RWTH AACHEN UNIVERSITY

DiskPlay

An augmented In-Track Navigation Display for Digital Vinyl Systems

Diploma Thesis at the
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Abstract

This bachelor's thesis introduces DiskPlay, an augmented in-track navigation display for Digital Vinyl systems. Although digital music has many advantages, DJs still favor vinyl records and turntables as their instruments of choice. Digital Vinyl systems build a bridge to unite the highly haptic nature and the tight temporal coupling of vinyl with the advantages of digital media storage. DiskPlay extends these systems and visualizes information on the record that gets lost through the use of generic timecode records. It combines visual and physical control on the record, reduces attention switches and enables the DJ to navigate faster within a track. A qualitative user study was conducted to evaluate the system. After that we will present related work and introduce concepts of DJing; we will describe the process of design and implementation of DiskPlay. The user study and interviews with DJs, as well as their suggestions for future development, will be presented and followed by a short discussion. Thereafter, we will give a summary and provide an outlook on future work.

Überblick

Diese Bachelorarbeit präsentiert DiskPlay, eine visuelle Erweiterung von digitalen Vinyl-Systemen zur Navigation in Musikstücken. Obwohl digitale Musik viele Vorteile hat, bevorzugen DJs Schallplatten und Plattenspieler als ihre Instrumente. Digitale Vinyl-Systeme schlagen eine Brücke und vereinen die höchst haptische Natur und die enge zeitliche Bindung von Schallplatten mit den Vorteilen digitaler Medien Speicher. DiskPlay erweitert diese Systeme und visualisiert Informationen auf der Schallplatte, welche durch den gebrauch generischer Timecode-Schallplatten verloren geht. Es kombiniert visuelle und physikalische Kontrolle auf der Schallplatte, verringert Aufmerksamkeitswechsel und ermöglicht dem DJ schneller in einem Lied zu navigieren. Um das System zu evaluieren wurde ein qualitative Benutzer Studie durchgeführt. Nachdem wir ähnliche Arbeiten und Konzepte des DJing vorstelle, werden wir den Prozess des Designs und der Implementierung von DiskPlay beschreiben. Die Benutzer Studie und Interview mit den DJs, sowie ihre Vorschläge für zukünftige Entwicklungen werden vorgestellt und gefolgt von einer kurzen Diskusion. Danach geben wir eine Zusammenfassung und präsentieren einen Ausblich auf zukünftige Arbeit.

Acknowledgements

First of all, I want to thank Prof. Dr. Borchers for supervising my thesis, making it possible to create and develop DiskPlay at his chair. I also want to thank Prof. Dr. Kuhlen for kindly being my second examiner.
Secondly, I want to thank Florian Heller for making his turntables available for science, his creative ideas and his advice on small and big problems.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition: *Excursus*

Source code and implementation symbols are written in typewriter-style text.

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The whole thesis is written in Canadian English.

Download links are set off in coloured boxes.

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Chapter 1

Introduction

Turntables and vinyl records are one of the oldest systems used to play back music. Over the course of time, many alternatives to vinyl records have been developed, altering the way we listen to and work with music significantly. Cassette tapes, and more particularly the Walkman, made music portable. CDs offer a much higher quality and demand much less space than vinyl records. Last but not least, digital audio, for example in the MP3 format, ultimately disconnects a song from any physical device, making it immune to wear and tear as well as enabling us to carry virtually endless hours of music with us on tiny storage devices such as a USB stick.

The evolution of music formats

But still, the vinyl record continues to play a big role today, especially in the DJ community, and it is easy to see the reasons for this. Experts share the opinion that the quality of digital music can hardly reach the quality of an analog vinyl record. Even nowadays music is often released only, or at least initially, on vinyl records and professional DJs hold the superior interaction possibilities of vinyl records in high esteem. A special "technical-ecosystem" exists within the DJ community; for example, the Technics SL–1210 turntable is the absolute reference model and can be found in almost every club or disco.

Why records still play a big role

We often find vinyl records as symbols of modern pop culture, depicting lifestyle and fashion. DJs have the same popularity as rock bands or movie stars and over the years, many DJs have honed their skills to perfection, propelling the vinyl system from a simple playback solution to a veritable creative instrument. This is probably the most striking argument, and is summarized in a quote by John Oswald:

”A phonograph in the hands of a ’hiphop/scratch’ artist who plays a record like an electronic washboard with a phonographic needle as a plectrum, produces sounds which are unique and not reproduced – the record player becomes a musical instrument” [John Oswald]

1.1 Different Types of DJs

Lippit [2006] described three types of DJs. A Mix-DJ plays a selection of pre-recorded music and creates a narrative flow by mixing songs manually into each other using a technique called beatmatching (sometimes also referred as beatmixing). As the DJ ’beatmaches’ two songs he synchronizes the beat of two records so that the transition between these two songs becomes continuous and often goes unnoticed by the audience. The DJ has to react to the atmosphere of the audience by selecting the right tracks and also needs to concentrate on creating an unnoticeable transition by operating the equalizers and watching for the right moment to change tracks. These DJs often play electronic, techno, or house music. Then there are Hip-Hop DJs, or so called battle DJs, who artistically perform scratch gestures on the records and manipulate the crossfader to produce special sounds. Hansen and Bresin [2003] describes some of the different techniques of scratching and tries to establish scratching models. Battle DJs meet regularly for challenges like the DMC World Championsips, where they perform their techniques on a stage in front of a large audience, commanding a broad public attention. A third type of DJ is identified by Lippit [2006] as the experimental DJ, who produces experimental noises with the turntable.

Three different types of DJs: Mix-DJ, battle DJ and experimental DJ

DJs have always been creative in their work. They tagged records with labels, scored the grooves of the record or constructed multi-arm turntables to achieve new artistic expression in their music (see Kid Koala or Janek Schaeffer for examples). With the rise of digital music and the connection between analog turntables and digital music, a vast number of new possibilities to create and play with music have opened up.

1.2 Digital Vinyl Systems and DiskPlay

CROSSFADER :
A crossfader is a potentiometer on a DJ mixer with which one can control the volume of two music channels. Beatmix DJs sometimes use it to create a transition between two channels. It is mainly used by scratch DJs who typically make distinctive sounds by quickly cutting the volume off and back on. As this is done very quickly, the crossfader values can, in an idealized view, be mapped to the binary values: 'the music is on' or 'the music is off'.

Definition: *crossfader*

Digital vinyl systems combine the best of both worlds. You have the haptic advantages of turntables and records and you can control digital music on your computer. This is achieved by using a special record with a timecode signal, which is translated by software into an absolute time position. DJs no longer have to carry all of their records with them, the record of a particular song does not wear out, and what is more the software provides various aids for the turntable in an everyday work situation. However, through the generic nature of timecode records, they do not provide the same level of visual information for in-track navigation.

From analog to digital: digital vinyl systems

Definition: *DJ setup*

DJ SETUP :
The minimal audio mixing setup for a turntable DJ consists of two turntables and a mixer. The turntable has a tonearm that is placed on the vinyl record and picks up the music with a small needle. A slider (pitch slider) controls the speed of the rotation. There is a button to turn the turntable on and off as well as two buttons to change the turntable's rotational speed from 33 $\frac{1}{3}$ rpm to 45 rpm and back. This change also results in rotational speed changes of the platter. The output of the two turntables goes straight into the mixer, where the DJ can alter the height and bass of the music, as well as change the sound level or mix the two sound sources together.

Figure 1.1: DiskPlay is an augmented interface for in-track navigation

Introduction of DiskPlay

DiskPlay wants to overcome this issue and introduces an augmented interface for in-track navigation, extending digital vinyl systems with a display shown directly on the record. The idea is to take visual cues from traditional vinyl or common DJ practices and display them on the record again. This approach fuses control and visualization, reduces the number of required attention switches and enables the DJ to fully concentrate on the turntable instead of the computer screen.

Structure of the thesis

This thesis is divided into four parts. In the first part we present related work – research that has been done on the field so far, as well as some basic definitions that give an introduction to DJing. Thereafter we describe the implementation phase of DiskPlay, explaining certain design decisions and exemplifying our implementation with the help of the most interesting parts of code. The system is evaluated via user tests and the results are presented and discussed. Finally we briefly summarize this thesis and provide an outlook on future work.

Chapter 2

Related Work

2.1 Digital Vinyl Systems

There are many systems for DJs that emulate the conventional turntable whilst controlling digital music files directly on a computer. Such systems are, for example, the Pioneer's DVJ-X1 or the Technics SL–DZ1200. These resemble a turntable but are entirely digital.

In 2001 Final Scratch was released by Stanton (Stanton) and Native Instrument (Native Instruments), using the classical DJ Setup and analog turntables to play back music on a computer. This is accomplished using special timecode vinyl played on normal turntables. The audio signal is converted with an analog-to-digital converter to a digital timecode, controlling the music through the position. The software then processes the generated audio back into the mixer. In order to do this, the DJ setup is extended with a so-called Scratch-Amp, which connects the turntable to the computer and the computer to the mixer. Additionally, you need software on your computer to decode the timecode. A typical setup of such a digital vinyl system is shown in Figure 2.1. The gap between this and a classical turntable system is very small and even DJs who have performed with analog vinyl for many years are able to interact quickly with this new system. In contrast to simple WIMP (Windows, Icons, Mouse, and Point-and-Click) applications on

How digital vinyl systems work

Advantages of digital vinyl systems

computers, this system provides haptic feedback for the user. Compared to the classical analog turntable system, the DJ doesn't need to carry records with him anymore, which removes a large burden (a record weighs approximately 200 grams). It is enough to have a small MP3 stick containing the music. The software also displays valuable information like a waveform representation, remaining time or cue points which can be set manually by the user.

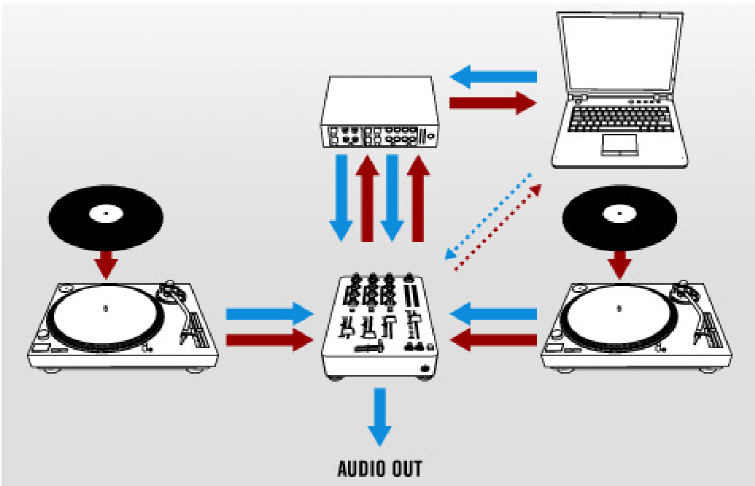

Figure 2.1: A setup of a digital vinyl system

Disadvantages of digital vinyl systems

On the other hand, such a system adds another layer of complexity to the task, making technical difficulties more likely to occur. This should not be underestimated in the context of working somewhere like a club, which is a very rough environment for precise electronics, and where the DJ has to maintain a constant music playback.

DiskPlay will be based on digital vinyl systems, especially on Traktor timecode records produced by Native Instruments.

2.2 Mixxx

Andersen [2003] introduce Mixxx, an open source software for DJs. The authors developed Mixxx to ”conduct interaction studies of novel interfaces in relation to the DJ situation”. Generally speaking, Mixxx can be described as a platform for experimentation with new visual interfaces and controllers for mixing pre-recorded music. Nevertheless, Mixxx is primarily a performance tool consisting of a setup of two playback devices and a mixer. It also enables further use of different MIDI controllers. The software that controls the digital music offers a GUI with a visualization, which can be seen in seen in Figure 2.2.

