D'GROOVE - A NOVEL DIGITAL HAPTIC TURNTABLE FOR MUSIC CONTROL

by

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Abstract

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Disc Jockeys (DJs) use creative methods to play pre-recorded music at social events. Their tools, however, are relatively archaic and there is a desire for advanced equipment with the capacity to increase the level of creativity involved in a DJ's performance. The overall goal of the work described here is to create an advanced DJ system that promotes creativity, allows control of digital music and improves upon previous DJ tools.

This thesis begins with an analysis of DJs using conventional tools and procedures, followed by a discussion of previous attempts to upgrade DJ technology. These findings led to our first prototype controller, D'Groove, a novel digital DJ system with haptic, visual and auditory interaction. Experienced DJs from a variety of specializations tested our prototype, resulting in useful feedback and the discovery of some exciting new expressive uses that we had not intended. They discussed the technological needs and wants of the next generation of DJs, providing input to our user-centered design strategy. While D'Groove is for DJs, the experiences of our experts provide insight to the general problem of interacting with digital media streams.

The main contributions of this thesis are a description of the processes and tools used by DJs; the design and evaluation of D'Groove, an advanced user-oriented haptic DJ system for manipulating digital music; and a summary of guidelines for manipulating digital audio in general.

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Chapter 1

1 Introduction

Electronic dance music has increased in popularity over the past several years as shown by its presence on television, in movies and at night clubs. This exciting genre is usually presented by disc jockeys (DJs), artists who mix and manipulate music while adding interesting and creative effects in real time. The music is often better appreciated when played live, as the performance of the DJ provides visual appeal and spontaneity, based on the audience's reactions.

Today's DJ performs with the same archaic tools that were used in the beginning of this art form. The vinyl record is still the conventional media, so most DJs perform with a set of turntables and an audio mixing board – the direct manual analog interface allows tight control over the music, as well as visual appeal. Turntables, however, are not perfect, leaving room for improvement regarding DJ tools.

Digital music is more prevalent today and it makes sense for DJs to make use of this medium as it has many advantages over analog media. Ease of storage, lossless audio quality and availability are just some the benefits. Thus, to promote digital media within the DJ community, we propose a digital playback device that provides the same level of control as the analog turntable. It also takes the form of a turntable because this form is so entrenched within the DJ community. DJs appropriated turntable technology and were among the first to start using turntables in innovative ways. Thus, one might say that DJing is defined in part by turntables.

This thesis focuses on the tools that DJs use in order to practice their art form and offers an improved alternative. The contributions of this thesis are in three parts: 1) an analysis of the procedures and tools used by DJs in order to perform; 2) the design and evaluation of D'Groove, an advanced DJ system that was used to suggest improvements to DJ tools; and 3) a summary of guidelines for DJ tools and digital audio manipulation in general. Each of these contributions was carried out in the order mentioned as the latter contributions depend on their predecessors.

In the first part, we analyze the current state of DJing, including the tools used and tasks done when DJs perform. This helps define the DJ domain and provides an understanding of the field. We also note common problems found with the existing methods and tools used by DJs, motivating some design features in our own prototype. We then discuss some previous attempts to improve the state of DJing and show the benefits and drawbacks of each. This is accompanied by a look at physical interface design strategies where we match tasks with input devices.

Next we introduce D'Groove, our attempt at building a DJ tool, based on the successes and failures of previous efforts. The system is introduced and explained in depth, noting key new features that have previously been unavailable to DJs. Such features include visual aids to help with standard tasks and the use of haptics to provide some new expressive outlets. We leaned towards a technology-centric approach when designing these features as most DJs are unfamiliar with the capabilities afforded by modern technology and, therefore are unable to express their wishes for new features. Our strategy was to showcase state-of-the-art features and collect user feedback on their usefulness.

This presentation is given as an observational study, in which expert DJs are asked to play with D'Groove and comment on the usefulness of its features and its ability to increase a DJ's creativity. The DJs compared our turntable with an industry standard turntable. The feedback helped us decide which of the new features in D'Groove are useful to DJs, allowing us to summarize the desired features for DJ equipment. We then use what we have learned to provide some guidelines for manipulating digital audio in general.

Chapter 2

2 The Procedures and Tools of a DJ

In this chapter we define a disc jockey or DJ. This is essential as one must fully understand the function of a target audience if one is to build a tool for such a group. We look at the role of the DJ, a DJs purpose and a history of how the art form has evolved. We also look at the common tools or instruments that DJs use to perform. This is important as DJing came into being as a result of the tools rather than the tools being designed for the art form. A discussion of common DJ procedures follows as these processes were based on the tools provided. Essentially DJs found innovative ways to use the current technology of the time. Learning the procedures of a DJ helps us understand the problems that DJs face and the limitations of their tools.

2.1 Role of the DJ

The primary goal of a DJ is to entertain an audience by playing a sequential set of previously recorded music in a manner that fits the ambience of an event. Often DJs are hired at social venues such as wedding receptions or music night clubs. Since its beginning, the practice of DJing has changed considerably. It was once sufficient for a DJ to simply play a song, wait for it to end and then play another, repeating the pattern until the event was over. Today, at least one stream of DJing has evolved into an art form that is an outlet for self expression and creativity. These new DJs blend segments of previously recorded music together into a seamless composition. They create new music, in real time, by 'gluing' bits of older music together. They create and control new sounds, unlike any instrument, by playing the music back and forth at various speeds. Thus, DJs have moved away from being simple players of recorded music and have entered the realm of musician.

The conventional tools of the DJ are two turntables and an audio mixing console (Figure 1). Using a collection of vinyl records, DJs are able to isolate certain sounds from one song (using the mixer) and combine them with sounds from another song. The output is displayed to the audience and is generally pleasing to the ear.

Figure 1 A DJ using a conventional setup: two turntables and a mixer.

Other methods of manipulating music include the use of CD players and, to a lesser extent, PC computers (usually laptops). Software exists, that allows DJs to combine music in real time using their mouse and keyboard. Although the output is comparable to a DJ performance involving turntables, it usually lacks visual appeal and laptop DJs are sometimes devalued when audiences feel that the computer is doing the majority of the work. Physical interfaces are highly preferred as they often provide more control and a sense of intimacy with the music.

As DJing has grown in popularity, the visual aspect of the DJ has become more important. Now top DJs must be visually entertaining as well as audibly satisfying. It is common for some of the well known DJs to perform certain hand movements, displaying skills of speed and agility over their instruments. Demonstrating the speed at which some of these movements are executed requires a certain level of talent and justifies the value of a live DJ set over a pre-recorded composition. DJs also give their audience a point of focus during a musical event. They provide a source to credit for the enjoyment of the music and their interaction with the audience through facial gestures and other behavioural nuances adds an important live aspect to an otherwise mechanically-derived form of music.

Most importantly, DJing is fun. It is a source of entertainment for both the audience and the performer. It provides a means to express oneself and is a form of creativity. Providing an enjoyable dance experience for an audience is a meaningful challenge for DJs and proves to be satisfying when accomplished. The popularity of DJing has grown so immensely that DJ turntables are now outselling guitars [37].

2.2 History of the DJ

In 1877, Thomas Edison invented the first hand cranked phonograph. It used a crude cardboard cylinder wrapped in tinfoil [1]. Almost ten years later, in 1886, Alexander Graham Bell files a patent for a device called a graphophone that used wax cylinders to record the sound and a floating stylus for audio clarity [10]. The name was later change to gramophone and the system changed from cylinders to records.

In 1887 Emile Berliner filed a patent for a recording system that used flat discs instead of cylinders [6]. At the same time, Edison improved on his phonograph with a battery driven motor to eliminate hand cranking the device [1]. In 1890, musicians began recording their music in two to four minute segments per cylinder. Longer recordings were produced by setting up several phonographs at once, each recording onto a cylinder [1].

Finally, in 1892, the first records were invented but were called gramophone discs at the time [1]. By the turn of the century a 10-inch diameter became the standard and the records rotated between 75 and 80 revolutions per minute (RPM) [6]. Most gramophones were capable of speed adjustments and eventually 78 RPM became the standard [6]. Each record could hold up to 5 minutes of audio (on the newer 12-inch records) and were one-sided until 1923 [6].

In 1948, the Columbia Company created a 12-inch record that could hold 25 minutes of audio on each side. It rotated at 33 1/3 RPM and was popular for many years, until RCA Victor invented the 7-inch 45 RPM record (known as ‘the 45’). This new format could only hold 5 minutes of audio per side but was much smaller, making the records easier to transport. Eventually, in 1958, the 45's took over the 78 standard as rock and roll became popular. By 1960, most music purchasers preferred the 12-inch 33 1/3 format as it cost less. [6]

It should be noted that 33 1/3 is less than half the speed of the original 78 RPM record, meaning the rotational distance to music playback ratio has decreased significantly. The drawback for DJs is that it decreases precision when selecting certain sounds to play. As a benefit, records must be moved less when scanning through them manually to find a sound.

John Cage was perhaps the first to use turntables as instrument devices for his composition of Imaginary Landscape #1 in 1939 [23]. Using several turntables and test tones, Cage created new music from pieces of previously recorded material. Around the same time, Pierre Schaeffer was using similar techniques to create a piece known as Musique Concrète. He claimed the turntable was perhaps the greatest instrument for it could play any sound [23].

During the 1940's the first disc jockeys (DJs) emerged. They took the form of entertainers for American troops overseas. It was much easier and cheaper to have someone play records of Benny Goodman and Glen Miller then to send an entire band. Two turntables were often used so songs could be queued faster. In the 1950's, the 7-inch record was invented. It rotated at 45 RPM as opposed to the previous 33 1/3 RPM, 12-inch records, and were much cheaper to make and easier to carry around. At the same time, Ska music was exploding in Jamaica and massively loud sound systems became popular as DJs would play records out of the back of mobile trucks. [1]

DJing increased in popularity over the next 20 years as discotheques started to emerge. Around 1969, DJ Kool Herc and DJ Grandmaster Flash were among the first to start manipulating dance music in a creative way. They would extend the most exciting portions of songs by continuously switching back and forth between two identical copies of a song using an audio mixer. This is arguably the beginning of hip-hop music as the term hip-hop is thought to come from DJs "hip-hopping" between songs. [1]

In the early 1970's, Technics released the SL-1200 turntable (Figure 2), today's industry standard [1]. Although improved slightly in the later half of the 70's, the design has not changed much since then. The popularity of the Technics SL-1200 may be due to its relatively high starting torque of 1.5kg-cm [1], enabling DJs to quickly get their records playing at the proper speed.

In 1975, the turntable's characteristic sound of scratching was brought into the musical world by DJ Grandwizard Theodore. As the story goes, Theodore was playing records in his room and his grandmother came in and asked him to turn the volume down. As she spoke, Theodore placed his hand on the record to prevent it from playing. His hand jerked back and forth a bit and he decided he liked the sound. [1]

In 1987, the Disco Mix Club held its first annual DMC mixing competition [1]. DJs competed by trying to mix records together more seamlessly than anyone else. In later years the scratch DJs started to win the competition with their scratch tricks and the competition turned into a scratching competition but still held the same name. The DMC competition continues to be the world's leading DJ competition and is held world wide every year.

From there, turntable culture has expanded as new tricks and techniques have been invented over the years. In the late 1990's, CD players were built with DJs in mind (section 2.3.3), allowing for tempos to be changed and in later years, the music to be 'scratched' (section 2.4.3 discusses scratching). These CD players gave DJs access to digital music but have not replaced the turntable as the main controller.

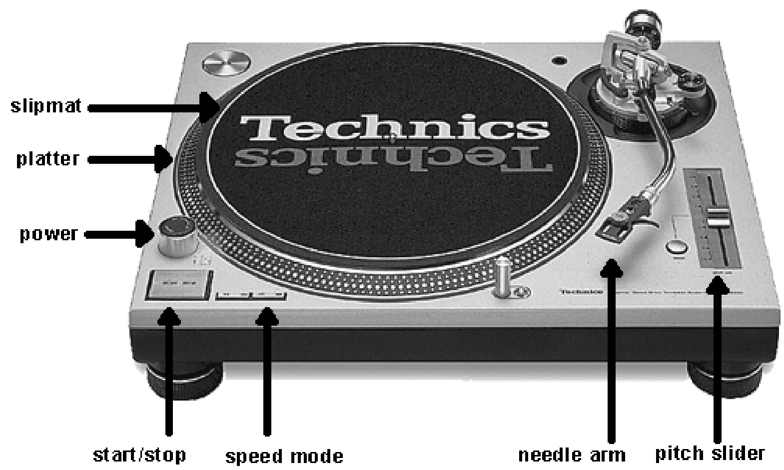
Specialized DJ audio mixers (section 2.3.2) have also undergone some evolutionary changes. Layouts and response times of controls have been improved to accommodate various styles of DJing. One of the more notable changes is the slope adjustment of the crossfader, a slider that linearly shifts the output of the mixer from one source to another. Newer crossfaders support increased slopes, causing an audio source's volume to reach its maximum level with less movement in the fader. This improvement has allowed for more scratch techniques to be developed, giving DJs a better visual and auditory appeal Turntable needles have been also been improved, causing less skipping and damage to vinyl. All of these improvements have expanded the art form and brought it to the technically precise state that exists today.

2.3 Tools of the DJ

In this section, we describe the conventional tools used by DJs when performing. Section 2.4 discusses some of the procedures that DJs commonly carry out with these tools. Newer tools that are uncommon will be discussed in Chapter 3. The goal of this section is to provide an understanding of what DJs do as their art form is highly defined by their tools. It also allows us to deconstruct the tools and explore the fundamental tasks of DJing. We can use these tasks to motivate the features of our own system.

2.3.1 Turntable

The turntable remains the dominant physical device used by DJs for controlling pre-recorded music. These devices play vinyl records, a physical medium containing audio in the form of a single groove that spirals from the outer rim of the vinyl. There are many types of turntables but the SL-1200 model, produced by Technics (Figure 2), has remained the leading industry standard in turntable controllers since its creation in the 1970's.



Features (from [1])
• quartz-direct drive • 1.5kg-cm starting torque • start up time of 0.7 seconds • slide pitch control ± 8% • 33 1/3 and 45 RPM speed modes • 31 lbs

Figure 2 A Technics SL-1200 turntable, the industry standard for DJing

Advantages of Turntables and Vinyl

Turntables and vinyl have many virtues:

a. The turntable's main advantage is that it affords direct contact with the musical medium (vinyl). DJs can touch the medium containing the music, interact with its movements and a material relationship is formed. This directness contributes to the high level of intimacy leading to expressive play, a notion discussed by Fels when dealing with physical interfaces [15].

b. The movements of the platter and even more so the record on top of the platter form a simple mapping with the relative playback point in the song. The record's speed and direction corresponds directly to the music's speed (i.e. tempo) and direction.

c. The turntable provides the ability to adjust the pitch and tempo of a track so that a DJ can control the playback rate of a song.

d. The needle on a turntable allows for fast access to sections of a track. A DJ can quickly skip to the middle of a song and/or easily review the contents of a song by placing the needle on various parts of the record.

e. A turntable can play music backwards and forwards allowing for interesting ‘scratch’ effects to be created. This allows new types of music to be played and turns the turntable into an instrument as opposed to a musical playback device.

f. The position of the needle, relative to the record, displays the temporal position within a song.

g. Records visually represent track information such as length and *breaks* (lulls in sound). Usually each side of a DJ vinyl record will contain one or two tracks. The DJ can easily see the grooves in the record with such a large surface for a track. A break or subtle moment in the song can be seen as sparsely laid darker grooves. Condensed grooves represent music with greater amplitude changes, signifying an exciting part of the song. By viewing the grooves (and the needle’s position relative to a type of groove), the DJ can anticipate changes in the track and act accordingly.

h. Vinyl enthusiasts insist that records produce a ‘warmer’ sound due to their continuous analog nature.

i. There is no latency between the movements of vinyl and the sound produced.

Disadvantages of Turntables and Vinyl

Despite their virtues, turntables and vinyl also have many limitations:

a. Needles become damaged and need replacing. DJs who ‘scratch’ (rub the needle back and forth within a groove to produce a scratch sound) their music a lot need to replace their needles every few months.

b. Conventional use of needles causes damage to vinyl records resulting in lower sound quality. Each time a record is played, its grooves are worn down from the physical contact of the needle. Eventually, the record will need to be replaced as the details in the grooves are worn down too much for enjoyable playback.

c. Heavy vibrations can cause the needle to skip resulting in an interruption in music. Dirt and debris in the grooves can also cause needles to skip.

d. Turntables have a limited pitch control. This means there is a limit to the rate at which a song can be played back. Sometimes it is desirable to mix a very slow song with a relatively faster song but due to the limit in playback rate, this is impossible to achieve.

e. Control of pitch and tempo are not separate. Altering one affects the other. Many DJs desire the ability to adjust tempo independently from pitch to avoid a high-pitched ‘chipmunk’ effect when playing naturally slow songs at fast rates.

f. Large amounts of vinyl are needed for a set. A typical DJ set usually runs between one and three hours. Approximately 30 to 50 records are needed to perform for this long. Vinyl is heavy and cumbersome to transport. Consequently, DJs must select their songs before they leave for the event, as carrying an entire record collection is highly impractical (but ultimately desirable).

g. Track selection or locating a specific cue point in a song may be difficult when trying to find the right groove. DJ events are often held in dark spaces, making the grooves on a record difficult to see. Finding the exact cue point in a song can be challenging and time consuming. Some DJs elect to mark their records (using stickers) to locate cue points. This renders a portion of the record unplayable. Other DJs refrain from selecting 'inner-song' grooves as it can be too difficult.

h. DJing with vinyl has a relatively high cost. Records are more expensive than most other musical mediums and often contain fewer songs. Professional DJs must always buy new records to maintain a collection of current music. Needles are also expensive and need to be replaced every few months.

i. There is a disproportional mapping between the amount of record movement (in revolutions) and the amount of music that is played. As the needle moves towards the inner part of a record, it travels less distance for the same amount of musical playback. This means the revolutions of a record do not visually indicate how much music has played, weakening the direct relationship between platter/record movement and musical playback.

Deconstructing the Turntable

The Technics SL-1200 turntable (Figure 2), the industry standard, has six controlling devices that can affect the music. The first three are the primary controls of the turntable as they are used the most often.

1) The record on the turntable itself can be moved back and forth by hand. This provides great control over the speed and direction of the music. By placing a hand on the record as it spins around the platter, the user can speed up or slow down the record, affecting the tempo and pitch of the song. A felt slipmat is placed between the record and platter to maintain the platter's forward circular motion while the record is held. When the hand is removed, the record resumes its designated speed. A relationship between the movements of the record and the playback of the song is formed from this straightforward mapping. Due to the slipmat, the same relationship does not exist between the turntable platter and the music playback.

   Manipulating a record can be useful for positioning the playback point of the music or temporarily adjusting the speed of one track to match another. It is also very useful in the art of scratching a record back and forth to produce new and unique sounds. Since the record can only travel back and forth across the needle, this is a one dimensional continuous task.

   Control intimacy is defined by Moore as the compatibility with the performer and his/her instrument when regarding the performer's psychophysiological capabilities versus the desired sound produced [32]. To clarify, control intimacy provides a satisfying feeling of control from the correct production of a desired sound, via the instrument and the performer's abilities to use it. Fels explores this concept further and suggests that direct interfaces promote control intimacy [15]. We believe that the direct tangible nature of the turntable provides a high level of control intimacy when used as an instrument.

2) A pitch/speed slider is located on the right side of the unit. It provides a modulation of the platter's speed within +/-8%. When placed in the middle, the platter should be moving at exactly 33 RPM or 45 RPM, depending on the speed mode; the 33 RPM setting is actually 33 1/3 RPM. When moved toward the front of the unit, the platter will speed up. When moved towards the rear of the unit, the platter will slow down. This is a one dimensional limited range continuous action that spans +/-8% of either 33 RPM or 45 RPM, depending again on the speed mode. If there is no power connected to the platter or the platter has been stopped, this slider has no effect.

3) The needle on the turntable provides random access within a song and temporal position feedback when it is placed in a groove. Placing the needle is a one dimensional limited range linear task.

4) The power switch is a dial on the bottom left of the unit. It has two modes (on and off) and is operated by turning the dial until it clicks, signifying a change in mode. This is a one dimensional binary task. If the power is switched off when a record is spinning, the record does not come to a complete stop. Instead the power for the motor is turned off and the platter containing the record continues to revolve until enough friction causes it to stop. This dial is housed on top of the red strobe light that illuminates the dotted sidewall of the platter. The strobing effect causes the dots on

the sidewall to move back and forth, allowing the DJ to determine if the velocity of the turntable platter and the position of the pitch slider are calibrated correctly.

5) A start/stop button is located next to the power dial on the bottom left of the unit. It is used for 'instant' starting and stoping of the record. Pressing this button when a record is revolving engages a braking mechanism on the platter, halting the record. Pressing this button when a record is motionless causes the platter to start revolving. The Technics SL-1200 has a starting torque of 1.5kg-cm and a start-up time (from full stop to 33 RPM) of 0.7 seconds [1]. This button is a one-dimensional binary controller with two modes: start and stop.

6) A speed mode switch is located next to the start/stop button and is used for setting the speed of the platter to rotate at either 33 RPM or 45 RPM. This consists of two buttons, each with a light to indicate the mode of the platter. If the light for the 33 RPM mode is illuminated and the 45 RPM button is pressed, the platter switches to 45 RPM. Likewise, if the 33 RPM button is pressed in 45 RPM mode, the platter reduces speed to 33 RPM. If the speed mode button of the current speed is pressed, nothing will happen. Interestingly enough, if the platter is moving at 33 RPM and the 45 RPM speed button is depressed as well as the 33 RPM button, the speed of the platter will speed up to 45 PRM until the 45 RPM button is released and then the platter will resume 33 RPM. This is useful for bending the speed (and pitch) upwards when trying to adjust speeds while beatmatching. If running in 45 RPM mode and both the 33 and 45 RPM buttons are depressed, the effect is to remain in the 45 RPM

mode. Thus the modulation can only be achieved upwards from 33 RPM to 45 RPM. This last feature makes the controller a one dimensional binary controller with two modes (33 RPM or 45 RPM) and modulation. We can modulate the speed (and pitch) of a track upwards, based on a mode switch and a proportional time modulation. The more we hold the 45 and 33 RPM buttons down at the same time (when in 33 RPM mode), the longer the modulation of the speed (and pitch).

