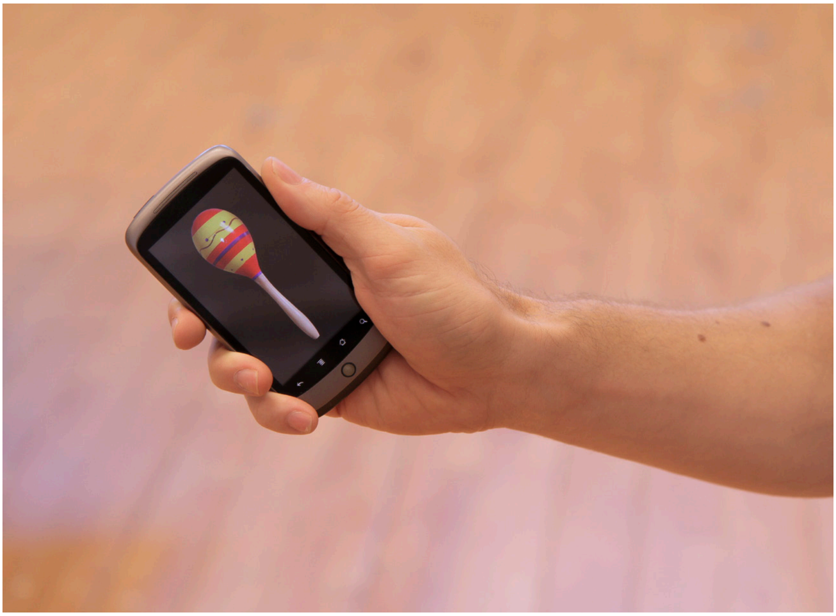


Figure 78: Haptic interface recreating the "natural" experience of a maracas.

When discussing this, it is important to note that the simulation of natural interactions is only one way to think about and develop haptics interaction. In any new systems or interface, it is possible to design haptic stimuli and haptic experiences based on both symbolic and abstract forms of representations, just like we do with other modalities. The seminal work on Tactons and Haptic Icons is an excellent example of such design explorations (Hoggan & Brewster, 2007; Maclean & Enriquez, 2003). Here, the design of the sequences of stimuli does not attempt to imitate past natural haptic experiences, but the sequences are rather optimized for recognition and discernment. Figure 79 shows some haptic melodies designed with optimal identification in mind.

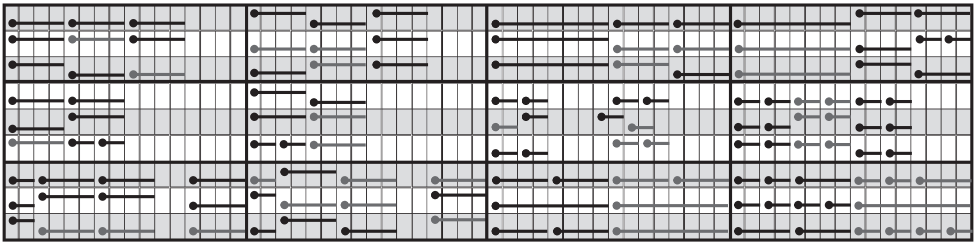


Figure 79: Haptic melodies for haptic icons. Grey notes are low amplitude, raised notes are high frequency. Adapted from Swerdfeger, Fernquist, Hazelton, & MacLean (2009).

While the field of interaction design has a rather well-developed tradition of favoring and using so-called 'natural' or reality-based models (Jacob et al., 2008; Norman, 2010), the design of haptic interactions presents a partly different set of challenges and constraints. In this space, the reign of a strong reality-based model seems obstructive for being able to creatively articulate new kinds of haptic interactions and expressions. It seems appropriate to explore more freely the synthetic and abstract stimuli that are fitting and evocative for a particular experience without resorting to a discussion about that stimuli's level of 'naturalness'.

Overall, while far from a complete depiction of the design space of haptic interaction design, the four dimensions discussed above help us scout and survey some of the possibilities and potentials of the design space. Because we are investigating a design space that is entirely non-visual, such conceptual tools might be even more useful for understanding it and being able to discuss it more specifically. Each of these dimensions and axes can be sliced, dissected, and worked on further to bring out the full richness of haptics as a design material. Each of them exposes considerations and issues of haptic interaction design that might otherwise be forgotten or overlooked. By turning the conceptual sub-spaces of haptic interaction design into simple charts and diagrams, and plotting our own designs and the designs of others, we can find empty spots that become incentives to try something new or do things differently.

Haptics relates to touch stimuli. This simple assertion might seem trivial, but as simple as it is, it has some significant consequences for design. Venturing into haptic interaction design implies a full commitment to work with the sense of touch, and this is easier said than done. Designing with haptics requires tools and processes related to haptics. Although it is possible to rely on other modalities to design haptics, some shortcuts and compromises are inadequate. Haptics is naturally best experienced haptically: images, words, or non-haptic representations have inherent limitations in their capacity to capture, encapsulate, or convey haptic qualities. For instance, the word *soft* can be interpreted in so many different ways when tied to haptic experiences: a soft bed, a soft breeze, soft leather, soft snow, etc. No matter how we put it, our language tends to fall short most of time to unfold haptic design in an articulate and meticulous manner.

As an analogy, music can be supported with the visual modality (i.e. through musical notation with the staff), but the actual experience of music is through hearing it. On its own, the musical notation captures only a narrow set of characteristics of the sound. The usage of the musical score is directly linked to our capacity to relate signs and signifiers to authentic or *real* experiences. Such trans-modal stand-ins are no matches for the in-modality richness.

One of the main practical challenges in carrying out the design of haptic interactions is to have haptic support, apparatuses, and hardware to be able to explore and evaluate haptic qualities as needed, preferably continuously. With vision, various display technologies allow for instant appreciation and evaluation of one's visual depiction. When it comes to sound, speakers generate audio renderings fairly easily. Displays and speakers can thus produce and reproduce on-demand a wide range of stimuli. With haptics however, there are no such generic haptic 'displays' or output rendering machines and the opportunities to engage in a dialog with the design materials are much more limited and challenging. Haptic hardware, be it static or dynamic, thus becomes crucial in such a perspective. Hearing and vision are relatively separate physically and functionally from other structures and mechanisms within the body, whereas haptics involve a variety of sensors spatially distributed throughout the body and highly integrated with motor mechanisms.

This work has argued that *to design haptics is to feel haptics*, the claim being that to move forward in the haptic design process you need to be able to directly feel and experience the stimuli you are designing. Designing haptics without haptic feedback is like drawing with your eyes closed—you might end up with something that others can see what it is supposed to portray, but it is far from its full potential. With your eyes open, metaphorically speaking, haptic stimuli instead become the perceptual qualifiers. If it feels right, it is probably right, haptic-wise. If it feels wrong, your haptic attributes are probably off.

During the activities of the second Microsoft Research internship, as discussed in part 2, it became evident that something was right about the *z-depth notches* experienced in one of my haptic hardware sketches. It was not just I as a designer that recognized this; everyone who tried the device with a particular range of settings immediately saw its adequacy and appeal. On the other hand, no one—including me—was able to really articulate and produce a full description of the exact haptic qualities leading to a satisfactory variation. This is a good example of being *lost in translation*, as referred by MacLean & Hayward (2008) when discussing the challenges of designing haptics.

To further expand and deepen this discussion of perceptual qualifiers, the following section introduces three haptic notions that have been particularly troubling but insightful in my haptic interaction design work. Apart from being based on and growing out of my design research work, these notions also build in part on the work of Klatzky, Lederman and Hollins, that have pioneered the psychophysics study of people's perception in relation to surface and material properties (Hollins, Bensmaïa, Karlof, & Young, 2000; Klatzky & Lederman, 1992; Lederman & Klatzky, 1987).

## RELATIVE HARDNESS

One of the most evocative exemplar of haptic quality relates to hardness. When qualifying a material or object as *hard*, it is expected to be solid or not compliant. In the haptics domain, especially when considering today's haptic interfaces, *hard* does not always feel exactly *hard*.

From my experience with different haptic platforms over the last few years, hardness is often relative. It can range from very mushy to very solid depending on a number of factors. Every mechanism and control system has particular limitations, and with most of them it is impossible to achieve a level of hardness we would commonly expect from the non-simulated analog material world.

A solid impenetrable wall of infinite density feels very springy on a Phantom Omni (an open-loop impedance controlled system), no matter how refined the rendering algorithm is. The same hard wall configuration will feel much more solid and hard in comparison to an admittance system like the HapticMaster (see figure 9). Hence, the idea of hardness can easily be diluted as it goes from a design ideal or a set configuration settings until it reaches the human interface and then forms that percept. This notion of relative hardness is not foreign to material science. On a macroscopic scale, materials like metals might be labeled hard, but under varying loads and forces solids do exhibit elastic and plastic deformations at the atomic level. A bridge made of steel feels very hard and robust for the layman, but a structural engineer will consider the same bridge as flexible and not-perfectly hard.

Hardness, hence, is a relative term and depends very much on the context of investigation.

## TEMPORAL SHARPNESS

The second major notion or qualifier worth highlighting pertains to sharpness. The sharpness being referred to here is temporal rather than spatial; it has affinity with timeliness, distinctness, and temporal acuity. A haptic perception that is sharp has clear boundaries or is clearly delimited in time. Its envelope is finite, tight, and could be referred to as a *haptic packet*.

As an example, using a hammer to hit a nail leads to a sharp haptic sensation, a hit; hugging a soft pillow and squeezing it results in less-sharp haptic sensations. From an input-output oriented perspective, we can see that it is less sharp because the onset and end points are much more difficult to perceive and recognize.

Chapter 2.3 offered a discussion of the small but very perceivable delay found in vibrotactile motors; they require spin-up and spin-down transition time to switch between active and non-active states. That in-between phase, where the device's state changes, is the source of reduced sharpness. There is activity, but that activity can be difficult to perceive, acknowledge, or identify—a blurred, uncontrollable state that might not be what the designer of haptic interactions most wanted, but because of how the particular technology is implemented, it is unavoidable. The problem is inherent to actuators in particular, as the physics of bridging a digital signal (control) to a physical entity cannot be deceived. Going from an atomic scale electric signal to macro scale movement and actuation simply takes a bit of time and no amount of clever programming and wishful thinking can sidestep this reality.

Overall, each and every actuator, sensor, and processing unit have their own particular built-in 'time curves' capabilities. For example, a vibrotactile motor technically requires a minimum of 100 ms to produce vibration whereas a LRA actuator can achieve optimal acceleration within just 15 ms. As a reference, the human sense of touch has a temporal acuity of ~5ms at the fingertips (L. Jones, 2001).

The challenge for haptic interaction design in this is not to constantly look for the fastest and sharpest signal, but to understand the temporal implications of each haptic element and be able to use them to orchestrate appropriate haptic compositions. Sharper haptic sensations might be relevant for high-bandwidth interaction, but may at the same time be rather unpleasant for more calm and ambient use.

