



# Fingertip

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A stylized, handwritten signature in black ink, likely belonging to Peter Gassner. The signature is composed of several loops and strokes, with a prominent 'P' and 'G' visible.

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### **Abstract**

I seek to widen the field of tactile research by shifting the focus from creating hardware to designing tactile interactions. I propose that tactile touch screens have many inherent possibilities – the most prominent one being their interactivity – with which more can be done than just simulating virtual button clicks. In order to do this research, a tactile touch screen has been built using piezo actuators, haptic sensations have been created using audio tools, and six applications have been programmed.

# Contents

<b>1</b>	<b>Introduction</b>	<b>2</b>
1.1	What Is Touch . . . . .	2
1.2	Why Should We Care About Haptic Feedback . . . . .	4
1.3	On Creating Haptic Sensations . . . . .	4
<b>2</b>	<b>Analyzing the Possibilities of Tactile Feedback in Touch Screens</b>	<b>9</b>
2.1	Where to Use Tactile Feedback . . . . .	9
2.2	Types of Tactile Interactions . . . . .	10
2.3	Inherent Interaction Techniques . . . . .	11
2.4	Using Hardware to Gain Deeper Insights . . . . .	12
<b>3</b>	<b>Designing the Tactile Experience</b>	<b>13</b>
3.1	Creating the Tactile Hardware . . . . .	13
3.1.1	Piezo Actuators . . . . .	13
3.1.2	Amplifying the Sound Signals . . . . .	14
3.1.3	Choosing the Display . . . . .	14
3.1.4	Putting It All Together . . . . .	16
3.2	Designing the Tactile Feedback . . . . .	17
3.3	Designing the Tactile User Interface . . . . .	17
3.3.1	Application Launcher . . . . .	18
3.3.2	Tightrope Walk . . . . .	19
3.3.3	Undo/Redo . . . . .	19
3.3.4	Composition . . . . .	20
3.3.5	Videoflow . . . . .	20
3.3.6	Structures . . . . .	21
<b>4</b>	<b>Discussion</b>	<b>22</b>
<b>A</b>	<b>Appendix</b>	<b>23</b>
A.1	Acknowledgments . . . . .	23
A.2	Copyright Notice . . . . .	23

# Chapter 1

## Introduction

Finger operated touchscreen interfaces are being used in many places like information kiosks, point-of-sale systems, automation systems and even mobile phones. The operation of these devices is very intuitive as they can be operated directly with one or several fingers. But they all have one big deficiency: no matter what interface element you touch, you touch the same unresponsive glass. It's like trying to feel the world around you through very thick gloves.

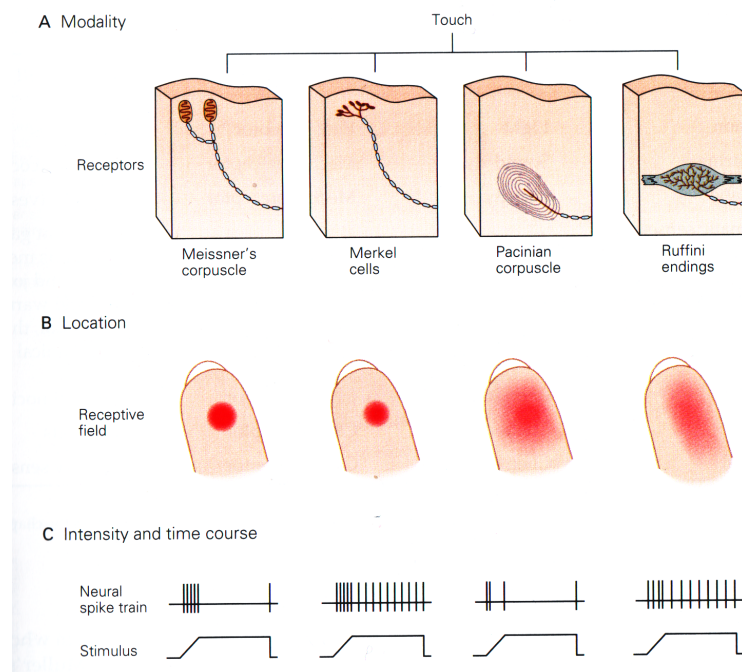
And this despite the fact that humans have a very developed sense of touch [1]. Imagine flicking through the pages of a book without feeling them go through your fingers or brushing your teeth without feeling how hard you press and whether you are actually touching your teeth or your gums. If you think of all the occasions you are “seeing through touching”, you'll be surprised how many there are and how you do not even notice them consciously.

In this thesis I will present some arguments on why and where tactile technology can be useful and then continue to show you my own tactile touch screen and the software I built for it. But first, I will give a short overview on the topic of touch, to make sure everyone is on the same level.

### 1.1 What Is Touch

Touch is known to everyone as one of the five senses, but few people realize how diverse a system touch really is. Touch consists not only of mechanical stimulation, but also of other sensory modalities like temperature, proprioception (body position) and nociception (pain). Because all these modalities are necessary to create the impression of touch, this sense is more precisely referred to as the *somatosensory system*. The various modalities in turn depend on the stimulation of *mechanoreceptors*, *thermoreceptors* and *chemoreceptors*. These sensory receptors can be found in many varieties all over the body, from the skin to joints to internal organs [2].

Relevant to this thesis are four types of mechanoreceptors found in the hand, the Merkel cells, the Meissner's and Pacinian corpuscles and the Ruffini endings (Figure 1.1). Depending on what receptors are activated, different tactile sensations occur: firing of all four receptors produces the sensation of contact with an object while selective activation of the Meissner's and Pacinian corpuscles creates the sensation of vibration. This differentiation is possible because the two corpuscles adapt rapidly to constant stimulation and fire only if they are deactivated and reactivated again [2].



**Figure 1.1:** These are the four mechanoreceptors found in the hand. The sensory system encodes four elementary attributes of stimuli: *modality*, *location*, *intensity*, and *timing*, which together form the sensation of touch. Each receptor has its own specialities, e. g. the Meissner's and Pacinian corpuscle both adapt rapidly to constant stimulation (as can be seen in the neural spike train), whereas the other two adapt slowly. Meissner's corpuscles and Merkel cells work best at locating a stimulus because they are densely distributed and have a small receptive field. (Kandel et al. [2])

As well as providing information about surfaces and textures, touch is an important component of nonverbal communication in interpersonal relationships, and vital in conveying physical intimacy. The study of touching behavior is called *haptics* [3].

*Haptic technology* refers to technology which interfaces the user via the sense of touch by applying forces, vibrations and/or motions to the user [4].

*Tactition* is the sense of pressure perception and specifically excludes the perception of pain and temperature. In spite of the exclusion of these other modalities, there is still disagreement as to how many distinct senses are involved in tactile reception, because of the many pressure receptors that create the sensation of touch *together* [5].