2.3.2 DJ Audio Mixer

An audio mixer is a device that takes multiple audio inputs and allows the user to blend them together for a single output. Typically a DJ would have a combination of turntables and/or CD players feeding into a mixer while the output is sent to an amplifier.

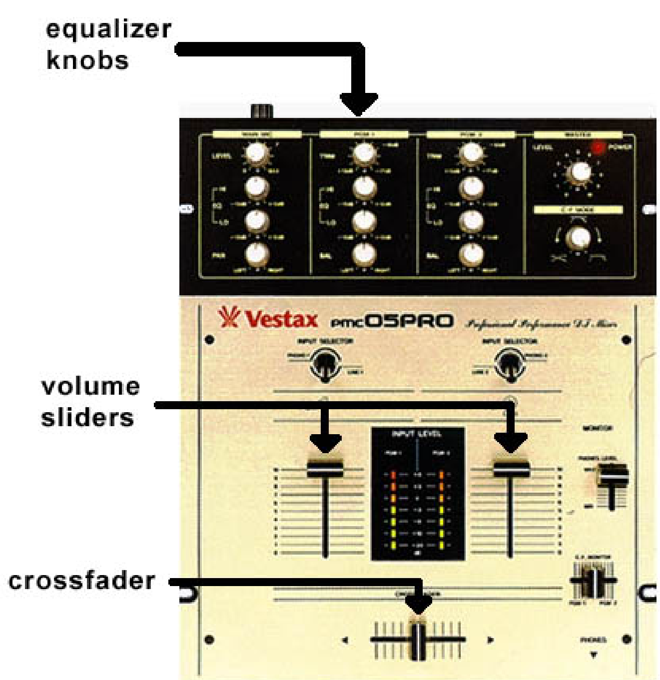


Figure 3 An audio mixing board.

A standard DJ mixer has yet to be created. Most come with at least two channels, a set of three equalizer controls for each channel and a crossfader to fade smoothly between each channel. Each audio source (e.g. a turntable) connects to one channel on the mixer.

Deconstructing the Mixer

1) Each channel has a volume slider that controls the source's loudness. There is usually also an LED meter to indicate how many decibels a channel is emitting. Controlling the volume of a source is a one-dimensional continuous task. Knobs or sliders could be used. Sliders are generally preferred as they provide better visual feedback on volume level, relative difference between two volumes and are easier to control as the hand must move up and down instead of twisting around.

2) The equalizers for a channel usually consist of three knobs that allow the user to adjust the low, middle and high frequencies. Bass tones are generally in the lower frequencies of a track. Vocals and instruments, like trumpets and pianos, reside in the middle frequency ranges and higher tones such as hi-hats and cymbals are found in the high frequency ranges. Each mixer is different and there is no standard as to the exact frequency ranges each of these knobs will control. DJs can choose which instruments of a track are accented by adjusting the equalizer knobs. Some mixers allow the DJ to cut those sounds out completely while others provide a range from -32dB to +32dB in sound. Generally, if a frequency range is cut back to anything less than -12dB of sound, it is difficult to hear and the DJ can 'pseudo-eliminate' it by

playing sounds from another source within the same frequency. Adjusting each frequency range is a one-dimensional continuous task that is usually performed with knobs. Sliders may provide more speed with this but take up more room than knobs. Also, most mixers only allow access to three preset frequency ranges and do not let the DJ decide where the boundary between the ranges exists. To clarify, the boundary between the frequencies controlled by the low frequency equalizer knob and the middle frequency equalizer knob is predetermined. A sound that resides across both ranges must be adjusted with two knobs instead of one. This also limits the amount of control within a certain frequency range. One low frequency knob can control an entire frequency range, limiting precision within that range. For instance, a DJ cannot adjust frequencies in the lower half of the range represented on one knob without affecting the upper half as well.

3) The crossfader is one of the most important aspects of a mixer for DJs who want to perform tricks while mixing. The crossfader allows the DJ to move the output of the mixing board from one channel to another in a manner that incrementally decreases the volume of one source while proportionally increasing the volume of the second source. The crossfader is a continuous control that slides back and forth between two channels. When it is on one side, the output consists of just one source. When it is on the other side, the output consists of the other source. When in the middle, the output is an equal combination of both sources. Some mixers allow the slope of this change to be altered, allowing an audio source to come to full volume with little crossfader movement. By snapping the crossfader back and forth with accuracy and

speed, a DJ can perform certain tricks with the music such as stutters, snapping sounds and quick shifts in music. Most crossfaders wear out in time and start to 'bleed'. Bleeding is when the crossfader is completely on one side but some of the other source can still be heard 'bleeding' through the mixer. This damage is caused by the repetitive snapping of the crossfader on the sides of the control and the constant wear of the potentiometer inside the device.

4) Most crossfaders come with a hamster switch that reverses the signal of the crossfader. Normally the right side of the crossfader plays the right hand turntable and the left side plays the left turntable. If the hamster switch is activated, the opposite is true. This is useful to some DJs, who prefer to do tricks with their opposing hand and thus find it easier to reverse the function of the crossfader.

2.3.3 DJ Compact Disc Player

The CD (Compact Disc) Player is currently the main method a DJ has of accessing digital audio. In order to qualify as a valid CD player for the purpose of DJing, the unit must provide a pitch control that gives the DJ the ability to speed up or slow down the tempo and pitch of a CD. This is to ensure that a DJ can synchronize the beats (beatmatch – see Section 2.4.1) of two tracks so that they can be mixed properly. Without this feature, it would be impossible to manually make coherent mixes of tracks. Of course, computer algorithms could be used to synchronize two songs but according to Foote [18], Dixon [12], Scheirer [40], Belle [42] and Goto [20], a fail-safe method of beat detection has yet to yield adequate results.

Unlike the turntable, less culture has been developed around CD players. Perhaps this is due to the relative amount of time CD players, as opposed to turntables, have been used with the DJ community. DJing began with people finding innovative ways to use turntables. Then CD players emerged; their goal was to provide a means of applying the same techniques (as defined by turntables) to digital media. Thus, instead of taking an entirely new direction, CD players generally follow the direction set by turntables.

Figure 4 The CDJ-1000. The 7-inch diameter dial in the middle is a scratch pad.

Advantages of the CD Player

CD players have some worthwhile virtues:

a) CDs are cheaper, smaller and less fragile than vinyl.

b) CDs audio does not lose sound quality with each play.

c) A DJ can produce his/her original music and easily transfer it to a playable medium.

d) CD players provide looping features for music

e) CD players provide more precise information about the length of a song and the current temporal position within a song. This is usually done via an LCD display on the top of the unit.

f) The tempo of a song can be adjusted without affecting the pitch (on newer CD players).

Disadvantages of the CD Player

CD Players also have some limitations:

a) CD Players generally do not provide the same level of control over the music when compared to a turntable. Moore describes this important concept as ‘control intimacy’ when describing the drawbacks of MIDI [32]. It refers to the compatibility between the performer and his/her instrument.

b) CD players do not generally have a motorized platter. Thus they lack the important mapping that exists between the movements of a record and the playback of a song, as found turntables.

c) CD DJs are not as visually appealing as turntable DJs.

d) Moving to different parts of a song involves manually fast-forwarding through the song or setting up cue points, prior to performing.

e) Audiophiles claim digital music does not sound as ‘warm’ as analog music.

f) Latency is often associated with some operations on CD players.

g) Many of the latest dance songs are released on vinyl months before they are released on CD. DJs who strictly use CDs must purchase the tracks on vinyl and record them to CD before being able to play them.

There are many manufacturers of DJ CD Players and as it is a relatively new method to mix music, an industry standard has yet to emerge. As the turntable maintains popularity within DJ circles, the manufactures of CD players are constantly trying to create a CD player that emulates the turntable. Common features found on most turntables have been ported to the CD domain in the hopes of causing a migration towards CD units. In moving to the digital realm, the CD player can also offer some features that a turntable cannot.

Deconstructing the CD Player

1) As stated above, all DJ CD players must have the ability to alter the pitch/speed of the music. Some models of CD players offer a selectable pitch range from +/-8 %, +/-16% and even +/- 100%. Some models also allow the speed of the music to change while the pitch remains constant. This feature is called master tempo.

2) Instant starts - enabling the onset of digital music to begin with no noticeable latency at the push of a button - are becoming a standard. This is a one dimensional binary task whose states are start/stop.

3) Pitch bending is the ability to temporarily bend the tempo/pitch of a song in either direction. This is useful when two tracks are running at the same tempo but are not in phase. This is a one-dimensional continuous task whose options consist of speeding up or slowing down a track. On a CD player, pitch bending is done with a special jog-dial. Turning the dial in a clockwise motion speeds up the music while turning it in a counter-clockwise motion slows the music down. It should be noted that the jog-dial cannot be used to manipulate a CD like a vinyl record (i.e. the dial will not slow the music to a halt or play it backwards). Its function is equivalent to slightly pushing a record forward or applying a small amount of pressure to slow down a moving record. Normally a buffer is used to achieve the jog effect.

4) When using vinyl, one can note the density of grooves in a track to anticipate what will happen in the music as the song plays. Dense areas indicate exciting music while sparse areas indicate lulls or breaks. This feature is implemented differently on CD players. A visual display of the song's waveform is used for viewing the song structure. CD players can also provide accurate information on the time remaining and time consumed for each track. This can be useful in determining when new tracks need to be mixed in as older ones are close to finishing.

5) On-the-fly looping can be performed by setting cue points throughout a track and having the CD unit loop between two cue points to create a seamless looping section of music. On a turntable this would equate to playing a piece of music, lifting the needle and starting it again on the same place without pause (an impossible feat).

Vinyl DJs create seamless loops with records by using two copies of the same track. When one section of music is played, they cue up the same section on another turntable. When the first section finishes, they cut the output over to the second section and resume play, as if the track has looped. This involves two turntables and two copies of the same track. The same effect can be achieved with one CD player, one copy of a CD track and a looping feature. Also, assigning cue points within a track provides the ability to jump to certain sections of a track, effectively creating a remix of the track. Creating cue points within a track is one-dimensional binary task that involves simply labelling a time within a track with a cue point. This is commonly done by pressing a cue point button. Depending on the memory capabilities of the CD player, each unit of time within a track can either have a cue point or not.

6) Newer DJ CD players come equipped with the ability to 'scratch' a CD, in an attempt to provide one of the long sought-after features of a turntable. On a turntable, the vinyl record can be pushed and pulled back and forth under a needle, causing a unique sound known as a 'scratch'. The sound of a scratch is affected by the groove, the needle and the sound sample that is contained within the groove.

CD players that offer this feature use a dial, often labelled a scratch pad (the large dial on the device in Figure 4), where the DJ can create a digital scratch by moving the dial back and forth, much like a record. It differs from a vinyl scratch in two ways. The first is that, the sound produced differs from the analog sound of a vinyl record being scratched. The buffering mechanism involved in a CD scratch must resample the section of track very often and very quickly in order to keep up with the movement of the dial. This buffer is played linearly in both directions to produce the sound. The sound of the physical needle rubbing along the physical vinyl groove is also not present in the digital version of the effect. The second way in which scratching a CD differs from a vinyl record is the physical interface associated with each unit. On a CD player, the scratch pad dial is often no bigger than a CD itself. A vinyl record is typically 12 inches in diameter, providing a much larger surface on which the entire hand can be used. Turntables also have motors that exert a force on the hand when moving a record back and forth. The latest CD players on the market have no motors and so the persistent tug of the platter is not present. Some scratch tricks are performed by interacting with the motor and this is not possible on these CD units.

One benefit to CD scratching is the lack of skipping that occurs over the turntable method. Worn needles will often skip out of the groove when scratching a vinyl record. A CD player will almost never skip when being scratched. Scratching on either a turntable or a CD player is a one-dimensional continuous action where the track either plays forwards or backwards at various speeds.

2.4 Procedures of the DJ

This section provides a detailed description of the processes involved in a DJ’s job. This was established from a number of sources: observations of over one hundred live DJ performances, interviews with over thirty DJs, DJ related films [37, 38]and websites [1, 2, 4, 5], and the input from the author, a DJ of 13 years. Recall that the tasks in this section were developed around the available technology during the onset of DJing (i.e. turntables).

In Section 2.5 we categorize DJs into two types: mix DJs and scratch DJs. Here we discuss the four main tasks of a DJ: beatmatching, mixing, scratching and beat juggling. The first two tasks are necessary for all DJs to master. The last two are usually carried out by scratch DJs.

2.4.1 Beatmatching

Beatmatching is the act of synchronizing two beats so that they have the same tempo and are in phase. When shifting the output source from one track to another, the transition between tracks can appear seamless if the beats are beatmatched. This section explains the basic techniques of beatmatching.

Loops and Downbeats

Nearly all modern Western dance music consists of a series of loops, each containing 2^n beats, where $n > 0$ (i.e. $n = 2,4,8,16,32,...$). Typically a modern dance track will consist of a series of 16-beat loops, each broken down into four bars containing four beats. Figure 5 demonstrates this concept.

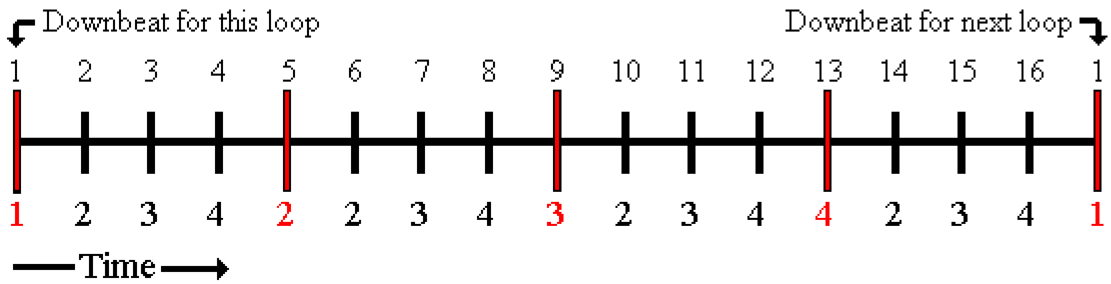


Figure 5 One 16 beat loop in typical 4/4 dance music.

There is generally an extra sound or accent (such as a high hat or crash symbol) that occurs on beat 1. This signifies the beginning of a loop and lets the DJ and listener know what position of the loop they are listening to. We will label this first beat as the *downbeat*. It is the most important beat in a loop when learning to mix as it signifies the beginning of a loop. It is critical for a DJ to know when their music is playing a downbeat and when it is not.

The speed of each track is given in beats per minute (BPM). If Figure 4 represented 1 minute of music, there would be 17 beats played (the 16 beat loop plus the downbeat of the next loop) and this track would be a 17 BPM track. That is an extremely slow example as most modern dance music ranges from 80 BPM to 180 BPM.

Mixing the Beats

At least two (and rarely more than two) tracks are involved in a mix. The track that the audience is listening to is called the *outgoing* track as it will be stopped once a new track is played. The track that is about to be played is called the *incoming* track. While the outgoing track is playing, the DJ will cue up the incoming track and prepare it for play.

When ready, the DJ will mix the two tracks together in a seamless manner so that the audience hears the illusion of one constant song. During the mix, the DJ will move the musical output completely to the incoming track and remove the outgoing track from the playback device. Then the process starts again and the track that was previously the incoming track is now labelled the outgoing track. A new incoming track is used and the music continues without pause.

Synchronizing Tempo and Phase

To mix two tracks together, two things must happen. First, the two tracks must have the same BPM (i.e. the same tempo) and second, their downbeats must be in phase (i.e. lined up in time). When both of these conditions are met, the records are synchronized. Figure 6 is an example of two beats that have the same BPM but are not in phase.

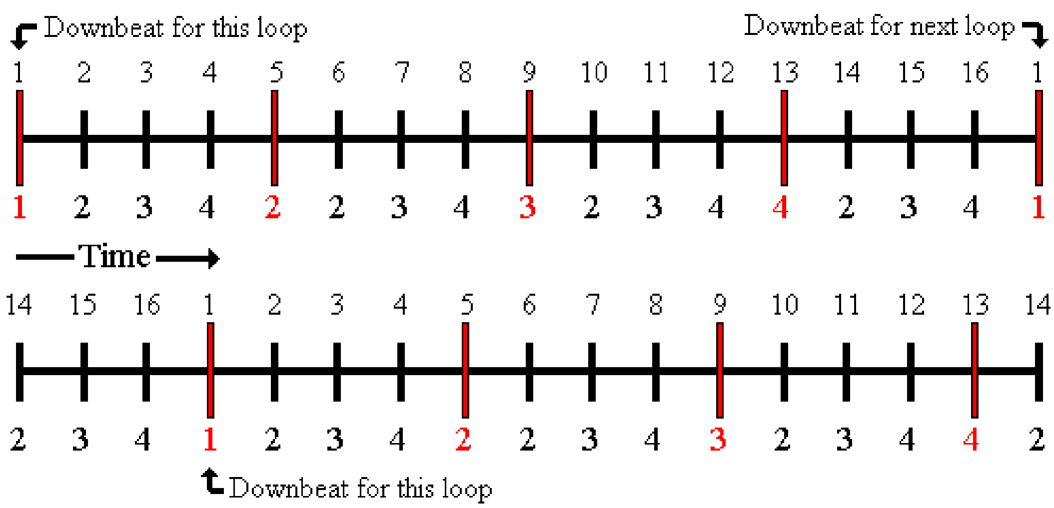


Figure 6 Two 16 beat loops that have the same tempo but are out of phase

When two tracks have the same BPM but are not in phase, they will not sound coherent when played with each other. Events relating to the downbeat in one track will occur at disproportionate times in the alternate track. There are 15 different ways to have two 16-beat loops in two separate tracks out of phase (but with the beats lined up). The downbeat of a loop in the incoming track can commence on each of the non-downbeats of a corresponding loop in the outgoing track. Thus, we can say that for a loop with *n* beats, there are *n*-1 ways to mix it out of phase with the beats lined up.

When two tracks do not have exactly the same BPM, they will eventually go out of phase as the duration between beats of each track will continually drift further apart. Thus, a DJ can synchronize the phases of two tracks but they will soon desynchronize as the beat of the incoming track drifts. Figure 7 is an example of an incoming beat that has a slower BPM and thus, falls out of phase with the outgoing beat. The slower beat is on the bottom.

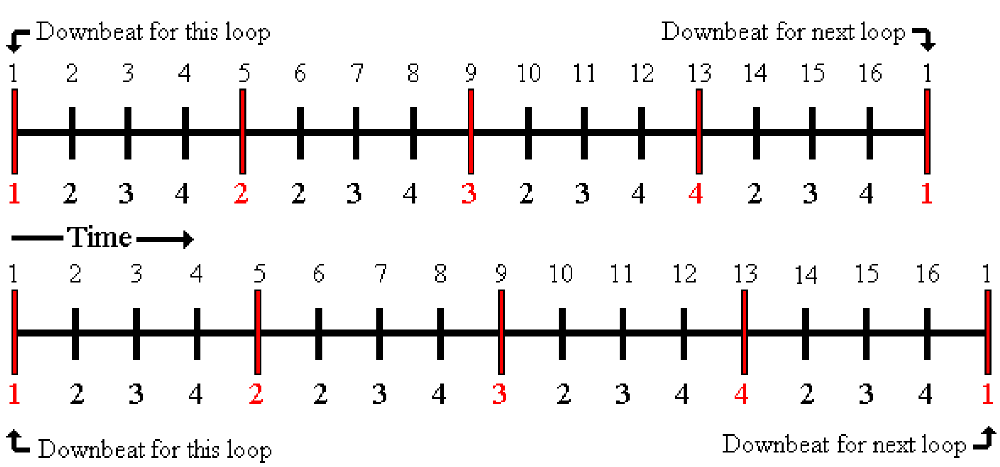


Figure 7 Two 16 beat loops that start in phase but do not have the same tempo.

When two beats are in phase and have the same BPM, they are beatmatched as shown in Figure 7.

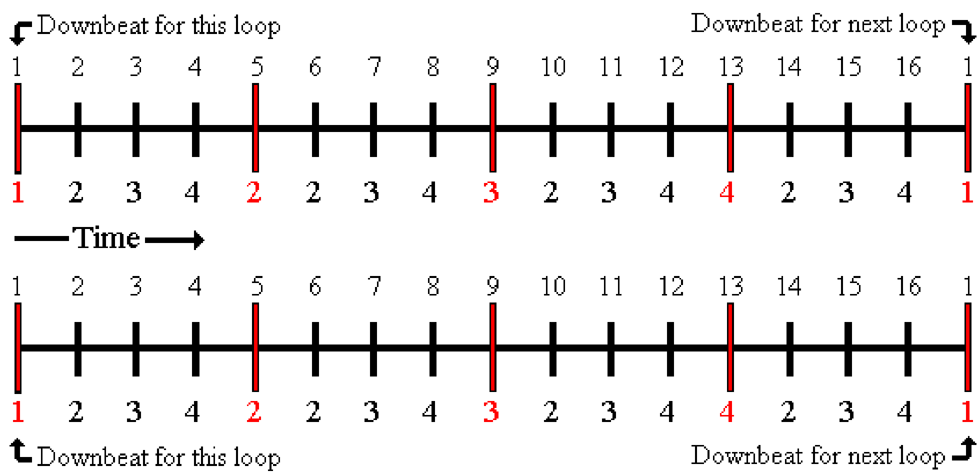


Figure 8 Two 16 beat loops that are beatmatched - synchronized in phase and tempo

Synchronizing Bars of Different Lengths

Let $b_1 = 2^n$, $n > 0$ (e.g. $b_1 = 2,4,8,16,32,...$).