## CONSISTENCY

Consistency is at the core of our perceptual-motor system (c.f. chapter 1.2). As humans, we tend to function properly in the world because our actions and reactions are guided by a predictive model of our movements and perceptions. Our predictive system is constantly refined, reinforced, adjusted, and corrected based on our actions in the world and on the repeatability and variability of the stimuli we take in.

The design of haptic interactions involves managing consistencies and inconsistencies of haptic signals over time, across people, and across different contexts. On the one hand, we try to build reliable mechanism to produce haptic stimuli that are consistent over time. This consistency is required to align perception and meaning, and for learning stimulus-meaning associations (MacLean & Hayward, 2008). If there were no form of consistency, we would just have noise and chaos, with no particular meaning. On the other hand, inconsistencies are also valuable and profitable, and are the essence of haptic interaction design in a way. We often design (or want to design) haptic stimuli where it is currently absent and the creation and introduction of new stimuli disturb our known stimuli patterns. The key is to make the haptic stimuli fitting and interesting enough so they can be assimilated and learnt.

Various design fields such as architecture and industrial design draw on a long history in visual aesthetics on topics such as harmony, balance, and proportion. There is a potential for a similar kind of aesthetics to be developed around touch, but it has so far not been articulated or explicitly exposed. From my experience, our sense of touch should be the fundamental judge for evaluating haptic interaction designs. Ultimately, haptic qualities are not to be reasoned or drawn, they need to be directly experienced and felt. This perspective requires designers to abandon their strong visual appreciation and embrace a modality known to them, but an unfamiliar one to be tackled by and for design.

The current tools and techniques for designing haptics are limited. We collectively lack a rich vocabulary for haptic sensations, developed notions of aesthetics of touch and various metrics for haptic actions/units. Vision has photometry and radiometric measures to characterize illumination: luminance, spectral wavelength, energy, etc. And designers are familiar with RGB/CMYK color spaces and various visual units like pixel, point and millimeters. Audition has frequencies (Hz) and decibel (dB), plus various perceptual and acoustics properties to support auditory qualities and characteristics. Haptics has a few metrics related to forces, mechanical measures, and textures, but overall there is a dire need to expand the haptic vocabulary.

In summary, this work has exposed some of the many angles, dimensions, and qualities that make haptics a unique design material, and an interesting and vibrant design space. The nature of haptics, being entirely non-visual, highly physical, and tangible can be baffling to designers seeking to enter the design space. For them, the haptic sense is interestingly obvious, yet evasive and present at the same time. In light of this, the simple haptics approach frames haptics so it becomes designable—it shows ways in which it becomes possible for designers to hone core haptic qualities in the design of haptic interactions.

## 3.2.4 METHODOLOGICAL CONTRIBUTION

The principal methodological contribution of this work relates to the mixed longitudinal approach put forward in my design research activities. The approach to the exploration of haptics for interaction design has been a persistent oscillation between self-initiated individual design activities and grounded empirical-style group activities with others. While this style of working connects strongly to a research through design methodology, my work sought out to articulate it consistently and judiciously for an unfamiliar modality and a new field of design.

The following section dissects and reviews elements of this mixed longitudinal approach towards haptic interaction design. The mixed methodology consists of a well-grounded interplay between my personal inquiries and external perspectives. It exposes specific processes, approaches and strategies that are regarded as effective and insightful for venturing into the new field.

The discussion starts by exposing how this mixed perspective fits into Fallman's (2008) model of interaction design research. It then moves on to address the primacy of attitude over tools. This is followed by a sub-section dedicated to naming and the use of sketching aids to work and make sense of haptic interaction design. The final point revisits the *Make to Learn, Learn to Make* approach I initially presented in chapter 2.4. The discussion details the important notions put forward by this approach and how it relates to educational considerations valuable for the design of haptic interactions.

### Drifting and Roaming in Fallman's Interaction Design Triangle

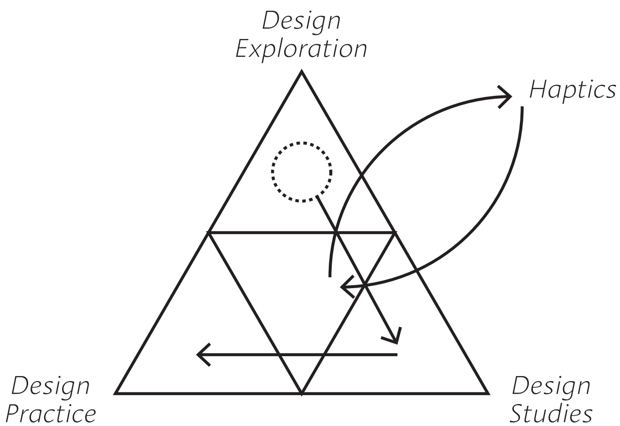



Figure 80: My progression in Fällman's model of Interaction Design Research. Adapted from (Fallman, 2008).

Chronologically, this work set out to explore the field of haptics as a personal reaction to an overly pixel-heavy interaction design domain. Thus the work originates from a design exploration position in Fallman's model. The idea was that our sense of touch deserved stronger design consideration in today's technological spheres and that interaction design ought to be less screen or display-heavy, which was and still is the underlying ideal being advocated and articulated by my research.

With my ideal crystallized, I started literally designing my object of research: haptic interaction design. My one-person design team embarked on a journey to build haptic interaction design, for real, and to the best of my ability. My collaboration with industry helped cast my work with *pragmatic* and *synthetic* qualities. As my research and design practice came together under the design practice pole, my concerns started to drift again. Now my interest in making and building haptic interfaces changed from *exposing my ideas through hardware sketches* to a more general excuse for *developing a larger design affinity with haptics*. Consequently, my activities became more educational and imbued with foundational inquiries, drifting towards the design studies activity area in Fallman's model.

Although this description represents a larger roaming pattern within the model, it also links with an entity external to the model and to interaction design: the domain of haptics. I have repeatedly been going back and forth between the fields of design and haptics to discover, learn, and to some extent even contribute to both fields.

## ATTITUDE FIRST, TOOLS SECOND

Designers excel at asking the right questions and seeing opportunities, but they are not necessarily as good at answering those questions. This exercise of *framing, reframing* and *deframing* inquiries commands a different perspective on the approaches and tools used. As presented in parts 1 and 2, prototyping and sketching in hardware have been central themes of my doctoral work. I have taught and reflected considerably on the nature of prototyping and making in and for design in general, but also specifically for haptic interaction design. From working directly with different haptic hardware platforms and devices, and from noticing how other researchers leverage varying tools and approaches in developing haptics, I have realized that activities of prototyping and sketching depend mostly on the attitude of the designer, not on the quality and nature of the tools used. Put simply, prototyping is not about the tools one use; it is what you do with the tools.

By definition, a *tool* is an artifact of some sort used to achieve a goal. From my experience and supplemented by teaching insights, it is fairly common to let the tool define the action or drive the goal. This approach can definitely have educational merits, but prototyping should be first and foremost about informing and supporting *design moves*, as Schön puts it (Schön, 1984). Every prototyping activity is best articulated when it has a specific goal or intent, even if that intention is unclear or blurry. Here, one could argue that prototyping or sketching can be initiated and successful without a clear objective too. My answer would be that there is a goal in that assertion: the intention then is to explore without pre-defined boundaries and let the activity and acquaintance drive the evolution of the inquiry. Acknowledging a particular goal or objective greatly helps to frame the activity, it sets the boundaries and conditions around it: the resources needed, the measures of success, justification, etc. It is futile to evaluate a prototyping activity without knowing its conditions and frame of reference.

The work presented in this thesis has carried out prototyping and sketching activities that were rather nontechnical, with inquiries like: What interesting haptic interface can I make with bungee cords? Can I feel a weight moving around in an enclosed box? How does a glued assembly differ haptically from a screwed or bolted construction?

Such activities are more concerned with use qualities than with resolving technical aspects, they are about 'getting the right design more than getting the design right' as Buxton has stated (Buxton, 2007; Tohidi, Buxton, Baecker, & Sellen, 2006). They help cast a particular perspective for the *making* and *doing* activities to come. Expertise in prototyping is about articulating the relation between a particular goal and the activities most likely to fulfill such questioning. Prototyping, viewed from this perspective, relates to a particular attitude where one sets and takes action to gain insight. The choice of which tool to use is more important than mastery of a particular tool.

During the workshop series described in part 2, all participants had to state explicitly their goal very early on in their sketching endeavors, as a means of emphasizing this attitude-focused approach. They were also requested to present their prototypes or sketches at the end of each session by stating, above all, what they gained from making, using or testing it, not how the thing *worked*. I would like to think that this approach is beneficial in its way to cast sketching and prototyping as a practical quest for informing design, well above the sole usage and mastery of tools.

## NAMING, SKETCHING AIDS, AND OTHER SHORTCUTS

In the passage on perceptual qualifiers above, we noted the limited vocabulary commonly available to describe and communicate haptics. This challenging situation is well known in the haptic community (Luk et al., 2006; MacLean & Hayward, 2008; Teinaki, Montgomery, Spencer, & Cockton, 2012). To the best of my knowledge, no agreed upon guidelines exist for documenting complex haptic stimuli or experiences in writing. Researchers and engineers typically seem to adopt fit-for-purpose solutions based on their background and type of work they are realizing.

The work presented in this book has tackled this vocabulary problem by systematically naming all the realizations and sketches that have been made. The names are selected according to a mix of experiential haptic qualities and mechanical considerations. For example, my work at Microsoft Research Cambridge (chapter 2.2) came out with names such as: *Slacker, Springer, Spinner, Winder,* etc. This simple naming scheme is much more evocative than for instance actuator 5 or other common forms of identification and numbering. By just mentioning a name like the *slacker*, one starts imagining and envisioning what it would feel like, even without having access to the actual device.

Another aspect of naming used extensively in my work involves the use of action verbs to either kick-start or explain haptic interaction design explorations. Inspired by Avila's *prepositiontools* (Avila, 2012), this exercise consists of developing a list of action verbs that convey movement, action, and actuation (figure 81). It has proved very useful with students, especially in order to kick-start a new project, or to avoid the common tendency to just work with vibration when first venturing into haptics.