The topic of this thesis is a *vibrotactile* touch screen where the somatosensory information is transported through mechanoreceptors that are specialized in detecting vibrations.

## 1.2 Why Should We Care About Haptic Feedback

A lot of people I talked to about tactile feedback seem to think it's something for the blind. This is a big misunderstanding in my opinion. The blind can cope with most everyday situations by replacing the information not available through vision by using the other senses and are thereby showing us how powerful these senses really are.

If you think about the many occasions we touch during a day it becomes obvious that this is a very important sense indeed (aren't they all?). Some examples: when shopping for peaches we are able to tell the good ones from the unripe ones through touching alone. When we grab for the mouse we don't have to look to find it, we know where to reach to and can keep our eyes on the screen. When we open a door we know exactly how hard to push it to keep it from banging into the wall. When we tear something out of a newspaper we can do so without ripping up the whole page.

As diverse as these examples may be, they have one thing in common: muscle memory. We know how something should feel and where something is located without consciously learning it. So if we can give a user haptic cues, she will learn and remember them *completely for free* – just because they are available.

But touch doesn't have to be this practical at all, it can also be a very emotional and personal channel, e. g. when stroking a cat's fur or appreciating the texture of a fabric. Haptic language is intuitive. It can reduce visual strain, allows for multi-modal interaction, it has a very high temporal and spatial resolution and best of all, it can be ignored if not needed [6].

These are but a few examples that should make it clear that haptic interfaces allow for interesting interactions and should not be ignored.

## 1.3 On Creating Haptic Sensations

### Technology

There is a lot of research going on to create devices that are capable of creating haptic sensations.<sup>1</sup> I will briefly present four *tactile* devices here to give

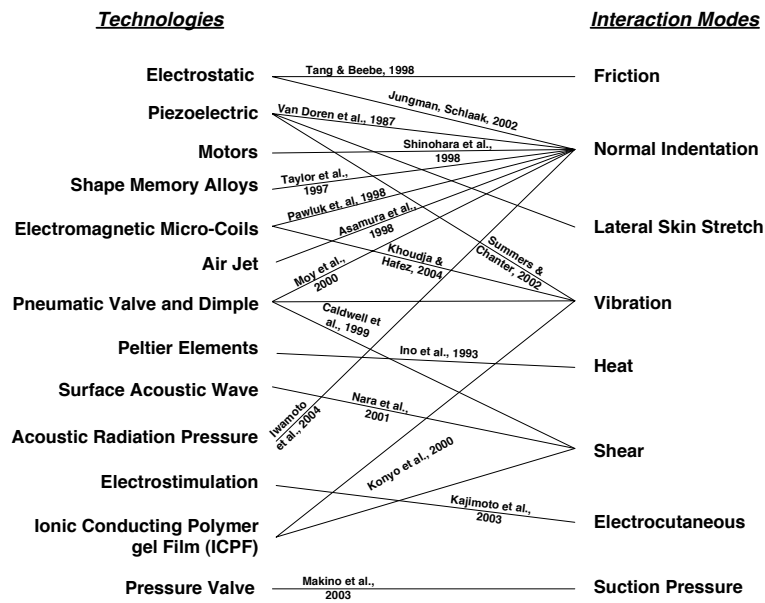
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<sup>1</sup>A good place to find out more is The International Society for Haptics, <http://www.isfh.org/> (access: 26.5.2008)



an impression of what's possible and refer the reader to two papers by Pasquero [7] and Benali-Khoudja et al. [8] as well as Figure 1.2 that give a more in-depth overview of the available technology.

I only present *tactile* devices because this is the topic of this thesis. However, there are many more applications for haptics, e. g. in virtual realities, games or devices for the blind.



**Figure 1.2:** An overview of how various technologies are being used in combination with modes to create haptic sensations. From Pasquero [7].

**Active Click** is a mechanism for adding tactile feedback to touch screens and thus combines the visual and the tactile in a very direct way. It works by actuating the body of a PDA or the backside of a touch panel [9]. This device has been improved by Poupyrev and Maruyama [10] and is the basis of this thesis.

**FEELEX** is based on an array of rods where each rod can be moved 8 mm vertically. This produces an actual three dimensional landscape onto which a user interface can be projected. Several applications have been proposed: the presentation of a tumor to a medical doctor, 3D shape modeling and a barrier-free touch screen for blind people [11].

**STRESS**<sup>2</sup> uses the skin's sensitivity to distributed lateral deformation to create tactile sensations on the finger pad. The users explore a 11 × 6 cm virtual surface by moving the display within an allowed workspace. Wang et al. [12] used this device to create a tactile memory game.

**T-PaD** is short for Tactile Pattern Display. It creates texture sensation through variations in surface friction. The user's finger moves on a plate that is vibrating in the ultrasonic range thereby creating a film of air between the plate and the finger. By varying the amplitude of the vibration and tracking the finger's position and velocity, texture sensations like smooth bumps or file gratings can be created during active exploration [13].

## Design

The creation of haptic sensations does not end with selecting a technology, it only just begins there. With a technology in place there are many *design* problems to be solved which can not yet be answered by looking them up in a pattern library<sup>2</sup> or a collection of theories<sup>3</sup> because haptic technologies are only just beginning to become available to a broader public.

This situation is very different from the visual design discipline, where a lot of problems like color, contrast, form, rhythm, grouping or interferences are more or less understood. It's probably not so different from the audio design discipline, where the potential of audio for interface design was only pushed forward in 1989 when Gaver [14] introduced the Sonic Finder, even though many games at the time already used sophisticated sound effects to communicate game state. Visual people tend to forget about other sensory information, it seems.

Haptic feedback is often most effective when associated with other sensory modalities and must be designed in conjunction with them [6].

There is some research on how many values of vibration rate (Sherrik, via Gunther et al. [15]: around 3–5) and intensity levels (Gill, via Brewster and Brown [16]: no more than four) can be distinguished. I think it is easier to keep the following quote by MacLean [6] in mind:

“We are used to talk about visual things like colors and we can name them easily. This is not the case with tactile experiences. It is possible to discern between the softness of cats fur and the roughness of sandpaper. But it's difficult to memorize the different grades of sandpaper, even though we can feel them easily.”

A very interesting aspect of haptic feedback is its *interactivity*. Unlike an industrial design object that certainly has haptic qualities like surface texture or comfortable weight, haptics in human-computer interaction can *adapt* to

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<sup>2</sup><http://ui-patterns.com/> (access: 26.5.2008)

<sup>3</sup><http://www.colormatters.com/colortheory.html> (access: 26.5.2008)

a given situation, *react* to the users input and also *provoke reactions* from the user.

This is very important to think about when designing for haptics, in my opinion. The designer should not only recreate the feeling of a click on a virtual keyboard, but also take advantage of the possibilities inherent to the medium (see Section 2.3).