Let $b_2 = 2^m$, $m > 0$ (e.g. $b_2 = 2,4,8,16,32,...$).

It is possible to mix any loop with b_1 beats with any other type of loop that has b_2 beats. To do this, one only has to line up the downbeats to occur at the same time. A 4 beat loop will have 4 downbeats in the same time that a 16 beat loop has one downbeat. Thus we can say that any loop consisting of b_1 be*ats* will be mixable with any other loop consisting of b_2 beats. This, of course, applies to other musical time signatures but we are only concerned with 4/4 time as it is the primary time signature that DJs use.

Physical Procedure of Beatmatching

Beatmatching involves two physical procedures: 1) starting a track and 2) adjusting a track's pitch/tempo. Altering the pitch/tempo of a track is a one-dimensional continuous task with two directions: faster or slower. Once an incoming track is cued to begin on a downbeat, starting the track is optimally a one-dimensional binary task (whose modes are playing or stopped). However, most physical devices (such as turntables) do not support an instant start and, instead, take a small amount of time to accelerate the track to its desired tempo. Thus the DJ must manually 'push' a track, providing the necessary acceleration, in order to make sure that its downbeat matches that of the outgoing track. Starting a track is a one-dimensional continuous task that depends on the speed at which the DJ pushes the track.

Cognitive Demands of Beatmatching

In order to beatmatch, the DJ must use two ears, one listening to the track that the audience is hearing (the outgoing track) and one listening to the incoming track. This will require splitting one's attention to accommodate two audio inputs and organizing how things should sound. Most DJs focus on the outgoing track and force the incoming track to follow the beat pattern of the outgoing track. It is common to see a DJ tapping his/her feet to the outgoing track, as he/she concentrates on its beat. Then he/she cues the incoming track, initializing it to start on a downbeat. When the next downbeat of the outgoing track occurs, he/she starts the incoming track so that the downbeats match. Next the DJ quickly adjusts the BPM of the incoming track so that the beats remain in a constant state of synchronization. This manipulation of the incoming track's speed requires a device that supports altering the tempo of the track.

Beatmatching is one of the hardest tasks that all aspiring DJs must learn to do. It requires tremendous attention and puts strain on the auditory part of the brain. The hands are used to complete the task and the ears are used to confirm its completion. As each ear is focused on a different sound source, novice DJs often become confused as to whether the incoming song is playing too fast or two slowly. Common mistakes include misinterpreting the speed of this signal and speeding up a song that is already playing too fast. Beginners (and some seasoned DJs) also find it difficult to locate the downbeats within the incoming and outgoing songs, to cue an incoming song's downbeat to begin at the onset of the outgoing song's downbeat.

2.4.2 Mixing Music

One form of DJ creativity stems from the choice in music selection and how the music is presented. DJs can blend pieces of separate songs together in realtime to create remixes (new versions) of songs. The ability to seamlessly mix music so that the audience does not realize a new song has been added to the mix is a process that involves learning a skill and thus provides a feeling of satisfaction when done properly. Learning to seamlessly mix music is one of the main tasks of a DJ.

Mixing two pieces of music involves following five phases:

1) **Beatmatching** is the first step in mixing music. Truly expert DJs can beatmatch two tracks after hearing only four beats of each. Amateur DJs often require the entire length of outgoing song to beatmatch the incoming

song.

2) **Starting a new track** is often done incorrectly by amateur DJs. The most common mistake occurs when a DJ successfully gets the incoming track running at the same tempo as the outgoing track (in terms of BPM) but fails to align the downbeats. Starting a track is different from introducing (see below) it in that the audience may not hear a track being started, whereas they will hear when it is introduced. Thus starting a track can be done 'behind the scenes' prior to introducing the track. Most DJs will start their incoming track and then introduce it, thus mixing two tracks, after the first loop has passed. A few DJs set the tempo and start a new track without hiding the initial start of the track from the audience. When this occurs, starting the track and introducing it are done at the same time. To do this, the DJ must have the ability to push the incoming track with the correct amount of force so that it matches its tempo with the outgoing track in minimal time.

   It should also be noted that a track does not have to start at the very beginning of the actual song. If the DJ chooses, he or she can cue up the track at a different point. It is not always necessary to start tracks on a downbeat but they must still have their downbeats lined up. If an incoming track is cued to start on the third beat of a loop, then it should be started on the third beat of the outgoing track's current loop.

3) **Introducing a track** occurs when the audience first hears the new incoming track in the mix. Prior to this, the DJ could have been cuing up the track to the desired starting point. There are three main ways to introduce a new track. The introduction can be a straight cut, where the music shifts abruptly from one track to another. It could be a half cut, where the incoming track snaps into the mix and plays with at the same volume as the outgoing track. It could also be a fade, where the incoming track fades into the mix. Different DJs like different styles and the type of track being played is also suited to different types of introductions.

   It should be noted that in modern dance music, most changes within a track occur on a downbeat. Thus the obvious time to introduce a new track (thus changing the musical mix) is on a downbeat. Mixes often sound more coherent if the audience hears the new track introduced on a downbeat. If done properly, they may interpret this as only a change in the current track without realizing that a new track has been played.

4) **Layering** two tracks is the heart of musical mixing. This occurs when two tracks are being played simultaneously as if they were one track. To layer two records and make it sound coherent, the melodies of each track must make harmonious sense. A common rule of thumb is never to mix two vocal portions as it causes two distinct streams that the audience must follow and does not allow for unification within the music. Beats must remain in line, so

slight variations in BPM must be adjusted to make sure that the mix is going smoothly.

Expert DJs can layer two tracks for their entire length. Amateur DJs may only be able to layer for a short while and will opt to fade one track out quickly to insure that a there is no incoherent beatmatching occurring in the mix (resulting in a ‘train wreck’). While layering, the DJ can adjust the equalizers for each track, thus accenting various instruments within each track.

For mix DJs, layering is generally considered the most satisfying part of DJing because this is where the DJ can use creativity to produce new pieces of music and to accent parts of the music. There are many tricks for using different parts of a track to produce different effects, such as building up the energy in a song or relaxing it by removing the drums, or creating new beats (called breakbeats) by cutting the different drum loops in each song back and forth.

5) ***Outroing* a track** involves moving the mix completely over to the previous incoming track and removing (or taking out) the outgoing track from the mix. This can be done by fading the old track out, cutting it off or waiting for it to finish. Some DJs' can perform tricks on the “outro” such as stopping the track abruptly, causing a screeching sound or cutting the power to the turntable so

that the record slowly comes to a halt. Backspinning, forcefully spinning the record backwards in a quick spurt, can be effective for outroing as well.

Appendix D illustrates an example for mixing two tracks together.

2.4.3 Scratching

The most common type of trick on a turntable is the ‘scratch’. This means to move the vinyl back and forth so that the needle remains within a groove and rubs along the groove, as opposed to across the groove (a common misconception of the term ‘scratch’). Scratching produces a scraping sound, formed from a combination of the sound sample used and the physical attributes of a diamond tipped needle rubbing across a vinyl plate. By snapping the crossfader (or, to a lesser extent, the volume sliders) back and forth in various patterns, the DJ can allow snippets of audio from the scratch to be heard, giving it a cleaner, tighter sound. Typically the dominant hand operates the crossfader on the mixer while the non-dominant hand rests on the vinyl. This suggests the crossfader is manipulated with much greater precision than the record and that the audio sets the context for crossfading as discussed by Guiard when referring to bimanual tasks [21].

When scratching, a felt slipmat is placed under the vinyl to aid in pickup time. The mat allows the motor to continue rotating the platter underneath the vinyl in a forward direction while the DJ manipulates the record in a combination of forwards and backwards motions. When releasing the vinyl, the motor propels the slipmat and the record forward. In a sense, the use of a slipmat causes the relationship between the movements of the turntable platter and the playback of the music to be different from the movements of the record and the music's playback. In actuality, it is the relation between the angular position of the record and the music's playback point that is important to the DJ (hence DJs interact more with records than platters). Thus, it may make sense to couple these two one-dimensional controllers (i.e. the platter and the record) into one controller.

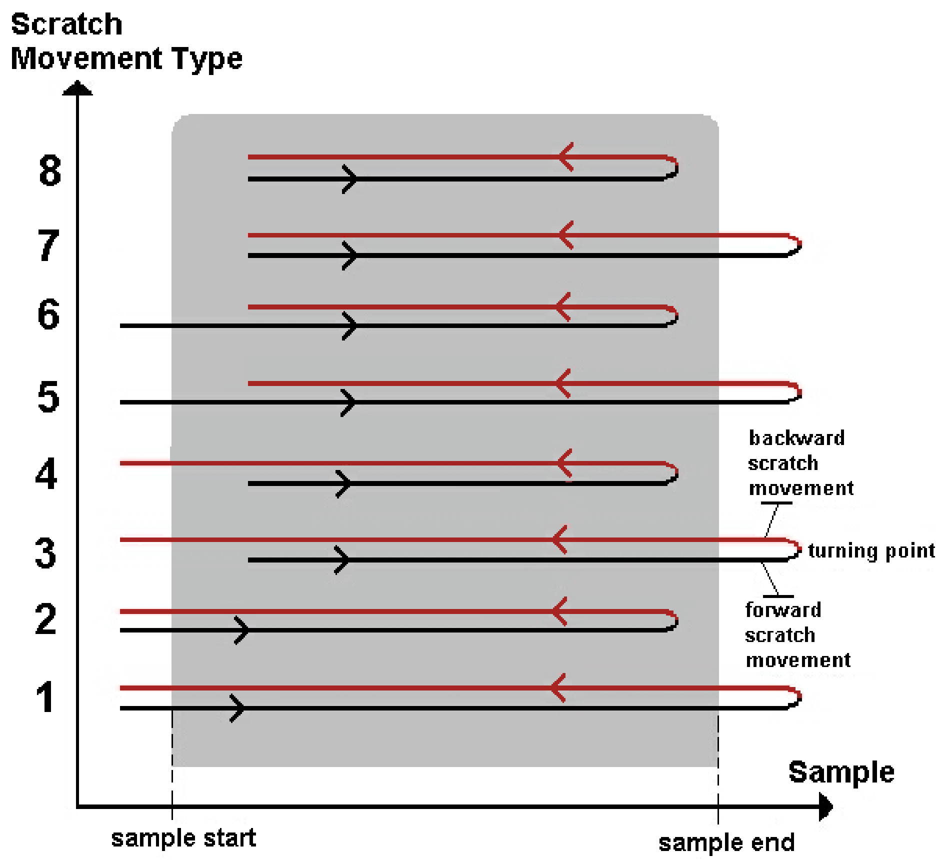


Figure 9 Eight scratch patterns. The middle (grey) area represents when music is heard (controlled via the crossfader on the mixer). The arrows show the direction of the record's movement. Image courtesy of Kjetil Hanson.

There are many patterns that can be produced when cutting the sound in and out, combined with moving the record back and forth. Figure 8 shows eight different patterns that can be performed with a combination of moving a record back and forth once, while cutting the sound on and off with a crossfader. Appendix C lists the names and descriptions of several scratch patterns, as described by the scratchDJ website [1].

Clearly there is a limit to the number of patterns and tricks that a DJ can do with the current tools. Once having mastered the patterns in Appendix C, the only new changes that can be brought to a musical set is to apply the patterns to different sounds (via different records). To increase the creative outlet of a DJ performance, it would be desirable to create new patterns or use devices that would allow a DJ to perform new tricks that cannot be performed at present on conventional DJ equipment.

2.4.4 Beat Juggling

Beat juggling is, quite simply, the act of juggling beats. A DJ will play a few beats from one record while cuing up another. Then the output of the mix shifts to the record that was being cued and it plays for a few beats while the first record is re-cued. The process shifts back and forth quickly, allowing the DJ to create entirely new rhythms from samples of each record. DJs can create seamless loops by juggling two copies of the same record. They can create new timing signatures by playing varying numbers of beats from each record. With beat juggling, a DJ can produce almost any type of beat with the right selection of records and a good sense of timing. If done improperly, however, a slight error can be noticed by even mildly attentive listeners.

A DJ places a marker (usually a piece of tape or paint) on the inner rim of a record when beat juggling. This serves as a visual indicator for the playback point in the song with respect to the position of the record. It is used to indicate how much of a backspin is required to re-cue a song. It also helps identify how much rotation is necessary to play a certain portion of music. For example, a DJ might note that a certain pattern exists in a 45° arc as shown by the marker. Without listening to the pattern, the DJ knows how much backspinning is required to re-cue the pattern once it has played.

Beat juggling involves two one-dimensional tasks. Re-cuing each record is a continuous task but switching the output from one record to the next is a binary task.

2.5 Types of DJ

We classify DJs into two groups: mix DJs and scratch DJs. Mix DJs concentrate on producing coherent seamless mixes. These DJs blend songs together to create new sounds. They are more interested in creating an auditory atmosphere with their music and thus try to make the changing of songs unnoticeable to the audience. Scratch DJs do quite the opposite. They often do a 'cut and paste' method of mixing, where songs switch abruptly and it is the onset of a new song that causes excitement within the music. Scratch DJs also use the turntable more as an instrument than a playback device. Through scratching, these DJs can produce new sounds in a song. They can control pitch, tempo and even timbre of the scratched sound. Both styles have creative elements and neither one is more dominant than the other. It is common to see elements of one style mingle with another for a truly encompassing performance.

DJs can also be classified into *expert* and *novice* groups. Expert DJs are often professionals with a number of years of experience at the art form. They commonly take only a few seconds to beatmatch songs and can perform turntable tricks with relative ease. The number of novice or "bedroom" DJs has risen since the trend of DJing and DJ music has gained in popularity. These DJs practice at home, sometimes entertain their friends at small social gatherings and are often fuelled with a desire to become a famous DJ. They often take several minutes to properly beatmatch songs and tend not to perform any sort of turntable tricks until they have mastered the skill of beatmatching. Tools that help novices learn certain aspects of the art form may be attractive because these tools can help speed a novice's progress towards expert status.

2.5.1 Receptiveness to New Technology

Mix DJs are generally more receptive to trying new technology whereas scratch DJs tend to rely heavily on their old tools. Perhaps this is because scratch DJs have spent more time perfecting certain skills with a turntable and are reluctant to try newer, improved devices as their skills may be devalued. Likewise, there exists a set of mix DJs who feel that performing on a turntable is more difficult than performing on a CD player and thus, turntable DJs are thought to be more talented. Some DJs have a notion that converting to new technology and especially using digital media is 'cheating' as it can often make performing easier. These DJs do not want technology that does their job for them. They have respect for those who have taken the time to learn the tools and can find innovative ways of using them.

To counter this, there exists another set of DJs who crave the latest devices which they feel will give them a competitive edge over the many DJs that exist in the field. These DJs are looking for a way to increase their creative output and are striving to be unique. As the popularity of DJing has grown, the numbers of unique styles has not. The DJ world has been flooded with thousands of DJs that arguably sound the same and add nothing new to the art form. This trend threatens the future of DJing because a new art form that cannot grow often suffers the fate of a fad. DJs who feel this way about their field desire to use new technology, enabling them to break the standard DJ mould. These DJs want a tool that will enable them to stand above the status quo and become "the next big thing".

Chapter 3

3 Digital DJ Interfaces and Design Techniques

This chapter covers some previous work on DJ interfaces and design techniques in general. Reviewing past attempts at upgrading DJ technology helps us learn from the triumphs and mistakes of others, prompting reflection on what has been accepted and rejected in the DJ community and motivating some design decisions in our own contribution. Reviewing common design techniques helps one understand how to match interfaces with essential tasks. When designing a new feature, one can look at past interface design research, noting what works in certain situations.

3.1 Previous DJ Related Work

Most research concerning DJ controllers has been conducted by commercial companies, and remains unpublished. This section outlines some of the more notable commercial products and comments on some academic projects that are related to the field.

The CDJ-1000 [36] by Pioneer is a commercial CD player, designed to emulate the turntable (see Figure 4). It houses a rotary touch pad that is supposed to act like a turntable platter. In vinyl mode, a DJ can rotate the platter back and forth to produce scratch-like sounds. The platter itself does not rotate unless touched. When the DJ releases the platter, the music continues to play forward as if a record were spinning, however, the platter remains motionless. This lack of synchronization causes the CDJ-1000 to break an important turntable metaphor because it lacks a motor. Although it seems rather simple, the rotation of the turntable platter signifies to the DJ that music is playing; he relates the movement of the platter to the playback of the music. The DJ understands that if the platter is stopped, the music stops. If the platter is spinning, the music is playing. And if the platter is spinning faster, the music is spinning faster. Thus a DJ controls a relatively difficult task (the playback rate of music) by controlling a relatively simple task (the rotational speed of a spinning platter). The CDJ-1000 fails to acknowledge the important relationship between rotation and the progression of music as it does not rotate freely on its own.

The CDX1 [34] is a commercial CD player from Numark that has not yet been released. It appears to have solved the problem of the CDJ-1000 by including a rotating platter complete with a vinyl record. The platter has a torque of 4.5kg/cm. This looks to be the best attempt at a turntable-type CD player but, from a scarce amount of information attainable from Internet sites, it does not appear to provide any new means of control beyond that which has already been made available via turntables or previous CD units. The author, however, is eager to try the device when it is released into the market.

Figure 10 The CDX1 CD Player. The 12-inch vinyl record on top is used to manipulate digital audio.

FinalScratch [16] is another commercial product made by Stanton that is used with standard turntables. It is composed of two special vinyl records that each send an audio-encoded position signal through the turntable's needle to a nearby computer. The computer uses the position signals to control the output of two audio streams sent to a standard DJ mixer. The records are used in the same way that normal vinyl is used: the position of the turntable's needle dictates the playback point in a song, providing random access, and the speed of the record directly affects the speed of the music. This is impressive technology as it finally allows DJs to play with digital music while using a familiar interface (i.e. turntables). Skills transfer nicely to this product; however, it does have some drawbacks. Most DJs report a slight, noticeable latency (12ms as reported from [16]) but claim they can overcome this with practice. Also, FinalScratch still uses needles and vinyl, which means that damage can still occur to these components. They still need to be replaced and, since the same vinyl is used for all songs, if one of the records becomes damaged during a performance, all of the songs played from that record will be damaged. Finally, FinalScratch does not add anything new to the tool set of a DJ. DJs still perform as they would with regular turntables and, aside from permitting the DJ to access digitally encoded media, new kinds of performance are not enabled. The product does not fully harness the capabilities that are afforded when working with digital media.

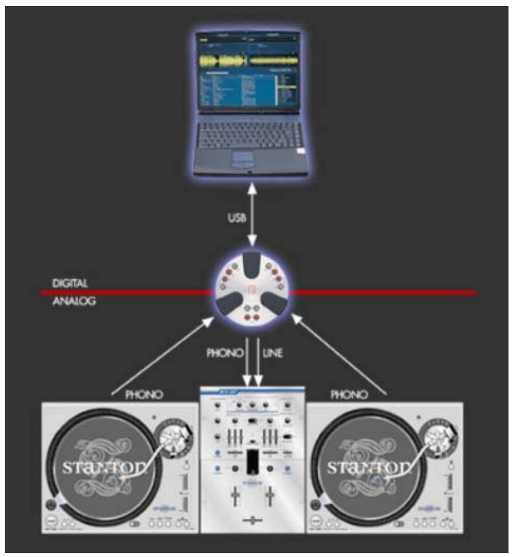


Figure 11 FinalScratch. The output of the turntables goes into a special amplifier that decodes the audio signal and communicates to a computer.

In 2001, four students from Stanford (Halderman, Lee, Perella and Reiff, under the supervision of Bill Verplank) connected a Technics SL-1200 turntable to a computer using an encoded wheel instead of a needle. The wheel was placed on the vinyl and rotatef as the vinyl moved underneath. This signal was sent to a computer and was used to control the playback speed of a song [43]. Their work is closely related to FinalScratch in that it uses the same external components (i.e. a turntable and some records). It has much less wear on vinyl as there is no needle involved but does not provide random access within a song; the song must be played from beginning to end. Since the project never reached maturity, we are unable to comment on its effectiveness as a DJ tool.

Related to the study of turntable sounds, Kjetil Hanson studies scratch sounds produced by turntable musicians [23, 24]. He is looking for sonic differences between analog scratching on real turntables and digital scratching on various CD players. From a pilot study conducted from his website [22], where he asked ordinary people to judge which sound they liked better, he found that approximately half the participants liked the digital scratch sound better than the analog sound. This is promising news for digital scratching applications. He is also working on a model of the scratch sounds produced by turntables [25]. This work is interesting because it may enable us to produce new digital scratching sounds with our interface.

At the M.I.T. Media Lab, Chris Csikszentmihalyi has built DJ I Robot, a robotic system that uses three turntable platters and a collection of records [11]. The robot knows how to manipulate vinyl and needles in order to cue and scratch. It works by following a script of commands, ignoring any feedback provided by the audio playback. Thus, if the needle accidentally skips, the robot will be none the wiser. This is an interesting project as Chris has pitted the robot again several famous DJs (having yet to win a battle), however it lacks any form of the human creative qualities that one would normally find in a DJ set. There is no interaction between the robot and the audience. The interesting component is that Chris is able to have a robot repeat all the physical motions required to perform a short scratch composition with precision.

More closely related to haptics and audio navigation, Lonny Chu is working on a haptic dial for navigation in an audio editing task [9]. His work does not focus directly on DJing but demonstrates some success in using haptic force feedback, generated directly from an audio stream, to find features within the audio. Lonny's work was being completed in parallel with D'Groove and many features of the two systems are similar.

3.2 Previous Interface Design Research

In this section, we review some important concepts in physical interface design. Since our goal is to produce a physical interface for DJs, it is important to study past work on interfaces in general and attempt to apply this knowledge to DJ interfaces.