**ACCELERATE, COMPLIANT, EXPLODE, SHRINK, SCALE, ROTATE, PULSE, EASE IN/OUT, IMPLODE, FLICK, DISAPPEAR, RAMP, SOFT, CLUTCH, RELEASE, HOLD, SCREW, PIN, PROMPT, CONFIRM, STABLE, GLIDE, SLIDE, COLLIDE, STOP, HIT, CANCEL, AUGMENT, INCREASE, DECREASE, SHAKE, TWIST, GROW,TRANSFORM, AGITATE, CYCLE, GUIDE ,RICOCHET, FOLLOW, GRAB, REPEAT, CIRCULATE, CONSTRAIN, CHANNEL, FORCE, LEAD, SMOOTH, HARD, CAPTURE, HARSH, SOLID, BOUNCE, SPRING, BREAK, STOP, REST, PERMUTE, REACT, BOB, KICK, INVITE**

Figure 81: Action verbs and keywords to initiate haptic explorations

When the students were building their own haptic sketches during the workshops described in part 2, it was specifically asked that they would name their realizations. In general, the names were aptly chosen and came to add to the whole understanding of the apparatuses, their ideas, and the project, especially if the sketch turned out to not be working exactly as planned.

The naming process was often associated with various non-speech sounds and vocalization. During my first internship at Microsoft Research, my tutor and I frequently elaborated at length about the clutching qualities of the slacker sketch: that it could engage, release, reload, let go, slip, and freeze, often associated with corresponding sonification of the clutching. The non-speech auditory cues were very evocative and could extend about the minute details of clutching, even if the hardware could not provide such refined variation.

## SKETCHING AIDS

Sketching aids denote an approach to building and prototyping that allow for immediate control at runtime, as discussed in chapter 1.3 as well as in part 2. By considering variation as a design requirement, a large number of configurations or predefined settings can be readily available to experience, compare, tweak, and comment by oneself as a designer or among peers. An ideal scenario might be to offer such flexibility directly without interrupting the session, quitting the application, or reprogramming the units. Unfortunately, this development direction can greatly impact the complexity of the projects to an extent when they become more like platforms than sketches. The difficult part is to balance variability and complexity in the particular project at hand.

The sketching aids being considered are similar to graphic design tools like rulers, squares, compasses, and stencils. They are not required for achieving great results, but they significantly ease, accelerate, and support the realization of the work. For example, a knob allows adjusting and tweaking a threshold value much faster and easier than having a hardcoded value specified in software. Another sketching aid could be a few status lights indicating how the device is currently operating and communicating. This way, one can quickly make sure the device is working properly and as expected. It removes a lot of guessing and assuming when things do not go as planned, which is often the case in such explorative work.

Figure 82 shows two possible sketching aids for The Slider haptic sketch (discussed in section 2.2.4): one via a graphical user interface, the other using knobs to modulate the variables associated with haptic rendering sequences.

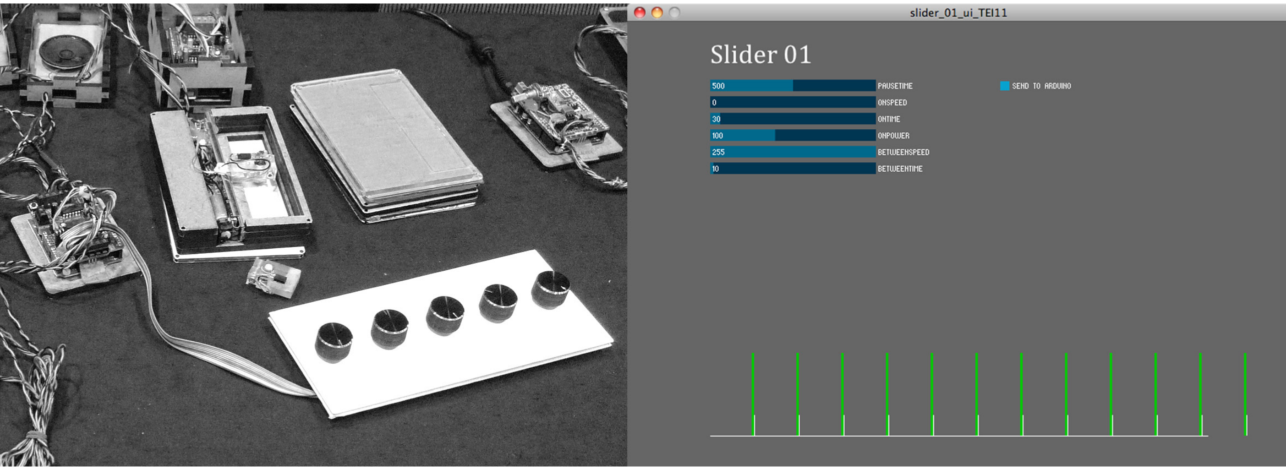



Figure 82: Two sketching aids to allow rapid modification of haptic parameters instead of recompiling code. The right image shows a graphical user interface (GUI). The left image displays physical knobs used to modify the same variables.

## MAKE TO LEARN, LEARN TO MAKE

Make to Learn, Learn to Make, is an ideal to learning that I have adopted, inspired by Schön's "Learning to Design and Design for Learning" (D. Schon, 1992, p. 139). This scheme captures many observations, experiences and challenges from my workshop series.

The *Make to learn* perspective suggests that making activities are essential in activities of learning haptics. Currently available commercial haptic interfaces do invite the discovery of and further familiarization with haptics, but only in a quite limited and narrow band of possibilities. Actively sketching in hardware and building various hardware apparatuses that can sense the world or produce stimuli allow for a much larger gamut of haptic qualities to be experienced. The personal making of stuff also provides continuous and direct contact with the materiality and physicality of this world. Such expanded exposure invariably leads to a refined sensitivity to all aspects of the built environment, its underlying attributes, and natural as well as man-made aesthetics.

*Learn to make*, on the other hand, unpacks the design of haptic interactions into a surge of learning activities of various sorts. Skills in making are vast and diverse and everybody has room to grow and expand their knowledge in the area. Participants can start at any level and from any discipline and move up from there. As mentioned previously, expertise in prototyping and sketching in hardware mostly pertain to how the different tools and artifacts are put to use. The main challenge of sketching in hardware is to learn how to best utilize the resources at hand in concert with time constraints. Detours, compromises, and shortcuts are inevitable in the haptic interaction design realm—like in any design activity. Learning which detours and compromises are acceptable and advantageous is however a lifelong enterprise.

## NO SPECIFIC STARTING POINT, NO PARTICULAR END POINT

To design haptic interaction is truly a multi-faceted activity, allowing the exploration and discovery of various aspects of haptics from many different angles: technology explorations, mechanical engineering challenges, sensori-motor tasks, control and sensing algorithms, haptic illusions, multimodal interfaces, somatic awareness, and so on almost indefinitely. Hence, haptic interaction design has almost no limits as to how far it can be developed. But on the other hand, the same is true if we look at graphic design; there are so many skills, tools, and methods that one can master: layout, typography, color theory, support mediums, rendering processes, static versus dynamic, etc.

*The Make to Learn, Learn to Make* scheme relates heavily to my proposition of simple haptics as the intentions and objectives are in agreement and very much alike. The methods and techniques also resonate heavily with each other: making, sketching, hands-on discovery, and entering into a dialog with the design materials. What differs though is their scope: Make to Learn, Learn to Make is applicable to a very large potential domain, whereas simple haptics is specifically concerned with the field at the confluence of haptics and interaction design. In a way, one could argue that if Make to Learn, Learn to Make is the class, simple haptics is the specific instance for tackling haptic interaction design.

To sum up, the methodological contribution of this work consists of a continued oscillation between self-initiated activities and grounded empirical-style group activities in the domain of haptic interaction design. Such a mixed approach balances the role of personal discovery of haptics — which is very personal— with semi-detached critical perspectives from others to help corroborate new knowledge.

## 3.2.5 IMPACT CONTRIBUTIONS

**"Design is a funny word. Some people think design means how it looks. But of course, if you dig deeper, it's really how it works."**

Steve Jobs, Wired, 1996

The third type of contributions of this work relates to impact. This type of contribution looks at how the five or so years of work on this thesis has affected, is currently affecting, or ought to have affected people and activities around me. A part of it requires looking back, noticing the outcomes of courses and workshops, but it also means some degree of speculation, stating in all modesty how my research work might have been evocative and enriching to others.

The impact contributions are divided in three poles: impact on industry, impact on education, and impact on other disciplines. The specific discourse regarding the impact on design is bundled with design contributions in the next section.

### IMPACT ON INDUSTRY

The work presented in this book started primarily as a self-initiated doctoral research endeavor. It was born out of my own personal and professional preoccupations at the junction of design and haptics. My journey started as a solitary exploration, but it quickly became clear that my interests resonated significantly with some current research and development agendas in industry. On many occasions during the course of this work, companies have contacted me directly to learn more about my research and to seek out ways to collaborate.For instance, Tinker.it—a London based technology consultancy—solicited my expertise to help them refine a new prototyping toolkit. The three week long collaboration concluded with a set of strategic considerations and guidelines for the commercialization of their prototyping toolkit. ACC acoustics, a major electronic components manufacturer, invited me to their office in China to discuss haptic interface prototyping with their engineers. We elaborated on upcoming development kits to experiment with piezoelectric actuators. Immersion Inc., the leading innovator in haptics technology, also became interested in my work, provided me with a suite of their development tools, and eventually invited me to give a presentation at their research division in Montreal.

It is difficult to report the actual impact or outcomes from these industrial visits from the perspective of the companies I was in contact with, but it seems that my work did receive some circulation within these organizations and has at least provided food for thought to numerous engineers, scientists, and other designers.

Admittedly, of course, the main impact of my work with industry relates to my rather deep collaboration with Microsoft and more precisely with the Microsoft Research division. My work consisted of two different semester-long projects as a visiting researcher intern directly relating to the design of haptic interactions. As far as I have been able to understand, my work has been very well received both at their United Kingdom branch in Cambridge and at their headquarter in Redmond in the US. The tangible results of this collaboration, i.e. the design sketches in the form of a set of boxes with haptic behavior and some other haptic sketches, have been shown both internally and externally by Microsoft. To my knowledge, the CUE group in Redmond is currently continuing the development of haptic projects using part of my work relating to Haptic Kinect (chapter 2.3). Generally, the main impact of my work on Microsoft Research might reside in the way to sketch *with* and *for* haptics, something that was not really considered possible or feasible within this organization before my projects there. My work proved that this style of working was not only possible and feasible, but that it in fact contributed to new, innovative haptic interface concepts and a series of opportunities to develop further.

The final impact on industry links to a recent partnership with TactileLabs Inc., which is a non-profit organization with the mission of offering experimental haptic interfaces and making them available to the greater research community. My recently commenced collaboration with this organization aims to develop a haptic toolkit for facilitating the design and exploration of haptic inputs and outputs. The work is ongoing at the moment, but the first results, a 'haptic synthesizer' module, should be commercially available in early 2013.