## Psychology

Optical illusions are an example of how vision can be duped. Pasquero [7] gives four examples of similar phenomena in haptics:

**Masking** is a phenomenon by which the performance at identifying a target stimulus is decreased by the prior or subsequent presentation of a masker stimulus.

**Vibrotactile adaptation** is the tendency for sensitivity to decline with prior exposure to a vibratory stimulation above threshold.

**Vibrotactile enhancement** is the opposite to that of adaptation and is expressed by an increase in the magnitude estimation of a vibrotactile target stimulus following the presentation of a conditioning stimulus with significantly higher magnitude.

**Change blindness** is known from the visual system and manifests itself by the failure to detect a change in a tactile pattern that is presented repeatedly in-between interstimulus.

## Information

Haptic communication is, like all means of communication, about information. As has been seen, we take up a lot of information through the somatosensory system. Haptic devices can be used to encode textures, emotions, virtual reality surfaces, mechanics, and so on. Encoding such information is mostly very intuitive, because we know them from everyday life.

I want to briefly touch on two special ways to encode haptic information to see what is possible.

**Tactons** Brewster and Brown [16] suggest Tactons as a means of transporting *structured information*. E. g. a two note falling Tacton could represent a file and two rising notes a folder. These Tactons can then be combined to create compound messages like “create file” or “delete folder”. This mapping is abstract, not intuitive, it has to be learned.

The learning of Tactons may be more successful when combined with other senses (multimodal vs. unimodal sensations) [6].

**Hapticons** Address a different problem than Tactons. They want to use the same “active” haptic interface like a knob or a joystick and differentiate different functions with different haptic properties of the same device. This means, depending on the situation the joystick is used for, it feels differently.

They introduced a haptic editor which has a big influence on Tactons as it allows for a graphical creation of haptic icons [17].

## Chapter 2

# Analyzing the Possibilities of Tactile Feedback in Touch Screens

Bringing tactition to touch screens creates many new possibilities for human computer interaction. Some, like the virtual click of a button, are more obvious than others, many probably have not yet been thought of. The experiences learned from designing interactions for touch screens can certainly be applied to *tactile* touch screens as well, but the learned rules will have to be challenged in order to make progress.

Interface designers should not view tactition as a supplement to visual interface design, but as a way to *communicate*. Instead of simply copying impressions of surfaces, new kinds of interactivity can be revealed.

### 2.1 Where to Use Tactile Feedback

As with any other technology, there is no easy answer to where to use tactile feedback in an interface. Consider this quote by MacLean [6]:

“Concerned with creating a successful interaction rather than to using haptic feedback, an application designer will take a ‘top-down’ approach. This begins with a need – to provide an effective interface to a given application – and finds a solution from a suite of technologies and methods.”

I do agree that the top priority of a designer is to create a successful interaction. But I think taking a “top-down” approach will not lead to surprising results and new discoveries, which I think are necessary in the relatively young field of haptics. There is very little experimentation going on in this field at the moment, partly because there are almost no affordable devices on

the market yet – something that will hopefully change during the next few years – but also because the people designing with haptics are mostly engineers and psychologists who do not have a design background. Thinking about where to use tactile feedback should not only be guided by measuring a users performance, but also by experimentation and silly ideas.

The silly ideas are why I chose the topic of this thesis to be tactile feedback: I see a need for this technology and the possibility of ubiquitous devices in the near future which will lead to interesting innovations because a lot of people will be able to experiment with the them. This is also the reason I factor out more expensive or complex haptic technologies like virtual reality or 3D modelling and try to focus on touch screens.

Nevertheless, I think a successful design is a balanced design. To achieve this, a lot of experimentation has to happen on where or where not to use tactile feedback with or without visual representations.

## 2.2 Types of Tactile Interactions

Most of the time a user wants to get information from a computer as easily and quickly as possible [18]. Sometimes he will use the computer as a tool which will involve a lot more interactions. So it has to be considered what a user does, how he does it, and why he does it to understand how much tactility is needed. Very little in one case, as much as possible in the other.

The user can be awaiting feedback or get surprised by it, depending on whether he is touching an interface element actively or passively. A user can touch an element searching for precise information or just for a general status check. He might notice the state of an object even though it is not visible.

Some interactions are not tactile at all: an early idea I had was a visual color picker where you can feel the colors. This, of course, is utter nonsense because it doesn't respect the *value of the visual information*. When selecting colors a user is most interested in the visual appearance of the color itself which means the color has a high value. Where haptics can help in this situation is not with the feeling of the color but with finding the color selection tool and feeling its boundaries in order to be able to select the color without being distracted by finding the right knob in the interface visually.

Replacing visual feedback seems to be especially useful to me in finger operated devices because the finger oftentimes conceals the object that is being acted on. Also, because there are no hover-states in finger operated devices, tactile feedback can replace the visual feedback for hovering over an object through tactile feedback.

There are also things that can't be achieved by keyboard, mouse or touching in traditional display systems. In video editing there exist several alternative input methods like jog dial A/V controls or multibutton video controller devices. These allow the user to feel how far the wheel is turned and thus allow the user to "feel" how fast the video moves. Some of these hap-

tic controls can be achieved by tactile feedback systems and will allow for a greater variety of input possibilities, also in mobile devices.

## 2.3 Inherent Interaction Techniques

When designing interactions, it is important to think about the basic kinds of interactions that are inherent to any given technology. An example from today's graphical user interfaces would be the tooltip that appears when the mouse pointer hovers over an element; this is made possible because of how the mouse was designed. If it were only active when clicked, the tooltip maybe would not have been invented. In preparation of my experiments with my own tactile touch screen, I have collected some examples of such, as I call them, *inherent interaction techniques* for tactile touch screens.

**Live Buttons** I propose *live buttons* to be virtual buttons that give feedback depending on their state. E. g. when a user did not fill out a web form completely, hitting the submit button will indicate this error to him through a modified haptic response. I find this to be a good example of what I mean by an inherent interaction technique. It illustrates that the properties of a real button should not be translated one-to-one to a virtual button because this doesn't pay respect to the possibilities of the medium. Of course virtual buttons with tactile feedback [19, 20] are useful and necessary, but they miss some possibilities if executed without further examining the medium.

**Grabbing** Fitts's law postulates that a closer and larger target can be better hit. I'm proposing a technique I call "grabbing" that uses tactile feedback to simulate a bigger target and thus uses Fitts's law to create a better experience. When a user clicks on a target and misses it by little, he can pick it up through a small sweeping movement of the fingertip without having to click again. In a different situation he may want to pick up some objects and sweeps over them, picking them up one by one. Grabbing allows the user to search through tactition.

**Live Gestures** I think gestures are an interesting and natural way to interact with a touch screen. I believe that the use of gestures can be improved in a tactile touch screen because touch has very fast response times. The user could feel that a gesture has been accepted before he sees it.