Related to tangible interfaces, Fitzmaurice's work suggests that graspable interfaces promote space-multiplexed I/O [17]. By this he means that each function (e.g. changing a volume) in a physical interface has a dedicated transducer (e.g. a volume slider) as opposed to time-multiplexed I/O where one transducer (e.g. a mouse) is used to complete many functions (e.g. scrolling, selecting, etc.). Lots of examples of space-multiplexed I/O are seen in conventional DJ equipment. We believe this concept is important for performers as it allows multiple functions to be carried out concurrently and promotes the use of visually appealing motor skills.

We recall two interesting principles from the work of MacKenzie [30] when he reviews the concepts of degrees of freedom (DOF) and bimanual skills. From our analysis of DJ tools in Section 2.3, we note that all DJ tasks are 1-DOF, reducing their complexity. This leads us to believe that simple operations are important to DJs. Studying bimanual tasks such as scratching (where the preferred hand usually utilizes the crossfader and the non-preferred hand utilizes the record), suggests that precise movements are usually carried out on the crossfader whereas more coarse motions are performed with the record. This makes our task less demanding as we are concentrating on building a turntable tool and not a crossfader.

Vertegaal *et al.* matches musical tasks to input devices [44] based largely on work from Mackinlay *et al.* [31]. This work suggests that faders are good for positioning tasks. Rotary potentiometers and modulation wheels are good for rotary position tasks. Rotary velocity can be matched to dials and force sensing can be accomplished with pressure pads. This suggests that a slider or fader should be used to denote temporal position within a song, formerly a function of the turntable's needle. Since a turntable is most like a dial, it suits the task of controlling rotational velocity or, in our case, the continuous velocity of the music. However, the turntable also controls temporal position within a song. We could replace the turntable interface with a motorized slider or we can think of the turntable as a rotary positioning device, controlling position linearly instead of circularly. As turntables are more visually appealing in DJ performances, we believe the latter choice is the correct one.

Chapter 4

4 D’Groove – The Digital Haptic Turntable

In this chapter we discuss D’Groove, our own advanced DJ system, incorporating a physical interface that promotes audio, visual and haptic feedback. We discuss the goal of D’Groove, its components, its implementation and design decisions, and new features provided by the technology. D’Groove is our attempt at improving the state of DJ interfaces through increased feedback mechanisms, a greater sense of immersion and heightened control intimacy.

4.1 Purpose of D’Groove

The primary goal of D’Groove is to provide DJs with a means to play digital music with the same level of control they have with an analog turntable. In addition, D’Groove is meant to increase a DJ’s level of creativity and provide more information about the music. To aid with these goals, we embedded simple, single degree of freedom haptics into the DJ setup. Since DJing is already a very hands-on task, we felt that it would be natural and valuable to provide more musical information through the sense of touch. Active haptics in the turntable permits the DJ to receive this information as well as control the musical progression. At the same time, we believed we could increase the DJ’s intimacy with the system and offload some perceptual load from the auditory senses to the visual and haptic senses. In some cases the DJ can play with the haptic effects, thus heightening the creativity of the DJ and allowing him/her to perform new tricks, not previously possible on standard turntables.

We observed in Chapter 2 that beatmatching is one of the toughest tasks that all DJs must learn. Therefore, another goal of D'Groove is to make it easier for DJs to beatmatch songs, to allow novice DJs to learn more quickly and experienced DJs to concentrate on higher level audio effects. A beatmatching aid is discussed in Section 4.3.1.

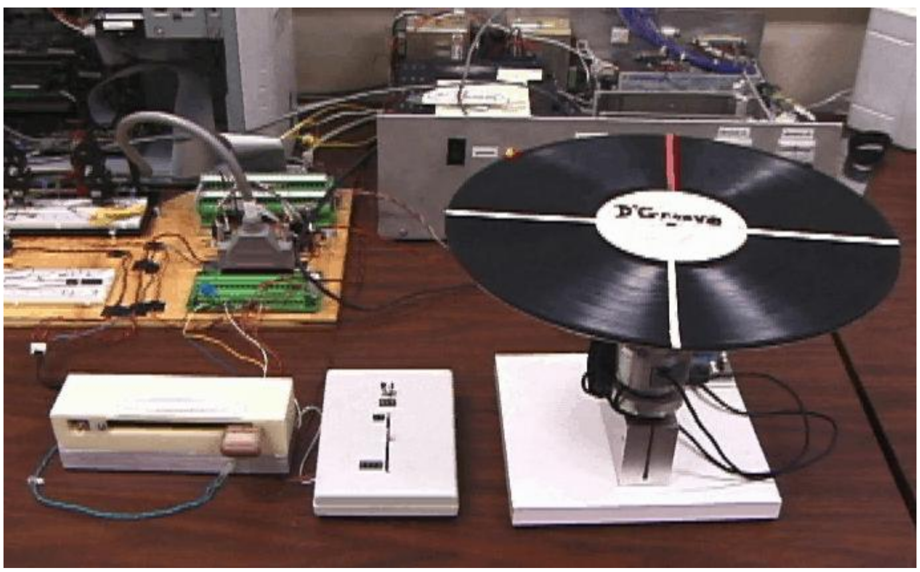


Figure 12 The D'Groove System. From left to right: the Q-slider, the pitch slider, and the turntable.

Applications involving media browsing, manipulation and, in particular, creative expression, require both tight temporal coupling and creation of new interactive techniques and hardware to facilitate a sense of control [27, 41]. Thus, we went to great lengths to provide a physically rich interface with minimal latency, enabling intimacy from its directness.

4.2 Overview of the Interface Components

D'Groove consists of four primary interface components: the turntable, the pitch slider, the Q-slider and the graphical user interface (GUI). The first three components are meant to replace the three primary controls found on a turntable: the platter/record, the pitch slider and the needle. The graphical user interface is used to alter parameters and switch between modes. Figure 25 depicts a schematic of how each of the components are connected.

4.2.1 The Turntable

The central part of the interface is the turntable platter. It is driven by a 90 watt, 1070 nMn (stall torque) DC motor by Maxon (series RE035) which was chosen for its ability to produce haptic effects and its relative power/torque, compared to other haptic motors. The motor is fitted with a dual channel post quadrature 14,400 counts per revolution (CPR) encoder. A relatively high resolution is required as we want to preserve the analog qualities of sound when moving the turntable at slow (less than 33 1/3 RPM) speeds. The higher resolution permits finer precision between the movements of the turntable and the playback of digital audio. The encoder is decoded locally, using a 16 bit counting chip (LS7166), and is interfaced to the computer through a digital port on a DAS-1602 Keithley Metrabyte I/O board. Appendix A shows the circuit diagram for the encoder-decoder chip.

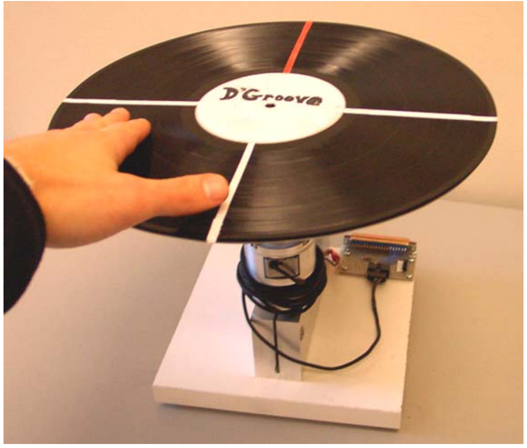


Figure 13 The Turntable Platter

A 12 inch aluminium platter is attached to the drive of the motor and a vinyl record (also 12 inches) is fixed to the platter. The platter is 1.36 mm thick. The record is 1.84 mm thick. Together they weigh 382 g. The record is used to provide the same tactile texture as using vinyl on a conventional turntable. Four coloured lines (one red and three white) are drawn on the turntable to represent the four beats in a bar of music. The red line denotes the current beat while the remaining white lines denote the following three beats. The significance of these lines in relation to the beats will be discussed in Section 4.3.1.

The purpose of the turntable platter is to control the playback rate and direction of the music. As the platter rotates, the velocity of the musical playback is directly affected. The DJ is able to override the power of the motor, having ultimate control over how the music is played back. Using the turntable is done much like using a conventional turntable. The DJ sets the platter in motion with a start/stop switch and uses a hand to scratch the music or pitch-bend it upwards and downwards.

Like a conventional turntable's platter, D'Groove's turntable is a one-dimensional continuous rotary controller, affecting musical speed (i.e. pitch and tempo). Unlike a conventional turntable, we do not use a slipmat or a record separate from the platter itself. On a conventional turntable, a DJ stops the record to stop the music while the platter continues to move underneath (via the slipmat). On our turntable, the DJ stops the platter (and the record fixed to the platter) to stop the music. We felt DJs interact with records more than platters, thus our platter is intended to be associated with a vinyl record. A slipmat would make the haptic effects (Section 4.3.3) very difficult to implement as the DJ would be feeling a separate record interface instead of direct contact with the motor. Since it is the record's movements that the DJ is interested in, we made the record and the platter into one interface.

Records are an excellent example of tangible media in that they represent the information contained within them. Furthermore, they are able to display that information in an analog manner, in the form of record grooves. When designing our digital system, we elected to forego tangible song selection as we felt it was impractical to carry many physical components, each representing a song. The groove information is retained but in a different form. Using the Q-slider (section 4.2.3), we chose a haptic method of feedback to fulfil the purpose of grooves as we felt that DJs had a difficult time seeing and selecting grooves.

4.2.2 The Pitch Slider

The pitch slider is used to set the desired velocity of the turntable (resulting in a pitch change in the musical output). It is a one-dimensional linear controller like the pitch slider on a conventional turntable. It is composed of a two-way switch and a linear, non-actuated, sliding potentiometer, both connected to analog inputs of our DAS-1602 Keithley Metrabyte I/O board. Moving the slider upwards increases the desired velocity of the turntable platter and causes the music to play faster. Moving the slider downwards decreases the platter's velocity, thus slowing the music. The switch determines whether the reading from the potentiometer affects the velocity of the turntable platter. The desired velocity of the turntable platter will change only if the switch is in the 'on' position and the DJ moves the slider.

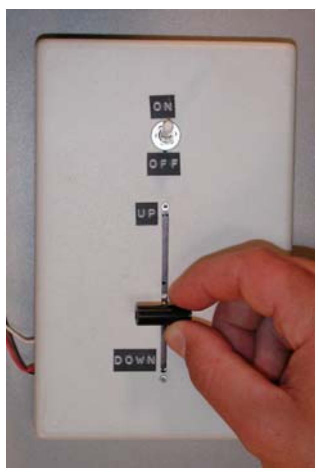


Figure 14 The Pitch Slider

The pitch slider can be "scrolled" in a manner that is referred to as "clutching" by Zhai [45]. If the DJ reaches the upper limit of the slider and still desires to increase the platter velocity further, he or she can toggle the switch off, reset the slider to the bottom, toggle the switch on again and slide the slider up some more. This is similar to lifting a mouse up when it has reached the end of the table surface and placing it down again so that further mouse movements in the same direction can be made. This differs from a conventional pitch slider in that we do not have a limited range.

The pitch slider is set to alter the desired BPM of the song, which in turn alters the desired velocity of the platter. The range of the slider has been divided into ten segments or units. The gain or proportionality of the change in BPM per change in unit can be altered in the software. It is usually set to one change in BPM per one change in unit. Sometimes, if more precision is desired, this number is switched to a change of 0.1 BPM per one unit change in the slider (it can be changed to any value using a GUI). The range of 10 units is rather arbitrary as the toggle switch permits unlimited range.

4.2.3 The Q-slider

The Q-slider is used to replace two functions of the needle on a conventional turntable; it provides random access and visual temporal position feedback within a song. It is made up of a motorized sliding potentiometer with a pressure sensor on the handle. The DC micromotor is made by Faulhaber (series 1524-SR) and has 2.6 watts of power and a stall torque of 0.957 nMn. The motor is fitted with a 400 CPR (post quadrature) encoder also made by Faulhaber (series IE2-16). Again, the encoder is decoded locally, using another LS7166 counting chip that is part of the same circuit as the turntable’s decoder chip (see Appendix A).

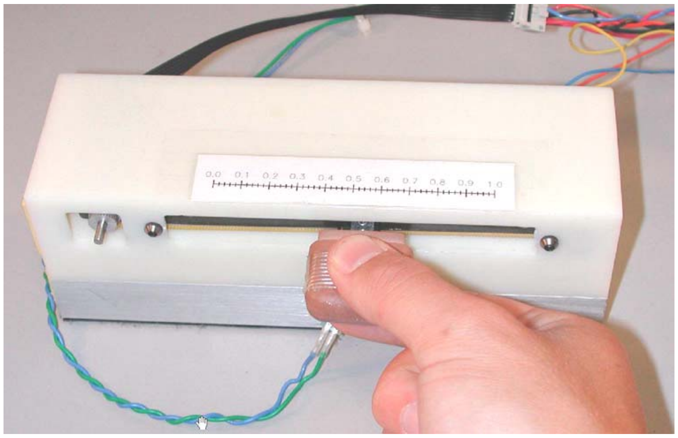


Figure 15 The Q-slider

The potentiometer is made by Penny and Giles (series PGFM8000) and is driven by the motor via a toothed belt. The amplifier circuit diagram is in Appendix B. The device allows the DJ random access to parts of a song and provides a means for large jumps throughout the song. The length of a song is mapped to the length of the slider and, as the songs plays, the motor moves the potentiometer's handle along the track from left to right. A tight position control loop is used to guide the handle to the correct location. If the DJ squeezes the handle, setting off the force sensor, the motor changes control methods (described below), allowing the DJ to freely move the slider along the track to a new location. The haptic feedback denotes the 'musical energy' of the song. Releasing the force sensor sets the motor to its original control mode once again. The potentiometer and pressure sensor are connected to analog inputs in the DAS-1602 Keithley Metrabyte I/O board.

Like the needle on a conventional turntable, the Q-slider is a one-dimensional, linear, limited range controller that provides random access within a song and visual feedback on the temporal position. The difference here is that a conventional record is scanned visually for desired needle placement (i.e. playback point placement). The Q-slider is scanned haptically for playback point placement. A record's grooves are transferred from the platter area and onto the Q-slider's haptic force feedback. The Q-slider is also disjointed from the platter, whereas a conventional needle is coupled with the turntable platter. Since the essential functions of the needle (i.e. random access and position feedback) are disjointed from the platter, we thought we could separate the controllers. Our decision was accepted in our evaluation with experienced DJs (Section 5.3.3).

4.2.4 The Graphical User Interface

A simple user interface (written in Tcl/Tk [35]) allows the user to select various modes for the turntable, such as regular turntable mode, spring mode, sine wave bumps or resistance patches. Each mode is selected from a set of buttons at the top of the GUI. This causes the haptic sensing/control-loop to switch its motor control algorithm. Within each mode, the user can alter various parameters, such as desired tempo, desired position and the parameters for the proportional-integral-derivative (PID) controllers. Parameters that are not available for a certain mode are greyed out. Modifiable parameters are located in the boxed section, under the mode buttons. The user must enter a value into the text box and click on the Set button to submit the value to the realtime motor controllers. Two extra buttons, "Zero K_i" and "Zero Position", are located in this section as well. "Zero K_i" sets the integral value of the current PID controller to zero, eliminating any built up error. “Zero Position” sets the current position of the turntable platter to the zero mark in the counter.

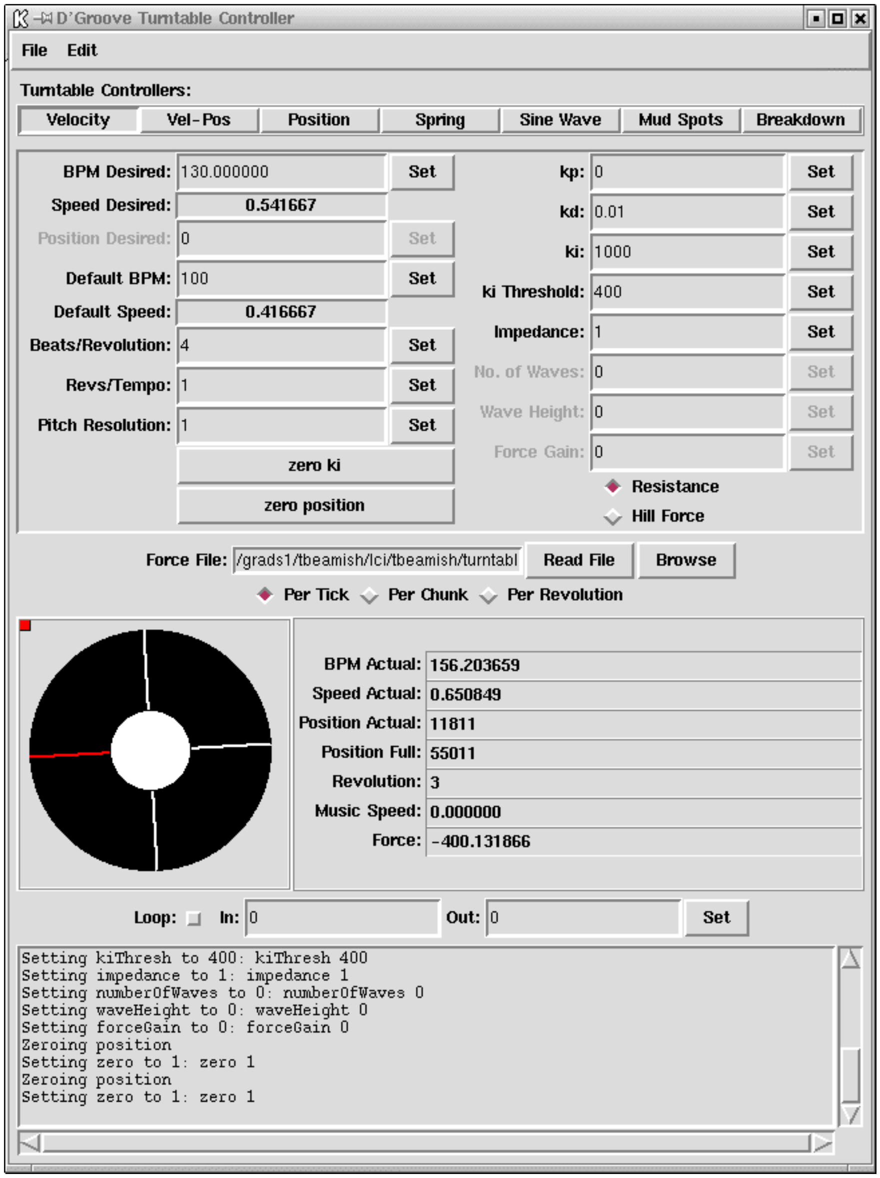


Figure 16 D'Groove's graphical user interface

Below this section is where the DJ selects the force file to use with the song. Force files are computed offline with a different program. The songs themselves are loaded separately from the GUI, using a command line interface to the JASS audio engine (Section 4.5.5).

The next section, below the force file section, is used for monitoring the system. The turntable graphic on the left is used to understand how the motor controller is interpreting the movements of the turntable. The remaining values to the right of the graphic provide feedback on the current position, velocity and force of the turntable.

Below the monitor portion is a looping section. Seamless musical loops at the one-bar level can be created by programming D'Groove to rotate between certain revolutions. For example, a DJ might program a loop to start at revolution 1 (bar 1) and finish at revolution 3 (bar 3). When the turntable rotates to the end of revolution 3, its next rotation (i.e. position) is reset to the beginning of revolution 1 instead of 4. The music follows the position and loops.

Finally the bottom of the GUI contains a simple text box used to display output from the program. As commands are issued, a message is displayed in this box to indicate which actions have been performed. This is mainly used for various status messages.

The GUI polls the monitor program for update values at 10 Hz. The monitor program handling communications between JASS, our audio engine (Section 4.5.5) and the haptic motor control system (described below in Section 4.5.3) has access to the shared memory in the realtime kernel and replies to the GUI each time a request for more information is issued. The user can alter the update rate of the GUI from the Edit menu.

Each time the GUI is shut down, it saves all of the user-set parameters in a file called controlSettings.tcl. The file consists of a script written in Tcl/Tk and is read upon execution of the GUI program, causing the last instance's parameters to be reused.

4.3 Innovative Features

This section describes the new functionality that D'Groove brings to the task of DJing. The features discussed here are not available on any DJ tool today. Each feature is meant to either improve upon a difficulty, as outlined in Section 2.4, or provide a new creative outlet for DJs.

4.3.1 The Beatmatching Aid

Beatmatching (see Section 2.4.1) is one of the toughest tasks that all DJs must learn before performing. In the conventional setup, DJs must learn to listen to two audio sources at once by using each ear to concentrate on a single source. The task usually involves just using the ears as the method of feedback.

D'Groove has a beatmatching aid to help DJs master the task of beatmatching by incorporating the visual sense in the task. We have not automated the task as previous work [12, 18, 20, 40, 42] suggests that adequate automatic beat detection of songs proves difficult. Thus we manually provide the correct BPM information. The basic paradigm behind our aid is to link the rotational velocity of the turntable platter to the song's tempo so that one revolution of the platter maps to *n* beats in a song (since DJs primarily play dance music with a 4/4 timing signature, *n* is chosen to be four). Thus one revolution on D'Groove plays back exactly four beats (or one bar) every time. This is not true with a conventional turntable as the amount of distance the needle travels around the record decreases as the needle moves towards the middle.