## IMPACT ON EDUCATION

As discussed in detail in part 2, the research work presented here has encompassed a considerable amount of educational and semi-educational activities, most often in the form of workshops, with the explicit aim to get designers and non-researchers more familiar with haptics. Since 2009, following the author's initiative, a course within the Interaction Masters program at Umeå Institute of Design called *Experience Prototyping* has incorporated a specific module on the design of haptic interactions. This started as a tentative new exploratory topic, but the response from students and the program director were immediately quite positive. The students have reported a very high satisfaction for this module, especially mentioning the experimental and hands-on approach to working with the sense of touch. The projects realized during this module tend to be more physical, visceral, and personal compared to the other, more traditional interaction design projects they carry out, which are often screen-based and largely visual or sound-based. After having taken the course module, several students have continued to explore the haptic modality throughout the remaining of their studies. For instance, in 2010, interaction design student Benjamin Lopez completed his Master's Degree project entitled *Family Album of Sound Memories* using multi-sensory interfaces centered around haptics and auditory feedback (Lopez, 2011). Overall, the introduction of this new module has been successful, and there have been plans to expand it into a foundation module for the first year of the interaction design program.

Apart from this, numerous educational lectures, workshops, and other education-related activities have been conducted outside my home department. For the most part, these have been well received and appreciated. My work in terms of the overall simple haptics approach and perspective on sketching haptics, has been incorporated into courses at Chalmers University in Gothenburg, Sweden, and at TU/e in Eindhoven, the Netherlands. In addition, a workshop I organized and led on this topic at the TEI 2012 conference in Kingston, Canada, was the most attended studio of the conference (Moussette, Kuenen, & Israr, 2012).

In 2011, professor Karon MacLean and I started to collaborate on the update and restructuring of some courses within computer science BA and MA programs at University of British Columbia, Canada, where we worked together to introduce a sketching in hardware and design approach to the design of haptic interfaces. More specifically, she adapted the structure of my sketching haptics workshops series (presented in part 2) to her semester-long course entitled 'CPSC 543: Physical Interface Design & Evaluation' (see http://www.cs.ubc.ca/~cs543). The new course was first offered in January 2012, with apparently great results and a new level of energy and excitement from the students. Professor MacLean's experience of revising her course ultimately reached the haptics education circles in the spring of 2012 at the Haptics Symposium in a special tutorial on the best practices of haptics education (see figure 83). She highlighted the new *simple haptics* approach to haptics with new and simpler tools and platforms and invited other educators to also consider it seriously. In terms of impact and dissemination of research findings in education, this is clearly a recognition of the practical value of this work in teaching situations.


Figure 83: Professor Okamura introducing the "Best Practices for Teaching Haptics" tutorial at Haptics Symposium 2012 in Vancouver (Canada).

Finally, another aspect of my work that can be framed as an impact for or on education relates to the role of documentation activities. Over the years, my work has been assembling various online resources at the convergence of design and haptics. My Ph.D. blog and corresponding wiki (see: http://www.partly-cloudy.com) has gathered and now presents a vast array of haptic projects, course materials, suggested readings, code samples, and a catalogue of hardware components specifically relevant for exploring haptics from an interaction design perspective. The website regularly receives a few hundred unique visitors monthly, with people explicitly emailing to thank me for this valuable source of information and asking questions. Measuring the direct impact that this online resource has on the general development of haptic interaction design field is obviously quite tricky, but the level of activity with the direct recognition and communication with others has been positive and conclusive.

## IMPACT ON OTHER DISCIPLINES

Although the material in thesis is primarily intended to contribute to the interaction design discipline and to a design research audience, some signs point to noticeable impact on other disciplines as well. The various aspects of prototyping, making, and sketching in hardware that are put forward in this book should indeed be relevant to other design fields, human-computer interaction, engineering, interactive arts, computing science, informatics, and experimental psychology, just to name a few. However, the main discipline outside design benefiting from my work is undoubtedly haptics research. While the simple haptics approach has been primarily developed for designers, many haptic researchers have voiced their enthusiasm and appreciation about the approach too. This is partly because the new generation of electronics platforms and prototyping materials are new to them, such as Arduino, Processing, polymorph, etc. When they get involved in simple haptics however, they not only discover cheaper and easier-to-use tools and materials, they also learn about design and its unique methods and processes. This has a potentially significant impact on the field of haptics research.

The impact of this work and the ideas discussed here on haptics research is relatively recent, yet it seems as if the interest of the haptic community for design is quite substantial and real. In March 2012, I was invited to co-organize a workshop entitled 'Tools and Techniques for Prototyping Haptic Interfaces' with three senior haptic researchers ("Haptics Symposium 2012," 2012). This workshop came out as the most popular and heavily attended event of the Haptics Symposium 2012. My contribution included the exact same considerations and notions found in this thesis and the response from the attendees was on the whole very positive and supporting. They commented favorably on my design-focused approach for quickly prototyping new haptic interfaces, and especially fancied the idea of realizing one prototype per day.

Eventually, an aspect of design-oriented and prototype driven design research approaches that should not be underestimated is the life the artifacts we produce can have on their own, outside the context of a book or a academic paper. Parts of the work presented in this thesis are slowly reaching a larger audience via general printed publications. For instance, a number of the haptic sketches discussed in this thesis have been selected for publication in the forthcoming book Prototyping Interfaces – Interactive Sketches with VVVV (n.d.). This entails that some aspects of simple haptics will reach a larger audience in interaction design and human-computer interaction.

## 3.2.6 DESIGN CONTRIBUTIONS

The final type of contribution of this work that will be discussed relates to design contributions. They are somewhat of a mixed breed, in part guidelines, in part strategies *in* and *for* design, and in part courses of action towards impact. Maybe the best way to understand design contributions is to think of them as the ways and means that have been found to be favorable or desirable for accomplishing design activities. Alternatively, design contributions also try to capture the tacit knowledge of designing, the design of haptic interactions in our case. The printed text format is far from the ideal medium for the sharing of such tacit knowledge, especially when dealing with a non-visual modality such as haptics, but this thesis has to make do with such limitation.

The main, overarching design contribution of this work is that *haptic interactions have to be realized physically and tangibly to be explored and considered fully*. Designing haptics commands knowledge, tools, techniques, and skills to distill the haptic qualities of various design endeavors. It requires finding ways to access and manipulate the substrate from where haptic qualities and haptic experiences emanate. The following discussion hints at how this can be achieved practically.

## MATERIALS, MECHANISMS, AND ASSEMBLIES

Sketching haptics involves an intricate mix of not only new and creative ideas but also some very practical considerations at the material and mechanical levels. This is also the level where the haptic stimuli come into being, where it 'lives'. The characteristics of that environment greatly affect its transmission and propagation and sketching haptics involves knowing about material qualities and assembly techniques.

For example, metal and wood convey vibration very differently. Gluing, welding, riveting, and screwing yield very different mechanical properties that in turn support or suppress certain kinds of haptic stimuli. The fields of materials science, mechanical engineering, and industrial design are tremendous resources to tap into for inspiration and guidance.

When it comes to physical mechanisms and structures, we as designers do not have to reinvent the wheel. The field of engineering already provides thousands of mechanical designs that we can exploit, tweak, and adapt creatively.

## A PRIMACY OF HAPTIC QUALITIES

The simple haptics approach suggests that the realization of haptic interfaces should always aim at exposing the haptic qualities first and foremost. Any other considerations should be relegated with lower priority or be knowingly neglected.

For instance, the discarding of visual attributes and cues has been found to be a greatly influential and rewarding means for this in my design explorations. Seeing the inner working of a haptics interface acts as a definite primer for the haptic stimuli to come and takes focus and engagement away from the subtle touch sense. Most of the time, those visually derived expectations of haptic behavior can be deceiving as well. Masking or hiding the visual details of an interface give full precedence on the haptic experiences that ensue.

Discarding the visual elements also facilitates the building and prototyping activities. A particular sketch can be realized at a different scale than the ideal one, while maintaining its haptic qualities. For example, the vibration emanating from a large plate will feel the same as small plate, as long as the contact surface with the skin is similar. This strategy can significantly ease the technical requirements of such a project. Building larger apparatus, although not too large, is generally easier, cheaper, and quicker than developing miniature mechanical contraptions.

## SKETCH FOR INSTANT EXPERIENCE AND COMPARISON

The process of sketching involves the exploration of multiple alternatives and variations. In such, the simple haptics approach to designing haptics gains from rapidly being able to experience variations of a particular sketch. The design process should cater to this need of quick evaluation, modification, and comparison. For instance, building sketches that can be adjusted in situ or during use is clearly an advantage. Also, developing projects and sketches using a certain level of modularity is generally beneficial. Although it might require a bit more initial planning and resources, in the long run these parts and modules can be reused and mixed together in different combinations, often producing weird but interesting results.

## DESIGN CHALLENGES

The last sub-section of this chapter highlights some particular challenges involved in designing haptics. These points emerge for the most part from the direct activities of part 2, as well as from the findings of others. They are deemed useful to expose here under design contributions, as they constitute common barriers in approaching the design of haptic interactions. Although knowing about these points does not necessarily make them easier to cope with, at least they will not come as a surprise when starting a journey into haptic interaction design. One might consider them as road signs announcing tricky terrain that might require special attention and scrutiny ahead.

## DESIGNING FOR AN UNFAMILIAR MODALITY

Newcomers to haptic interaction design can easily be *lost in translation* (MacLean & Hayward, 2008), in that using known non-haptic design tools and techniques (often visual) with haptics can result in nonsensical or incongruous outcomes. This is because the modalities are so different and that transferring skills and knowledge from one modality to another often does not make sense.

One main challenge of designing haptics thus consists of being able to take control of the haptic sense. Often, one's design explorations adopt a trial and error pattern until a satisfactory solution surfaces. Ideally though, this trial and error pattern should be replaced or at least happen in parallel with an active learning method, where a sufficient understanding, comprehension and control of the processes is taking place. This takes time and requires a particular need for modulation and fine control over the haptic stimuli.

## ACTUATION IS NOT HAPTICS

From my experience, based on running the workshop series and introducing haptics to designers and design students, I have come across what seems to be a recurrent learning profile. The first day, the initial 5-10 hours, are always very difficult and confusing. Participants tend to make actuated sketches with physical mechanisms, but most of it is not haptics. Things move, change, explode or roar, but no haptic stimuli are typically created. Touch contact with the thing it usually optional. Once they realize that haptics actually, by definition, require some direct or tool-mediated stimuli, they go back and build simpler but haptic-enabled sketches. The following 10-20 hours of workshop work then usually yield interesting projects and ideas. The main challenges then relate to building something that is solid and stable, and able to produce controllable stimuli without destroying itself. The most haptically refined projects are often the ones where the participants have spent a reasonable amount of time wearing, using, and trying out their sketch. Repeated stimulation of a raw or unrefined stimulus is not enjoyable, and one rather quickly tends to notice the awkwardness or clumsiness of a concept once it is felt and experienced. It usually takes about an hour (or a few hours) of properly developing a refined sensitivity to haptic details and variations. Once that level is achieved, however, the haptic stimuli are generally bearable and not wholly unpleasant.