When programming my own application, it became obvious that gesture recognition is difficult to do while the gesture is made: is it an I or just the start of a U? Nevertheless I think this is an interesting approach for simpler gestures like click-and-hold or the flipping of a page.

**Live Sliding Controller** Because it is possible to monitor an ongoing activity [6], haptic feedback could prove useful in a sliding or similar controller. For example when adjusting filter settings for a photo in Photoshop

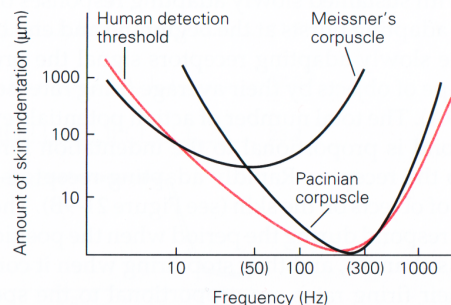
the eye could rest on the photo while the finger feels the strength of the setting. Or when fast-forwarding in a video application the user could feel the speed of the video if she needs it, ignoring it when she doesn't.

## 2.4 Using Hardware to Gain Deeper Insights

To be able to analyze tactile feedback, a hands on experience is mandatory. After all attempts<sup>1</sup> to receive sample hardware from several companies had failed, I had to build my own tactile touch screen.

For this thesis I chose the solution by Poupyrev and Maruyama [10] because it seemed feasible and was adequately documented [21]. They used piezo actuators to create vibrations in the screen of a handheld device. These actuators have a very small latency of only  $\sim 5$  ms which is necessary because touch has a very high temporal resolution. The actuators vibrate at frequencies between 1–1000 Hz.

Because vibration is the main means of communication in this tactile touch screen, it is interesting to know how vibration is being received: the intensity of vibration is signaled by the total number of sensory nerve fibers that are active rather than the frequency of firing, which codes the vibratory frequency. With an increasing vibratory amplitude, more distant Pacinian corpuscles as well as Meissner's corpuscles directly under the vibrator become activated (see Figure 2.1).



**Figure 2.1:** Detection of vibrations works best at around 250 Hz because a skin indentation of  $1\text{ }\mu\text{m}$  is enough to stimulate a Pacinian corpuscle at this frequency. For other frequencies, more indentation is required. (From: Kandel et al. [2].)

<sup>1</sup>I did get a grant for a Samsung i718 smartphone through the Immersion Haptic Research Program, but unfortunately there was not enough time left in my project. [http://www.immersion.com/corporate/haptics/haptic\\_research\\_program.php](http://www.immersion.com/corporate/haptics/haptic_research_program.php) (access: 27.5.2008)



## Chapter 3

# Designing the Tactile Experience

The output of this project consists of three layers which will be discussed in depth in this chapter. First, there is the hardware layer that uses four piezo bending motors to actuate a touchscreen. Second, there is the tactile layer that uses audio signals to communicate tactile sensations. Third, there is the user interface layer which allows the user to explore various kinds of tactile feedback.

### 3.1 Creating the Tactile Hardware

The hardware has to provide the physical feedback which is created by using sound waves to drive piezo bending motor. These are used as high fidelity vibrators and actuate the glass of the touch screen which is being touched by the user.

#### 3.1.1 Piezo Actuators

Piezo actuators have several advantages over rotational vibrators:

- They react almost immediately, whereas it takes some time for a rotational vibrator to start turning.
- They allow for a much higher diversity in vibrations.
- They can be built to have very high forces.
- They can be built very thinly which allows them to be placed between a screen and a display.

Finding piezo actuators with the right specifications for my purposes was very difficult, as most of them are targeted at industrial high precision

applications. This makes them both very expensive and difficult to work with because they require 300–1000 V to function. Compared with the 8–10 V that the custom built actuators from Poupyrev and Maruyama [10] require, this is a lot.

In the end I chose to buy five T226-H4-103Y bending motors from PIEZO SYSTEMS, INC.<sup>1</sup> because they only required  $\pm 40$  V and were affordable. Also, because I got five, I had a spare one to experiment with and get accustomed to the technology. On the down side, these actuators are very weak which required me to adapt the setup of the display accordingly.

I found some good instructions on how to handle piezo actuators from Pasquero et al. [22] and PIEZO SYSTEMS<sup>2</sup>.

### 3.1.2 Amplifying the Sound Signals

The mechanoreceptors in the hand respond to vibrational frequencies in the audible range and thus can be easily created using sound software. The line out signal of the computer is only around 0.4 V, though, while  $\pm 40$  V are needed for the actuators, so it is necessary to use an amplifier.

At first I used an op-amp (ST L272), but it couldn't handle the required voltage, so I got a National Semiconductor LM3875 power amplifier that is able to handle voltages up to  $\pm 82$  V. In the final setup I'm using two 30 V DC supplies that are connected in series in order to supply the power amplifier with +30 V and -30 V, respectively.

The gain of the amplifier can be configured using a combination of two resistors and some calculations:

$$V_{\text{out}} = V_{\text{in}} \left( 1 + \frac{R_2}{R_1} \right)$$

The setup I used is depicted in Figure 3.1.

### 3.1.3 Choosing the Display

It was a priority for me to build a touchscreen with a somewhat bigger screen than the ones that are being tested in mobile devices at the moment because there is more movement involved which allows for more generous interactions than just pointing and clicking and skimming through a list.

At some point I even thought of actuating the surface of a multitouch table we have available.<sup>3</sup> But because of the weak actuation my hardware delivers I had to go for smaller sizes.

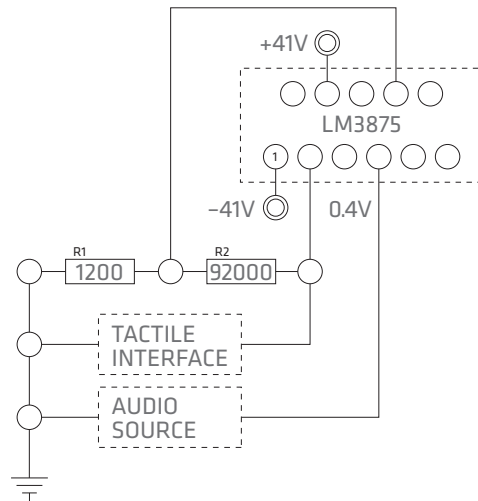
Also there could be problems with a big multitouch screen because a user can have several fingers on the screen and thus – using the actuation technology used in this paper – feels the same things in both fingers even if only one of them is over an active element. I think, this is more a problem

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<sup>1</sup><http://www.piezo.com/prodbmlbrass.html> (access: 27.5.2008)

<sup>2</sup><http://www.piezo.com/tech3faq.html> (access: 29.5.2008)

<sup>3</sup><http://iad.projects.zhdk.ch/multitouch/> (access: 28.5.2008)



**Figure 3.1:**  
Amplification circuitry using a LM3875 power amplifier chip.

of thought and less a problem of actual usage, though. Firstly, a user often works on one element on the screen, e. g. when enlarging a photo through a pinch gesture. Secondly, haptic cues can be easily ignored if not needed. Thirdly, the user probably will be able to tell where the haptic cue stems from because when doing an action he will also await a response. And lastly, a good system should involve all senses and thus in most cases it should be possible to tell visually where the haptic cue came from.