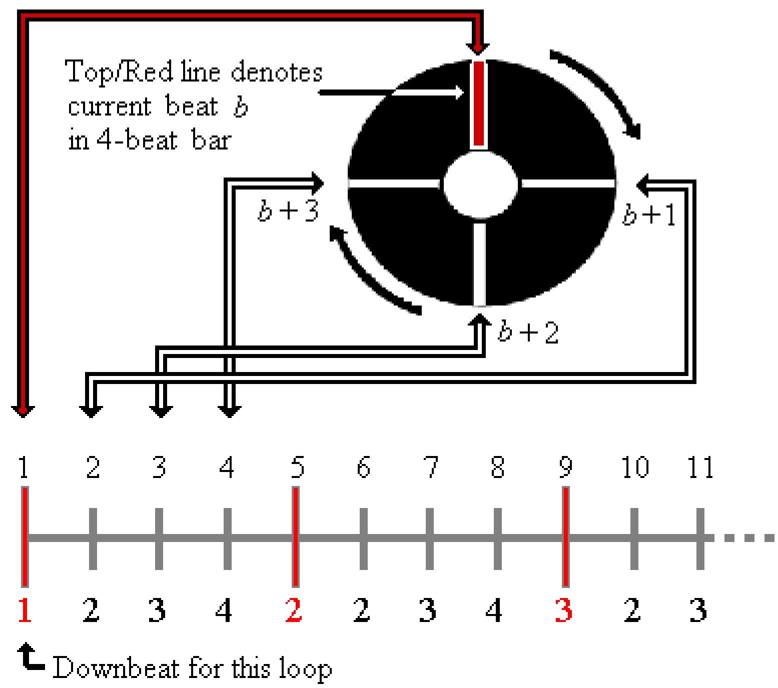


Figure 17 Lines on the turntable map to one bar. 12 o'clock marks the beginning of a bar.

By placing four visual cues on the platter, each one representing one beat out of a four-beat bar of music, the DJ can watch the beats rotate as the platter spins and visually predict when the next beat will occur, based on the position of the marker. DJs can confirm tempo matching between two D'Groove turntables from the display of each song's current tempo in their GUIs. If a DJ wants to just use the turntables, he/she can confirm that two songs are beatmatched by noting that the markers travel past a corresponding point on each turntable at the same time. This shows that they are moving at the same speed (thus having the same tempo) and are passing corresponding markers at the same time (thus having the same phase). Figure 18 illustrates this idea with four turntables rotating at the same speed. Because the rotation of the turntable is coupled with the tempo of the song, we can see the top two turntables are beatmatched. The lower left turntable is one beat out of phase with the top two and the lower right is half a beat out of phase. If the markers labelled “1” on each turntable pass by the markers labelled “N” on their respective turntable at the same time, we can say that the songs are beatmatched.

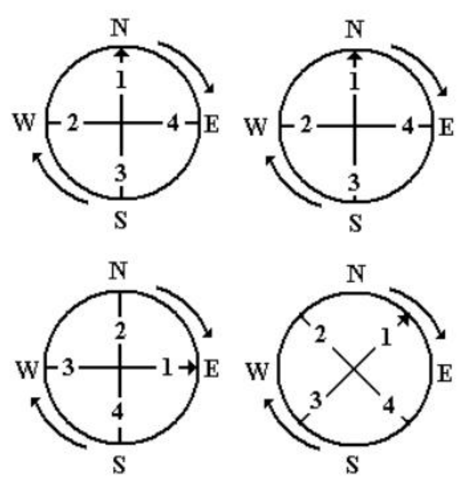


Figure 18 Four turntables rotating at the same speed.

This aid does not confirm phase-matching when lining up downbeats of bars that contain more that 4 beats, such as the normal 16-beat bar that occurs in many DJ-oriented songs. Figure 19 demonstrates how D’Groove can only achieve phase-matching at the 4-beat level. The top bar of 16-beats represents the outgoing track. The incoming track (represented by the lower 4 16-beat bars) can be phase-matched in 4 possible ways, using D'Groove's beatmatching aid. Only the top-most instance of the incoming track is correctly beatmatched in terms of the rules of musical timing.

This was implemented in this way for three reasons. First, forcing the turntable to rotate so that one revolution plays 16 beats, instead of four, causes the turntable to rotate too slowly. The 4-beat-per-one-revolution scheme causes D'Groove's turntable to rotate at speeds comparable to a conventional turntable's speed, thus the similarities between the two are increased. Secondly, it is uncommon but sometimes desirable to match the phases of two tracks so that their downbeats do not line up. This is done to produce interesting and unconventional mixes of tracks. When this is done, the downbeats of the two tracks are usually within a multiple of four beats from each other (as shown in Figure 19). Thirdly, a DJ still has to have knowledge about musical timing and understand which beat (in a set of 16) is a downbeat, thus retaining the value of their skills. If too much aid is given to the task of beatmatching, the fun in the challenge is lost and some DJs begin to loose satisfaction and feel devalued. In the end, a range of beatmatching aids is provided. DJs can choose to use the conventional audio feedback (no support), beat markers on the platter (additional support), the tempo information in the GUI (more additional support), or a combination of the three (full support).

With two D'Groove turntables, DJs can use the lines to visually compare tempos (now proportional to the turntables' rotational speeds) and phase (relative direction and magnitude of the offsets of the two red marks). With one D'Groove turntable, the multimodal quality of the feedback still aids the user as information in one modality (vision) helps guide attention to information in another (audition). This concept was discussed by McDonald [29] and Bertleson [7] but in their case audition was used to aid vision in a localizing task. We hypothesized the converse to be true and tested this in our user study (Section 5), using one D'Groove turntable and one Technics SL-1200 turntable.

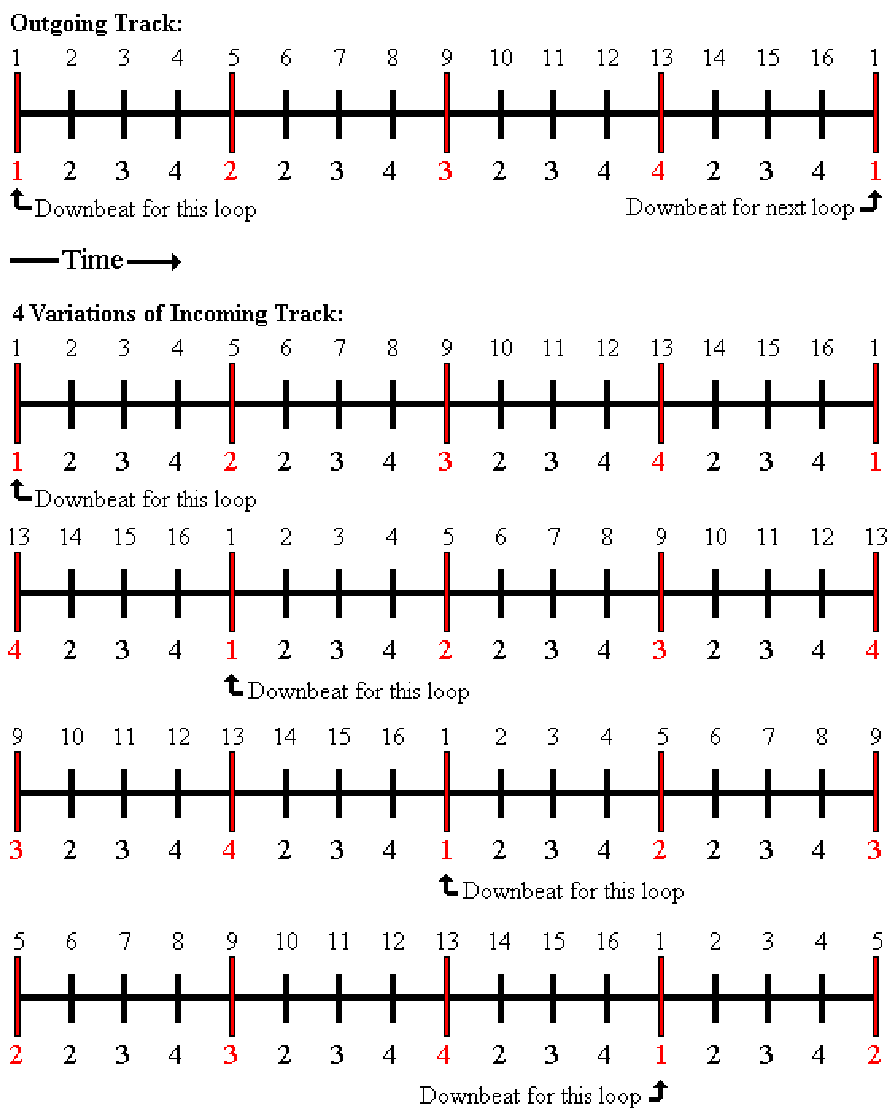


Figure 19 Four 16-beat loops out of phase with the top 16-beat loop by increments of 4 beats.

Another method of providing a beatmatching aid is the use of blinking lights to denote tempo. Some DJ mixers have flashing LEDs next to each channel. A flash denoted a beat, providing extra visual information when beatmatching, but ultimately the method was not accepted. The lights were too obtrusive and were commonly covered during performances. Our method is relatively unobtrusive as it does not demand attention and can be easily ignored. Also the difference in the rotational speed of our platter, versus conventional platter speeds, is minimal.

4.3.2 Setting the Scratch Distance

D'Groove is able to map any amount of movement from the turntable to any amount of playback in the music. Commonly, the four-beats-per-one-revolution rule is used to aid with beatmatching, as described in Section 4.3.1. However, scratch DJs sometimes find it useful to change this mapping, providing more precision when scratching. A DJ can decide how much movement they want in a scratch by specifying the distance the turntable must move in order to reach the limits of a desired audio sample. A long audio segment, that usually takes half a revolution of turntable movement to play, may be physically too great a distance for scratching. In this case, the DJ can alter the mapping, shortening the distance travelled by the turntable in order to play the same sample. Likewise, a DJ can map small audio segments to larger distances. This allows the DJ to customize the amount of hand movement associated with certain scratch tricks.

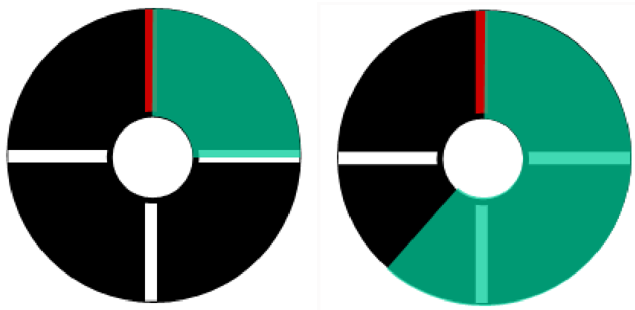


Figure 20 Stretching a sample's distance on D'Groove

It is possible to make a whole song play in one revolution. Likewise, the same song can be dragged out for several revolutions. Sometimes DJs want to play lots of sound (many samples) with a short hand movement. This can yield the effect of very fast scratching with relatively less effort. At other times, it is desirable to stretch a sound over a longer distance because the DJ wishes to perform a scratch trick with just one sound.

To change the mapping in this prototype, the DJ has to alter two parameters within the graphical user interface (see Section 4.2.4). The parameters are the number of beats per revolution and the ratio of revolutions per tempo. By altering these two parameters a song can play at its normal tempo while the turntable platter rotates ultra slowly or ultra quickly. As scratch DJs may need to change this mapping rapidly, the DJs in our evaluation expressed a desire to have two knobs on the turntable, allowing DJs to switch between settings for each parameter via a physical interface.

4.3.3 Haptic Effect Modes

Some of D'Groove's new functionality is in the form of several different haptic modes implemented on the turntable and Q-slider. Each mode is selected from the GUI and provides a new method of interacting with a DJ system. Certain modes, such as the spring, the beat-hills, the bumps-for-beats and the textured record mode, are designed to augment scratching. DJs would play a song on a secondary source, put D'Groove into one of these scratch modes, and use it to scratch over the music. Other modes, such as the resistance mode and, again, the beat-hills are used for exploration of songs. DJs would use these modes to gain information about songs when cueing them. Once satisfied, the DJ would then switch back to another mode before playback.

D'Groove calculates the position and velocity of the motors at each millisecond. These values are run through crafted controllers to create distinct textures and content-related effects. These effects were implemented with a technology-centric design as haptics have not yet been incorporated within the DJ domain. We wanted to show DJs some of the possibilities afforded with this new technology and let them decide if the effects were useful.

The Spring Scratch

The spring mode is implemented on the turntable. With a haptic spring, D'Groove can create new scratching techniques. A virtual rotational spring is simulated by the turntable motor, causing the platter to rotate back and forth about a given home position. The damping and spring strength parameters can be adjusted, allowing for a variety of spring feels ranging from very tight to loose and 'sloppy'. An undamped spring oscillates quickly while a damped spring settles quickly.

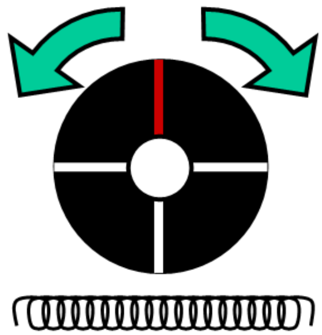


Figure 21 Scratching with a spring

The spring controller is implemented using a position PID controller to lock the desired position to a certain point along the platter. The chosen 'home point' is usually picked as the middle of a desired audio sample, causing the turntable to spring to the edges of the sample. The 'home point' is selected from the GUI. The music plays back and forth, along with the spring actions, sounding either very much like professional fast scratching (with a tight spring), or slow sloppy scratching (with a relaxed spring).

Using a spring allows the DJ to 'pluck' at the platter like a string on a guitar, instead of scratching it back and forth. DJs can push records away but the spring brings them back again. Likewise, DJs can pull on the platter and it pushes away when released. If left in motion after a push or pull, the record oscillates back and forth until it settles. This can often free up a hand – the DJ can set the platter into the motion with one hand and then use the same hand to operate functions on the audio mixer (whereas previously the hand was constantly occupied with making the scratching motion).

DJs can also use the spring to bounce the platter rotationally, much like dribbling a basketball. To do this, a DJ pushes the platter away from the home position and then temporarily releases the platter. As it reaches the stretch limit of the spring, the platter bounces back to the DJ's waiting hand, where the process is repeated. With practice, a DJ can create a static rhythm from the bouncing platter. This is an example of direct interaction with the spring model.

To imitate a scribble scratch, making the record oscillate quickly over a short distance (see Appendix C for a description of a scribble scratch), the spring can be tightened by increasing the gain of the PID controller. This causes the turntable to flicker back and forth wildly, creating short bursts of sound in either direction. It also allows the DJ to set the turntable into semi-autonomous motion while he/she turns to work on other areas of sound manipulation, for example by using the mixing board.

Navigating with Amplitude and Haptics

Conventional vinyl records contain grooves that relay information to the DJ about the content of the song. Usually one side of a record will contain one song and the DJ can see the breakdown of the song by noting the density of the grooves. Sparsely placed grooves denote a *break* (a relaxed part of the song) whereas densely spaced grooves denote more exciting music with greater changes in frequency. The needle on a conventional turntable is used to access the grooves and by replacing the needle with the Q-slider, we transferred the information from the grooves on a record into haptic feedback on the Q-slider.

Often, these grooves are hard to analyse, especially in dimly lit situations (a common occurrence in the DJ world). Thus, it is desirable to have an alternate method of navigating through a track. Two haptic models were developed for navigation.

The Resistance Mode

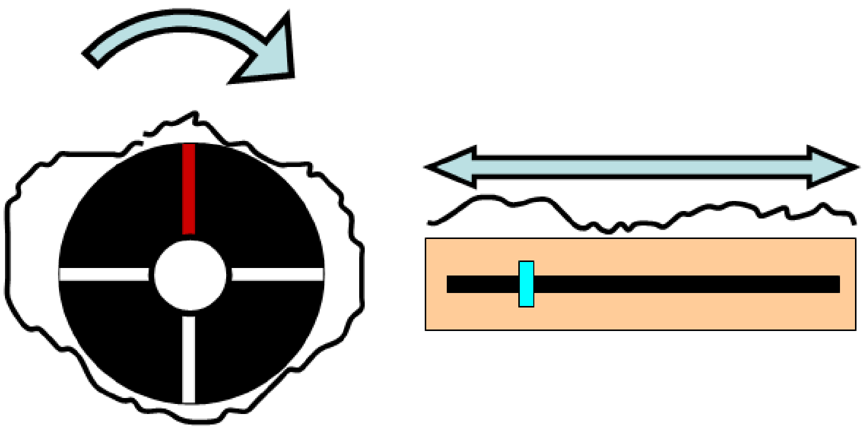


Figure 22 Resistance from audio amplitude is mapped to the turntable (left) and Q-slider (right). The arrows indicate movement and the lines indicate resistance.

In resistance mode, the current auditory amplitude of the song is mapped to resistance on the Q-slider. By applying a PID controller on velocity with the goal of the PID to make velocity equal to zero, the motor of the slider attempts to prevent the slider from moving. The gain of the PID controller dynamically changes, depending on the amplitude reading at the current point in the song. Larger amounts of resistance, like wading through a muddy patch, indicates moving from a low energy segment to a high energy segment. Lower energy portions or *breaks*, reduce the resistance and cause the slider to become easier to move. This allows the DJ to know when to release the handle on the slider. Thus, DJs can move the slider along the track until they get to a point that feels right and then let go, causing the slider to resume its movement along the track as the song plays. The haptic force feedback is only enabled when the user is squeezing the pressure sensor on the slider.

The same haptic model was also implemented on the turntable platter. As the platter controls finite position within a song and the Q-slider controls the current bar of a song, the precision of the turntable's feedback is greater. A DJ can feel tiny changes in the music, such as the onset of beats, by noting small changes in resistance. Finding these small transitions is useful to DJs as they can denote beats within songs. Like the Q-slider, the turntable can also convey mood changes with large overall changes in resistance.

The Beat-Hill Mode

The beat-hill mode is implemented on the turntable only. Like the resistance mode, it also relays information about the structure of a song to the DJ. A force command is sent to the motor that is based on the amplitude reading at the current song location. The effect is to turn areas of high energy (higher average amplitude) into virtual potential hills with greater resistance than areas of low energy. Pushing the turntable platter forward (in a clockwise fashion), at the onset of a high energy segment, feels like pushing something up a hill. Throughout the high energy section the force plateaus, yielding the effect of moving along a level path. Finally, when moving from a high energy segment to a low energy segment (a break), the turntable feels like it is falling down a hill. This process repeats throughout the song.

The beat-hill mode can sometimes act like the spring mode in that the DJ is able to bounce the platter off beat-hills. As the platter is approaching a burst of sound, a hill is created. If the DJ pushes the platter up the hill and releases it with the right amount of force, the platter can often roll back down the hill and into the DJs hand. Half of the beat will be played once forwards (going up the hill) and once backwards (going down the hill) and can be used to create a rhythm.

Creating the Amplitude Force Effects

The process of generating the proper force for each navigation effect is the same in both cases. The song is analysed prior to being played and a single file is generated containing force values to be used throughout the playback of the song. The force file is generated from the envelope of a condensed version of the waveform.

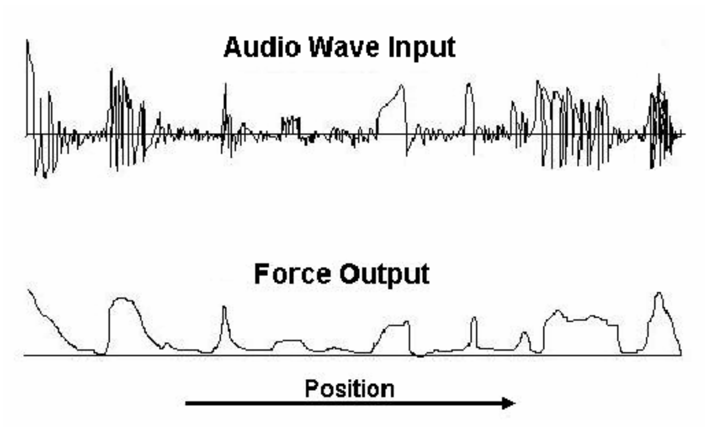


Figure 23 An audio input and the corresponding force output

There are 14,400 encoder counts per revolution of the turntable and r revolutions in a song. Thus there are t = 14,400r encoder counts in a song. Each count is assigned a force value that is contained in a lookup table. Most wave files are encoded at 44,100 Hz and all have a tempo measured in beats per minute (BPM). The idea is to re-sample the waveform with a total of t values. The value of t is calculated as follows:

Let s be the number of seconds in a song.
Let b be the BPM of a song.
Let n be the number of beats in a song.
Let r be the number of turntable revolutions in a song
Let t be the number of encoder counts in a song
Recall that there are 14,400 encoder counts per revolution
Recall that D'Groove requires 4 beats to be played per revolution

Thus we can say that:

$$n = s \times (b/60)$$

$$r = n/4$$

$$t = r \times 14{,}400 = 60 \times b \times s$$

Next, the waveform data is stretched or compressed (most likely compressed) to the size of t. The resultant waveform is squared to accentuate the difference in values and remove any negative data points. An acausal smoothing algorithm is then applied to the wave. This involves joining two successive peaks in the wave with a line, thus removing smaller valleys. The smoothing process is repeated one thousand times. The final data is used as the force values for the platter and Q-slider. There is one force value for each encoder count in the song.

To shrink the size of force files, the same algorithm is applied but instead of producing a force point for every encoder tick, a force is generated for each beat in a revolution (4 forces per revolution) or even a single force per revolution. These force-files are often useful as sometimes it is not critical for the level of detail in navigating a song to be as fine as one force per encoder count. A change from high energy music to breaks often occurs at the end of a bar, which corresponds to a complete revolution. If the goal is locating these moments in a song, then it is only required to generate a force for each revolution. For more complicated songs that make changes at the half-bar or quarter-bar level, a new force is generated at each beat, which corresponds to a quarter revolution of the turntable.

In resistance mode, the force data is used to determine the gain for the PID controller. Recall that the controller is attempting to set the velocity of the platter or Q-slider to zero so a higher force value will produce more resistance.