Introducing Mixxx, an open source software for DJs

In Andersen [2003], three applications are described: the mixer interface, a turntable, and the AudioFish visualization (see Figure 2.2). The mixer interface is a controller box that should resemble the look and feel of a scratch mixer. But in contrast to a normal scratch mixer output, the mixer interface converts the analog output of his sliders and knobs into digital MIDI messages, much as the commercial controller Xone:92 from Allen and Heath does.

The three initial applications of Mixxx

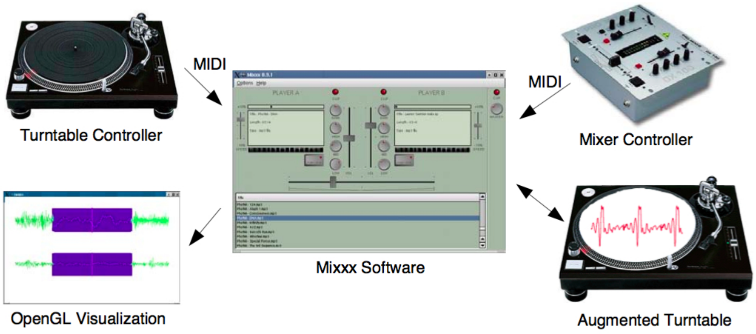

Figure 2.2: Mixxx

In the implementation described by Andersen [2003] the authors used modified turntables as playback devices. In contrast to the commercial system FinalScratch and the timecode vinyls, they decided to use another approach similar to the Tascam TT-M1 turntable controller use by Lippit [2006]. They still wanted to stay true to the turntable metaphor as it ”seems superior to most digital equipment”, but instead of using timecode vinyls, they measure the velocity of the deck plate via a motor and output it as MIDI signals. In this way they wanted to ”find new, better ways of navigating and giving inspiration to the artist”, whilst not wanting to ”limit more than open new design possibilities”. As such a device only allows linear navigation through a song, you can also navigate to random position by using the mouse and GUI of Mixxx.

AudioFish waveform visualization

The AudioFish is a visualization of a song as a waveform and was earlier presented in Andersen and Erleben [2002]. A fisheye zoom is used to display the region near the playback position. In this way you can still see the past and future of the song. In this implementation they use parallel arranged waveforms that should help the DJ to synchronize songs only by view. This visualization should provide the DJs with cues to the structure of a song without the need to listen to it. Size and zoom of the AudioFish are connected to the playback speed and change accordingly.

The augmented turntable

Another application for Mixxx is the augmented turntable, described in Andersen [2003], which is thus far only planned as future work. The authors want to display the AudioFish visualization directly on the turntable, not in a Cartesian coordinate system, but rather as a circular plot so that the ”notion of a vinyl groove is reused”. By eliminating the need for a computer display, the authors want to enable a much higher degree of communication between collaborating DJs. This would also imply the development of a point and click interface for selecting tracks or different parts of the tracks. On the subject of how to display this information they decided upon a projector which is mounted above the turntable as a ”simple and inexpensive solution”. They also consider using light emitting polymers, or head-mounted transparent displays (Augmented Reality).

Mixxx is written in C++ using the QT Toolkit. It runs on MacOS X, Windows, Linux, and other Unix derivatives. It is licensed under the General Public License and available for download:http://www.Mixxx.org/[1]. Over the years Mixxx has been developed further and expanded from

[1] www.Mixxx.org

a mere platform for interface experiments to a complete vinyl emulation software for timecode records that competes with commercial solutions like Serato Scratch Live or Traktor by Native Instruments. A current version of Mixxx is depicted in Figure 2.3. It is especially interesting for the development of DiskPlay as a foundation of our implementation. It processes the timecode, has an engine for the playback of music and offers the vinyl control function for coupling the timecode with the playback. Furthermore the augmented turntable and its visualization is relevant for the design process, as DiskPlay is aimed in the same direction. However, the augmented turntable was never built or implemented, so the information about it remains very vague.

Mixxx today: a vinyl emulation software

Mixxx as a foundation for the implementation of DiskPlay

Figure 2.3: GUI of Mixxx 1.10.0

2.3 D'Groove

Beamish et al. [2003] developed a system for the physical manipulation of digital audio, contrary to FinalScratch or other timecode vinyl systems. Although they also use the turntable metaphor, they took a completely different approach by mounting a vinyl record onto a stepper-motor to measure the play-speed, thus replacing the needle (Figure 2.4).

introducing D'Groove

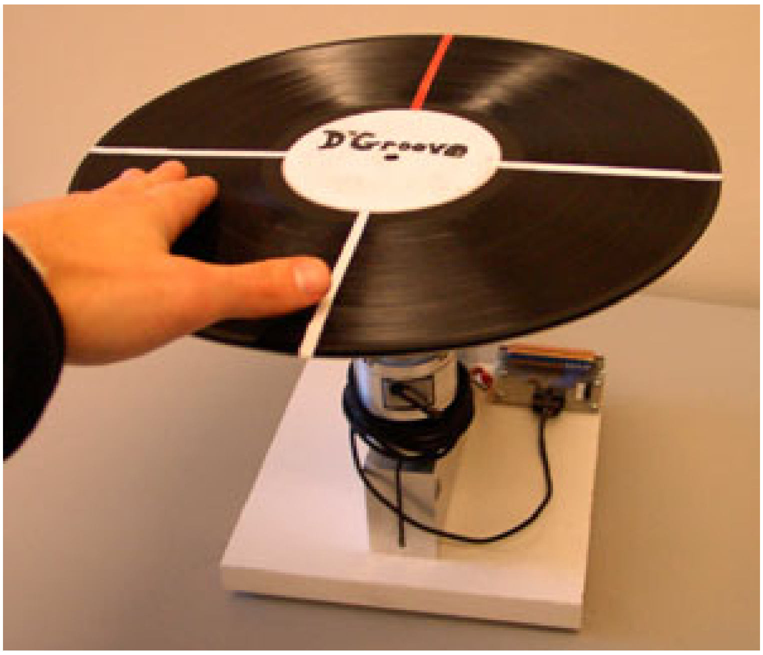

Figure 2.4: The turntable device of D'Groove

To navigate to random parts of the song they built a linear motorized slider that corresponds to the current play position of the song. This slider is shown in Figure 2.5.

D'Grooves pitch slider offers an infinite range

The third part of the D'Groove system is a pitch slider which has, compared to classical DJ turntables, an infinite range. This is realized with a mode, where the user can draw the pitch slider without affecting the pitch value, changing the mode and then affecting the pitch value again. When the slider is pitched by the user it doesn't affect the value, whereas it does affect the value if it is simply dragged without pitching it. Beamish et al. [2004] compared this to "lifting a mouse and resetting it to increase its reach". The authors want to reduce the cognitive load of DJs by applying haptic and visual feedback. The motor used for the rotating platter is a force feedback motor, giving the user different types of feedback. In *spring mode*, the turntable oscillates around a point, like a virtual spring. In *bumps-for-beats* mode the feeling of a virtual bump is generated on every beat, as the DJ rotates the platter, thus helping him to beatmatch a song not only by ear. As they used

reducing the cognitive load of DJs by applying haptic feedback

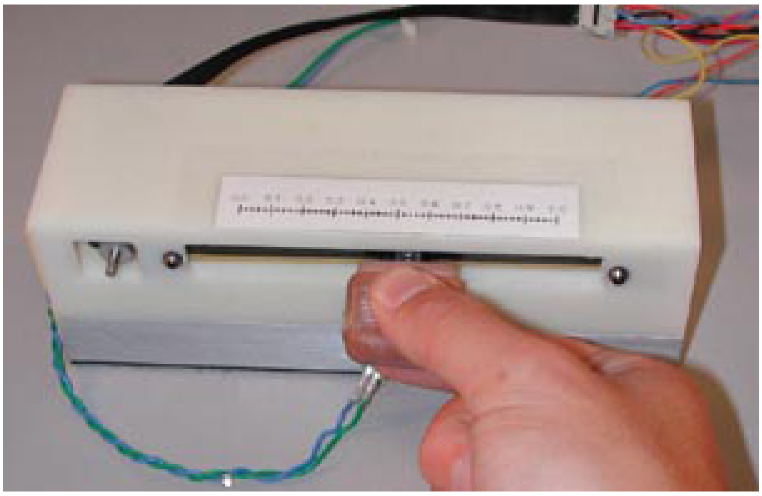

Figure 2.5: The motorized slider for navigation

a vinyl record which does not represent the actual song, the information of the music's mood and structure, which can be read in via the density of its grooves, is missing. In D'Groove they tried to compensate for this by applying the *resistance mode* to the turntable. In *resistance mode*, the platter is harder to move when there are greater variations in amplitude and easier to move when playing lower amplitude sections. The last mode for haptic feedback is the *textured-record mode*, creating a "bumpy road" and making the record wobble as the turntable is pushed in either direction. This helps the DJ to perform certain Scratch Gestures like the *hydroplane*, a gesture that is performed by moving the record with one hand and placing a finger from the opposite hand on the record such that it causes stick-slip friction, creating a distinctive sound.

In order to utilize the DJ's visual channel as well four lines were applied on the record, representing the beats of the track. The lines are arranged like a cross with its middle on the record's center. A red line denotes the first beat and the other three beats are white (see Figure Beamish et al. [2003]). One revolution of the record is a whole bar, which limits the DJ to only playing songs in 4/4 time, as most of the electronic and dance music is in 4/4 time, and only songs that have no tempo changes. The DJ can now see if two songs are in the same tempo and if the beats are match-

Four lines on the record represent the beats of the track ing simply by looking at the lines drawn onto the records. But as Beamish et al. [2004] found out in their user tests, the lines were not used and "DJs continued to rely entirely on their ears for beatmatch confirmation".

These observations and their thoughts about a visualization of the beats on the record also influenced the development of DiskPlay. The authors pointed out that such a visualization was not well accepted by the DJs. D'Groove has another big flaw, in our opinion; the substitution of the tonearm with a linear slider is not ideal, because DJs have already perfected their skills in navigating and skipping quickly through a song with the tonearm.

2.4 Vinyl+

Vinyl+, a design experiment with digital vinyl systems

Vinyl+ is a design experiment with timecode records. Circles are depicted on the record, changing their behavior according to rotational speed of the record and the position of the needle. Their behavior can best be described as balloons that are lying on the record, moving faster when spinning the record or exploding with a popping sound when hitting the needle (see Figure 2.6 for a picture or watch the vin). The assembly consists of a turntable, a white timecode record, and a projector mounted on top of the turntable. A plug-in for Pure Data (Pure Date), based on xwax, is used to extract the timecode data and is then used to render the animation according to rotation speed and needle position with Processing. The programs communicate with each other over osc.

Vinyl+ is more of an art project than a support for DJs in their work environment, but it is still worth mentioning because, in the words of author Jonas Bohatsch, "The combination of turntable, computer, and projector results in a new device, oscillating between analog and digital, hard- and software".

Figure 2.6: Vinyl+ on a turntable

2.5 A Tangible Interface for Music Browsing

Pabst and Walk [2007] present an interface for music browsing called TIMBAP. Their goal is to provide an interface for browsing and selecting tracks directly on the turntable, thus eliminating the use of mouse and a keyboard. The system is based on timecode vinyl, using Ms. Pinky for timecode processing.

An augmented interface for music browsing

As browsing through music files only with auditory feedback is very cumbersome, the authors decided to provide the user with a graphic representation and augmented the turntable with an interface projected directly onto a white vinyl record, which resembles the search behavior in the record case. In this way the turntable should become a complete tangible interface for DJs using digital vinyl systems. Pabst and Walk [2007] identified two search behaviors that are in turn reflected in two different search modes that they implemented.