Technically, I could imagine that inertia of a bigger screen's mass could lead to tactile feedback that doesn't feel as "light". This is just an impression of me, though. Unfortunately I didn't have a chance to really try such a device, e. g. the demonstrator from IMMERSION<sup>4</sup>.

In the end I chose to use a MM400-V2 7-inch display from CARTFT with a resolution of 800 × 600 pixels.<sup>5</sup> Because the size is small, my actuators actually work and because it is bright and has quite a high resolution it is a pleasure to look at.

The aspect ratio of the screen is distorted, though, which made it quite complicated to draw circles and the like, because they looked squished. This was also annoying the other way around: screenshots had to be resized to look right again. So a *video* display is not in all situations fit for computer use.

<sup>4</sup><http://www.immersion.com/industrial/touchscreen/demonstrator.php> (access: 28. 5. 2008)

<sup>5</sup><http://www.cartft.com/catalog/il/442> (accessed on 24. 5. 2008)

### 3.1.4 Putting It All Together

In order to keep the distance between the display and the touch overlay as small as possible, I took the display apart and built a custom bracket using several layers of plexiglass.

I placed one piezo actuator in each corner of the screen to work around their weak forces. This works well in many situations but if a user pushes the screen too hard the actuators can get blocked. To work around this limitation, stronger actuators would be needed. Unfortunately, these actuators were out of reach for this project because they are very expensive and require very high driving voltages.

The actual touch overlay was included with the display and works with TouchKit<sup>6</sup> drivers. The overlay is kept in place by the plexiglass bracket that is just tight enough to let the vibrations come through but not let the overlay move too much. I also tried to use various kinds of adhesive tape on one side of the overlay to keep it from wiggling, but this reduced the vibrations noticeably.

It should come as no surprise, that this setup is also a pretty good speaker and thus all vibrations can be heard pretty well – in fact, it is even possible to listen to music through this display. Of course, this is not what a *tactile* display is all about, but I don't seem to be alone with this problem. E. g. Leung et al. [20] report that one reason they used headphones in their experiments was to block the emitted sound when haptic pulses were rendered. As a countermeasure I placed the whole screen on foamed material and made sure there were no loose parts. I also experimented with putting the screen deep into a cardboard box which reduced the sound but was not very usable. It would certainly help, if the screen wasn't lying loosely on the actuators, but experiments with foam material that presses the screen slightly against the actuators reduced the vibration noticeably.

In the end, the emitted sound is a fact that has to be taken into account. It's not really a problem for the user, as the audible cues support the interaction. The problem is more a conceptual one: to really test how well the *tactile* part of the screen works, the user has to wear headphones so he doesn't get audible cues he shouldn't get.

To protect the actuators and the display hardware, I designed an outer shell that works like a clamp and pushes the display hardware into the foam material on the bottom. I chose this solution over a more fixated one because the CARTFT display has many round edges that may look fancy but are very impractical. Also, this allows for easy maintenance because everything can be taken apart without too much hassle.

The shell was built with sprayed plexiglass by KNECHT MODELLBAU AG<sup>7</sup>.

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<sup>6</sup><http://www.touchkit.com/> (accessed on 24. 5. 2008)

<sup>7</sup><http://www.knecht-partner.ch/> (access: 25. 5. 2008)

## 3.2 Designing the Tactile Feedback

For the creation of the haptic pulses I started out with observations collected by Brewster and Brown [16]: the frequency should be between 20–1000 Hz, with a maximum sensitivity around 250 Hz. Also, durations of less than 0.1 s feel like taps whereas longer durations with varied attacks and decays feel more like something rising up out of the skin.

This frequency range happens to be audible, thus the idea was born to drive the piezo actuators with sound waves. This turned out to work well, because of the low latency that today's sound hardware can deliver and a lot of easy-to-use sound software exists.

At the beginning of the project it was planned to generate the sound programmatically to create a varied tactile landscape. It turned out, though, that there was a very noticeable lag with generated sounds (using both the MINIM<sup>8</sup> and ESS<sup>9</sup> libraries for Processing), which made the interface unusable (doubly so, if one considers the high temporal resolution of touch).

So I switched the software to use sound samples that I created with Audacity 1.3.3<sup>10</sup> using the built-in methods to generate sound waves and arranged them on the time axis. This proved to be substantially easier than generating the samples because the sound patterns could be laid out visually and mixed together like Lego stones. Also, this allowed for a pretty good trial and error evaluation of the samples because varying samples could be deactivated selectively.

I also experimented with sound synthesizers and various sound samples like the Mac OS X system sounds. These didn't work well, because they have many fine nuances and frequencies that are not clear enough to be picked up haptically, even though they sound very nice to the ear. So a clear 10 ms 100 Hz saw wave is a lot better than Apple's Sosumi.

To quickly try out some frequencies on the actuators, the ANALAB electronic circuit training board turned out to be really useful as well, because it has a sine-, saw- and triangle-wave generator built-in that can be easily adjusted through knobs. That's how I found out how well 10 Hz saw-wave pulses work, by the way.

It turned out that sine waves and square waves can be told apart easily, with sine waves feeling a lot softer than square waves.

## 3.3 Designing the Tactile User Interface

The final interface is designed in a very reduced fashion for two reasons. First, even though the display was chosen for its brightness and high resolution, the image is not very clear because of the touch overlay (that can get very smudgy from the many fingers using it) and because it's distorted

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<sup>8</sup><http://code.compartmental.net/tools/minim/> (access: 24. 5. 2008)

<sup>9</sup><http://www.tree-axis.com/Ess/> (access: 24. 5. 2008)

<sup>10</sup><http://audacity.sourceforge.net/> (access: 24. 5. 2008)

horizontally by a factor of 1 : 1.25. This made it necessary to create a generous and clear visual interface. Second, the reduction in visual detail lets the user focus more on the haptic qualities, which this project is all about. The reduction also helps in clarifying that this project wasn't about creating detailed and finished applications but rather application sketches that show various qualities of tactile feedback.

Technically the application was created using the Processing<sup>11</sup> language because it features good video support, has many sound generation possibilities and is relatively close to the system which should lead to better performance. It turned out, though, that I didn't use neither the video nor the sound generation technologies because the performance wasn't good enough.

In the following sections I will describe all the tactile application examples I programmed in depth.

### 3.3.1 Application Launcher

All example applications are accessible through the application launcher. Because this is the first contact a user has with the system, it is a good place to give some examples of tactile feedback. That's why the launcher is not just a list with applications to click on, but more a kind of a puzzle with discs (applications) lying around and a bowl-shaped target area (launcher) in the middle.