In beat-hill mode, the *slope* of the smoothed force curve, calculated at the current encoder count, is used to determine the force sent to the platter. The points adjacent to the target point are used to calculate the slope. This value is negated. A negative force is produced when the signal is rising, causing the turntable to travel in a counter clockwise direction. A positive force value is produced when the signal is descending, causing the turntable to move in a clockwise direction. Higher magnitudes in slopes cause higher magnitudes in forces to be produced. The sign of the slope determines the direction of the force.

Bumps for Beats

A simple yet effective method for denoting beats in a song is to produce a haptic bump at the onset of a beat. We call this 'bumps-for-beats' mode and we implemented it on the turntable. These bumps can be generated without the large force files described above (in the section entitled *Creating the Force Effects*) as D'Groove knows that there are four equally spaced beats in one revolution located at every quarter turn of the platter. A haptic bump can be placed at these locations and each bump will match up with a beat in the song simply from knowing the tempo and timing structure of the music (note that we assume the tempo remains constant).

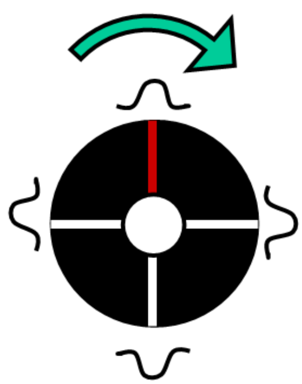


Figure 24 Haptic bumps at the four poles of the turntable

To produce these bumps, a sine wave algorithm is used. The force sent to the turntable platter is generated by taking the sine of the platter's current position. The number of sine waves and the height of each wave can be calculated through the following equation:

$$desiredForce = waveHeight \times \sin(position \times numberOfWaves)$$

To produce a bump at each quarter revolution of the platter, numberOfWaves is set to four. The position value used is the current position of the platter in radians. Adjusting waveHeight affects the force amplitude of each bump.

This mode is useful for quickly locating a certain beat within a revolution with the touch sense. Using the touch sense can be helpful when trying to perform quick movements where the eyes and ears are often needed elsewhere. Beat juggling is an example where this effect might be useful as DJs can quickly feel how far they have rewound the platter without having to look or listen to it. During this task, the eyes are often on the opposing record and headphones are rarely used to cue songs. This suggests that haptics may be an optimal feedback method for this task but further testing must be performed prior to making this claim.

Textured Records

Another interesting mode on the turntable that can be produced, with the same sine wave algorithm used in the bumps-for-beats mode, is the textured-record mode. By increasing the number of waves in the sine wave algorithm to 50, a 'bubbly' texture is created as the record is moved around. This effect can be used to create a new scratch that we call the one-handed hydroplane scratch (this was invented by one of the DJs in our user study – see Section 5.3.2). In a traditional hydroplane scratch, the DJ moves the record with one hand and uses a finger from the other hand to produce friction (by moving the finger in the opposite direction of the record). This causes the record to jitter making a bubbly effect on the music. The sound is much like a hydroplane scratch and only one hand is needed for moving the record.

4.4 Electronics and Communications

The current D'Groove prototype consists of three controllers, one passive and two active. The active controllers are the turntable and the Q-slider. Both have separate power supplies and amplifiers. They are separately driven from two digital-to-analog converters (DACs) on a Keithley Metrabyte I/O board inserted in a Pentium PC running Linux. The I/O board also reads the circuit for decoding the encoders on both motors as well as the positions of the Q-slider's and pitch slider's potentiometers.

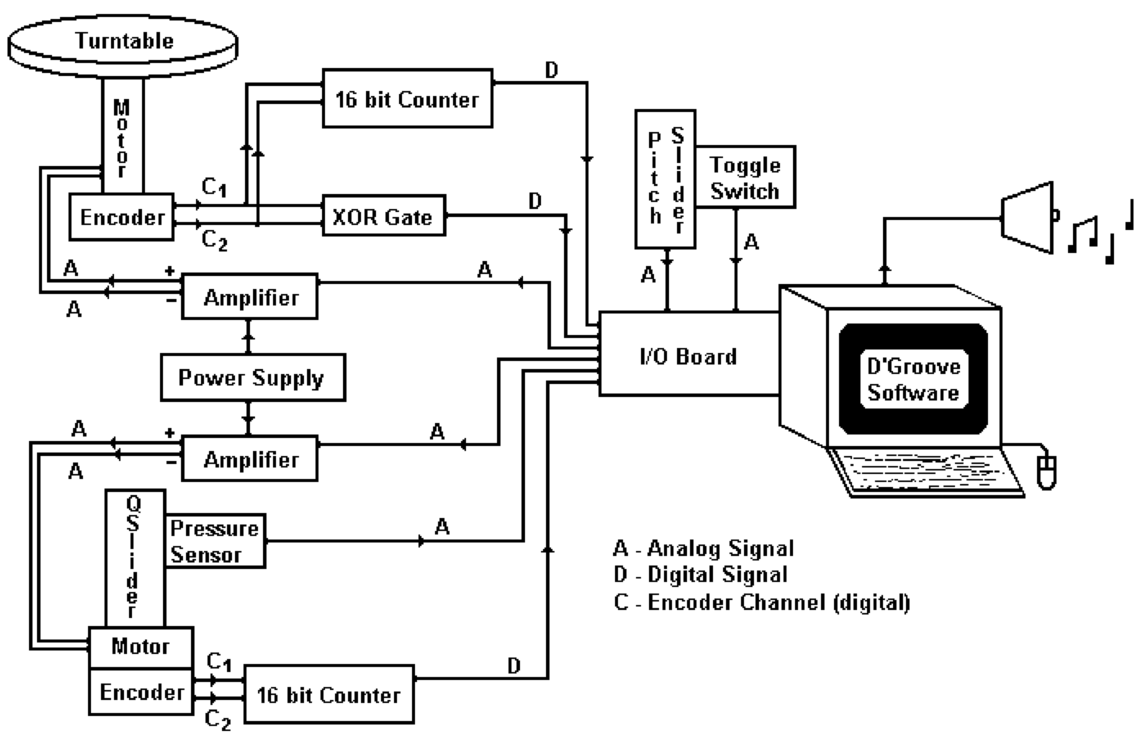


Figure 25 The D'Groove Component Schematic

The Keithley Metrabyte I/O board is a DAS-1602 model and has two analog outputs, 8 analog inputs and 16 channels of digital I/O (that can be configured for input or output). The two analog outputs are used to send voltage to the two motors. The analog inputs consist of the potentiometer on the Q-slider, the potentiometer on the pitch slider, the force sensor on the Q-slider and the on/off switch on the pitch slider. The 16 channels of digital I/O are used to send and receive messages from the encoder decoder circuit. This circuit decodes both encoders on the turntable and the Q-slider. A schematic of this circuit can be found in Appendix A.

4.5 Software Architecture

D'Groove is a realtime motor control and musical playback system. It uses two haptic control loops to invoke forces over the two motors as well as an audio engine to playback music at various tempos. The critical realtime code is run in the Linux realtime kernel and communicates with non-critical code in user space through shared memory. Thus, the software is comprised of four components, a series of hard-realtime motor controllers (written in C), an audio engine (written in Java), a soft-realtime user interface (written in Tcl/Tk [35]) and a monitor program to 'glue' the other components together (written in C). Figure 26 shows how the components are connected.

D'Groove's operating system and utilities environment, described below, is composed completely of Open Source components readily available from the Internet.

4.5.1 Realtime Operating System

A realtime operating system was required to control the forces of the motor without hindering the playback of the music. After an analysis of various realtime-operating systems, Real Time Linux (RTLinux) [19] was our choice. It appeared to have ample documentation and was freely available.

RTLinux comes as a free patch for most Linux kernels and splits programs into realtime and non-realtime components. The motor control loops are run as realtime components in the kernel. The musical playback software and GUI are non-realtime and are run in regular user space.

Andrew Morton's low latency audio patch [33] was also installed. It gives the audio playback portion of the system its highest chance for low latency. The patch delivers near-realtime audio playback with latency of 5 ms or less.

4.5.2 Software Schematic

Figure 26 shows the schematic for the software components in D'Groove. Software modules are run in hard-realtime in the kernel space and in soft-realtime in the user space. The two spaces communicate through shared memory. The kernel components communicate to the exterior components through the COMEDI API [3]. All haptic models and motor controllers/sensors are computed in the three kernel modules.

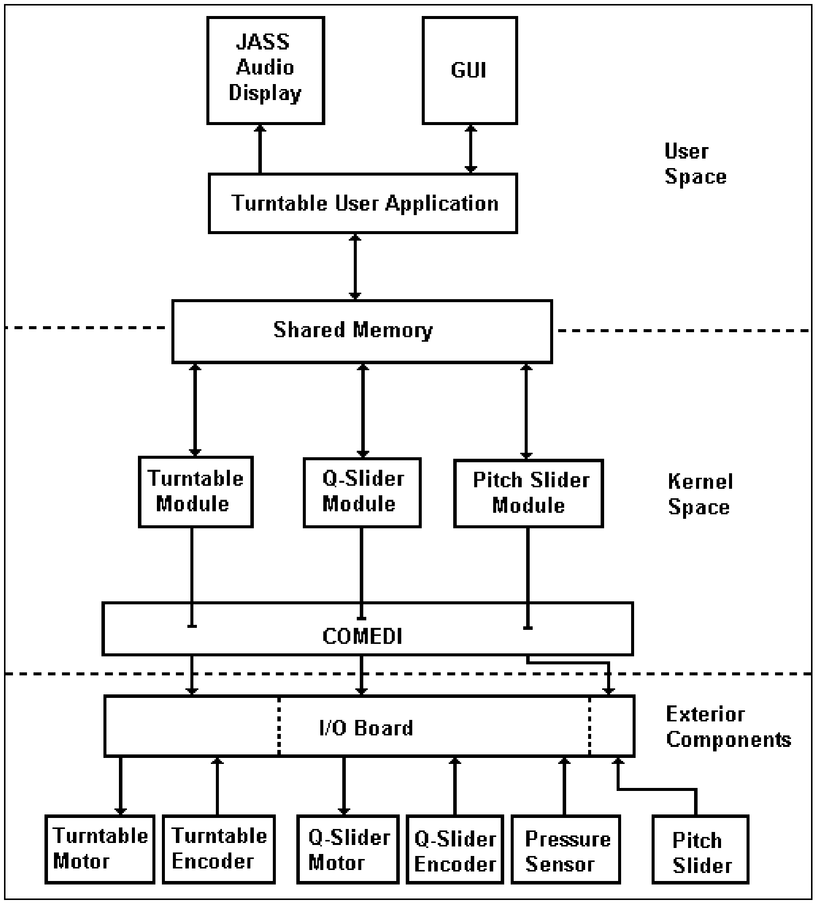


Figure 26 Software Component Schematic

4.5.3 Sensing and Motor Control Threads – The Kernel Threads

Three 1 kHz sensing/control loops are run in the kernel. Two of the loops each control one of the motors, driving the turntable and the Q-slider. The third loop monitors the pitch slider, which has no motor to be controlled.

Our main goal for the turntable was to maintain a constant velocity that may be over-ridden, just like a real turntable (i.e. the user can still feel resistance when over-riding, and in fact relies on it). For the Q-slider, it was desired to have tight control over position when not held, switching to a haptic mode when operated manually. In both cases, haptic force feedback effects were displayed through each motor (see Section 4.3.3).

Within the turntable loop, the encoder counter was queried and a velocity reading based on the last three position samples was calculated. A smoothing technique removes noise from the velocity estimate and makes the control more stable. To smooth a value, we use the average of the previous three velocity calculations. The smoothed value is the input for a PID controller on velocity, when the turntable is in conventional turntable-mode. The value of 3 was picked from a trial and error method until the turntable achieved a desired speed in minimal time, without a noticeable latency in musical playback.

The Q-slider works much the same way except we use position control instead of velocity control. We feed the position of the Q-slider into a PID controller on position and use the result to compute a force value. The desired position is determined from the current position in the song, which is determined from the movements of the turntable. If the pressure sensor on the Q-slider is held, control over the position of the song switches to the Q-slider.

The implementations of the control algorithms for each mode are explained, with their effects in the Section 4.3.3.

Managing a Floating Zero in the Encoder

The turntable encoder has 14,400 ticks per revolution and the counter counts from 0 to 65,535 before it wraps back to 0 again. Ideally, it is desirable to know the position of the encoder (from 0 to 13,399) so the position of the turntable can be determined, but the system only has access to the counter. As 14,400 does not divide evenly into 65,535, there is also a floating zero problem. The encoder position (in a range of 0 to 13,399) must be based on the counter reading (in the range 0 to 65,535). The same problem occurs with the Q- slider, as it has 400 ticks per revolution and runs on a similar counting chip.

An algorithm to determine the proper positions for the motors was implemented and inserted inside the haptic loops. The algorithm always returns a value between zero and the highest encoder tick. A pseudo-mapped counter value is used. Each time the real counter value flips (from 65,535 to 0 or vice versa), we map the counter's zero value to the appropriate encoder tick, updating our pseudo-counter value. This effectively removes the problem caused by the floating zero. A modulus operation on the pseudo-counter value and the encoder resolution is used to calculate the position.

Measuring the Velocity with Encoder Wraparound

A wraparound problem occurs when calculating the velocity of the turntable at the moment that the encoder flips from 65,535 (its highest value) to 0 (its lowest value). This is not generally encountered in haptic interfaces, since most configurations do not allow continuous rotation. If the distance is calculated by subtracting the current encoder reading from the last encoder reading, a relatively large magnitude occurs at this point. The computed velocity becomes huge and the system becomes briefly unstable.

To avoid this, the position is converted into radians and the sine and cosine of the encoder reading is used to determine the distance. This yields a continuous distance reading and removes the velocity jerk when the encoder flips.

Once the velocity is determined, we feed it into a proportional-integral-derivative (PID) control algorithm to calculate a force to send to the motor. The user specifies the desired velocity of the turntable using the pitch slider and the PID controller makes it happen. If the user touches the turntable, the PID controller senses an error and attempts to compensate. The integral component of the PID controller is necessary to reduce steady state error but causes windup when the user holds the turntable platter. The error between desired and actual velocity steadily increases, driving the force up. Therefore, requiring the implementation of an anti-windup cap that limits the amount of the integral component to a level that the user cannot perceive.

Achieving Steady Low-Velocity Motion

One of the more interesting challenges in controlling the haptic turntable was the need to achieve a truly constant velocity from the motor, when in regular turntable-mode. When in turntable-mode, the musical playback is determined by the position of the turntable. The current position of the turntable is controlled by a PID controller on the velocity of the turntable. The desired velocity is set by the user. If the velocity is not steady, the rate of playback is not steady. In the first design, we found our velocity estimate (differentiated from the encoder signal) was undesirably noisy, at relatively slow velocities. This caused undesirable wavering sounds in the music.

The basic problem is that at typical playback speeds, relatively few encoder ticks are received per millisecond sample period, even with a relatively high-resolution encoder. For example, we might play a song with a tempo of 120 beats per minute (BPM) on the turntable at 30 rotations per minute (RPM). This equates to 4 beats of the song per one revolution of the turntable, or ½ rotations per second. As the system is sampling at 1 KHz and using a 14,400 CPR encoder, 2 encoder ticks are expected to go by per sample. Occasionally, 1 or 3 ticks would be counted from the encoder. This translates into a huge distance offset of 50% and causes the PID controller to compensate for the offset. Even minimal compensation causes the loop to become unstable for 5 to 10 samples, as it tries to maintain 2 ticks per sample. This was apparent in the music as audible wavering, particularly noticeable when playing a pure tone through the turntable.

To solve the problem, the “1/T method” [8, 26] was implemented. It calculates the amount of time that occurs between each encoder tick, instead of the number of encoder ticks that occur in a given amount of time (in our case, 1 ms). This was implemented through the use of a callback routine and COMEDI’s data acquisition API. The two channels of the encoder were run through a simple XOR gate and that signal was sent into the interrupt pin of the parallel port. Then a small realtime callback routine was generated. It was invoked each time the XOR’d signal went from low to high. The routine read a timer on the PC's motherboard and calculated the number of nanoseconds that had elapsed since the last time this routine was called. It stored this value in shared memory so that it could be used by our 1 kHz haptic loop to calculate the velocity. It was important not to do too much work inside the callback routine as it needs to be very fast in order to work properly. A simple subtraction between the current time and the previous time was all that was needed and proved to be fast enough. When playing the turntable at high speeds, D'Groove returns to the original method of calculating velocity as too many interrupts can cause the system to freeze.

It should be noted that this callback routine was only invoked when the signal from the XOR gate went from low to high. The encoder actually advanced again when the same signal switched from high to low. Finding a suitable method to create an interrupt for every encoder tick proved difficult at the time. Instead, generating interrupts on every second encoder tick and dividing the result by two was implemented. In hindsight, a flip-flop with an OR gate or a strobe circuit may have worked better. Although our implementation is not perfectly accurate, it is a significant improvement over estimating the velocity from the number of encoder ticks that are measured in 1 ms, as was attempted initially. This method successfully provided the turntable with a constant velocity, removing any noticeable jitter in the resulting music.

4.5.4 I/O Library: COMEDI

COMEDI [3], an open-source Linux-based API, which supports many commonly used data acquisition boards, was installed. COMEDI allows code to be written that is not dependant on a certain I/O board. Thus, the I/O component of D'Groove can be run without modification on any Linux system supported by COMEDI.

4.5.5 Audio Display: JASS

The audio software was written using JASS [14], a unit-generator based audio synthesis programming environment, written in pure Java. It streams an audio file and reads the encoder data (read from shared memory through the JNI, the Java Native Interface) at a fixed control rate of $F_c = N/F_s$, where N (currently 128) is an internal buffer size and F_s is the audio sample rate (currently 44,100Hz). The internal buffer holds the audio that is played through the speaker.

The current encoder tick (t) and the previous encoder tick (t-1) are translated into seconds (in terms of the song's length). These two data points are passed to the JASS engine where we compute a past and a present pointer into the audio file (we can think of this as the virtual needle), which dictates the fragment of audio to be played. The duration of the audio fragment corresponds to the momentary time between encoder ticks, multiplied by the current playback speed. The audio buffer of length N is constructed by resampling this fragment.

For example, if the turntable is moving at 0.7 of the normal playback rate, the needle will have moved by 0.7 N/F_s seconds, which corresponds to 89.6 samples. If the past position of the needle was at 12.3 seconds, for example, this means we have a segment [12.3-101.9] of the audio file which we now resample with N=128 sample points. We use linear interpolation for the in-between sampling. This is the same technique used for the generation of van den Doel's scraping and rolling sounds as described in [13]. Note that speeding up the audio does technically introduce aliasing, but this does not seem to produce a negative side effect in the audio (especially when scratching).

The procedure is illustrated in Figure 27. A buffer of size N=4 is computed from the current (t) and previous (t-1) encoder ticks. These encoder ticks dictate the position of two pointers in the audio file (the past pointer and the present pointers). The pointers are used to resample a set of points from the audio file (the green circles) to create the buffer (the open circles). The sample values in-between the samples of the audio file are computed by linear interpolation.

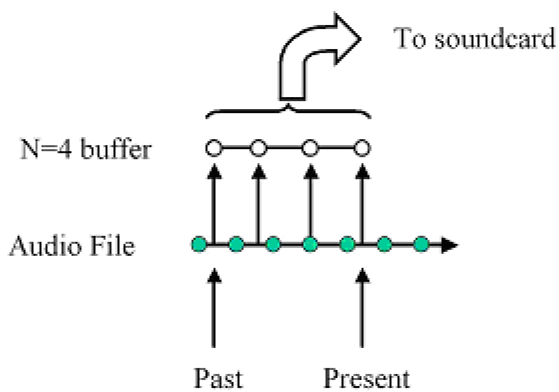


Figure 27 Computing a JASS buffer. Pointers 'Past' and 'Present' are positions from the turntable that are used to sample the audio file and create an audio buffer to be played.

After computing an audio buffer of length N, it is sent to the audio hardware for playback. The latency of the audio playback has been measured for a 1.2GHz system to be N/F_s = 3ms. JavaSound, the default audio implementation for Java, is known to have poor latency issues. We have achieved our latency by using JNI to access the audio hardware instead of JavaSound. For this the RtAudio [39] interface is used internally by JASS.

The audio processing algorithm is efficient and uses only a few percent of the processor on a typical 1GHz computer.

To load a song into JASS, the DJ must start a new JASS process, passing the name of an audio file as a command line parameter. This is rather crude as it takes relatively longer to search for songs and type them into a loading command. The important issues involve finding the right song and loading it into the system quickly. We realize that song selection is an important part of DJing and that this function needs to be embedded in a GUI. Ultimately, we envision a touch screen where songs are listed under genres. Selecting songs with a finger or another suitable pointing device would insert them into the audio engine.

In the first implementation of D'Groove, the Alsaplayer [28] was used for audio playback. It was replaced by JASS because the Alsaplayer used a velocity calculation in determining the proper speed for musical playback. JASS uses position. Since the sensor on the turntable is a position sensor, velocity is a contrived value and is subject to error. It was found that drift would occur between the movements of the turntable and the music. A full revolution in one direction and back again would not position the music at the same location. There was also a noticeable latency in the system. Upon the switch to JASS, both of these problems were solved.

4.5.6 Communication between Motor Control & JASS

The soft-realtime portion of D'Groove runs within the user space as opposed to the kernel. A monitor program (written in C and referred to as Turntable User Application in Figure 26) checks the position of the turntable by accessing the shared memory that is updated by the realtime kernel processes. The monitor also deals with input from the user and sends requests to the motor controllers. The monitor is also connected to our media player, JASS (written in Java), through shared memory. The monitor sends a position value to JASS, based on the calculated velocity and JASS takes care of playing back a song at the proper speed and direction. See Section 4.5.5 for a description of how JASS works.

Chapter 5

5 Functional and Aesthetic Validation

In this chapter we discuss an observational study where we allowed experienced DJs to try D'Groove and comment on its usefulness. We discuss the setup of the study followed by various reactions to the features of our system as well as new ideas that came about whilst playing with the tool. We also mention new tricks and unanticipated interaction techniques that some DJs discovered when using D'Groove. These are especially exciting as they demonstrate creativity exercised via the system – one of the goals of D'Groove.