## DIFFICULTIES IN COMPARISON AND EVALUATION

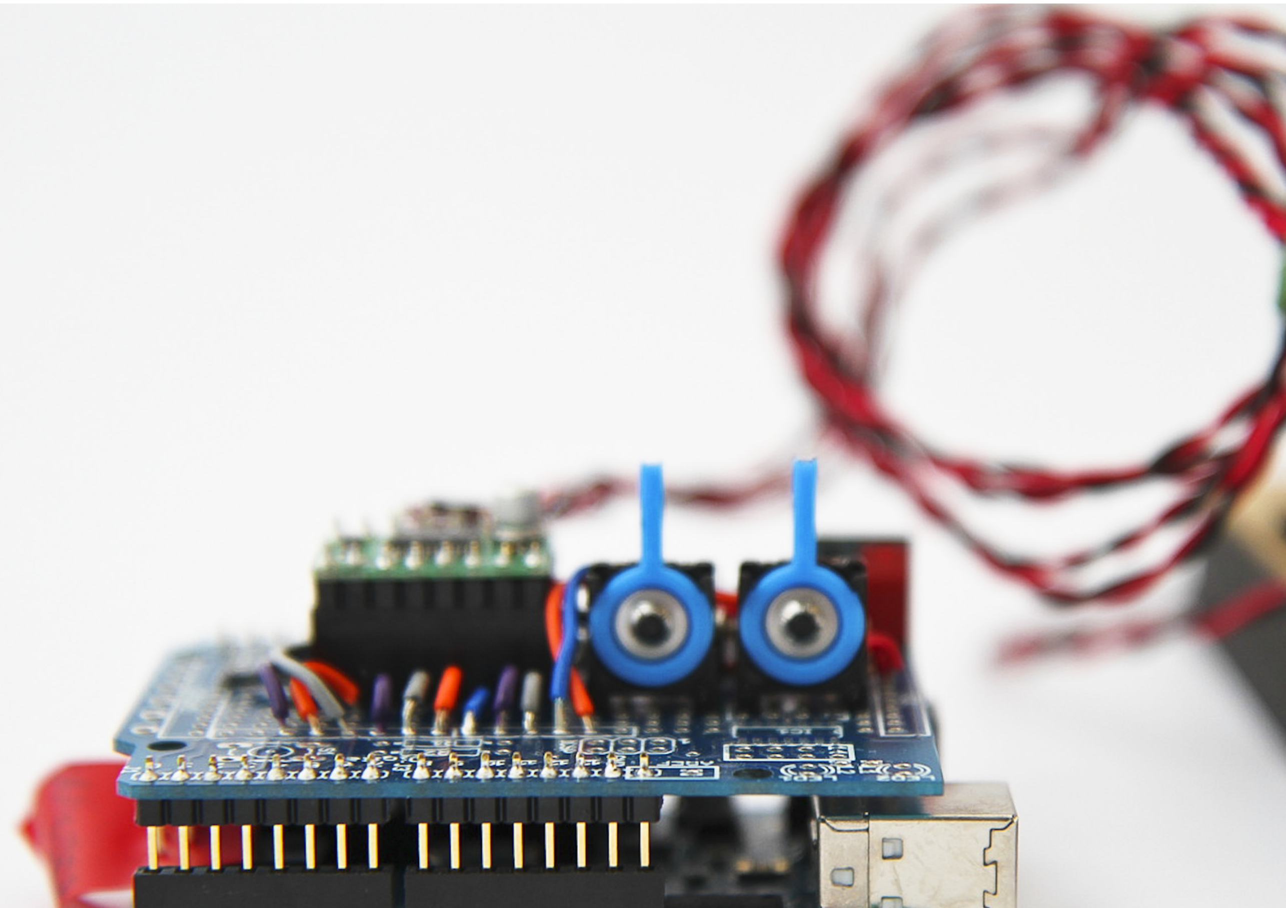
Designing haptics involve a complex set of variables, making it very difficult or even impossible to compare different haptic sketches directly. If design decisions are based on evaluation, it might be advisable to elaborate a proper usability study, which falls outside the scope of haptic interaction design and the simple haptics approach.

Haptic realization and evaluation are often short lived, with no time to learn and assimilate haptic styles and haptic interaction patterns on a larger scale. MacLean & Hayward discussed this challenge under the denomination of 'Evaluation in the Middle of the Learning Curve' (MacLean & Hayward, 2008). It is difficult to determine if latter haptic experiences are fuller or more successful because of extended use and training, or because they are inherently better designed.

## 3.2.7 CONCLUSION

This chapter has tried to make sense of my work and my activities as clearly as possible, and formulate the main findings into a set of contributions. Because of the explorative and iterative style of the design research process, it is rather difficult to exactly pinpoint the provenance or source of the experiences I have developed over the course of my haptic design explorations. Having said that, there are a number of ideas, advances, and results that can be clearly reported as contributions. The first one relates to my proposition of simple haptics as a way for designers to approach haptic interaction design. This proposition has been the driving force behind much of my activities in part 2. Simple haptics is the specific approach I suggest for designers to venture into the haptic interaction design field. The approach is comprised of three main lines of business: a reliance on sketching to engage with haptics; a fondness for basic, uncomplicated and accessible tools and materials for the design of haptic interactions; and a focus on experiential perceptual qualities of haptics. Simple haptics advocates a simplistic, hands-on, and to some degree naïve approach to the design of haptic interactions.

These contributions and this work in general have been intended to be useful to interaction designers and design researchers to intellectually and practically approach the design of haptic interactions. Interaction design students and design practitioners in other fields might also benefit from this work. It provides guidance and annotated techniques to discover haptics from an interaction design perspective, using common tools and approaches. Lastly, this work fits into contemporary haptic research as a new and refreshing approach to haptics. From these contributions, haptic researchers ought to learn about design, and that design enterprises can yield distinctive insights and results for haptic interfaces.



# CHAPTER 3.3 PERSPECTIVES

**"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail."**
Abraham Maslow (1966)

This last chapter of this part is about larger perspectives and a contextualization of the work. It is the last occasion to frame and locate my work in the grander worlds of design and haptics. It involves taking a few steps back and observing the bulk of my work from afar. This disengagement and separation are essential to gain richer perspectives on the work accomplished with this research project. It is analogous to climbing on top of a hill to gain a clearer vantage point, scanning the horizon, locating where we came from, noticing the surroundings, and discerning where the path is next heading.

The first section involves going up to that lookout tower and gazing around at my work and its vicinity. This activity prompts a return to the role of cartographer, having to share what I now make out of the haptics landscape. The result is a new, more evolved map of the design of haptic interactions that chart the various elements of haptics as seen from a unique design point of view through the simple haptics proposition. This map helps grasp the full extent of where the work of this thesis comes from, lives, dwells.

The second section of this chapter examines what makes haptic interaction design significantly different than haptic research and how the two disciplines complement each other. The discourse introduces a reflection on the role and contribution that designers can have in the field of haptics.

The third section offers an examination of my work in relation to the contemporary design research agenda. It also includes a discussion about the positioning, framing and relevance of my work in the greater design realm. Lastly, the chapter ends with a discussion on some possible future directions for the work presented in this book.

## 3.3.1 AN EMERGING HAPTIC INTERACTION DESIGN CHART

Haptics is a very evasive term: it is annoyingly vague and omniscient in our human-human and human-world relationships. It relates to so many disciplines and activities that defining its exact constituents and boundaries turns out to be very challenging. Adelstein, a founding member of Haptics Symposium, offers a description of the elements of haptics (see figure 5) using three poles: sciences, technologies and biomedical engineering (Colgate & Adelstein, 2012). The cluster of disciplines and domains might summarize quite well the last 20 years of development in haptics, but looking forward, it seems that one element or discipline is clearly missing: design.

This book aims to develop this exact design facet of haptics. My contribution might not be the first to recognize the needs and opportunities at the convergence of haptics and design, but simple haptics provides an authentic, honest, and extensive design-led investigation into haptic interaction design. Because of my background and approach, my appreciation and assessment of haptics is noticeably distinct from most other accounts in haptics research.

In the first chapter of this book, it was mentioned that this work could be seen as the development of a haptic interaction design map or chart. I have however come to the realization that such a chart cannot be produced, as none of my tentative charts and their variations was satisfyingly intelligible and meaningful. Elaborating all the terms that fit under the domains of interaction design and haptics research is rather confusing and showing how they connect or relate is even more impractical.

What can be done however is to present a diagram of the role of simple haptics in relation to interaction design and to haptics research (figure 84).

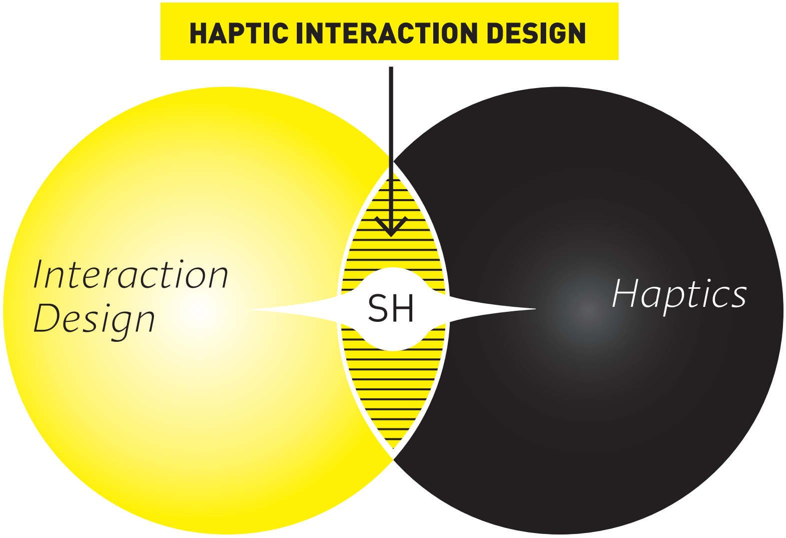



Figure 84: Positioning Simple Haptics (SH) in relation to the fields of Haptic Interaction Design, Interaction Design and Haptics.

The diagram shows that the two main fields of interaction design and haptics are overlapping. This shared overlapping area forms the nascent field of haptic interaction (ref. to chapter 3.1). The proposition of Simple Haptics lives in that space as a particular approach to nurture and develop the field of haptic interaction design. Simple Haptics does not pretend to cover all aspects of designing haptic interactions, far from it. It knowingly approaches the design of haptic interactions from particular angles—such as sketching and simple hardware—to maximize discovery, familiarization, and direct engagement. To do so, it borrows from its parent fields, interaction design and haptics. This connection to and from these sources is essential as it clearly acknowledges the strength, specificity, and validity of the inquiries in these parent fields. Simple haptics does not 'invent' new methods and practices out of thin air, it picks up relevant and appropriate knowledge, ideas, methods, and practices from two different fields and connects, mixes, and interweaves them. The result is a bridge between interaction design and haptics where inquiries are valid, relevant, and insightful for both sides. Simple haptics thus makes possible the design of haptic interactions and interfaces as well as develops haptics research from a design perspective.