Two modes for browsing

The first mode offers browsing by scrolling through your music files. For the scrolling function they use the playback position. This resembles a diashow, because the music files will pass one by one, if the turntable is simply running. Music files are displayed as circles with the album artwork as a texture, as you can see in Figure 2.7. As there are ”no means to issue a direct command” on a turntable, the item in the center is depicted as the biggest and therefore ”in focus”. To select an item it has to be in focus for a certain amount of time. After it has been selected, it grows to the full size of the turntable, so the DJ knows that this song is activated. The second mode provides a goal oriented search by di-

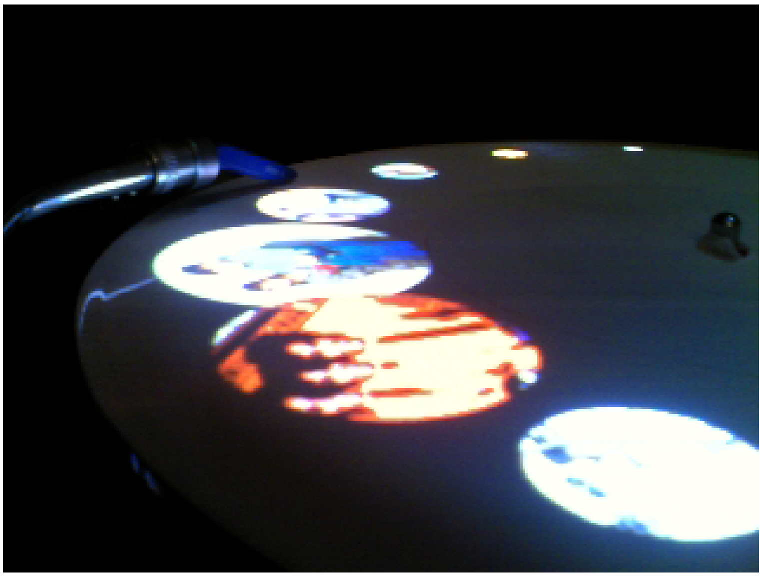

Figure 2.7: Circles with album artwork as texture are projected onto a white vinyl record (mode1)

rectly and absolutely positioning the tonearm, helping the DJ to search for a specific record, which they do most of the time, as Pabst and Walk [2007] found out. The music is sorted by a criterion which could be the artist’s name, label name, style, or even the predominant color in the artwork. The different options are aligned alongside the tonearm in an alphabetical tag cloud as seen in Figure 2.8. The font size of these tags is proportional to their occurrence frequency. If a tag occurs twenty times, it will be displayed using a font size ten times as big as one that occurs only twice. A certain threshold had to be introduced, to show only a certain number of tags, as the space on the record is limited.

The authors also implemented scratching gestures to switch the search criterion. For this they implemented a criterion switch in round robin manner if the user performs a *double baby scratch* (forward, backward, forward, backward).

DiskPlay and TIMBAP

Although DiskPlay aims towards in-track navigation, this work is also relevant for its development. For future work, one could imagine replacing the computer screen completely with an interface, displayed only on the record. A combination of TIMBAP and DiskPlay would focus in this direction, and may in fact already be sufficient for this. However, the turntable as an interface with a pointing device for selecting music is contradictory with the affordances a turntable really offers. The mode change from a mere playback device to a pointing device could particularly confuse the user.

Figure 2.8: Tag cloud of artists for goal oriented search (mode 2)

2.6 Two Turntables and a Mobile Phone

Bryan and Wang present a novel approach in using existing analog turntables to play back pre-recorded digital au-

Measuring the rotation of the record via a smart phone

dio. The system is an alternative to the previously introduced digital vinyl systems. For this system the authors used smartphones with accelerometers and gyroscopes and attached them to a prepared record, measuring the velocity via the sensors. You can see a sketch of the assembly in Figure 2.9. The smart phone is synchronized with a computer that plays the music according to the sent data. Using a smartphone brings some additional benefits like multi-touch interaction; no special hardware is needed and it opens the way for untethered performances by the DJ (e.g., shaking the phone in his hand). Hansen and Bresin [2003] require accurate and low-latency playback of the music as mandatory for a system that would be used for scratching. The authors therefore optimized the sensing of the data using knowledge of the domain. The accelerometer and gyroscope detect a three-axis rotation (pitch, roll, and yawn velocity). But as the smart phone is tightly attached to a turntable you can make use of the knowledge that only a single axis is affected and that the smart phone moves in a circular motion. Therefore, the authors claim their system to have a minimal latency and to be precisely enough to sense scratching gestures. In contrast to timecode vinyl sys-

Low latency is essential

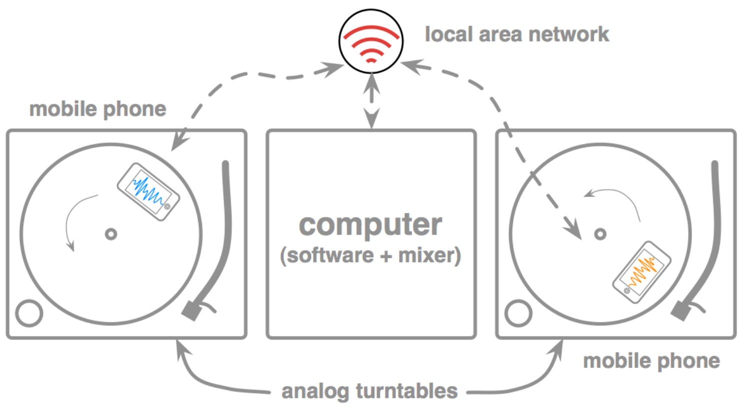

Figure 2.9: Two mobile phones are attached to a computer and send their data wirelessly to a computer

Visualizations on the phones

tems, this approach does not limit the length of the track. It also avoids physical interference with the tonearm and needles cannot jump anymore. The direct visual feedback on the record should also help the DJs in their task of beatmatching. The waveform of the current track is shown on the phone's display and can be zoomed in/zoomed out through pinch gestures (see Figure 2.10 and 2.11). In the

Figure 2.10: An iPod touch and a stanton turntable are used

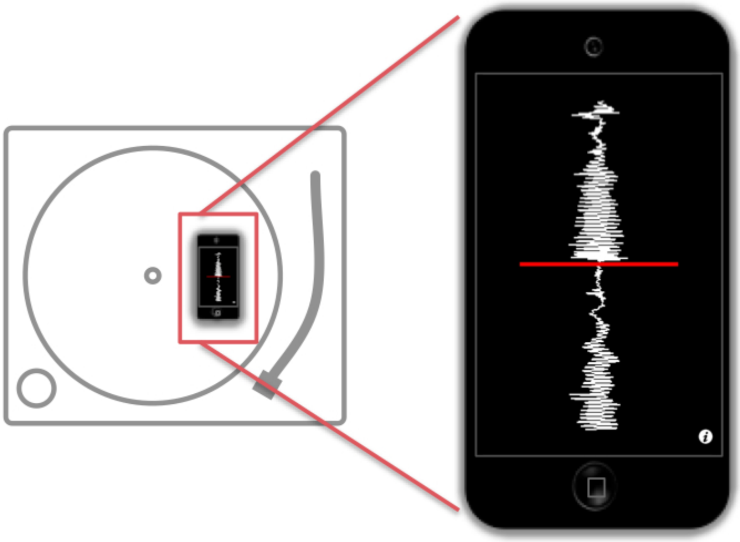

Figure 2.11: The visualization on the phone

future, the authors consider covering the complete surface with a multi-touch display. They also thought about implementing ”virtual paint markings, tape, or Post-its” for scratch DJs, to mark special parts of a sound visually. At the moment the system does not support a "placing the tonearm" functionality, which would allow the user to jump quickly to another position in the track. This functionality is also planned for future work.

Another interesting observation made was the impact of the smart phone's position on the scratch gesture. Depending on how far the phone is away from the center of the record, the scratching gesture can be amplified or dampened.

"Two Turntables and a Mobile Phone" is an interesting creative approach towards detecting the rotation of the platter. The combination of smart-phones and digital vinyl systems will probably play a big role in future work on this topic. For the development of DiskPlay it was particularly the visualization on the phone that was of interest.

2.7 DJ Scratching Performance Techniques

Understanding and modeling turntable scratching

Scratching transforms the turntable into a musical instrument. As with all instruments, certain techniques exist to produce the desired outcome. In Hansen and Bresin [2003], scratch techniques on the turntable are analyzed and synthesized. The objectives of this study are to "understand and model turntable scratching as performed by DJs" and to be able to "design a gesture controller for physical sound models". To collect the data, a typical DJ setup consisting of two turntables and a mixer was equipped with sensors.

Scratching in general can be broken down to the manipulation of a maximum of two variables: altering the play position of the track by moving the record backward and forward, and cutting the sound on and off with the crossfader. The authors used a potentiometer to track the vinyl movement, mounted to the vinyl with the help of a stand. To measure the crossfader slider movement, they connected two cables to the mixer's circuit board. The results of the recordings of some scratching techniques can be seen in

Figure 2.12 visualized as idealized models. As the models

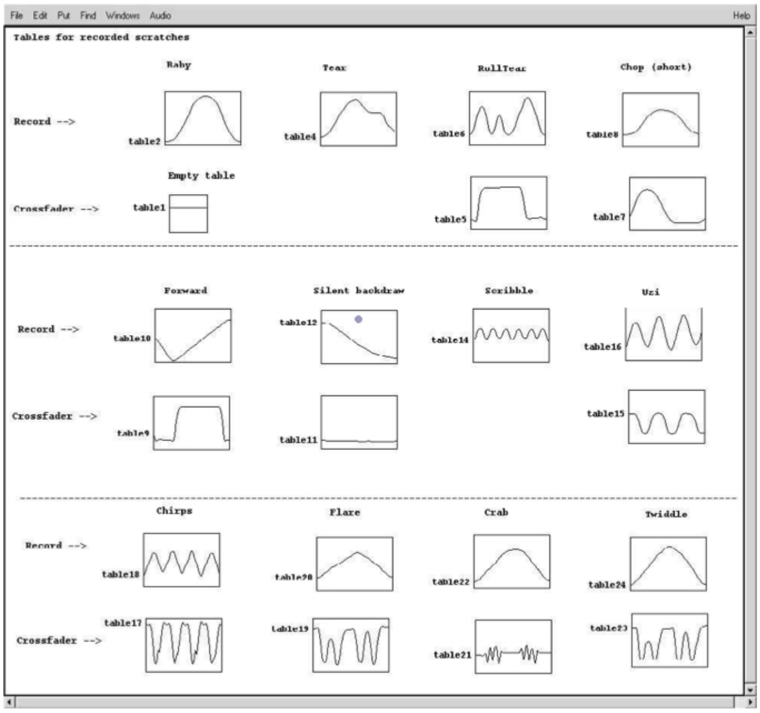

Figure 2.12: The models of the different scratching gestures

of the scratching techniques were developed, a Pure Date patch called "Skipproof" was also developed. This patch is used to manipulate the audio by physical means. In Hansen and Bresin [2003] they used a Radio Baton, which had an area for scratching and twelve smaller sub divisions used for predefined techniques. Evaluating the radio baton system with professional and novice users, the authors found out that the system has some clear disadvantages compared to the normal turntable and vinyl setup. Firstly, the radio emitter that is attached to the hand to control the radio baton must be wired to the antenna, interfering with the motions of the hand, and secondly, the detectable area of the radio baton is more spherical than cubical, thus making it difficult to learn.

Using a Radio Baton for scratching

DiskPlay is an interface for DJs in general. Although it aims mainly at beatmix DJs, its cue point function maybe also of interest for Scratch-DJs. This paper offers an insight

Scratch-DJs are potential users of DiskPlay into scratching techniques and develops idealized models of different scratch gestures in order to aid understanding of the development of devices for Scratch-DJs.

2.8 Haptic Design for Digital Audio

In Chu [2002a] and Chu [2002b] haptic feedback for digital audio is designed and evaluated. The author focuses on digital sound editing software. Typically, mouse and computer keyboards are used to navigate and edit audio providing no haptic feedback related to the audio file. The author wants to incorporate haptic feedback and states to ”substantially improve the user experience, including greater efficiency and gratification”.