5.1 Purpose of the Observational Study

We were eager to have expert DJs come and try the first D'Groove prototype. We wanted to see if the DJs found the new features useful, what they liked and disliked about our system and whether they missed using vinyl. We also wanted to learn about what other features they would like to see.

5.2 Setup of the Observational Study

The study consisted of six expert DJs who each volunteered for a single study session. The DJs were recruited by personal invitation, and uncompensated; they were attracted to the study from an enthusiasm for new DJ technology.

Because DJing is an art form and a means of self expression, we felt it was more important to collect qualitative than performance data. Thus, in each session the participant played with D'Groove for at least two hours with the experimenter present; and was afterwards engaged in a structured interview. Throughout the session, the DJs were encouraged to speak aloud. The sessions were videotaped.

The six DJs were categorized into two groups: three scratch DJs and three mix DJs. For clarification, each was given a moniker: Scratch1, Scratch2, Scratch3, Mix1, Mix2 and Mix3. Scratch1 was a committed scratch artist whereas Scratch2 and Scratch3 were comparatively new to the art but were keen on developing their skills. Mix1 was an adamant mix artist with no interest in the scratching aspect. Mix2 was the only female interviewed as males are more common in the discipline. All three of the mix DJs were familiar with the procedures of scratching but did not practice the art. All the DJs were between the ages of 21 and 30. Experience levels ranged from 3 to 12 years, but all DJs had had ample experience performing in front of an audience and could beatmatch vinyl records in less than 10 bars.

Figure 28 Expert DJ using D'Groove

The audio output of D’Groove was connected to a common DJ audio mixing board, the Numark Pro SM-3. A Technics SL-1200 turntable was also connected to the mixer to complete a DJ setup (one conventional turntable and one D’Groove turntable). This setup allowed the DJs to compare the differences and similarities between D’Groove and the industry standard turntable. Figure 28 and Figure 30 depict the setup; the scratch DJs requested placements of D’Groove on their left side so their preferred hand was using the crossfader as shown in Figure 28. After a tour of D’Groove’s features, the DJs were asked to mix back and forth between the Technics SL-1200 and D’Groove. They were also asked to try scratching with D'Groove and were encouraged to invent new tricks using D'Groove's features.

5.3 The DJs' Responses

All of the DJs said they were impressed with the technology and most claimed that if the appearance of the system and the turntable torque were improved, they would attempt using it on-stage.

5.3.1 Functional Features

Digital Vinyl

The most popular feature was the ability to play digital music as if it were on vinyl (i.e. having the sound of the music change as it would when a traditional record is manipulated). Scratch1 was the only DJ who found fault with the sound quality; however, it was only when the turntable was moving at relatively slow speeds. This is understandable as slow speeds produce a higher amount of interpolated sound. We used a standard sampling rate of 44,100 Hz with our test songs. The output of D'Groove is always 44,100 Hz and we must resample the input song, no matter what speed it is playing at, to produce the correct number of output samples for each second. If the turntable is rotating at half speed, we have to derive half the sounds to maintain our output frequency. If we doubled the sampling rate of a song, then we could reduce its speed by half without deriving new samples.

Low Latency

Scratch1 was the only user who detected a noticeable latency. He claimed that it occurred only when making a quick direction change from backwards to forwards. He also added that it was very slight and could be compensated with ample practice. The remaining DJs were impressed with the reaction time (less than 6 ms) when comparing it to a conventional turntable.

Visual Beatmatching Aid: Beat Markers

The second most popular feature was the visual beatmatching aid (i.e. the lines) on the turntable. We designed this feature, believing it would enable visual confirmation that the beats of D'Groove were matched to the opposing vinyl record, as they could watch the red line (the first beat in a bar) hit 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock for each of the four beats in the bar. Interestingly enough, none of the DJs actually used the lines in this way - they relied entirely on their ears for beatmatching confirmation. Instead they found new uses for the red line. For example, they used the red line when cueing D'Groove to the beginning of a bar. Mix2 used the red line to indicate the passing of a bar when the platter was in motion. Some of the DJs liked interrupting the playback of the turntable by grabbing it and scratching while it was playing alongside the conventional turntable. They could then easily resynchronize D'Groove with the conventional turntable by re-cueing it so that the red line was at 12 o'clock and then releasing it (so it plays on its own) at the next downbeat. Each DJ was asked if they envisioned the red line as a beat traveling around the turntable. The reply, in all cases, was "no". The white lines (symbolizing the remaining three beats in the bar) were not used at all by any of the DJs.

Interestingly, Mix1 noted that some dance songs contain a rest that counts for a single beat between two bars. Thus, the bar after the rest would begin five beats after its preceding bar as opposed to the normal four beats. He claimed that the red line would loose synchronicity after the rest. It was agreed that these songs were uncommon and familiarity with the music ahead of time would allow the DJ to prepare for these special cases. The solution would be to note that the red line would signify the beginning of a bar at the 3 o'clock position after the rest as opposed to the normal 12 o'clock position.

Location of Beat Bar in Relation to Beat

Scratch1 and Scratch2 preferred to have the first bar start at the 9 o'clock position. They claimed it was analogous to the way they would affix tape to their records to denote the same musical point on conventional vinyl. Therefore we re-synchronized D'Groove for these DJs so that songs began at 9 o'clock instead of 12 o'clock. The remaining DJs did not complain of this and were left with 12 o'clock bar starts.

Beat Juggling with the Beat Bar

All of the DJs, especially the scratch DJs, noted that the red line would be extremely useful when beat juggling. Normally a DJ has to memorize the position of a piece of tape (or paint) on a record. This mark is used to discern the position of the record in relation to the current bar. D'Groove's red line does an even better job because its position always signifies the same place in a bar. Backspinning to re-cue a bar is easy as DJs do not have to remember how much to backspin for each bar in a song.

Turntable Power

The main complaint about the system was the power of the turntable platter's motor. Admittedly, the motor does not have the same amount of torque as a Technics SL-1200 motor. All of the DJs commented that they could learn to deal with this over time however, more torque would be desirable. Scratch2 spoke about how a Technics SL-1200 turntable feels "almost alive" and "bursting with power". He desired these qualities in D'Groove. We chose our motor based on its ability to produce effective haptic effects and its relatively high torque (for a haptic motor). Effective haptics and high torque are tradeoffs as motor designs differ, depending on which of these features is valued. We were keen on demonstrating haptics in the system, thus our choice was a compromise. We now believe that we can achieve an adequate torque and still retain the haptic features if we use a braking system in conjunction with a stronger motor, producing similar haptic effects.

Turntable Sidewall

Mix1 wanted a sidewall on the platter. A sidewall is a rim, usually one inch wide, that runs perpendicular to the platter. Mix1 used the sidewall on the Technics SL-1200 for slowing down (pitch bending) a moving platter when beatmatching. The sidewall provides the highest amount of leverage since it is the further from the center of the platter. On D'Groove he achieved a downward pitch bend by applying slight pressure to the center of the platter. As D'Groove's torque is not as high as a Technics SL-1200's, the lack of sidewall was a mild discomfort, but inhibited the operation of a common gesture.

5.3.2 Evaluating the Haptic Modes

The Spring Mode

In terms of the haptic features, the spring mode was the most popular. All the DJs agreed that being able to bounce the turntable, like dribbling a basketball, would be fun to do in a live performance. They all agreed that they would need sufficient practice but that was normal with learning any new trick on DJ equipment. Scratch2 and Scratch3 wanted to have the turntable ping-pong back and forth between two predefined points. Also, all of the DJs agreed that they would like D'Groove to produce stiffer springs – for which more torque will be required.

Scratch1 discovered how to automatically make a scribble scratch, a type of scratch trick where the DJ's record arm is tensed, causing a high frequency jerk on the record (and producing a short snappy sound). When D'Groove's spring force was over exerted, the turntable would become unstable and overshoot its target rest position, springing back and forth rapidly in a metastable oscillatory state. The result was a short snippety, almost helicopter-like, sound. Once set into motion, the turntable could be left and the sound would continue without intervention.

The Bumps-For-Beats Mode

The bumps-for-beats mode was found to be of interest for scratching, as opposed to navigating. Again, the DJs learned to dribble the platter and bounce it off beats (as beats were represented by hills which could be bounced around). An example sound would be half a bass drum sample being played forwards (as the record went up a hill) and then played backwards (as the record fell back down). Scratch2 and Scratch3 desired control over the frequency of the platter bouncing constantly between two points – allowing for tempo control. The idea of placing the bump just after the beat was exciting as well because the bounce would produce two distinct beat sounds – one as it went up the hill and another as it fell back down again.

Scratch1 discovered how to perform a one handed hydroplane scratch trick by increasing the amount of bumps around the platter. A hydroplane is normally done by moving the record with one hand and placing a finger from the opposite hand on the record such that it causes friction in the movement. The result is a bubbly, scratchy sound. By inserting many tiny virtual bumps along the turntable's path, Scratch1 could move the record back and forth with just one hand and achieve the same effect. He also reported being able to achieve very nice hydroplane sounds by setting the platter in normal turntable mode and using his friction finger on the underside of the platter, as opposed to the top (as normally done). He claimed this was exciting because the underside of the platter gave him a whole new surface with which to play and his hands would never get in each other's way.

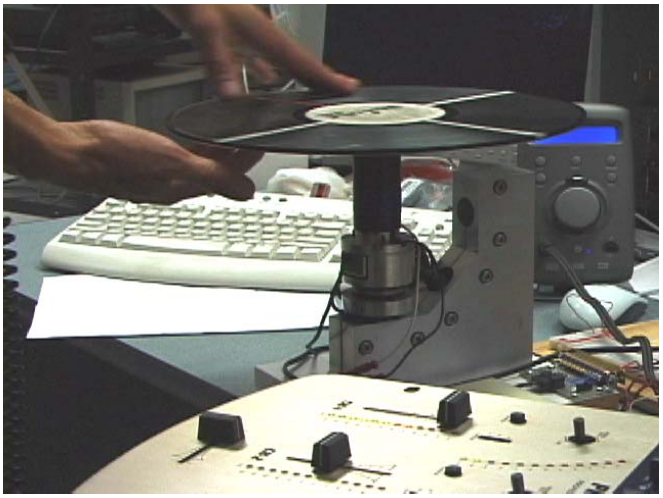


Figure 29 Expert DJ performing a hydroplane on the underside of the turntable platter

The Resistance Mode

The resistance mode on the platter was thought to be interesting but not immediately useful. None of the DJs thought they needed mood change information on the platter as it rendered the platter difficult to use for playback. They could not see any navigational or performance advantage with this mode. Their response to the resistance mode when implemented on the Q'slider is described below.

5.3.3 Evaluating the Q-slider

All of the DJs seemed to like the Q-slider. Mix2 liked our design but the other DJs asked for a graphical display of the song to be added to the slider so they could visually see the layout of the music. All DJs were asked to locate a transition from high energy music to low energy music. This is done on a conventional turntable by placing the needle on the part of the record where there is a noticeable difference in the density of the grooves. Surprisingly, it was done with equal if not better efficiency on the Q-slider, with the use of the resistive haptics. Ironically, all of the DJs in our study stated that, when mixing, they usually start all their songs from the beginning and that it is uncommon for them (though not unheard of) to cue a song to start on one of these transitions. Thus, this feature is useful but not as valuable as we had anticipated. The important issues are being able to quickly move through a song and anticipate when a change will occur in a song that is already playing. Visual feedback is desired for the latter point.

Figure 30 Expert DJs exploring a song's structure with the Q-Slider.

Needle Dropping and Looping

Scratch2 discovered a fun way to use the Q-slider for needle dropping and jumping to different parts of the song. Needle dropping is done on a conventional turntable by picking up the needle and rapidly dropping it into a groove to produce a short sound. As the D'Groove turntable spun on its own (providing musical playback), the DJ would gently tap the Q-slider without moving it. This would effectively pick up the virtual needle from the music and place it back down again in the same revolution. Because the turntable was still rotating, the music cut in and out but no change in musical time was made. Also, a one bar loop could be produced if the Q-slider was tapped at the point of change between revolutions. If the DJ tapped the Q-slider at the very end of a revolution, when the tap was complete, the turntable would remain on the same revolution thus creating a loop.

This DJ also discovered that the Q-slider could be used to move around to different parts of a song and still keep it beatmatched to another piece of vinyl. As the turntable is freely rotating, the Q-slider is merely changing which bar D'Groove plays. The musical timing remains the same (as it is controlled via the turntable) and the song remains synchronized with the opposite record. This was great for quick remixes of songs.

5.3.4 Evaluating the Pitch Slider

The scrolling feature of the pitch slider was also well received by the DJs. None minded having to use an extra switch in exchange for more range on the slider. In fact all were quite relieved to have the extra range. When asked how much extra range was desired, Mix1 stated that he wished for the gap between the fastest setting on a 33 1/3 RPM turntable and the slowest setting on a 45 RPM turntable to be closed. Mix2 decided that double the range would suffice but triple would probably not be necessary. Mix3 thought that having a limit on the range of pitch was pointless if it was easy to remove. For discussion purposes, two alternatives for the device were mentioned – having two sliders (one for large jumps in pitch and one for smaller jumps) instead of a switch, and using a mouse-wheel-device instead of a slider. All the DJs thought that the two slider idea might be a more suitable alternative than the current implementation but all rejected the idea of a mouse wheel replacing the slider.

Four of the DJs (Scratch1, Scratch2, Scratch3 and Mix1) also wanted the movement of the pitch slider to be heavier or more resistant. On a Technics SL-1200, the pitch slider is fitted with a heavy knob. D'Groove's pitch slider is comparatively easier to move as its knob is substantially lighter. Since pitch changes are usually done with great precision, it is desirable to make small changes along the slider, a feature provided with extra resistance.

5.3.5 Evaluating the Acceptance of D'Groove

When asked if any of the features of D'Groove would enable a DJ to "cheat" at certain tasks by doing them more easily than a conventional turntable setup, the DJs had a variety of opinions. Scratch1 commented that he had spent hours of time learning to perfect certain moves and he wanted to be able to show these skills to an audience. If someone could have D'Groove performing a scribble scratch automatically or making a hydroplane easier, then it would take away from the importance of his skills. To counter this, Mix1 commented that he believed there was no point in making something harder than it needed to be. Adding help-enabling features was valuable as it made his job easier. This suggests that there needs to be a continuum for aid. DJs should be able to select the appropriate amount of aid, depending on their comfort level, and, if an aid is not desired, it should not be obtrusive to the DJ.

At the end of the session, each DJ was asked if they would replace their regular turntables with an improved version of D'Groove. The areas of improvement, as outlined from the DJs, would be the torque of the turntable, the unification of the components into a single unit and the overall appearance. Mix1 and Mix3 gave a resounding “yes”. The others said they would include D’Groove but they would keep at least one turntable around for nostalgic purposes and to make use of their existing record collection.

Chapter 6

6 Discussion

This chapter outlines a number of important points, noted after reflecting on our initial study on the processes of DJs, our design of a digital DJ system and our observations of DJs using the system. We interpret the reactions of the DJs in the observational study, consider the value of our design decisions and learn from our triumphs and mistakes. This process allows us to gather the important aspects of a DJ interface.

6.1 Aids vs. Cheating

In Section 2.5.1 we mentioned how some DJs regard new technology as "cheating". From our study we conclude that providing an extra aid for a certain DJ task is not universally considered "cheating", as long as the DJs still perceive themselves as valuable contributors to the music and/or working hard. Likewise, the audience must also feel these perceptions to believe they are experiencing a worthwhile performance. DJs must feel that they are the reason the music sounds the way it does. They must feel that they have the ability to alter parameters in the musical output at any moment. They must also perceive that it takes a certain level of skill to produce adequate sounds from a device.

After studying the process of beatmatching (Section 2.4.1), we found this to be a skill DJs have spent a great deal of time learning to perfect, making them feel valuable. Scratch2 even commented that is an enjoyable challenge in DJing. Successful manual completion of the task was gratifying. We chose not to entirely automate the beatmatching process, but instead, provide visual cues to help because DJs generally enjoy it and, according to recent work on beat detection [12, 18, 20, 40, 42], finding an algorithm precise enough to suit our needs is difficult to achieve. With our implementation, DJs still needed knowledge of musical timing and skills to manipulate a turntable properly. DJs still felt they had to do work in synchronizing the songs and did not see the aid as "cheating". Also, our beat markers could be ignored, as we observed in the study, showing that they are unobtrusive when not used.

Most of the control shifts to D'Groove when performing some of the haptically enabled scratch tricks, especially the textured hydroplane and spring scribble scratches. Both Scratch1 and Mix2 were concerned that these features may be "cheating mechanisms" instead of aids. We found this notion to be most apparent when the bulk of a task's work falls on the device as opposed to the DJ. Thus truly automatic features are not desired as the DJ becomes devalued.

We see this trend again when considering the beat markers as aids for beat juggling instead of beatmatching. In the former, the DJ must still decide the loop duration used to create a portion of the beat juggle. The DJ still has control over the manoeuvre and is required to complete most of the work. None of the DJs thought that it was "cheating" if the markers were used for beat juggling and we believe it is linked to the level of work (and to a lesser extent – control) that a DJ has to provide.

6.2 Confirmation of Beatmatching

Beatmatching is a conventional auditory task as its only form of feedback is via the auditory channel. This makes sense as it involves manipulation of audio. We had envisioned the beat markers on the turntable as visual aids when trying to beatmatch songs, thus providing feedback on both auditory and visual channels. It was found that experienced DJs still rely on their ears for this and tend to ignore other forms of feedback. Thus, the DJs did not use the beat markers as we had intended. We could think of three possible reasons for this:

1) Beatmatching is an inherently auditory task suggesting it's unsuitable for visual offloading or that people tend to rely on auditory feedback for auditory tasks.
2) The experienced DJs were too accustomed to using their auditory channel and needed more time to consider the visual cues. They have spent years training their ears to accomplish this task and may be unable to switch feedback sources as quickly as we anticipated.
3) There needed to be two D'Groove turntables in order for the effect to be useful. We felt this to be the weaker of the reasons as we believe it is possible to use the visual feedback, combined with the audio feedback from one source (i.e. a D'Groove turntable) and the audio feedback of a second source (i.e. a Technics SL-1200 turntable), to beatmatch.

That being said, the DJs in the study did not completely disregard this feature. In fact they agreed that the markers on this prototype may help novice DJs overcome the common confusion that occurs when sorting out the position of beats in one song, relative to another. The visual beat markers could be used to help train the ears, becoming a learning tool for novice DJs. One then has to consider if the beat markers would become a “crutch” and whether novices, who learned with beat markers, could then play equally as well on conventional turntables. A future study would be necessary to confirm or deny this notion.

6.3 The Role of Aesthetics

Aesthetics plays a major role in DJing. DJs want tools that look appropriate and feel sturdy. Scratch1 proclaimed that he liked the Technics SL-1200 turntable because it is simple, dependable and relatively bare in terms of features. This version of D’Groove lacks the slick appearance of a Technics SL-1200– a deficiency that was difficult for the DJs to overcome when testing the system. The DJs also wanted D’Groove to be more durable and contained in a complete unit – detached from a computer. We concluded that our next prototype should be a simple self-contained device.

When moving the aspects of the GUI to a physical interface, we think a series of mode-switching buttons are appropriate for changing the mode of the system. Limited range knobs with detents could be used to discretely select a value from a pre-selected range, when changing parameters in a mode. As each mode generally uses the same types of parameters, these knobs could be used within each mode. The range of settings could be reduced. For example, a single knob could control the spring force in spring mode as well as the height of bumps in bump-for-beats mode and the resistive force in resistance mode. It could have three settings: small, medium and large. Also, certain aspects of the GUI may disappear, such as loading force files, which would become automatic when a song is loaded. Naturally, any design decisions require testing with DJs before commitments are made.

6.4 The Need for Features

DJs need to be able to modify which features are available according to their own needs. DJs pride themselves on their unique style and as such, each DJ may require different features in their gear. Mix1 insisted that he would not want to hear great amounts of scratching in a DJ set and if everyone was given a tool that made scratching easy, DJ music would be inundated with this sound. For Mix1 many of the scratch features such as the spring and the bumps were not greatly desired. Instead, the ability to play digital music like one was using a turntable was valuable. Most of the DJs agreed that they wanted a system where features could be ignored if the DJs felt they did not need them. The lesson here is to provide a basic device that fulfils a DJs' minimum requirements and allows DJs to graduate to new features when they feel ready to explore additional avenues of creativity.

6.5 The Shortcomings of D'Groove

Based on the criticisms of the DJs during our observational study, we can say that the following are some shortcomings of D'Groove in its current implementation:

1) The torque of the turntable is not strong enough. It needs to convey a sense of power and/or strength.
2) The platter needs to have a sidewall, used for slowing it down or bending the pitch downwards when beatmatching.
3) The Q-slider requires a display to show the waveform of the song.
4) The buttons on the GUI need to be physical knobs and buttons integrated into the rest of the unit, and there should be fewer of them.
5) All three of the external components need to be a single unit. Preferably there would be no external computer in the system but this is not a major drawback.
6) The components need to be durable, especially the turntable platter.
7) The pitch slider may work better with two sliders instead of a slider and a toggle switch. Opinions on this matter differed.
8) The pitch slider needs more resistance and/or a heavier knob to promote small changes in pitch.

All of these deficiencies are valid and can be remedied in the next version of D'Groove. Despite this, D'Groove did serve its purpose as a valid prototype and was useful for providing feedback.

The most difficult of these new features will be the display screen for the Q-slider. This is both expensive and challenging to implement. In hindsight, we should have foreseen that a visual representation for the structure of the song is still a desired feature. DJs require knowledge of upcoming changes in a song so that they can apply creative schemes at the onset of the change. Interestingly enough, the DJs in the study wanted this information on the Q-slider and not on the platter/record as in the conventional setup.