As Korzybski wisely pointed it out: "A map is not the territory it represents" (Korzybski, 1958, p. 58). This diminutive map is my own comprehension, reaction, and understanding of the haptic interaction design field and how it is best tackled. The simple haptics approach frames most of the values and preoccupations I have worked with during my research.Ultimately, this representation aims to prompt and encourage other designers and researchers to discover this new haptic interaction design world, and in turn, develop the simple haptics approach further or find others approaches to come to grips with haptics in a designerly way.

## 3.3.2 HAPTICS RESEARCH AND SIMPLE HAPTICS

One important conclusion emerging from this book is that scientific haptic research inquiries are considerably different than activities relating to the design of haptic interactions. From a general standpoint, haptic research aims to investigate and comprehend the haptic sense and its capabilities, while haptic interaction design aspires to develop haptic interfaces and haptic experiences that are useful, relevant, and appropriate. Naturally, the two are heavily connected and interdependent, but it is crucial to recognize that the two activities differ. They differ in their methodology, approach, deliverables, and measures of success. The first relates more to basic research, generally relying on the scientific method to advance its inquiries, and offering one final prototype. The second pertains to design work, consist of highly explorative and tentative work, and generally offers a multiplicity of alternatives and unfinished prototypes.

The work of this thesis has been to expose the needs and opportunities for a designerly take on haptics. As the field of haptics is developing and maturing, trying to reach mainstream markets, the need to develop usable, appropriate and enjoyable haptic solutions has greatly increased. Whether it is intentional or intended, the rhythm of technical advances far surpasses our collective capacity to make sense of haptic interactions. We know, partly at least, how to build haptic systems but we often do not ask ourselves why and how this is ultimately fitting and desirable. We could say this is a form of *technicism*, an over-confidence in new technology for society's good.

Simple haptics is a call to mitigate this situation and nurture the new field of haptic interaction design. The introduction of this design approach is seen as way to question haptics' reverence for technical considerations. Simple haptics posits that great haptic interfaces and experiences are possible using non-technical and less-technical solutions. The correlation between complex technology and valuable haptic experiences is worth reexamining or reconsidering. In the general enthusiasm towards new haptic systems, it seems that we have abandoned or neglected haptic experiences derived from middle-level or simple interactions. Here the attribute *simple* is very relative. I see *simple* interactions as less complex than projects involving complex 6

DOF haptic arms and virtual reality setups. At the other extreme, I see *simple* interactions as haptic experiences more instrumented than a handshake or a caress (where no tools, objects or apparatus are used). That middle level of everyday interactions with others, with tools, and with the world, is prone to very rich haptic interactions that we ought to willingly develop and design.

The work of this thesis advances that designers, and particularly interaction designers, are aptly qualified to lead this reexamination. Their strong abilities to balance people's desires and needs with fitting technological solutions make them ideal candidates to embrace a new form of haptics. In this new haptic interactions domain, technology is fortunately not the top priority—use quality of the interactions is the primary concern. Quality in use, or the experience of using a haptic interface, is dependent on a deep understanding of context of use, personal and social considerations, and on embodiment and perceptual attributes. Technical elements and materials are surely needed, but they play a supporting role more than a leading role.

The domain of haptics is reaching an inflection point where design is increasingly relevant and necessary for developing compelling and fitting haptic experiences and interfaces. Designers are now able to learn about and embrace the haptic modality with greater ease, thanks to new tools and a growing body of scientific knowledge about our haptic sense. Having designers contribute their creative methods and general empathy towards people is a welcome addition to haptics. It will greatly complement the research efforts of engineers and psychophysicists towards a large recognition and acceptation of haptics.

### 3.3.3 SIMPLE HAPTICS AND THE DESIGN DISCIPLINE

Design is a discipline constantly in flux. Its evolution and preoccupations are tributary to the development of neighboring disciplines. Industrial design has its origins in new industrial mass-production techniques. Plastic products and molding processes have been made possible due to advances in chemical engineering. In the same way, interaction design exists in symbiosis with digital technology and the technical disciplines that makes it possible. Science and technology make design possible and design drives the development of new technology. In turn, advances in technology are generally accompanied by social changes, or vice versa, and social changes command new technical and scientific endeavors.

This view of design is highly simplified but denotes its ever-changing nature. Design has to constantly adapt and reinvent itself to stay relevant and pertinent. The frontier of what is desirable and what is possible is a moving target, always being refined and updated.

Haptics is one of these current new frontiers of design. As presented in chapter 3.1, haptics constitutes a rapidly growing field of investigation and research. After decades of basic research, we are increasingly capable of measuring, understanding and explaining how our haptic sense works, and what are the processes underlying haptic perception. We are increasingly more familiar and preoccupied with this modality, and consequently we can—and ought to—start designing for and with this modality.

Despite a growing interest in haptics, the roads into the design of haptic interactions are still fairly rough. Specific tools and techniques for the design of haptic interactions are mostly nonexistent or very crude. At best, they are simplified engineering or psychophysics tools.

This thesis has been hinting at how such tools could be developed. The activities of part 2 demonstrated that tools and equipment supporting variation and experimentation were particularly valuable. The need for sketching haptics is high, and the currently available tools do not fit well with such a perspective. Knörig advances that design tools for tangible interaction ought to fully embrace creativity, craftsmanship, and practicability (Knörig, 2008). The work of this thesis reiterates this view.

On a larger perspective, the work on simple haptics provides a concrete use case showing that design activities yield different kinds of domain knowledge. The knowledge development using a research through design approach resulted in new considerations of and for haptics. The comprehension of haptics by a designer is different than one of an engineer or a cognitive psychologist. Its usefulness and desirability are specific to one's values and paradigms.

In conclusion, haptics is one of the new frontiers of design. The haptic sense might be an unfamiliar modality for design, but it holds great potential. It is the only modality that can both sense and act on the world around us. It forms the basis for our manipulation and action in this world. We are increasingly capable of understanding its processes and capabilities. The time is opportune for designers to play an active role in the development of this promising domain.

### 3.3.4 FUTURE DIRECTIONS

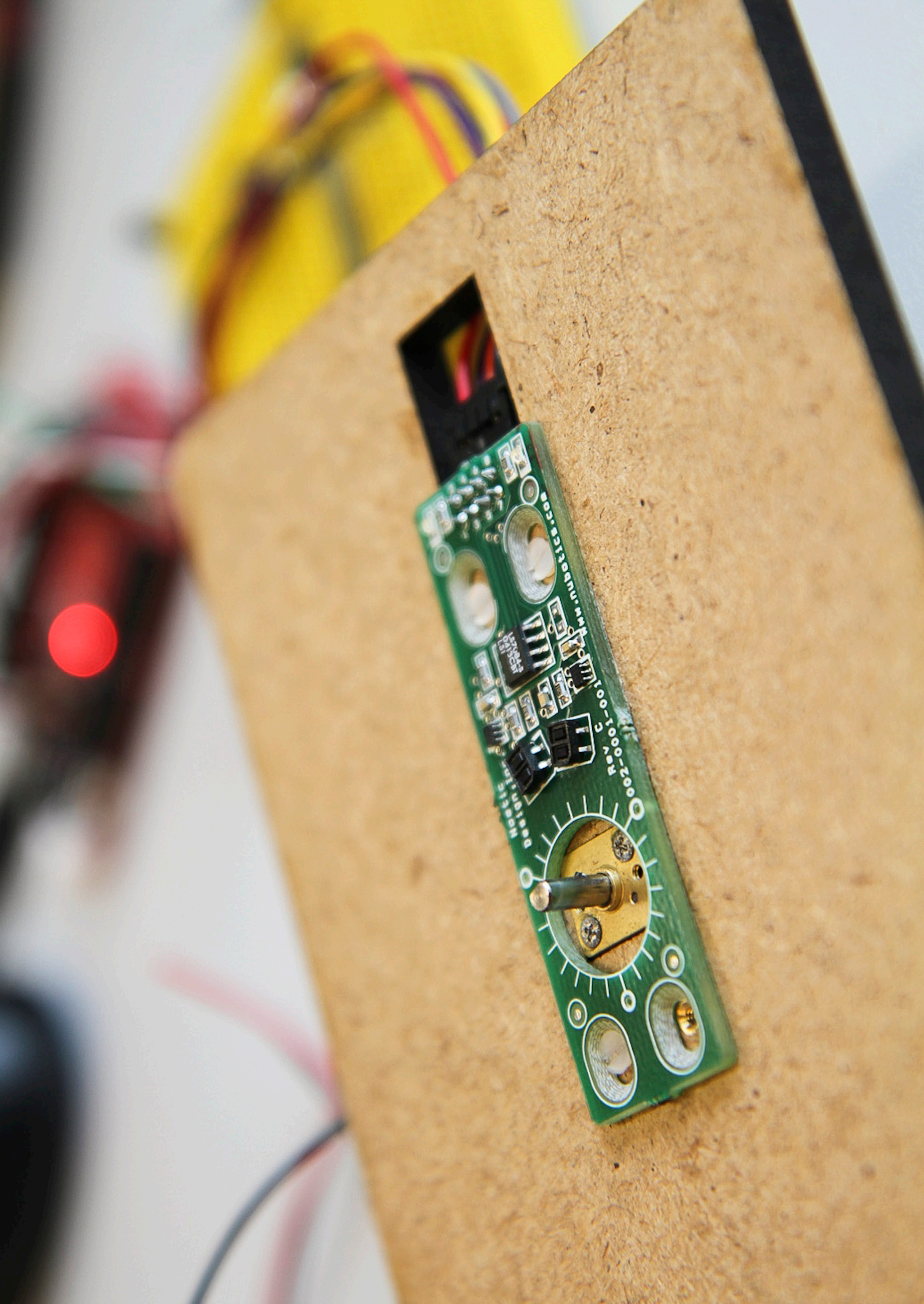
My research journey into simple haptics is now almost over, although it feels like it is just barely starting. It feels strange to have to leave so many questions unanswered and to have to keep such a long list of unrealized haptic interface concepts to myself. Invariably, these considerations and new haptic sketches will have to wait.

There are two major directions of my work that have not received the level of attention that I would have liked. It is these two tracks that feel particularly relevant and appropriate to bring my proposition of simple haptics to its full potential.

The first relates to proper design tools for haptic interaction design. The tools that are used today for controlling, modulating, and working with haptic stimuli typically favor accuracy and precision over variability and accessibility. I would like to flip this assertion around and see the emergence of tools that are built primarily for variability, exploration, and sketching. These would be design tools, probably modular, and built towards electromechanical sketching activities. This ideal simple haptics toolkit would allow very immediate and visceral control over the creation, recording, and playback of haptic sequences and haptic experiences. It would automatically transform a whistle or a vocalization into the proper haptic renderings. From my understanding, this toolkit is feasible to construct using basic electronic component and a selection of current sensors and actuators. It is technologically possible, it just has to be elaborated and put together with the right sensibility to haptics sketching.