The importance of haptic feedback in audio editing

The conceptual model of audio editing is rooted in the past, where sound editors worked with reels of magnetic tape. The length of the tape corresponds to the length of an audio file. To meet this conceptual model, Chu [2002a] developed an active knob, which can be seen in Figure 2.13, that works with springs, detents, and textures. The limited 1-D movement of the knob corresponds to the movement of a tape. Rotation in one direction plays the tape forwards and in the other direction rewinds it. According to Chu [2002a], the knob has further advantages like ”clear affordances for manipulation”, ”the interface reduces interaction complexity and confusion” and it eliminates the layer of abstraction that is added through keyboards and shortcuts. As fields of application two common tasks in audio editing were identified from user observations. The first task is zooming, which is frequently employed to navigate through the audio file and find the desired area for editing. As the knob rotation corresponds to the velocity of the sound playback, ”one can play the sound quickly (as if one were zoomed out), or play the sound slowly (as if one were zoomed in)”. A second task that is commonly performed is the exact localization of specific points in the audio file one wants to edit. This is often done with a combination of looking at the waveform and listening to the current section, a fairly ”difficult task to perform visually, and especially aurally, since scrolling is usually quite slow and sound playback occurs

Two common tasks in audio editing

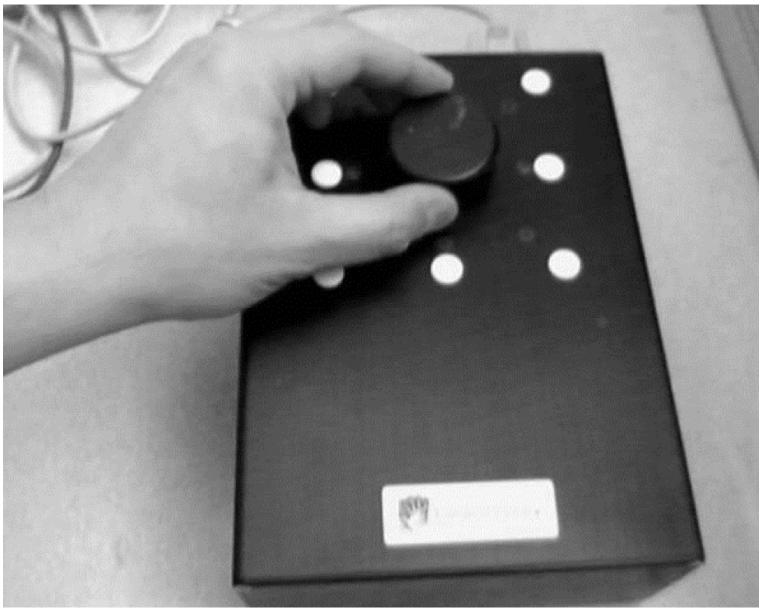

Figure 2.13: The knob used for evaluation

at a slow rate".

For the implementation of the system, two different modes were evaluated. On the one hand the position control, whereby the rotational distance corresponds to the linear distance in the audio file (for example, one revolution of the knob advances the sound file by one second). In this mode, the system makes use of detent, texture, and spring effects. On the other hand, there is the rate control mode in which the knob has a center position with two springs located on either side. In this way the knob is always pulled back into the center region. The further the knob is pushed into a spring, the faster the playback of the audio file will be. Depending on which spring the knob is pushed into, the file is played forwards or backwards. In control mode, detents are used to mark strong beats in the music, springs signify a sloping amplitude in a sound that is "not drastic enough to be a beat", and textures give the user a haptic feedback during the song, according to parameters such as magnitude, period and phase. Pops are used in rate control mode and occur when sound playback reaches a beat in the music.

Two different navigation modes

Chu [2002a] also proposes to use his interface for mix DJs who require a certain precision for matching two songs and wants to optimize the haptic effects in further design cycles.

DiskPlay and sound editing

This paper shows the necessity of haptic feedback in designing devices for audio applications. The behavior of a knob is also very similar to the behavior of a turntable, with the exception that a turntable also offers non-linear search through the tonearm. This encourages the consideration of also using DiskPlay in a sound editing environment, as was described in this work.

2.9 Disk-type I/O Interface for Browsing Digital Contents

Introducing IODisk

The IODisk developed by Tsukada and Kambara [2010] is an interface for navigation through digital content, like pictures or videos. Similar to D'Groove 2.3—"D'Groove", it consists of a disk (in this case not a vinyl record) mounted on top of a force-feedback motor. A rotary sensor is sending the rotational values to the computer to control a video browser that was developed for this purpose. The disk is transparent and full color LEDs under the disk provide visual feedback. The authors also included a RFID reader for detecting RFID objects (e.g. Phicons in Ishii and Ullmer [1997]). The video is played back according to the rotational speed of the disk; when the user turns the disk faster, the video is also fast forwarded; if the user turns the disk backwards, the video is played in reverse; stopping the disk results in stopping the video. The system also keeps up the spinning speed, even if the user does not manipulate the disk anymore.

The application field of browsing, which is described in this work, could be interesting with regards to the future development of DiskPlay. The technique used to detect the rotation is interesting and could also be considered for the implementation of DiskPlay.

Chapter 3

Design and Implementation of DiskPlay

In this chapter we describe the idea behind DiskPlay. First sketches are shown, explaining our design decisions. Thereafter the most important code segments are shown and explained.

3.1 The Idea

As mentioned in (2.1—"Digital Vinyl Systems"), many DJs today use digital vinyl systems to play their sets. But the timecode vinyl has one crucial disadvantage in comparison to analog records; due to the generic characteristic of timecode records, important information for the DJ, which he could gain from analog records, is lost. This is obvious information, like the track name and artist, but also information regarding the song's mood and structure. The DJ can, for example, see on the record's surface where a track starts and where it ends as the grooves in the lead-in and lead-out areas (before and after the track respectively) have a much higher spacing. For an example of a lead-out area see Figure 3.1. Additionally, the grooves in louder parts of

Generic timecode records lack information on their surface the track are larger and need more spacing than those in quieter parts of the track 3.2. This is directly visible and gives a quick and simple overview of the track's structure. All this information is collected in the GUI of the vinyl emulation software, but with the consequence that DJs have lost visual control over the record and navigation is made much more complicated.

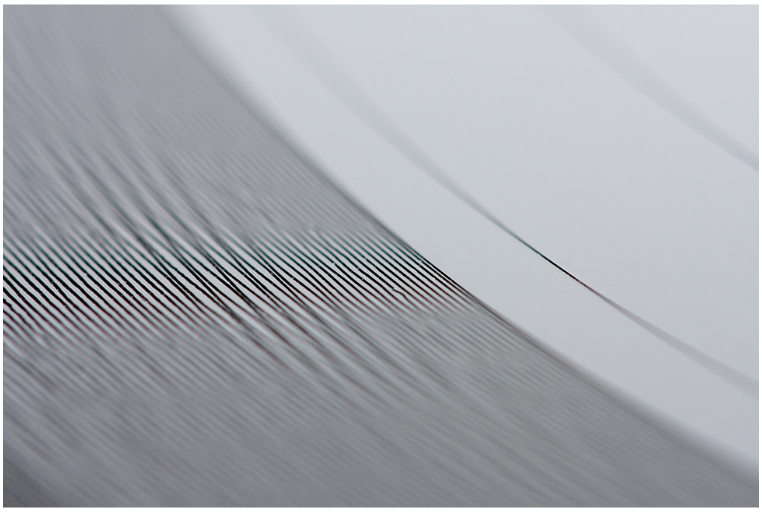

Figure 3.1: Lead-out area on an analog record. Can be distinguished through different spacings between the grooves.

Use the record as a display

The idea of DiskPlay is to provide DJs with information directly on the record once more, returning visual control to them and enabling them to navigate faster and more conveniently through a track. In the long run, the idea of DiskPlay is to completely eliminate the need for a computer display, making the reduction of attention switches between computer display and turntable the guideline for design and development of DiskPlay.

3.2 Design

Collecting information for the design of DiskPlay

For the evaluation of a first sketch we collected information about the activities of a DJ. We watched videos of DJ performances online (for example, the videos of the DMC World Championsips) and visited a showcase organized by

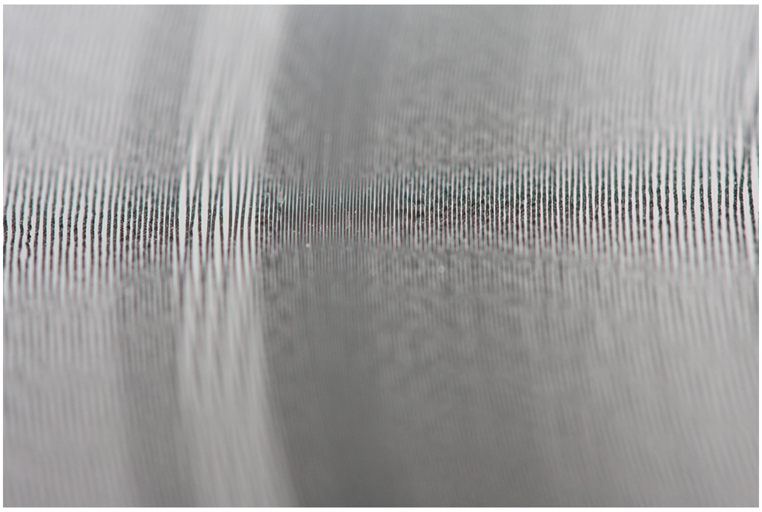

Figure 3.2: The groove spacing varies depending on the volume of the audio signal.

Rane and Serato with DJ Clay-369. DJ Clay-369 has an active DJing career of more than 10 years and has played in many clubs, as well as done promotion and demonstration shows for companies like Vestax (DJ equipment), Serato (DJ software manufacturer) or Rane (audio equipment). He mixes Hip-Hop music and combines the mixing with scratch sounds.

Based upon observations and interviews, we identified two main applications that should be covered with DiskPlay. Firstly, DiskPlay should give the user an appropriate visualization of the song, thus helping him to navigate through the song. Such a visualization has to include basic information like when the song starts, when it ends, where the current play-position is, and how long the whole track is. Secondly, we wanted to include cue points on the record, helping the DJ to find positions within the track that he had specifically marked beforehand. Cue points also have the function to give a scratch DJ a clue of how many degrees he has rotated the record, helping him to find the beginning of the position where he started his scratch gesture.

Information that DiskPlay should visualize

Our aim with the conception of the interface was to build a bridge with analog vinyl records, keeping the visualization clean and simple and avoiding overloading it with complicated features that the DJ would not necessarily need. Figure 3.3 shows a sketch of DiskPlay.

The song is represented through circles with different colors, which are mapped onto the timecode vinyl according to their duration and placed concentrically to the center of the record.

The visualization of a song

A timecode record holds either 10 or 15 minutes of timecode information, so a track is usually covered by only part of the record. This is visualized through the red area, where the track is already over. The green and blue areas stand for the track itself. More specifically the green area depicts the portion of the song that has already been played, and the blue area the portion that is still to come. The colors can easily be distinguished because of their complementariness and they are symbolic of their function; red indicates a 'danger zone' which the needle should never cross; green shows the 'safe area' of the record, which has already been processed; and blue as a rather neutral color, giving the user a hint of where he can place the tonearm without danger. The transition between the blue and green area is always right beneath the tonearm and the transition between red and blue right at the end of the track.

Colors for the circle representation and their meaning

Estimating the remaining time with timecode segments

The grooves of the Traktor timecode records that we used for DiskPlay are segmented into groups of one minute. Therefore the DJ can roughly estimate how long the track will still be playing, how long the full track is or the position of the current section simply by counting the corresponding groups of grooves that are covered by the blue circle.