Producing a high torque turntable is generally achieved with a high powered motor. Most turntable motors are designed to travel very smoothly in one direction. If we are to include haptics in the system, we need a turntable that has the ability to switch directions quickly. High torque and quick directional changes are usually tradeoffs, however, the use of braking can be used to help a high torque motor switch directions faster.

6.6 The Virtues of D'Groove

In summary, the expert DJs from in our observational study found the following contributions for the current D'Groove prototype:

1) It is good at playing back digital music, with tight control between the movements of the turntable platter and the associated changes in the music. Latency and sound quality are both acceptable.

2) The visual beat markers are useful in cueing the music to a certain bar. They provide an excellent point of reference when beat juggling and indicating the point in a bar at which the music is playing.

3) The spring mode and bumps-for-beats mode both provide a valuable new scratch trick, allowing DJs to dribble the turntable platter like a basketball to produce interesting scratching sounds.

4) The bumps-for-beats mode makes certain scratch tricks (i.e. hydroplaning) easier as they can be performed with one hand instead of two.

5) The Q-slider is a valid alternative to the turntable's needle when cueing to a point where the mood changes in a song. It is also a valid replacement for indicating the temporal position within a song.

6) The Q-slider provides a new way to create on-the-fly loops.

7) The Pitch Slider is an excellent way to provide a means of altering the pitch, without imposing a limit on the pitch's range.

6.7 Our Approach to D'Groove's Design

Given our time and the resources available with which to build an acceptable prototype, D'Groove was rather successful. This is mostly attributed to the fact that D'Groove took the form of a standard DJ tool – the turntable. Had we presented our ideas in an unconventional fashion, they may have taken longer to understand and been harder to comment on in a DJ context. The value of the turntable was seen repeatedly throughout our initial study of DJ tasks and tools. DJs are committed so faithfully to the turntable that it practically forced us to follow this design. Had we forgone the initial study, and simply created a tool for manipulating digital music, without regarding DJs, we may have been left with a "cool" tool that sought target users.

Considering the popularity of the Technics SL-1200 in DJ circles, it may have been more beneficial for us to have created D'Groove inside or from a Technics SL-1200. This would have insured the aesthetics were correct and would have sped-up the acceptance of the system. The downfall of this approach is the extra time required to reverse engineer a Technics SL-1200 turntable and redesign it to accommodate our new features.

Another approach is to use FinalScratch (Section 3) as the basis for our system since it already handles the playback of digital music from an encoded physical interface (a special record). This handles the audio playback aspect for us and we just have to deal with building the right turntable. At the beginning of this project, FinalScratch was just being released. Obtaining the system was difficult and knowledge of its design was heavily guarded for commercial reasons. If we were to start building D’Groove now, FinalScratch might make an attractive foundation for our system.

Chapter 7

7 Conclusions and Future Work

This chapter discusses the value of D'Groove and its role as a DJ tool. We use the experience of designing and evaluating our tool to offer guidelines for general digital audio manipulation. We also discuss some ideas for future versions of the system, outlining where we need to improve and brainstorming some fun features for future consideration.

7.1 Conclusions

DJing began as a technology-centric art form. DJs appropriated the traditional turntable technology and pioneered innovative ways to use it. In a sense, the turntable is part of what defines DJing. This explains why commercial DJ CD players work hard to emulate a turntable. It also helps us understand why turntables are so entrenched within the DJ community. The turntable has become "synonymous" with the DJ.

7.1.1 D'Groove

Because any successful new approach to DJing must meet the old standards set by the turntable, we built D'Groove in its form. This first prototype allowed us to gather user feedback on a wide range of technical enhancements: its essential form was familiar to our target users, but it was flexible enough that we could implement new features on the fly. This is both a technology-centric and user-centric form of design. It is technology-centric in that we are able to show DJs some new capabilities, afforded by new technology. It is user-centric because it demonstrates these features in a tool that is readily acceptable to DJs. Thus, D'Groove serves as an excellent test platform to implement new ideas for DJ tools.

We believe that the success of D'Groove was based largely on the fact that the angular position of the motorized turntable platter maintained the same relationship with the musical playback point that the angular position of a record does on a conventional turntable. This simple mapping is not found on many digital DJ CD players and is vital for providing a sense of control intimacy and understanding about the movements of the music. When finite control over media is required, analog systems provide the best form of control. Thus, when moving to digital media, a similar replication of the analog control method makes sense.

D'Groove was designed using HCI principles, resulting in both anticipated and unexpected results. The response from highly critical DJs was positive overall, confirming that this prototype represents a viable means of manipulating digital audio based on a familiar form of physical control.

7.1.2 Generalizations to Digital Audio Manipulation

We can relate what we have learned from our study of D'Groove to digital audio manipulation in general and offer these suggestions:

1) To maintain control intimacy and convey a sense of manipulating a material form of digital audio, there should be no perceived delay between the motions of the physical device and the auditory response. Musical instruments especially require minimal latency as virtuosity becomes difficult when compensating for delays. Levitin *et. al.* suggest a latency of less than 10 ms for this type of task [27]. D'Groove has a latency of less than 6 ms.
2) Mappings between the physical device and the auditory response should be straightforward and consistent. The simple fact that music only plays when a conventional turntable rotates provides such a mapping. We improved upon this traditional, non-constant relationship between a single record rotation and the consequent duration of musical playback, offering visual feedback and giving our turntable's rotation a more consistent meaning. This was unobtrusive as the speed of our rotations were relative to normal speeds of conventional turntables.
3) Uncoupling functionally different controls may not affect their perceived value. The Q-slider appeared to maintain a function of the needle but was detached from the platter whereas the needle was integrated with platter. This separation seemed to be acceptable to the DJs.
4) Informative feedback may switch sources when uncoupling functionally different controllers. The DJs in our study requested structural information about the song be added to the Q-slider whereas it was previously available on

the record. As D'Groove's record contains no needle, this type of information does not make sense on the platter. The platter shows the playback within a bar whereas this information is better associated with the playback point in regards to the entire song, fitting well with the function of the Q-slider.

5) It may be difficult to substitute another modality for auditory feedback during auditory tasks. In our case, DJs preferred to use their ears for beatmatching and rejected haptic modes, such as the resistance mode, because it disrupted the auditory channel.
6) For performance, creating sounds in new ways may be valued as highly as creating new sounds. Our haptic spring and textured-record mode gave the DJs a new visual appeal while creating an old sound.

7.2 Future Work

With feedback from experienced disc jockeys, we can now improve on D'Groove's first prototype.

In the next prototype of D'Groove we will concentrate on aesthetics, durability and torque. Our goal is to create a self-contained turntable unit that conveys a sense of power and would draw attention in a night club performance. We plan to increase the platter's motor strength to provide better haptics and give a greater sense of the device's power when using the turntable. The DJs in the study complained of this the most and thus it is of utmost importance to address. The consensus is that more torque is better and our goal is to meet or exceed the 1.5kg-cm torque of the Technics SL-1200 turntable as this is the standard all turntable DJs seem to require.

In hindsight, our decision to replace the visual feedback from a record's grooves with haptic feedback on the Q-slider was unsuccessful; our users preferred the visual channel for discerning the current musical point and the song's entire structure in a single step. We plan to add a screen to relay this information.

We also need to improve the GUI, moving many of its buttons into a physical form and adding capabilities for song selection and organization. Some of these functions may be moved to the mixing board instead of the turntable. In some cases, we can think of alternatives to simply moving a numerical selection on the GUI to a selectable knob on the turntables. An example is the setting the scratch distance (section 4.3.2). Currently the DJ alters two numerical values in the GUI to achieve the desired mapping. Perhaps a better method of altering this mapping would involve the DJ selecting the audio sample through a playback motion on the turntable, followed by selecting a distance through a similar motion. In this case, a button is required to switch between audio selection mode, distance selection mode and normal playback mode.

After testing this prototype, we think it may be easier to implement some of the haptics, such as the resistance mode, using a braking system. Also, the spring mode may be implemented using real springs that can be repositioned around the platter. These ideas might enable us to use a motor with higher torque and still retain the effectiveness of the haptics.

We would like to implement a ping-pong spring feature that makes the turntable platter bounce between two different points. Frequency control as well as the position of these points is desired. This provides a new trick for DJs when performing and is relatively easy to implement.

We would also like to implement a scratch recording option where DJs can record the physical motions associated with a certain scratch pattern. We envision professional scratch patterns being available from the Internet and beginners learning from experts by downloading an expert's scratch. We also envision experts experimenting by performing a physical motion with one sound and then applying that same motion to new sounds.

In the far future, we would also like to implement a multi-track song feature where a song is broken into multiple tracks, each one containing a single instrument of the song. This allows a DJ to customize a mix by selecting precise instruments (instead of a frequency range) from each song. This feature may not happen in the immediate future as digital song deconstruction is a relatively new field.

We believe that the future of DJing needs an increased level of virtuosity in performance. Ultimately, we would like the world to consider all DJs as musicians. To promote this, we need to increase the amount of control a DJ has over their music, enabling them to alter the music from its original state. This can be achieved through improved mappings between the DJ’s actions and the musical output. We can still explore open channels of perception to see where further mappings can be accommodated, increasing the intimacy of a performance. The visual aspect of a DJ’s routine is also an area that can be expanded. New motions can be created as well as spectacular devices that link the movements of a DJ to auditory and visual outputs. And as expressive technology evolves, so to does the innovative facets of DJing.

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Appendix A: Encoder Decoder Schematic

This circuit is used to decode the Q-slider and turntable encoders

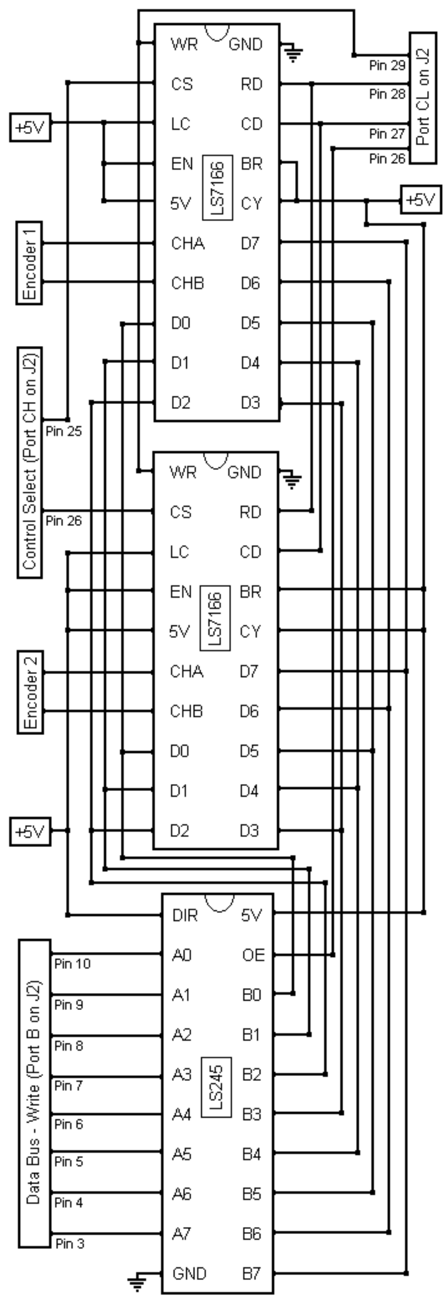

Figure 31 Encoder-decoder Circuit

Appendix B: Q-slider Amplifier Schematic

Amplifier Diagram for Driving the Q-slider's Motor

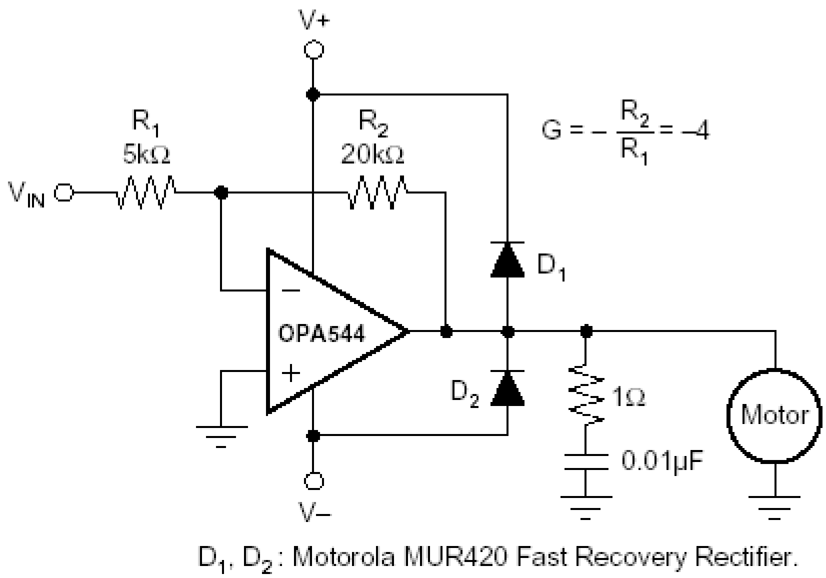

Figure 32 Amplifier for Q-slider Motor

Appendix C: Scratch Tricks

Scratch Tricks – sourced from the scratchDJ website [1]

Baby Scratch

The simplest of scratches as the baby scratch is performed without using the crossfader. The record is simply moved forwards and backwards (or vice versa) once.

Bubble Scratch

The record is moved back and forth while one of the EQ settings is altered from maximum to minimum, creating a wah-wah pedal sound effect. DJ Noize is credited in finding this technique.

Chirp Scratch

The record is pushed forwards while the sound is faded out with the crossfader. Then the record is pushed backwards while the sound is faded in again. When done quickly a chirp sound is created. This is one of the hardest tricks to perfect but DJ Jazzy Jeff is known for demonstrating this scratch quite well.

Crab Scratch

As the record is being pushed back and forth, the DJ quickly taps the crossfader knob with 2 to 4 different fingers in a sequence starting with the pinkie (when doing 4 taps) ring finger (3 taps) or middle finger (2 taps) while using the thumb as a spring to bounce the fader back out after each tap. The result is much like a very rapid transformer scratch. It is possible to perform a crab in a cyclical motion, producing a “never ending” type of sound.

Flare Scratch

Flares are much like transformer scratches but the DJ starts with the sound on and cut it off rapidly. Each time the DJ bounces the crossfader off the side, it produces a ‘click’ sound. Thus flares are named according to clicks. A one-click flare would involve a sound being played forwards or backwards while the crossfader briefly cuts the sound off in the middle of the playback sequence. This creates two distinct sounds. A two-click flare cuts the sound off twice in the same fashion. This trick was invented by DJ Flare and developed further by DJ Qbert.

Forward and Backward Scratches

Forward and backward scratches are fairly simple scratches. A sound is played either completely forwards or completely backwards. The crossfader is used to cut the sound off when the playback portion has finished. Commonly DJs will perform 2 or more forward scratches in a sequence (thus cutting the sound off when they rewind the audio to the beginning of the sample for the second forward scratch). This scratch is also known as a stab scratch.

Hydroplane

As the DJ scratches with one hand, one or more fingers from the second hand are used to apply pressure to the record without stopping its movement. When done properly, the finger bounces slightly off the record and a bassy friction sound is the result.

Orbit Scratch

Technically an orbit is any scratch move performed both forward then backward or backward then forward in a sequence. Generally flares are done using an orbit technique. For example, a one-click forward flare and a one-click backward flare in quick succession (altogether creating 4 distinct sounds), would be a one-click orbit. Likewise, a two-click forward flare and a two-click backward flare in quick succession (6 distinct sounds), would be a two-click orbit. DJ Disk is usually credited as the inventor of this technique.

Scribble Scratch

A scribble scratch is done by tensing the forearm of the record hand, causing the record to jerk back and forth creating the shaky scribble sound.

Strobing

Strobing is a mixing trick usually done with two copies of the same record. The records are beatmatched so that they are playing the exact same beats at the same time. Then one record's speed is adjusted to play slightly behind the other. Once setup, the DJ shifts the output (using the crossfader) back and forth, creating a stutter or strobing sound as the beats repeat). DJs Shortkut and Yoshi are credited with this trick.

Tear Scratch

The tear is much like the baby scratch but a short manual pause is inserted halfway through either the forward or backward motion (or both).

Transform Scratch

The transform scratch involves moving the record very slowly forwards and/or backwards, while cutting the sound (via the crossfader) on and off very quickly. The result is a stuttered tremolo effect. DJ Cash Money and Jazzy Jeff are credited with inventing this scratch.

Tweak Scratch

The tweak scratch is performed with the motor of the turntable turned off. You can manipulate the record back and forth in any manner and cut the sound on/off with the crossfader. The result is best achieved with long tone samples and usually provides jerky sounds as your hand hits the record in a different direction. DJ Mix Master Mike is known for performing this scratch.

Zig-Zag Scratch

A zig zag scratch is a move where the DJ uses one hand to push the record, while the other hand briefly taps the record and adjusts the volume fader. If scratching with the right hand on the record the technique would be as follows:

1. the right hand pulls back sound and lets the record go to play the sound forward.
2. the left hand taps the record as it is playing forward, making a quick pause and creating two distinct forward sounds instead of one.
3. then the left hand quickly moves and taps down the volume fader (up or down in a sequence) a small amount
4. repeat the pattern until the volume is all the way down or all the way up.

Appendix D: An Example of Mixing Tracks

To illustrate the concept of mixing, let's look at a mixing scenario. We will use the traditional turntable as our input device. First we play a record. Let’s call it record1 and let it consist of 13 32-beat loops. That means one loop consists of 32 beats and there are 13 of them in the song. Each 32-beat loop is broken down into 8 bars and each bar contains 4 beats. We can count each beat as follows:

ONE two three four

TWO two three four

THREE two three four

FOUR two three four

FIVE two three four

SIX two three four

SEVEN two three four

EIGHT two three four

Record1 is a standard dance song that consists of an introduction, a middle and an end (or outro). The intro is rather boring and consists of a bass drum that occurs on each beat (32 bass drums per loop) and a bass guitar that plays a tune. It plays for 2 loops. The outro is even more boring as it has the same bass drum on each beat and a hi-hat on the off beat (occurring exactly in the middle of two successive beats. The outro is 1 loop long. On the downbeat (labelled ONE) of the entire track there is a crash symbol sound. Thus we hear the crash symbol once every 32 beats. The middle is 10 loops long and contains the ‘meat’ of the track. Here we hear guitars, pianos and trumpets. As with all dance music, each new instrument begins and ceases to play on a downbeat. The song is 120 BPM and there are a total of 416 (= 13 * 32) beats in the song.

Record2 is another standard dance song that has an intro, a middle and an outro. It has 18 loops and in this case, each loop is 16 beats long. The intro and outro are both 2 loops long and consist of the bass drum (occurring on each beat) and some congas and bongos that play between and on beats. The middle of this track consists of an energetic female vocalist singing at full steam. Record2 is 122 BPM and there are 288 (= 18 * 16) beats in the song.

We heard both tracks before and know when the middle part of record1 ends. At this time we want to start playing record2 so that the 32 beats of outro on record1 line up with the 2 sets of 16 beats on the intro of record2. The plan is to make the middle portion of record2 begin just as record1 finishes. Thus we want to start record2 on the downbeat (labelled ONE) of the last loop in record1.

We begin with record1, starting on its first loop and playing through. We select record2 and place it on the turntable. We cue it up by listening to record2 in the left side of our headphones. Our right ear is listening to the speakers playing toward the audience while our left ear is listening to record2, the incoming track. We cue up record2 so that the very first beat is directly under our needle. On the 33rd beat of record1 (the downbeat of the second loop), we release record2 and set it in playing mode. We are not actually introducing it now, but rather setting up its BPM to match record1's BPM. As the beats of the two records play, we can tell that record2's bass drum is occurring a little before record1's bass drum. We apply a slight amount of pressure on record2 to slow it down with one hand and adjust the pitch controller so that the rotation of the record is slower with the other hand. The more we slow down the pitch controller, the less pressure we have to apply to record2. While continuing to listen we find that record2's bass drum is now occurring just after the bass drum of record1. We have slowed record2 down too much and need to adjust the pitch controller while pushing the record ahead just a little to compensate for the difference. After 16 beats have gone by from record1, we decide that we now have record2 at the correct BPM setting (120 BPM). We start record2 off from the beginning again to test and make sure. We cue it up to start on its first beat and set it in play mode at the beginning of the third loop in record1 (the 65th beat). The two records ride nicely together and the beats seem to be in synchronization. Let's introduce a little of record2 to the audience. We snap the cross fader into the middle position on the 81st beat of record1 while record2 is on its 17th beat (the beginning of the second loop for record2). This is the middle of the 3rd loop on count FIVE for record1. Note that we did not introduce the track on a downbeat. But we still follow the rules of 4/4 time because we introduce a new element in the music at a multiple of 4. Essentially, we cut the 32 beat loop in record1 in half by introducing a new element in the middle of a loop. Now our mix consists of a piano, a trumpet a guitar and some conga and bongo drums (along with the bass drum). We let this mix ride for 16 beats and then fade it back to record1 so as not to let the melodies of the middle section in record2 interfere with an opposing melody that is occurring in record1.

Now the audience has a taste of the second record and thinks that the new conga and bongo drums are part of record1. We inject them a few more times into the mix by re-cueing record2 and mixing the first 2 loops into record1. Finally, when the middle section of record1 is about to end, we start record2 off on the first downbeat of the next loop in record1. This time we let record2 ride all the way through without fading it out. Our mix now consists of a bass drum, some conga and bongos and a hi-hat. After 2 loops (and 32 beats) in record2, record1 comes to and end and record2's middle section begins. The audience is used to the conga and bongo drums by now so there is coherence in the mix. Upon record1's finish, the exciting vocal of record2 begins and the audience does not miss record1 as they are enticed by the new elements brought into the mix by record2. We now remove record1 from the turntable and select a new track to mix into our set.