The second direction pertains to education. This thesis was about my personal journey of discovering haptics, but I am most excited about seeing others embarking on a similar journey. It is a collaborative effort across students, teachers, tutors, practicing designers, and haptic researchers to nurture the development of the haptic interaction design field. The field will only grow and evolve if more people are actively learning and sharing. The educational activities I conducted during my doctoral research were fairly short and intense, always framed under a workshop format, and always related directly to the issues discussed in this book. Hence, the sketching and designing haptics activities were always kept at an introductory level. I see great possibilities to develop longer courses and projects of haptic interaction design, where students, designers, and professionals genuinely develop their skills, knowledge, and sketching techniques over weeks and months. It is commonly said to take about 10 000 hours of experience to master a particular skill (such as carpentry or playing the violin). Undergraduate programs in industrial design typically dedicated 2-3 full courses to CAD and 3D modeling. Why not make haptics a compulsory course in future design education?

# PART 4
# CONCLUSION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**As our circle of knowledge expands, so does the circumference of darkness surrounding it.**
Albert Einstein

The adventure leading to this book started with a simple assertion regarding my ability or inability to design for different modalities: why could I comfortably design in the visual universe after just a few years of training, but could not in the haptic realm? Was it me, my tools, my education, or something about the design tradition that made me seemingly inept at designing haptics? Why did I not have a design base for leveraging our touch sense and its rich capabilities? My formal training in Industrial Design and Interaction Design provided me with a variety of skills and tools to develop user-centered, functional, usable, and aesthetically pleasing products or systems. But once confronted with the touch modality during a particular project, my design knowledge and tools became very deficient, or simply inadequate.

Figure 85: Puce project: a small vibrotactile puck providing haptic notifications in personal communication systems.

The project in question, called Puce and realized in 2004, consisted of a wireless vibrating device for less intrusive notifications in personal communication systems. It was very difficult to argue for—or against—the use of haptics in the first place, but also for the design of the different haptic patterns (sequences of buzzing). It seemed that, at that time, the only reference available to ground my design decisions on were my own common sense, intuition, and crude user testing. It was shocking not being able, as a future designer, to develop haptics more intelligently than 'good/no good'.

The guiding motif throughout the development of this thesis has been (and still is) a desire to design *for* and *with* the human haptic sense. It is a quest centered on the advent and the development of a field now labeled haptic interaction design. This nascent field lives at the confluence of the haptics and interaction design domains, and encompasses a plethora of new considerations, notions, possibilities, and promises for the ways we design for human use.

Viewed retrospectively, the journey consisted in demystifying, surveying, and discovering that new haptic interaction design field. The work builds on a considerable research through design account, as well as on the experience and feedback from others through a series of workshops, to investigate the characteristics, qualities and dimensions that make up that new field. This thesis not only lays bare this new haptic interaction design field, it actually proposes a method, or a program, to ease its discovery for designers: *simple haptics*. The simple haptics scheme is proposed as a fitting approach for designers to successfully venture into haptics and ultimately come to evolve a design repertoire for designing haptic interfaces and haptic experiences. We will return to the simple haptics scheme, but for now let us first explore how it came about.

## THE FIRST MOVE

While this proposition emerged from a personal course of action at the confluence of the haptics and design domains, it obviously draws from already existing knowledge from both fields. Consequently, this thesis starts with an exploration of its foundations in the domains in question.

After exposing the background, context and motivation underlying this thesis, the document states the basis of my research, points to relevant and influential works, and positions my work in the grander haptics and design research domains. Overall, this part of the work divulges my role as an explorer or cartographer for venturing in the new haptic interaction design expanse that lies straight ahead.

First, it offers a highly condensed introduction to haptics research. It revisits the origins of the discipline, and looks at how its historical development can be divided into two major tracks: a body-centric approach and a techno-centric one. Those two tracks illustrate fairly adequately how haptics has been researched and developed up to this day. Despite these diverging directions, it is crucial to also investigate and take into account what exactly *makes* haptics: the details of the human skin, its receptors, the neural mechanisms, and the basic technical considerations underlying the realization of haptic interfaces. Far from constituting a thorough review of the domain of haptics, this succinct presentation serves me well for explicating and contextualizing my proposition.

Second, the same foundational examination is realized for design, and more precisely for design expertise in the field of interaction design: how design representations and activities of prototyping and sketching support design knowledge development. The terms *prototypes, models, sketches, prototypes and mock-ups* were revisited and discussed, as various communities of practice make different use of the terms. Following a deeper examination of *prototyping* versus *sketching*, we denote a preference for the term *sketching haptics* as the most evocative description of the work put forward in this thesis.

Having stated that, the core elements of my proposition emerge and draw from a number of practical design activities. It is for this reason that these activities have been presented and detailed at length in the second part of this book. As a matter of fact, my proposition draws largely from my own activities and ultimately aims at the multiplication and proliferation of this kind of activity more than anything else.

This part of the book adopts a first-person perspective to directly expose my concrete, real, and practical experiences of designing haptic interactions. The work is presented and discussed 'as it happened' throughout my doctoral journey. It shows the challenges, mishaps, and successes encountered along the way of designing haptics.

The first activity reported involves the realization of a multimodal usability study. It exposes the details of the experiment and how a non-visual audio-haptic interface was developed and tested. The content of this chapter avoids the exact details of the usability study, but focuses instead of the experience of designing haptics in the context of a scientific study. The realization of this prototyped multimodal study revealed that there was very little design consideration in the traditional lineage of haptic research. Consequently, this deficiency led me to present my wish to design haptics differently.

The second activity is a tentative endeavor to tackle haptics from a full designerly perspective. This chapter reports on my sketching in hardware activities with haptics, realized at Microsoft Research in Cambridge during the spring of 2010. It displays my program of looking at how *making* and *sketching in hardware* could lead to haptic knowledge creation. It showcases and discusses multiple haptic sketches, from inception to realization, with the goal of exposing the richness of knowledge gained from the direct design engagement with haptics. This work developed the argument that semi-abstract design tools were particularly fitting and relevant for supporting designers familiarizing and embracing the haptic interactions.

The third activity went on with similar self-initiated practical inquiries, but this time based on activities of designing haptic feedback for Kinect, Microsoft's then just-released gestural controller. The work consisted of a series of design explorations using two different form factors: hand-held devices and wearables. This work came out of a second internship with Microsoft Research, and depicted another real and pragmatic instance of tackling haptics from a design perspective. It introduced a particular z-depth haptic notches concept that came as particularly striking, pleasant and interesting among all of the other haptic explorations.

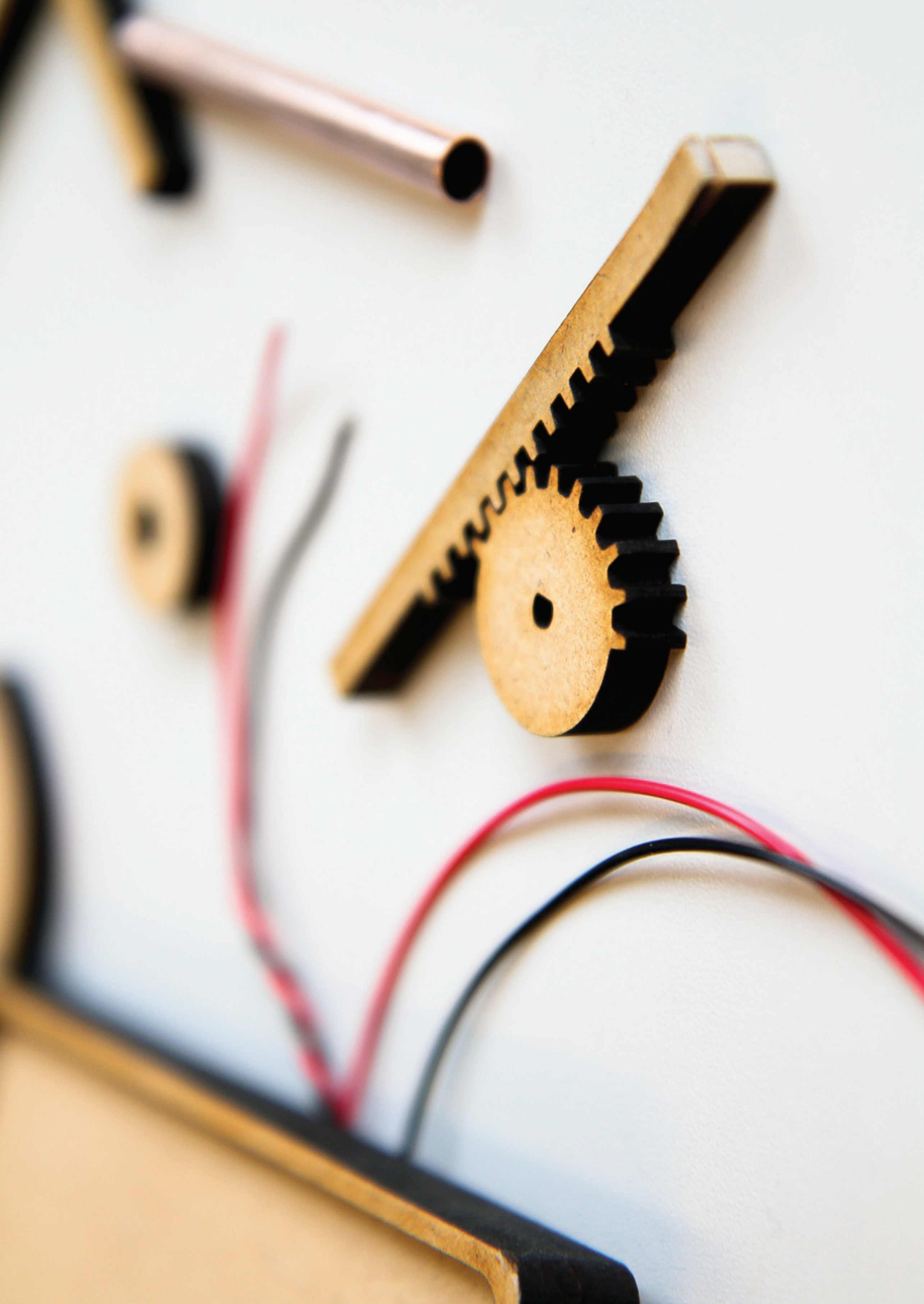
The fourth activity included empirical work of a different kind. This chapter retells the educational activities from a series of Sketching Haptics workshops realized with various students and designers over the last two years. This activity complemented my personal experiences reported in chapter 2.1 through 2.3 with external perspectives—of others—about haptic interaction design. These additional observations and insights allowed for a less-biased perspective about my research, by framing it within a larger audience of interaction designers.