DiskPlays cue point function and its visualization

Cue points are represented through little circles. To stick to the record metaphor, they are rotating at the same speed as the record, making it look like they ware attached to it. To distinguish the cue points from the colored circles, we decided to paint them yellow if their position is after the current play-position and grey if it is before the current play-position. The yellow color should give the impression of a glowing LED, standing for an active cue point that has not yet been played, whereas the grey color should depict an LED that is turned off, deactivated and therefore already

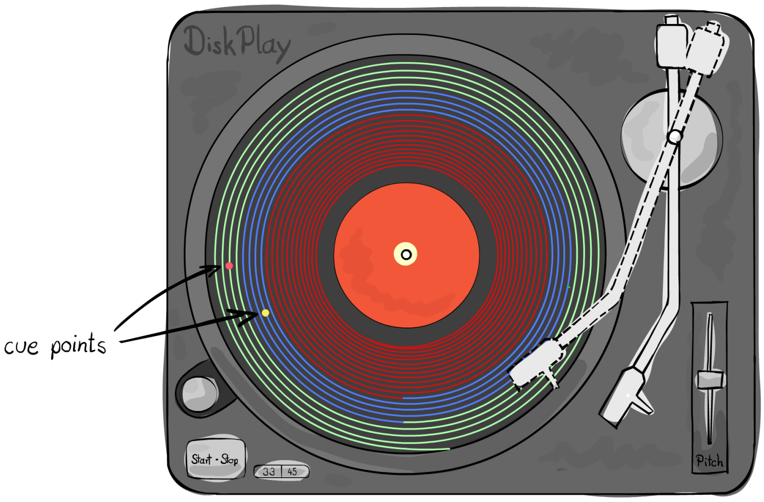

Figure 3.3: A sketch of the augmented interface DiskPlay. The green area denotes the part of the song that has already been played, the blue area the part of the song which yet has to be played, and the red area indicates the end of the song. Cue points mark remarkable parts in a song.

played. As an additional clue, the orbit on which the cue point rotates around the center of the record is depicted as a black line. The user can navigate to the cue point simply by placing the stylus on the line and then spinning towards the actual cue point position.

An aid for finding the cue point

3.3 Additional Features and Why They Were Left Out

In the design process we thought about different features that could be integrated into DiskPlay. The waveform representation used in Mixxx, for example, gives a visual representation of the song in the GUI and gives the DJ orientation about where in the song he currently is. In DiskPlay this functionality is already covered through the colored circles, which respond to different positions of the tonearm and therefore already depict the current position in the song. We tried to keep the visualization simple and de-

A waveform representation is left out

cided to leave a waveform representation out.

Beamish et al. [2003] painted four lines on the record to give the DJ a visual aid for beatmatching two songs. But as they found out, "DJs ignore the visual feedback" and instead "continue to rely on their ears" for beatmatching. This was confirmed by DJ Clay-369 and led to the decision that lines are not sufficient as visual aids for beatmachting and could also be left out.

No browsing feature for DiskPlay

The Traktor timecode record offers an area for scrolling through your music library. So, very quickly the idea came up to integrate a browsing mechanism that works on the record itself, similar to the approach of Pabst and Walk [2007]. However, this would not have supported the in-track navigation purpose of DiskPlay in any way and would have added a new feature to the interface, also adding a new layer of complexity to the system. Therefore we did not integrate such a function in order to avoid 'creeping featurism', as Don Norman called it in his Book Norman [2002]

There is also the information about which track by which artist is currently playing to consider, but seeing as the DJ has selected the music himself and is constantly hearing what is on the decks through his headphones, we decided that this information is also an unnecessary overload for the visualization.

3.4 Implementation

3.4.1 Hardware

Lots of different information is needed to implement DiskPlay. The duration of the song and the current play position are important for the visualization of the song in the form of the colored circles. We have to know the cue point's position in a song and need to calculate when a cue point hits the tonearm. There are several ways to implement such a system and access the desired information. One could use a camera to track the position of the tonearm, measure the rotation of the tonearm and the vinyl record, or go with a vinyl emulation software, for example. We chose the latter, and although the only information you get from the timecode is the current play-position, you can still use it to estimate the position of the needle. This algorithm is explained in more detail in 3.4.2—"Software"

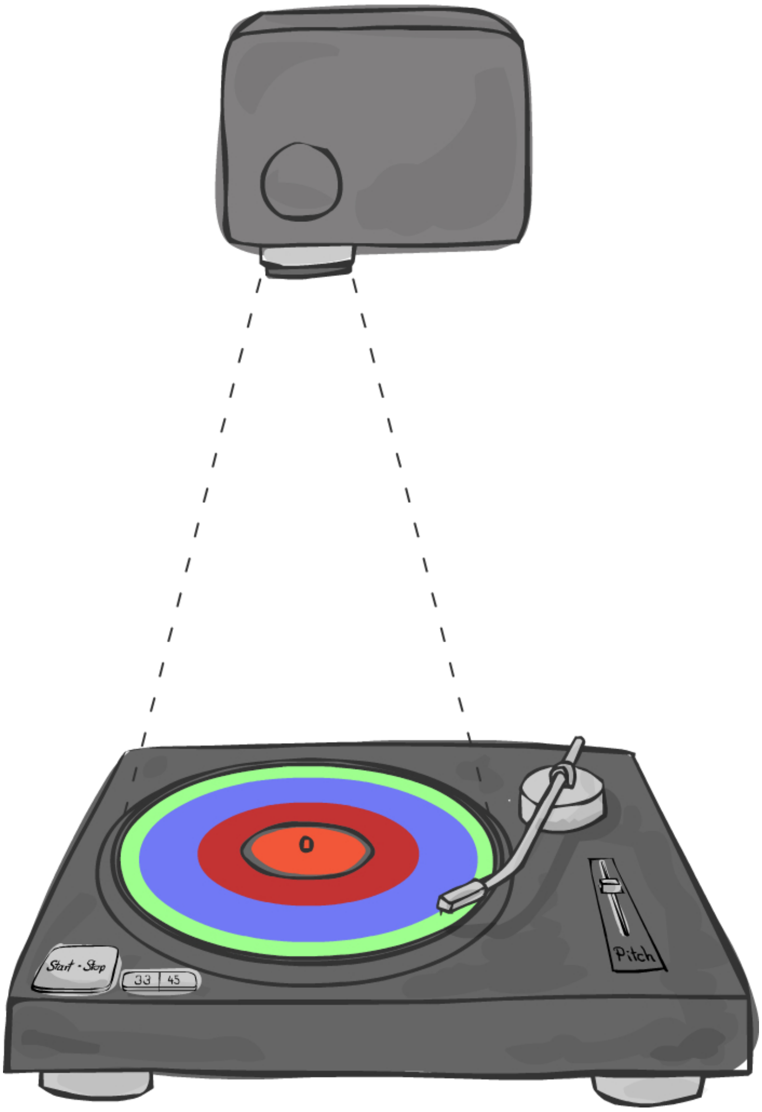

Figure 3.4: This is the hardware installation of DiskPlay. A projector mounted above the turntable displays the visualization directly on a white timecode record.

Hardware and assembly of DiskPlay

To display the augmented interface in the hardware prototype, we decided to use a projector mounted above the turntable (see Figure 3.4 for comparison). This was the quickest and most convenient way of displaying the interface on a record, as no new hardware had to be ordered or old hardware disassembled. The prototype setup included two Technics SL-1210 MK5, a standard DJ- mixing console (Gemini BPM–1000) and the interface Audio 4 DJ by Native Instruments, which connects the turntables to the computer and channels the audio output from the computer back into the mixer. Only one of the two turntables was equipped with DiskPlay to make direct comparison to the current standard toolset. The turntable equipped with the projector had a white timecode vinyl for a better view of the projection. Next to the setup was a display for the vinyl emulation software and everything was connected to an Apple Mac Pro.

3.4.2 Software

Using Mixxx as a foundation for the implementation

Our augmentation bases on the open source software (2.2—"Mixxx"). This has the advantage that we do not need to process the timecode anymore and also have an engine playing music synchronized to the timecode. As the GUI of Mixxx is very similar to common commercial vinyl emulation software, it is also suitable for user tests with professional DJs that can resemble the GUI from software they already use. To correlate to our visualization we use Mixxx in absolute vinyl control mode.

Calibrating DiskPlay

The existing code of Mixxx was simply extended with our implementation, integrating DiskPlay into the Mixxx software in its own window. This window can simply be dragged onto the displaying area of the projector and be expanded to full-screen. To make the calibration of the system simpler, you can set six points in the window that correspond to specific points on the record and the tonearm (see Figure 3.6 for a comparison). This way the projector does not always need to be perfectly placed over the turntable, making it possible to calibrate the system very quickly.

Figure 3.5 shows the structure of a standard Traktor time-

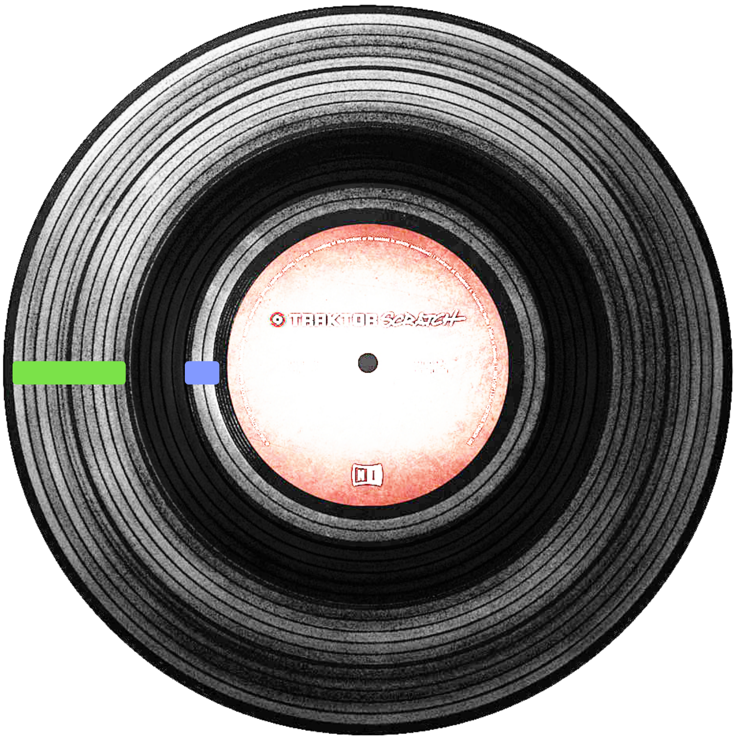

Figure 3.5: This is a ten minute timecode record from Traktor with increased contrast and brightness for better visibility. Colored bars are added to mark the different sections. The green bar marks ten minutes of timecode which is divided into two segments with five sub-segments each. The blue bar marks the grooves for scrolling.

code vinyl. You can roughly distinguish three segments, which are divided into smaller sub-segments. The first two big segments contain a timecode for playing music files on your computer. Every segment is divided into five sub-segments, which each correspond to a minute of timecode. The third big segment is an area for scrolling. It gives you the possibility to scroll through your music library in the vinyl emulation software itself.