When a disc is picked up, a "clicking" sound is made. The disc then has to be dragged into the bowl which is only open on one side. When it's dragged into the sides or bottom of the bowl, a "sharp" feedback is given to indicate that this doesn't work. The stronger the user tries to drag, the stronger the feedback.

If the disc is dragged into the open top side of the bowl, it gets sucked in, which is indicated by a "slurping" sound. The selected application will be launched thereafter. To explain to the user how to get back to the menu, it moves slowly out of the frame and a big arrow appears where the menu vanished to indicate the way back.

In a first sketch of the application launcher I planned to use three different target areas. Each area would have accepted a subset of all applications and indicated haptically whether it accepted or rejected a dragged-over application. This turned out to be difficult to understand, though. Also, it led to frustration, because the rejected applications were spit out again without launching anything. This gave the user the impression that he did something wrong.

I also tried to use tactons with each disc having its own tacton (Section 1.3) to help the user remember which is which. The creation of these tactons was more difficult than I thought, because a lot of experimentation with frequency and especially rhythm has to be made. In the end, the con-

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<sup>11</sup><http://processing.org> (access: 25. 5. 2008)

cept was not understandable intuitively in this context of the application and was more disturbing for the user than it was useful, so I had to remove them.

### 3.3.2 Tightrope Walk

This example started out as a tactile labyrinth, where the user had to move from one end to the other without touching the walls too much (while not seeing them at all). Whenever the user moved into a wall, a tactile error feedback was given and the map was shown for a short period of time. This just didn't feel right, though, because feedback was only given *after* an error occurred, instead of *preventing* the error in the first place. Also, the labyrinth was too complex and distracted from the task at hand. Because the user could get lost in it, the experience was frustrating: after all, the user stayed on the path as requested, but if it was the wrong path there was still no way to the end.

Thus the second example was born, where the user has to follow a single path he can't see and tactile feedback indicates whether he is still on it (strong feedback) or whether he slowly moves away from it (weaker feedback). This worked, but the continuous feedback became annoying after some time of use, there was just too much vibration.

In the resulting example the experiences of the two prior ones were mixed together. The single path proved to be successful but it was not clear enough that there was a path to be followed at all: the example looked to much like the application launcher, where the items could be dragged everywhere without problems. So I introduced a gradually fading visual indication of the path that shows the path in the first half of the course to teach the user about it and then vanishes to let the user feel his way through by himself. Also, the continuous feedback was inverted, with no feedback when the user was on the right path and gradually stronger feedback if he diverged from it.

What the evolution of this example shows is that it is very important to find a good balance between giving or not giving feedback. If the feedback is given too late, an error can already have happened. If it's given continuously it can get annoying. But if the feedback is given in the right places, errors can be prevented without annoying the user with continuous confirmation of his doing right.

### 3.3.3 Undo/Redo

This example was created because I wanted to test an idea I had while discussing the interface of my fellow students' iPhone keyboard.<sup>12</sup> They introduced several gestures to delete letters: a swipe to the left would delete a single letter while a to and fro movement would delete a whole word. This works well, but is exhausting when several words or letters have to be deleted – and retyped if too much was deleted.

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<sup>12</sup>C. Schmid, J. Stucki, <http://bachelor.kenda.ch/> (access: 30.5.2008)

The idea in this example is to use a circle gesture to move back and forth in time. Two kinds of tactile clicks are used to indicate direction. When doing the gesture, each letter can be felt as it is removed or added and the eye can focus on the text.

Because text entry was needed, I had to add a keyboard. Instead of programming complicated text entry algorithms to wrap the text around, I chose to put this work upon the user as part of the game. When the user enters the letters, he can feel the keyboard click. At the end of the line, the feedback will change to indicate, that no more letters can be entered and the user has to enter a line break to go on writing. Also, if two or more spaces are entered, the keyboard complains through changing the tactile feedback, because this is not allowed in this example.

### 3.3.4 Composition

This example started out with a couple of bars that moved in various speeds over the screen and where each of them produced different feedback. To me it was clear that I had to put the finger anywhere on the screen and leave it there to experience the feedback. What happened with users, though, was that everyone was trying to catch the bars by repeatedly touching the screen. Most of the time they missed them and got frustrated.

So I introduced a single element in the middle of the screen that consists of two separated halves of a circle. When a user touches this element, the two parts of the circle connect and bars start appearing on the screen. As soon as the user takes away his finger, everything will become quiet again.

When clicking on the circle it is very pleasing to see *and* feel the two pieces connect together. I think this connecting button is a good example of how vision and tactition can be combined.

### 3.3.5 Videoflow

This example shows how tactile feedback can help the user when browsing through video footage. There exist many hardware input devices for video editing because they enable the user to feel what's happening, e.g. the further a jog wheel is turned, the faster the video plays. This is a very direct haptic feedback that is not possible visually: there is no way to tell, how fast the video is playing because not all frames are shown and single frames start to blend together at twenty-four frames per second (which is also the whole point of video).

Also, with a jog dial and a bit of practice it's easy to go past the frame you are looking for and then quickly turn the dial and go back more slowly. This fine regulation of speed is not possible visually because the user would have to observe both the video and the mouse position.

For this example, I first tried to make the play/pause button tappable so the video would play without any user interaction. After a while of playing on its own, the playhead vanished and only the video was shown. This



sounded very useful in theory, but turned out to be confusing for the user, so I reduced the example to just the forward/backward slider.

For very slow speeds I chose to use a sine wave whose amplitude rises with speed to create a trough. I think, this can be enough at slow speeds because the eye can see what's happening. At higher speeds, the continuous sine wave feedback is replaced by ticks.

### **3.3.6 Structures**

This last example is an experiment with two types of textures. On one half of the screen a fish scale like structure is shown. When a user brushes over it from top to bottom, it will feel spiky while the opposite direction feels smooth. The faster the moves, the more accentuated the feedback.

The second half of the screen is a layer of bubbles that will “burst” when moved over. Bigger bubbles feel stronger than smaller ones. This was done to experiment with the creation haptic feedback that feels like the pop a bubble makes when it bursts. So in a way, I worked the other way around here, first creating the feedback and then finding an application for it.

## Chapter 4

# Discussion

This project started out as explicitly content oriented, because a lot of research is put into methods for creating tactile feedback and not so much into possible applications – apart from the usual ones like buttons or scroll bars.

But because I could not rely on existing hardware and the building of the hardware prototype was quite involving, the focus has shifted away from finished and complex to more experimental and lighter application examples. I think this was a good thing for the project because more elaborate applications tend to be complex and thus possibilities for experimentation are lost. Also, in order to present the screen to a broader public – which was part of the reason why I wanted to build such a screen: to raise awareness for this interesting technology – the examples had to be clear and to the point to keep it fun for the user.