## THE THIRD MOVE

The last part of this book, *A Way Forward*, is about delivering a thorough reflection and analysis of the nascent design space of *haptic interaction design*: what it is, why it is relevant and opportune for today's interaction design discipline, and how to best venture into that new field. It serves as the forum to discuss, relate and distil crucial aspects of my work, advance my proposition of Simple Haptics, and ultimately examine the ensuing research contributions. After presenting my activities 'as they happened', my work is now examined retrospectively and from a meta-perspective.

Firstly, this section reviews and examines the current state of affairs of haptic interaction design using four assessment points: interest and motivation towards this new field; the availability of materials; the availability of tools; and finally, skills and knowledge to support haptic interaction. It identifies a genuine and growing interest towards haptics and design. This examination also recognizes converging forces feeding the development of haptic interaction design. It shows that new tools and materials are slowly emerging, and expanding what is possible and conceivable for the design of haptic interactions. At the same time, the examination highlights a particular shortage or lack of knowledge and skills for the design of haptic interactions. In summary, it establishes that working, manipulating, adequately designing haptics remains quite an undertaking today.

Building from this state of affairs, this thesis advances a particular proposition to nurture the haptic interaction design field. The proposition is labeled Simple Haptics and consists of a simplistic, unsophisticated and almost naïve approach to the design of haptic interactions. Simple haptics is a program and a strategy to realize and advance haptic interaction design. It advocates an



effervescence of direct perceptual experiences in lieu of technical reverence. It recommends a familiarization of haptics through simpler but direct haptic experiences. This approach involves playing, testing, changing, and exploring with haptics to develop a fuller comprehension and design appropriation of this modality.

Secondly, this document addresses the contributions my work has had, or is expected to have, on research and practice. The contributions are elaborated under four specific categories: knowledge contributions, methodological contributions, impact contributions, and design contributions. Taken as a whole, the contributions shape more precisely what the simple haptics proposition entails.

The main knowledge contribution has been aptly labeled the *massification* of haptics and denotes the intentional realization and appropriation of haptics as a non-visual interaction design material. It advances various ways to make haptics concrete, graspable, sensible and approachable for designers, by seeing through the 'obviousness' of everyday haptic interactions, and posits that haptic interactions can be intentionally and knowingly designed. The massification of haptics hints also at a few dimensions and qualities of haptic interactions that have become available, perceivable, and *designable*.

The central methodological contribution of this work comes as a mixed longitudinal approach, a persistent oscillation and interplay between self-initiated individual design activities and empirical-style group activities with others. This particular strategy has provided very real, direct and concrete experiences of designing for the unfamiliar modality of touch, but also gave enough detached and external perspective to allow critical inquiries to take place.

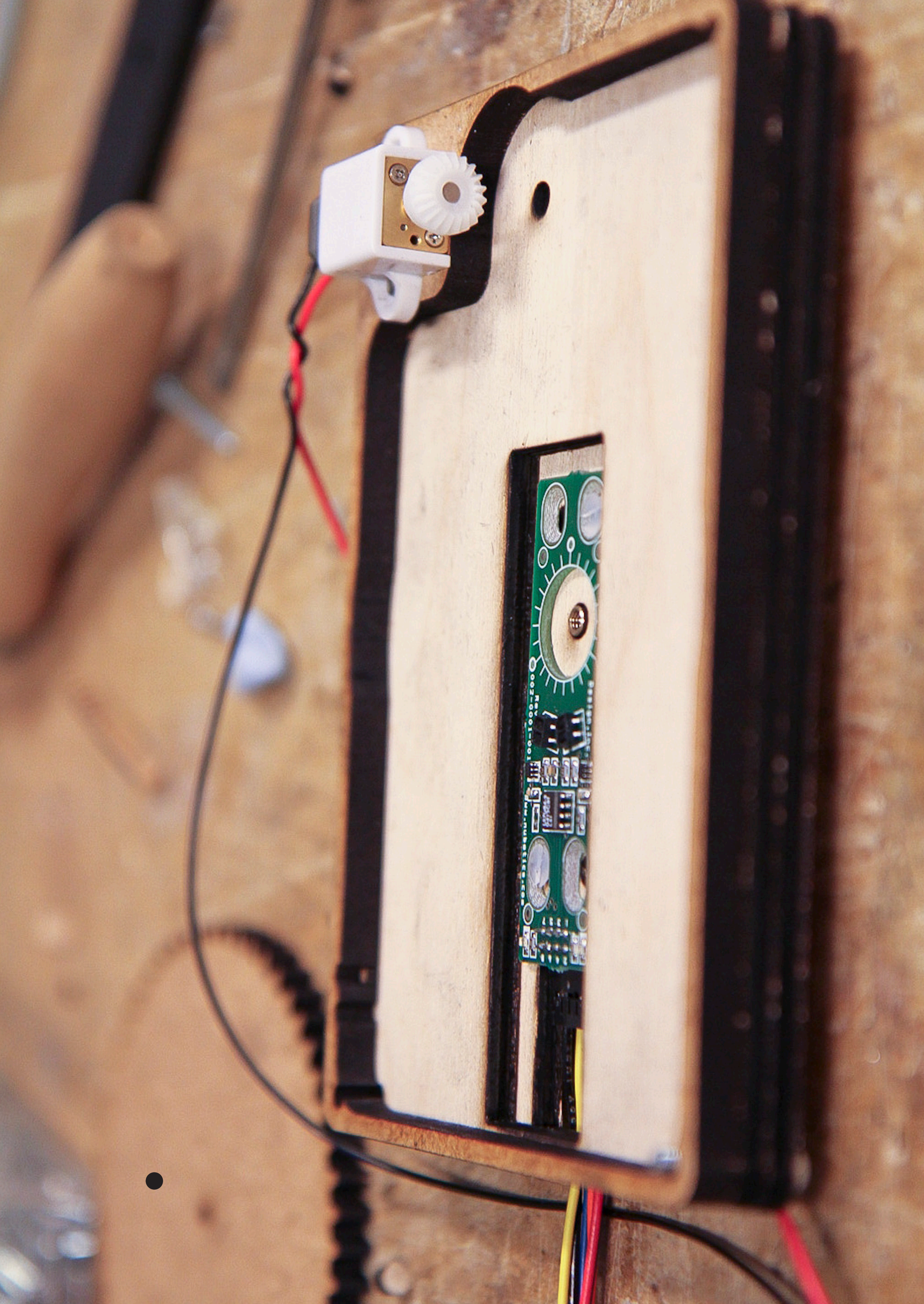
As for the impact contributions, the work has showed direct influence on industry via continued collaborations with Microsoft Research and numerous other organizations. This work has also had substantial impact on education, by elaborating new course curriculum at universities in Sweden and Canada. The sketching approach to the design of haptic interactions has been praised in the haptics education circles.

Additionally, this work offers a selection of design contributions, as ways and means to tackle the design of haptic interactions for designers. The design contributions are practical advices, tips and guidelines to facilitate the discovery of this new design space. These design contributions also highlight challenges and difficulties that have been shown to require particular attention and scrutiny when embarking on a design journey with haptics.

Finally, the thesis ends by putting this work in different perspectives, both current and future. It specifically discusses what makes haptic interaction design different than haptic research: the former being centered on design action, the latter pertaining to scientific inquiries. It also addresses how haptic interaction design relates to the contemporary design research agenda, seeing that the new field tackles crucial design issues, as the physical bridges the digital world, and vice versa. And lastly, the discussion hints at future directions regarding Simple Haptics and the larger haptic interaction design field.

## THE FINAL MOVE

This book has presented my journey into the design of haptic interactions, an adventure that lasted more than five years. Five years of probing, reading, asking questions, attending conferences and seminars, talking to experts, with one principal objective: designing haptic interactions. Even after five full years of investigation, I feel that I only scratched the surface of what the field of haptic interaction has to offer. My realizations and contributions are only the initial seeds to what I now see possible to achieve and develop in this new design space. The potential for designing new haptic interactions is so vast and wide, at so many different levels. I can only hope that others—design students, practitioners and researchers— will be inspired by this work, and in turn decide to venture into haptics. For those taking on such challenge, I believe that my proposition of Simple Haptics can help make this discovery as pleasant, joyful and rewarding as possible.



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# RESOURCES

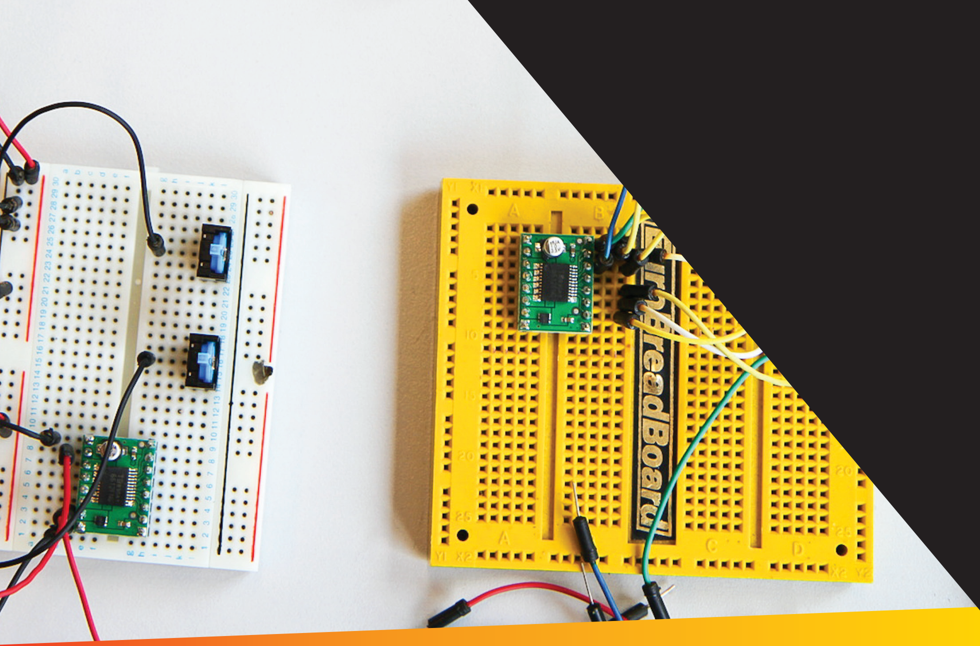
**http://www.simplehaptics.se**
Video, more images, sources files and additional resources

**http://www.partly-cloudy.com**
Ph.D. blog and wiki [Design + Haptics]

**http://www.sketchinginhardware.com**
Electronic toolkits review and resources

**http://www.guchmu.com**
Personal site, portfolio and curriculum vitæ

**WWW.SIMPLEHAPTICS.SE**



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