Calculating the circle representation

As you can see in Figure 3.5, the sub-segments, representing one minute are all equally large. Although the circumference on the outside of the vinyl is much larger than the circumference on the inside, every groove holds the same

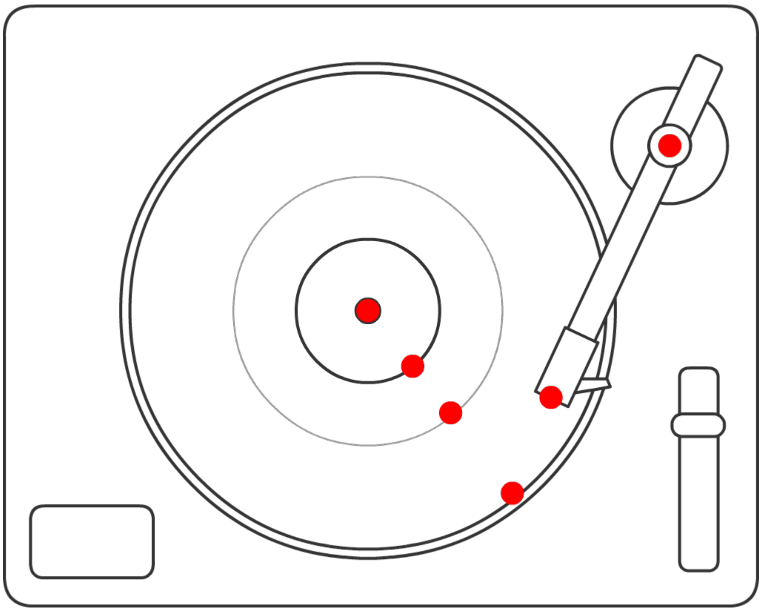

Figure 3.6: The distinctive marks for calibration are shown by the red dots and as follows (from left to right): 1. center of the record 2. outline of the record label 3. end of the timecode for playing back the audio 4. outline of the record 5. tip of the tonearm 6. tonearm shaft

amount of time for one revolution. This is due to the constant speed of 33 revolutions per minute, which makes it very easy to calculate the radius of the circles in the visualization of DiskPlay:

Listing 3.1: Calculate radius of colored circles

```
int RecordView::getRadiusForTime(double
    time)
{
    return (int)((double)(1-time) * (
        radiusOfRecord - radiusToTrackEnd) +
        radiusToTrackEnd);
};
```

radiusOfRecord and radiusToTrackEnd are calculated from the calibration points and stand for the distance from the record center to the end of the ten minute track and the outer border of the record respectively. The variable time is a value between 0 and 1 and describes a position in the ten minute track as a percentage. This function is used to paint on the one hand the circle that limits the song – indicating the length of the song – and on the other hand the circle that depicts the current playback position. This function is also used to calculate the cue points later on. Although the area for the timecode is separated by a larger gap right in the middle and many small gaps in between, this linear interpolation is sufficient for the purpose of DiskPlay and offers enough precision that after some initial tests no refinements had to be made.

Requirements for the cue point visualization

The calculation of the cue points was a bit more complicated, as the exact position of the tonearm is needed. The rotational speed should match the rotational speed of the turntable platter, to visualize the cue points as naturally as possible and meet the metaphor. Otherwise it would also feel like the cue points were slower or faster than the actual record, leaving a deficient impression. More importantly, the cue point's position on the record has to match with the position in the song. If the user is placing the tonearm on the groove of the cue point, he has to be near the cue point. As already mentioned, the projector resolution is insufficient for groove-level visualization. Therefore it is possible that you could have to spin the record a few times, although you have already hit the orbit of the cue point with the stylus. When the stylus reaches the cue point, the corresponding part of the sound has to be played. With these principles in mind, we designed the following function that returns the coordinates for a cue point's position in the track in a matter of seconds:

Listing 3.2: Get the position of a cue point for a given time

```
QPoint RecordView::getTonearmPosition(int
    radius)
{
    return intersectCircles(recordCenter,
        radius, tonearmCenter, tonearmLength
        );
}

QPoint RecordView::getPositionForCuePoint(
    double time)
{
    double
```

```
    currentPlayPositionInSongInSeconds = currentPlayPositionInSong * trackInfoObject->getDuration();

    // on which groove is the cue point?
    double r = getRadiusForTime(time/LENGTH_OF_RECORD);

        // calculate the cue point offset to the zero line for the right position in the groove
    double cuePointOffset = modulus(time * NUMBER_OF_SPINS/LENGTH_OF_RECORD,1);

        // calculate a tonearm offset to the zero line (this makes the cue points spin)
    double tonearmOffset = 1-modulus(currentPlayPositionInSongInSeconds * NUMBER_OF_SPINS/LENGTH_OF_RECORD,1);

    double cuePointOffsetInRelationToTonearm = (1-(cuePointOffset+tonearmOffset);

    // go from the tonearmposition on the groove to the actual cuepoint position
    // (with the offset we calculated earlier)
    int radiusTonearmPosition = getRadiusForTime(currentPlayPositionInSong*this->songDuration);
    QPoint tonearmPosition = getTonearmPosition(radiusTonearmPosition);
    double tonearmRadiant = atan(double(tonearmPosition.x()-recordCenter.x())/double(tonearmPosition.y()-recordCenter.y()));

    double helper =
```

```
        cuePointOffsetInRelationToTonearm *
        360 * (M_PI/180))-tonearmRadiant
    QPoint cp = QPoint(-1*sin(helper)*r+
        recordCenter.x(), cos(helper)*r+
        recordCenter.y());
    return cp;
}
```

An imaginary zero line, drawn from the record's center to timecode zero is used as a reference to calculate offsets for cue points and the tonearm.

Calculating the cue points

The idea of the algorithm is the following: First, find the groove on which the cue point is spinning and then calculate the cue point's offset to the zero line, positioning it in the right angle. The cue point's groove is calculated with the getRadiusForTime(**double** time) function described earlier. This radius covers a specific span of time in which the cue point lies. To find out the right angle of the cue point, according to the zero line, we calculate a cuePointOffset, which describes the cue point's distance to the zero line. NUMBER_OF_SPINS/LENGTH_OF_RECORD describes how much the record revolves in one second as a percentage, whereas NUMBER_OF_SPINS is the number of spins during the 10 minutes (for a ten minute timecode record this is 333) and LENGTH_OF_RECORD is the length of the record in seconds (in our case 600 seconds). Multiplied by the cue point's position in seconds and modulus 1, you maintain the cue point's offset to the zero line. The value 0.5 for this variable would mean that the cue point is half a revolution away from the zero line. Values 1.0 and 0.0 describe the same cue point position on the groove, because the distance is described in a circle. modulus(**double** a, **double** b) is a helper function, because C++ natively only supports modulus for integer numbers.

To make the cue points spin, we also calculate the tonearm's offset to the zero line in the same manner. By adding this offset to cuePointOffset in the variable cuePointOffsetInRelationToTonearm, we let the zero line, which is the reference for the cue points, spin virtually at the pace of the play speed.

Calculate the tonearm position

The tonearm describes a round course from the outside of the record to the inside. To determine the tonearms position as precisely as possible with the given data, tonearmPosition is calculated with the function getTonearmPosition(**int** radius), which simply returns the lower intersection point between a circle around the hinge of the tonearm with a radius of the tonearm's length and the circle around the records center, which has the radius corresponding to the current play position (the radius of the blue circle so to say).

In helper the radiant of the tonearm's position is then subtracted from the radiant of the cuePointOffsetInRelationToTonearm. In this way, we ensure that the cue point is at the right position and hits the needle. To return the coordinates of the cue point, sin(**double** a), cos(**double** a) and the radius r of the cue point's groove are used to determine the cue point's position on its groove, which is then translated to the center of the record, giving the absolute coordinates of the cue point.

Figure 3.7: The augmented interface DiskPlay. Next to the tonearm is a cue point which spins on its orbit, denoted through a black circle.

Performance issues

During the implementation we struggle with performance problems, which are a very big issue as low latencies are essential for a DJ's performance. As soon as we enabled vinyl control in Mixxx and connected the turntables to the laptop, the visualization began to jerk. Setting the timecode processing to every 10 ms instead of 1 ms was an improvement, but nevertheless not a solution. Higher latencies in Mixxx would make the software unusable for professional DJs, so we changed the implementation and exchanged the callback function that provides the timecode data with a Signal and Slot mechanism of Qt - again an improvement, but still not the solution. As a last step, we uncoupled the timecode function from the original Mixxx code and implemented a timer in our DiskPlay that fetched the timecode data every 20 ms. This was sufficient enough and provided a constant frame-rate at which the visualization could be drawn. For the last 20 to 30 percent of performance the project was moved from the laptop to an Apple Mac Pro which let the program run smoothly at last. The final visualization of the system can be seen in Figure 3.7.

Chapter 4

Evaluation

In this section, DiskPlay is evaluated. We describe the design of the user test, which was conducted with professional DJs, and present the results followed by a short discussion.

4.1 User Study Design

Evaluation of DiskPlay

For the evaluation of DiskPlay, we conducted an observational study with 4 professional DJs, hereafter referred to as DJ1 . . . DJ4. The DJs had between 5 and 20 (average 12) years of experience, including between 0.5 and 5 (average 2.5) years of experience with a digital vinyl system. The main purpose of DiskPlay is to support the DJs in their artistic expression, so we focused on a qualitative evaluation. We also conducted a small quantitative 'seek task', where DJs had to find dedicated positions in a song while we measured the completion time under different circumstances (only with the GUI of Mixxx, only with DiskPlay, and only by hearing).

Structure and Design of the user study

The course of the user test was as follows. At first the users had to fill out a survey (see survey in A.1—"Survey" in appendix A), detailing their experience level, DJ-type (1.1—"Different Types of DJs"), working habits, and the equipment they use. Thereafter, the users had a 25 minute accommodation phase working with the assembled setup. They had time to get used to the GUI of Mixxx and the turntable setup (two Technics SL-1210 MK5 and a standard DJ mixer Gemini BPM–1000), before DiskPlay was switched on in phase two. The DJs worked for 30 minutes with the augmented DJ setup, beatmixing several songs. During these two phases, the DJs worked without interruptions, whilst we were standing behind him observing his actions. The DJs were encouraged to think aloud and to reference potential peculiarities.

After the silent observation, the seek task was performed, measuring the navigational speed of the new interface.

These tests were followed by a semi structured interview, capturing the DJs thoughts on the DiskPlay system and ideas for further development.

In the upcoming section we will shortly describe the observations made during both phases in which the DJs worked with the turntables with and without DiskPlay. After that we will summarize the interviews, followed by a discussion of the results.

4.2 Results - Quantitative Study

Design of the quantitative study

The seek task was structured as follows. Three songs were picked by the user, in which they marked a distinct position with a cue point. The task was to find this position as fast as possible, starting with the tonearm lying on its detent. This was done three times, using only the visual feedback of DiskPlay, using only the visual feedback from the GUI of Mixx and only by hearing. The order was randomly chosen. The measurements of the seek task can be seen in table 4.1.

Quantitative conclusions

The variance of the measurements is very high and due to the small number of users, a conclusion can hardly be drawn based on these values. It is notable that almost every time it took the DJs longer to find the cue point only by hearing. Therefore we can draw the conclusion that a visual

Table 4.1: Measurements of the seek task.

$User$	$Mixxx$	$DiskPlay$	$bhearing$
1	11 sec	5 sec	25 sec
	8 sec	3 sec	12 sec
	11 sec	8 sec	15 sec
2	8 sec	3 sec	24 sec
	9 sec	7 sec	12 sec
	11 sec	31 sec	15 sec
3	24 sec	28 sec	42 sec
	9 sec	18 sec	9 sec
	5 sec	8 sec	9 sec
4	14 sec	5 sec	21 sec
	10 sec	24 sec	25 sec
	12 sec	20 sec	22 sec

representation is essential for navigating quickly through a track. In future development, a larger field study has to be conducted to gain more significant numbers.

4.3 Results - Qualitative Study

Observations during phase 1 - control condition

As the DJs started using the system, none of them had any big issues in using Mixxx as a vinyl emulation software. Mixxx resembles the commonly used commercial software solutions like Traktor from Native Instruments or Seratos Scratch Live, which is the software used by the DJs, so they did not have to get used to something completely new. It was very interesting to see the different techniques and forms of working with the digital vinyl system. During the task of beatmatching two songs, every DJ had their own technique to synchronize two songs. One DJ only dragged or bumped the record, another rotated the motor shaft, and yet another DJ used the buttons that change the rotational speed between 33 $\frac{1}{3}$ rpm and 45 rpm to apply small temporal speed changes to the record, matching the beats of the

Control condition

Differences between the users

tracks. The DJs also showed different behavior regarding the computer screen. The number of attention changes differs largely and ranges from heavy usage to usage only for selecting a new track. It was noticeable that the usage of the software GUI had nothing to do with the amount of time that the DJs had already been working with vinyl records, as one might have estimated. DJ1, who had worked with turntables for 8 years and only half a year with timecode vinyls, made heavy use of the software and its visual aids, whereas DJ3, who had worked for five years with turntables and 3 of them with digital vinyl systems, barely used the aids of the GUI at all.