Finding the balance between research, design and the final exhibition turned out to be quite difficult because they all speak to a very different audience. This is also exciting, though, because it is necessary to think of the same product on very different levels.

After having worked with the prototype for a while now, I think it is a useful technology. But because of the noise the device makes, it is difficult to judge how much tactition is really being used and how much information is recognized through hearing. Also, it would have been nice if the actuators were stronger, because it is possible to block the actuators through too much pressure. Which makes it more difficult for the user to touch because he has to think about not touching how he normally would, but to touch lighter.

I certainly think that experimentation with this prototype should continue, with a deeper focus on creating the tactile language in conjunction with visual and auditory cues, because they can certainly be built more complex when done with more care and lead to new ideas.

It would also be interesting to try this technology in a very information dense application like a visualization of complex data structures.

## **Appendix A**

# **Appendix**

### **A.1 Acknowledgments**

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### **A.2 Copyright Notice**

All work in this thesis was done by the author, Peter Gassner, with friendly support from his tutors and fellow students. All sources have been disclosed to the authors best knowledge.

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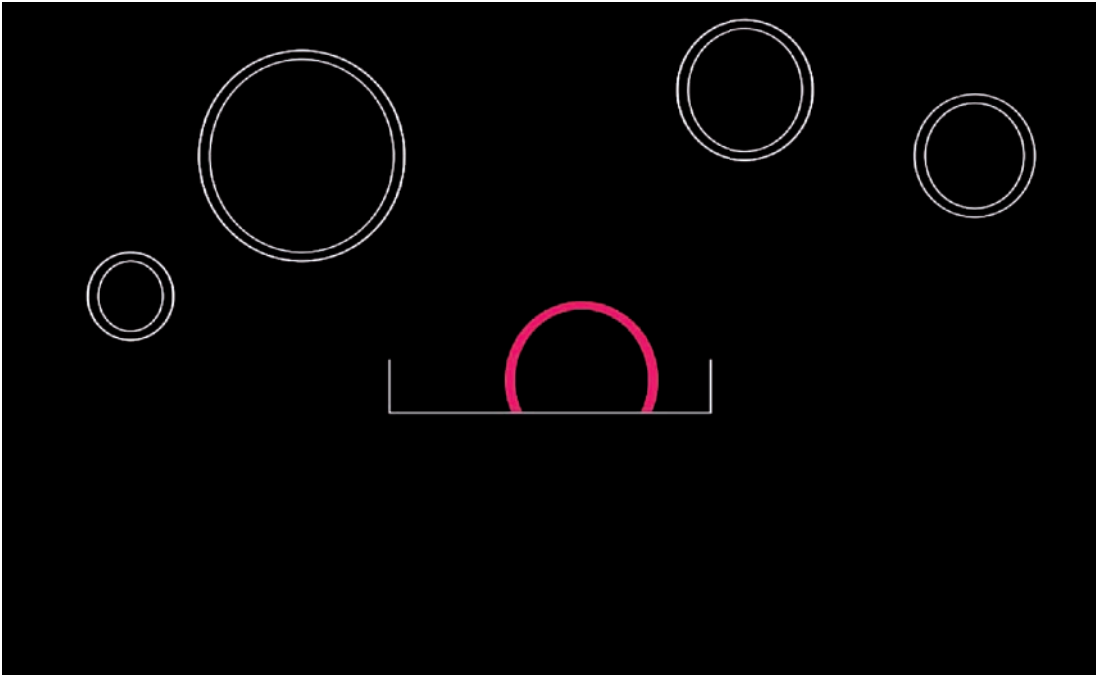
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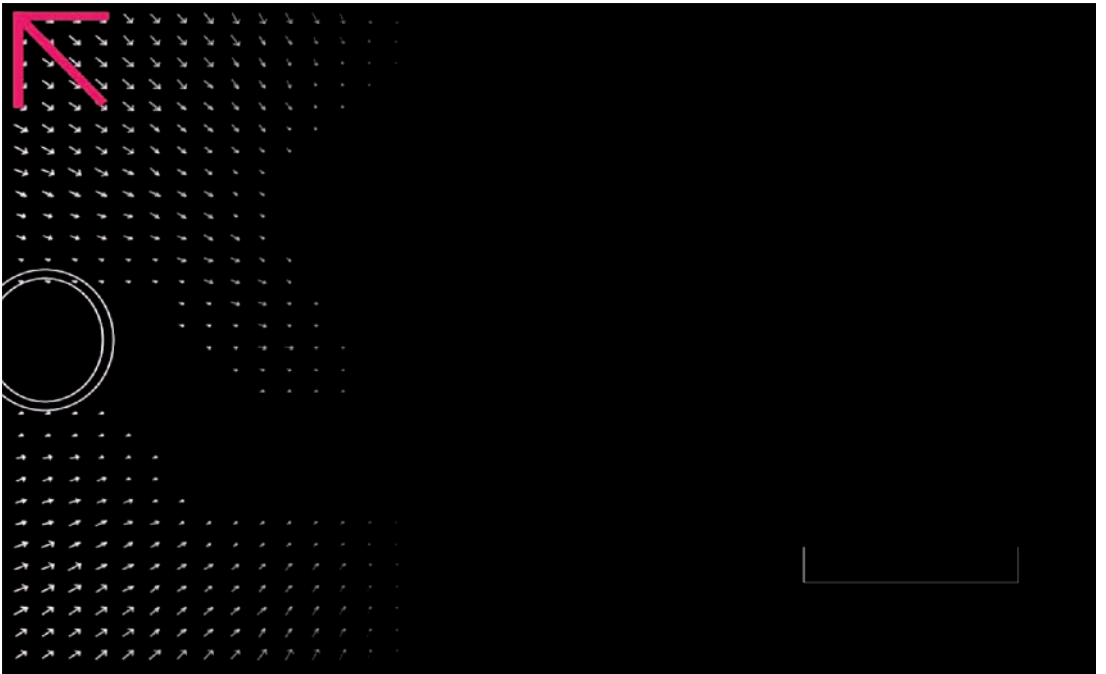
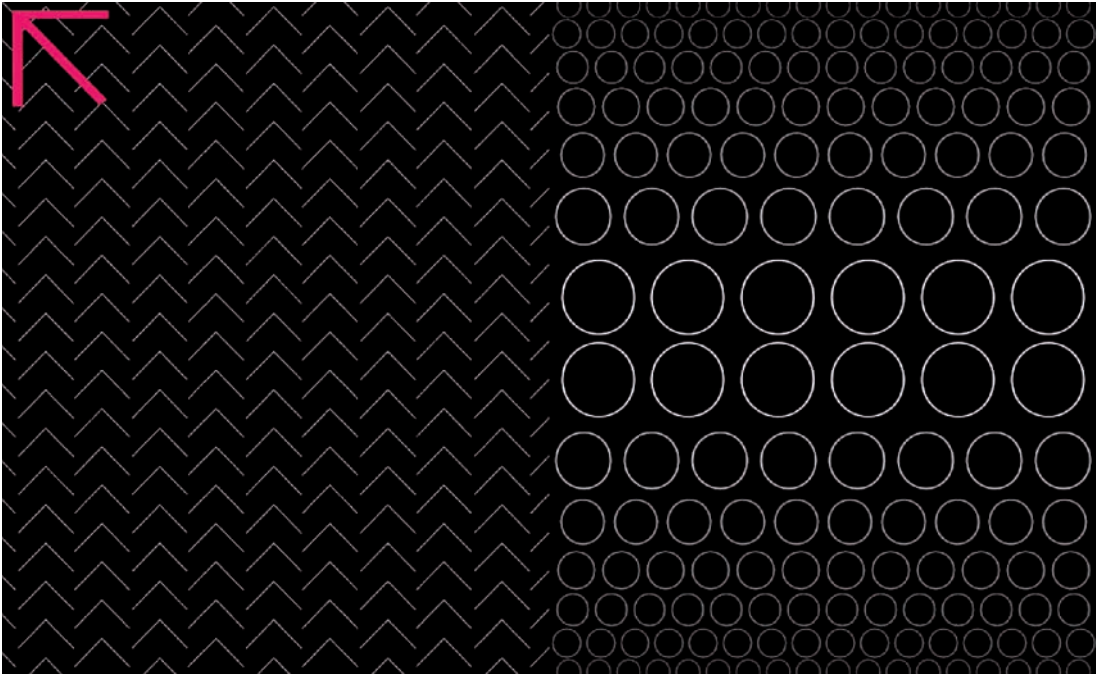
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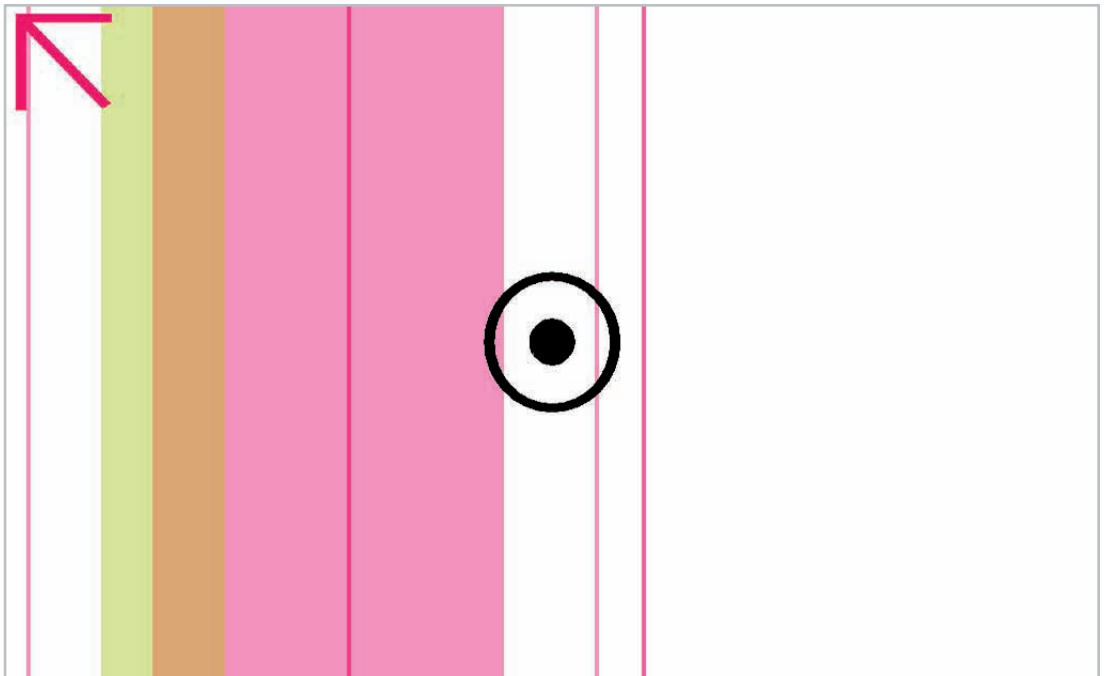
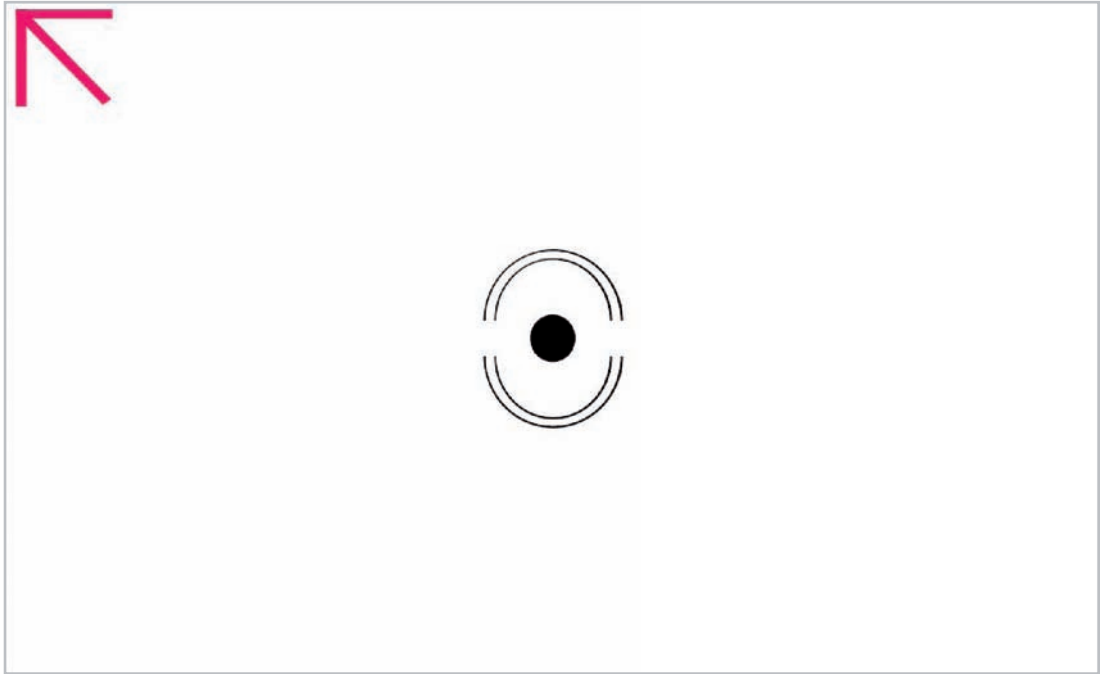
Produktentwicklung



Application Launcher  
Videoflow  
Textures  
Tightrope Walk







Combinations  
- *initial state*  
- *active*  
Undo/Redo



HAPTI