Similarities between the users

Despite these differences, a common denominator exists. The course of how one song is mixed into another is equal among the DJs, although the techniques may differ in detail. As one song is playing, the DJ hears both songs on his headphones and compares the speed. With the pitch slider, he matches the speed of one song, such that the beats match. With the equalizers, the bass is taken out of the song to let the transition appear seamless. Now the DJ positions the tonearm over a beat. Scratching back and forth over the beat, the DJ kicks in the new song at the right moment. Often, small speed changes (e.g. by dragging or bumping the record) are applied, to synchronize the two songs (compare Beamish [2001]). DJ1 and DJ4 used the waveform representation as a visual aid, and DJ4 used the waveform to find the second beat of a song. DJ2 and DJ3 relied mainly on their hearing for approaching the beat. The DJs also used the display for checking the progression of the song by looking at the remaining time.

Display use of the users

Observations during phase 2 - experimental condition

None of the DJs knew what to expect, so the first thing they did was to play around with the system, testing its accuracy and setting cue points out of curiosity.

The cue point function was only used by two DJs

The cue point function was mainly used by DJ1 and DJ4, as the other DJs have never used this function before. DJ1, for example, used it to mark the position in a song after an intro when he did not like the intro. DJ4 used the cue point functionality for marking the beat of a track that he wanted to start with. In this way he did not need to look at the waveform display to localize the beat.

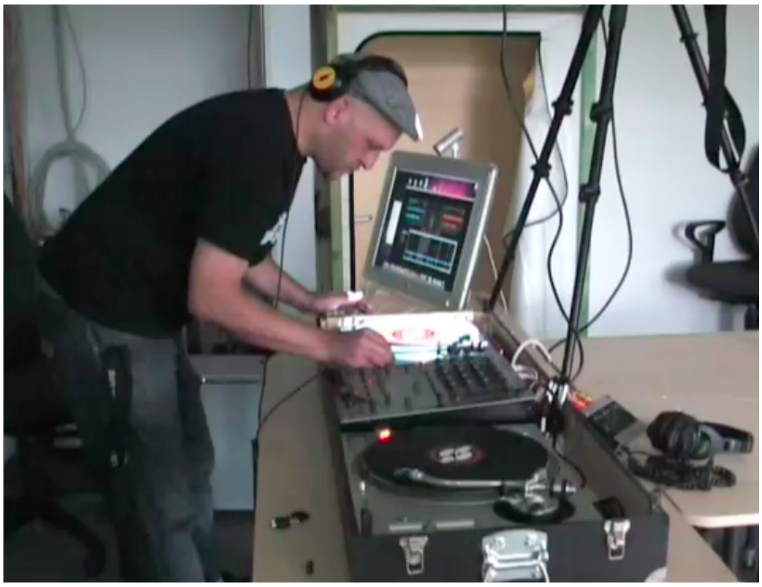

Figure 4.1: A DJ uses DiskPlay during the user tests at the RWTH Aachen University

Follow up interview

In the interview following the test, questions were asked regarding DiskPlay and its features and about things that attracted our attention during the observations. The users also had the chance to give free feedback.

The users feedback on the colored circles representation

First of all, and most importantly, the visualization of the song was very well received by all of the DJs. The users used it to estimate the remaining duration of the song and always had in sight roughly how long a song had been playing. As DJ1 stated: *"The most embarrassing thing that can happen to a DJ is that the song is over before he notices it and therefore has no time to generate a smooth transition by beatmatching"*. This happened to one of the DJs during the accommodation phase, leading him to propose a visual alert in the interview afterwards. This alert should appear shortly before the song is over: *"Something flashing would be nice"*. A similar functionality is already built into Traktor, but due to the fact that the DJ is concentrated on the turntable most of the time, it would make a lot of sense to show the alert on the record as well. To see when the track is about to end is really essential for the DJs, but in some situations, like when the DJ wants to get something to drink or has to leave the turntables for some minutes, he needs to know the absolute time that remains. Therefore the DJs were all in agreement about the following: DiskPlay is lacking an absolute time measurement to know *"how many minutes and seconds are left"*.

Visual aids for beatmatching

The BPM (Beats per Minute) of a song are very important for beatmatching. These are calculated by the software and the DJ can use this information to roughly match two songs in their speed by adjusting the pitch slider. DJ3 wishes this information to be displayed *"somewhere on the turntable, such that it doesn't interfere with the rest of the display"*, instead of showing it directly on the record. After two songs have the same BPM, the songs need to be synchronized to match the beats. DJ1 had the idea to guide the user in this task. Arrows on the record should indicate whether the DJ has to push or drag the record to show him in which direction the beats are differentiating. If an arrow was pointing towards the spinning direction of the record, the DJ would have to push the record, but if it was pointing in the opposite direction, the user would have to drag. Different lengths of the arrows could indicate the force that has to be applied, showing a small arrow when only small speed changes are necessary.

Eliminating the display for a better communication between DJ and audience

One very interesting aspect was mentioned by DJ1 who noted that *"Most people in the audience don't know what the DJ is actually doing during his performance. It would be nice if the visualization could give the people an understanding of the DJs job"*. He says *"A more attractive visualization could be great to make DiskPlay an explicit part of a DJ performance"*. How the computer monitor affects the DJs appearance is also reflected in an anecdote told by one of the DJs. While he was playing a set in a club, one of the guests asked him if he was checking emails. How the audience perceives the DJ show on the stage can be crucial, because "watching the motions of the DJ during the performance can be almost as exciting as listening to the music being played" [Beamish, 2001]. The screen acts as a wall that hides the DJ from the audience and blocks a big part of communication.

Regarding the display, DJ3 mentioned that the display often *"deviates from the acoustic"*. As we asked one of the DJs why he looks at the display so often, he answered *"I often look at the display no matter if I want to gain information from it or not. It's a habit."* Because many attention switches affect the DJs concentration, they also affect the quality of his performance.

Although one DJ asked for a waveform representation showing the current play position, the other three DJs liked the simplicity of the system and rejected the need for such a visual aid. Although DJ1 and DJ4 made heavy use of the waveform representation to find a beat, there are maybe other ways to substitute this functionality. Beamish et al. [2003] worked for example with bumps for beats that address the DJ's sense of touch.

User feedback regarding the cue point function

DJ2 and DJ4 recommended the cue point specifically for battle DJs, like Kid Koala, for example. They make heavy use of records that they have prepared with labels and markers beforehand. DJ1 had a problem with finding the exact position of the cue point. After coarse navigation with the tonearm to the cue point's groove, he did not know if he had to spin one, two or three times, before hitting the cue point. The grooves of the timecode records are much more precise than the pixel representation of a groove, due to the resolution of the projector. Normally a pixel covers up to three grooves. Therefore, the visualization indicates you have hit the right groove although you still need to spin the record one or two times before you really hit the cue point.

To completely build a bridge to the vinyl record metaphor, we proposed to also show information about the mood of the song. All DJs agreed that this information is lost with timecode vinyls and DJ4, intrigued by the idea, proposed to visualize the mood and energy of a song *"through different shadings in the colored circles"*. However, this is not possible with the current setup, as the resolution of the projector is too low and a circle that is one pixel thick had to contain the information of three grooves.

An assembly with a projector is too complex for an environment like a club

Asked about the assembly and if the self occlusion of the projector bothered them, all of DJs rejected this idea and said that the shadow did not negatively affect their sight.

As one of the DJs said:*"The interesting part is the needle and the area before that. The DJ normally doesn't go there with his hand, as it would interfere with the tonearm"*. But DJ1 criticized the complexity of installing DiskPlay in a club. He called for a more compact solution or a screen that is built into the turntable.

Discussion of the user feedback

As expected, the representation of a song with colored circles, which resembles the surface of a traditional vinyl record, was well received by the DJs. It fulfilled its designated role and gave the user the right hint about where the track begins and where it ends. Nevertheless, the information of how long the track is still playing as an absolute value in minutes and seconds seems crucial. We think that such information would be a great enhancement to DiskPlay, leaving open where to display such information ñ perhaps alongside a BPM display somewhere on the turntable, as DJ3 mentioned. We also think that the visualization in general could be made more spectacular and accessible to the audience through a mirrored display. This would center the DJ in the interest of the audience and give him a platform to express his technical skills. Through the interviews with the DJs we sensed a very strong desire to get rid of the display as it blocks the connection between the DJ and his spectators. DiskPlay is a first step towards digital vinyl systems that no longer need displays, but there are still some refinements to be worked on. Many functions that cannot be mapped onto a turntable's interaction possibilities so easily need to be implemented. The cue point representation was generally well received, but the flaw that the resolution is not precise enough still remains, leaving the DJ to spin the record despite having already hit the groove according to the visualization. This problem could be eliminated using a higher resolution for DiskPlay. Also the representation of the track's mood should be considered for future work, as this would reconstruct all of the information that is lost through the use of generic timecode records.

Chapter 5

Summary and Future Work

5.1 Summary and Contributions

DJs still rely on turntables and vinyl records for their performance. Due to their haptic predominance they are preferred by DJs to any other system currently on the market. Digital vinyl systems ((2.1—"Digital Vinyl Systems")) make use of the natural feel of vinyl records. They connect analog DJ turntable systems with the computer, to play back digital music but still maintain the haptic advantages of vinyl records by using timecode records. These timecode records, due to their generic character, lack crucial information, like the start or end of a track, the duration of a track and also the progression of that track.

Digital vinyl systems connect analog turntables with digital music, but lack crucial information on the record

In this thesis we presented DiskPlay, an augmented interface for DJs. DiskPlay extends digital vinyl systems with a display that is shown on the record and visualizes the song, as well as the progression of the song, in the form of colored concentric circles. Cue points in a song are presented as colored dots, which are rotating at the pace of the platter around the center of the record. As an additional feature, the orbit of the cue point is drawn as a line, giving the DJ an aid in finding the cue point's groove with the tonearm. These visual aids should eliminate the drawbacks of

DiskPlay and its functions

timecode vinyls, helping the DJ to navigate in a track and supporting him in his performance.

Assembly of DiskPlay

DiskPlay was displayed via a projector, mounted on top of one of the turntables, on a white timecode record. This installation proved sufficient for a first prototype and the casting of shadows did not interfere.

Evaluation and its results

For the evaluation of this system, we observed and interviewed four professional DJs. They all played electro music and were mainly beatmix DJs and not battle DJs (1.1—"Different Types of DJs"). The evaluation showed that DiskPlay is very supportive for the task of beatmixing and is superior to normal digital vinyl systems. The DJ always has in sight how long a track still has to play, information that is essential as the DJ has to mix in a new song before the old one is over. The cue point function still has small flaws and can be improved upon in the future. Nevertheless, the DJs were convinced of the usefulness of this feature, especially for battle DJs. Due to the small amount of users, the quantitative data has to be extended in future research. Notwithstanding, we could draw the conclusion that the navigational speed of a DJ increases with the aid of a visual representation.

5.2 Future Work

As we interviewed the DJs, they came up with many creative ideas to further improve the system. The conversations were very inspiring and in the following section we will present a selection of ideas for future development.

Improvements on the cue point function

As mentioned before, the cue point function in particular will be improved in terms of usability and functionality in the future. Increasing the resolution is not the only solution to the problem described in (4.3—"Results - Qualitative Study"); one could also change the behavior. As the tonearm approaches the cue point, it could get bigger, giving the user a relative hint at how far the distance to the cue point is. Alternatively one could highlight the cue point's orbit as soon as the tonearm has entered it. As soon as the orbit is highlighted, the cue point is a maximum of one revolution from the tonearm. Furthermore a completely different approach could be taken by establishing a snap function, which lets the current play position automatically snap to the cue point's position as soon as the tonearm is dropped in the proximity of the cue point. This would have to be evaluated and further research has to be done to measure its effectiveness. Although none of the DJs were confused when the cue point stopped spinning while the record still was as soon as the tonearm was lifted, it would be nice to let the cue points rotate further. For this, one could interpolate over the cue point's preceding velocity and let them rotate at the same pace. However, as soon as the DJ changes the speed of the record with the tonearm in the air, the visualization would not match anymore and would probably confuse the user. Better would be a sensor that transmits the rotational speed of the record to the computer. Maybe this could be done with gyroscopes and accelerometers similar to the approach with the mobile phone (2.6—"Two Turntables and a Mobile Phone").

Eliminating the display

One big issue with digital vinyl systems is the requirement for a display. It acts as a wall, hiding the DJ from the audience. There are a lot of ways the display can be replaced. For selecting and storing the music, you could use a device like an iPod touch or a smartphone, as they offer storage for music and a GUI that is sufficient for browsing through a music library. All other visualizations can then take place on the record itself; no other input devices would be needed. You can also combine the approach of (2.5—"A Tangible Interface for Music Browsing") with DiskPlay. However, this would mean that the turntable has different modes; one for selecting the music and one for playing music. To further extend the cue point capabilities of DiskPlay, buttons could be assembled to set a cue point. Pressing a button would feel much more natural than clicking a button on a software GUI. Taking this a step further you could also replace the projector with a built-in display, for example one that is mounted under a transparent timecode record.

Additional features

Last but not least, a lot of research can be done on extensions to the current visualization. These would include a BPM indicator, a waveform representation, or a display showing the absolute time that is left until the end of the track.

Appendix A

Survey before the user study

A.1 Survey

Fragebogen

Teilnehmer: ____________________

1. Ich lege Platten auf...

☐ Zu Hause ☐ In Bars, Klubs oder Diskos

2. Welcher “DJ-Typ” bist Du?

☐ Scratch-DJ ☐ Mix-Dj

3. Welche Stilrichtung beschreibt am besten die Musik, die Du auflegst?

☐ Hip Hop ☐ Elektro ☐ Rock

4. Ich lege schon seit _____ Jahren auf, davon ____ Jahre mit Timecode Schallplatten.

5. Ich habe schon mit folgender Software gearbeitet (mehrere Angaben möglich):

____

6. Benutzt Du die Cue-Point Funktion der Software?

☐ Ja ☐ Nein

7. Benutzt Du die Wellenform Repräsentation zur Navigation im Track?

☐ Ja ☐ Nein

8. Welches sonstige Equipment benutzt Du beim Auflegen?

____

Figure A.1: The survey conducted beforehand user tests.

Appendix B

Results of the survey

User 1

1. Ich lege Platten auf: In Bars, Klubs oder Diskos
2. DJ Typ: Mix-DJ
3. Stilrichtung: Elektro
4. Legt seit 8 Jahren auf, davon 0,5 mit Timecode
5. Software: Traktor
6. Benutzt Cue-Point Funktion: Ja
7. Benutzt Wellenform: Ja
8. Equipment: Traktor S4, 2xTechnics 1210

User 2

1. Ich lege Platten auf: In Bars, Klubs oder Diskos und Zu Hause
2. DJ Typ: Mix-DJ und Scratch DJ
3. Stilrichtung: Elektro und Hip Hop
4. Legt seit 15 Jahren auf, davon 5 mit Timecode
5. Software: Serato, FinalScratch
6. Benutzt Cue-Point Funktion: Nein
7. Benutzt Wellenform: Nein
8. Equipment: -

User 3

1. Ich lege Platten auf: In Bars, Klubs oder Diskos und Zu Hause
2. DJ Typ: Mix-DJ
3. Stilrichtung: Elektro
4. Legt seit 5 Jahren auf, davon 3 mit Timecode
5. Software: Traktor
6. Benutzt Cue-Point Funktion: Nein
7. Benutzt Wellenform: Ja
8. Equipment: Technics 1210, Midi Controller für Loops und Navigation

User 4

1. Ich lege Platten auf: In Bars, Klubs oder Diskos
2. DJ Typ: Scratch DJ und Mix-DJ
3. Stilrichtung: Elektro und Hip Hop
4. Legt seit 20 Jahren auf, davon 2 mit Timecode
5. Software: Traktor und Serato Scratch Live
6. Benutzt Cue-Point Funktion: Ja
7. Benutzt Wellenform: Ja
8. Equipment: Vestax VCI 100 MK2 Controller, Alesis Air FX

Appendix C

Results of the user study and the interviews

User 1

Observations during phase 1 (playing music with timecode vinyls and Mixxx):

- looks a lot onto the PC display. Except when he is applying filters. Then he is fully concentrated on the mixer.
- When he is trying to match the beats by accelerating or slowing down the record with his fingers, he looks at the waveform.
- Irritated by the cracking noise that appears randomly
- Says the record is “waved” and sometimes hard to handle (needle is skipping)
- Plays long tracks and only works with the system if he mixes into a new song. Therefore he has parts, where he has free time so to say.

Observations during phase 2 (playing music with timecode vinyls, Mixxx and DiskPlay):

- Uses a CuePoint, because he doesn't like the intro of that song.
- Uses a second CuePoint, so he can fade out at the desired position and not at the actual end of the song.
- Uses waveform to find the beginning of a beat
- Uses DiskPlay to find the rough position of the cue point and switches than to the waveform. Maybe because of habits.
- User mentions that one doesn't know if he has to spin 1, 2 or 3 times to find the exact position of the cue point, after placing the needle near the cue point line.
- Makes heavily use of accelerating and slowing down the record.

Results of the seek task:

	Test 1	Test 2	Test 3
DiskPlay	5 sec	3 sec	8 sec
Mixxx	11 sec	8 sec	11 sec
By Ear	25 sec	12 sec	15 sec

Interview:

- He wishes to have “visual effects that support his performance as a DJ”
- “Part of the DJ Job is the show for the audience”
- “Most people in the audience don't know what the DJ is actually doing during his performance. It would be nice if the visualization could give the people an understanding of the DJs Job.”
- Likes the idea of a DJ environment without a laptop. Someone once asked him if checks his e-mails, during a live performance in a club, because the laptop was standing between him and the crowd.
- “The most embarrassing thing that can happen to a DJ is that the song is over before he notices it and has therefore no time to generate a smooth transition by beatmatching.”
- Uses the waveform to see the track progress (see quote above), for mixing (where is the

intro, outro and where are breaks) and for fast mixing as a visual aid.

- In the time between songs he does one of the following:
  - watching people
  - thinking about what to play next
  - chat with DJ collegues
  - take a toilette break
  - deal with song wishes
- He likes that he can see the track progression on DiskPlay but misses an absolute time measurement (“How many minutes and seconds are left”). On the other side he says that over time, one gets used to the visualization and could evaluate the time that is left.
- “In a environment like Djing, where skill plays such an important role, it is alowd to expect the user to learn the software.”
- The installation of DiskPlay is very complex and is not suited for a club or similar locations. The users wishes a more compact solution or even a more simple version with led projections
- “The shadows of the projector didn'g got in the way.”
- When asked if a waveform representation of the song would be helpful the DJ said:”No I like it that the system is simple. The design is very intuitive and self explanatory.”

User 2

Observations during phase 1 (playing music with timecode vinyls and Mixxx):

- User check the track progress on the display/waveform
- Says the white record doesn't seat solidly on the turntable
- Also irritated by cracking noise
- Uses no Display for beatmaching
- Works a lot with filters
- Uses the crossfader to mix the beats
- Works with scratch techniques during the song and plays with the crossfader
- Song ends before he could mix it with the second.

Observations during phase 2 (playing music with timecode vinyls, Mixxx and DiskPlay):

- Doesn't look to the display anymore (checks track progression with DiskPlay).
- Sets cue points to find the beginning of a beat
- Latency for scratching os too high
- Visualization supports him in finding the beginning of a song

Results of the seek task:

	Test 1	Test 2	Test 3
DiskPlay	3 sec	7 sec	31 sec
Mixxx	8 sec	9 sec	11 sec
By Ear	24 sec	12 sec	15 sec

Interview:

- Thinks the System is probably “interesting for BattleDJs” because they make heavily use of cue points
- Wants an absolute time information. Says he cant really estimate the time only with the circle visualization

User 3

Observations during phase 1 (playing music with timecode vinyls and Mixxx):

- Uses the 33 / 44 Buttons vor temporary acceleration of the record
- Uses the waveform to find the beginning of the track
- does the following steps over and over again:
  - find beginning of the track
  - during the song plays, make adjustments to the buttons
  - repeat

Observations during phase 2 (playing music with timecode vinyls, Mixxx and DiskPlay):

- Says shadow doesn't bother him, because the interesting part is the needle and the area before that. The DJ normally doesn't go there with his hand, because it would interfere with the tonearm.

	Test 1	Test 2	Test 3
DiskPlay	28 sec	18 sec	8 sec
Mixxx	24 sec	9 sec	5 sec
By Ear	42 sec	9 sec	9 sec

Possible problem: DJ didn't know that there is a line on which the cue point circulates.

Interview:

- That is what the user said about the information on the PC interface:
  - ”I often look to the display no matter if I want to gain information from it or not, its a habbit”
  - “Display deviates from the acoustic”
  - “always turning away from the turntables makes it harder to concentrate”
  - “grooves provide information about the mood of a song” (where are high frequencies, where does the beat start)
  - “I want to know if the Bpm are fitting”
- User wants the Bpm to be displayed on the turntable (not directly on the record)
- User wants optical feedback in the last 30 seconds of the track: “Something flashing would be nice”
- He wants to know the remaining absolute time: “How long do I have for mixing”

User 4

Observations during phase 1 (playing music with timecode vinyls and Mixxx):

- Mixes on second beat, not the first (uses waveform as an aid to find the second beat)
- Looks on the display to see “how long the track is still playing” and to see at what BPMs the song is currently playing to get an approximate feeling to which degree he has to manipulate the pitch slider (“only minor changes or am i off two beats in the minute)
- knows intuitively when to mix in the new song (e.g. Doesn't look so much at the waveform representation but rather listens to the track and follows intuition)

Observations during phase 2 (playing music with timecode vinyls, Mixxx and DiskPlay):

- Shadow doesn't bother him
- says the display is intuitive and self explanatory
- likes it that it is simple and compares it to the serato interface which is in his opinion much simpler to use than the Traktor interface and he therefore prefers.
- DiskPlay “doesn't disturb during the performance”
- BPM on the augmented interface is wanted

	Test 1	Test 2	Test 3
DiskPlay	5 sec	24 sec	20 sec
Mixxx	14 sec	10 sec	12 sec
By Ear	21 sec	25 sec	22 sec

Interview:

- “I match the beats only by hearing, I don't use any visual aids” (e.g. No arrows for draging or pushing the record are needed, they would be “too much”)
- “The display doesn't need to blink in the last 30 seconds. I have that information always in sight with the colored rings.”
- “Battle DJs always mark special positions on the record with labels, to see how far they can push and drag the record for scratching. The cue point functionality is probably useful for them.” (But latency has to be very low) see Kid Koala or DJ Craze
- “Waveform is not so important to me”
- “In the past you could see the mood (breaks and beats) of a song in the reflection of a vinyl, maybe this can be implemented in DiskPlay through different shades of the color. But nothing too exceptional, keep it simple.”

Appendix D

Git Repository of the Source Code

DiskPlay – source code[a]

[a] ssh://oliver.informatik.rwth-aachen.de/Public /Research%20Projects/DiskPlay/Software/DiskPlay.git

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