Optical Turntable as an Interface for Musical Performance

Nikita Pashenkov
A.B. Architecture & Urban Planning
Princeton University, June 1998

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Author: **Nikita Pashenkov**
Program in Media Arts and Sciences
May 24, 2002

Certified by: **John Maeda**
Associate Professor of Design and Computation
Thesis Supervisor

Accepted by: **Dr. Andew B. Lippman**
Chair, Departmental Committee on Graduate Studies
Program in Media Arts and Sciences

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Abstract

This thesis proposes a model of creative activity on the computer incorporating the elements of programming, graphics, sound generation, and physical interaction. An interface for manipulating these elements is suggested, based on the concept of a disk-jockey turntable as a performance instrument. A system is developed around this idea, enabling optical pickup of visual information from physical media as input to processes on the computer. Software architecture(s) are discussed and examples are implemented, illustrating the potential uses of the interface for the purpose of creative expression in the virtual domain.

thesis advisor

John Maeda
Associate Professor of Design and Computation
MIT Program in Media Arts and Sciences

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Nikita Pashenkov

thesis advisor

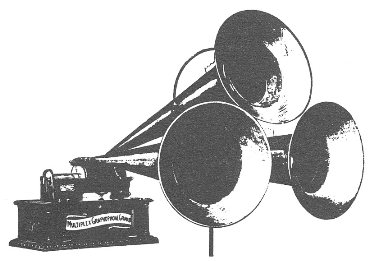
John Maeda
Associate Professor of Design and Computation
MIT Program in Media Arts and Sciences

thesis reader

Chris Csikszentmihályi
Assistant Professor of Media Arts and Sciences
MIT Program in Media Arts and Sciences

thesis reader

Joseph A. Paradiso
Principal Research Scientist
Technology Director, Things That Think Consortium
MIT Media Laboratory


MULTIPLEX GRAPHOPHONE

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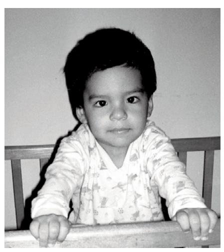
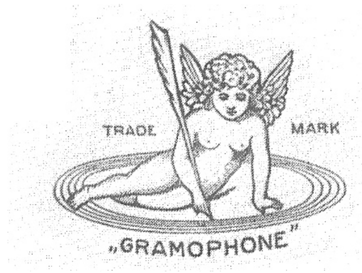


*This work is dedicated to my brother, **Nicholas**, who'll never know how it was like growing up without computers :)*

0. CONTENTS



1. INTRODUCTION

Research... is the name which prudently, under the constraint of certain social conditions, we give to the activity of writing: research here moves on the side of writing, is an adventure of the signifier, an excess of exchange - impossible to maintain the equation of a 'result' for a 'piece of research'. Which is why the discourse to which a piece of research must be submitted (in teaching it) has a speciality, besides its parenetic function ('Write'!), to recall the research to its epistemological condition: whatever it searches for, it must not forget its nature as language - and it is this which renders finally inevitable an encounter with writing. [1]

The epigraph above bears a signature style of the celebrated French critic Roland Barthes. In his collection of essays, entitled *Image-Music-Text*, Barthes theorizes that an act of writing is a necessity that "begins at the point where speech becomes impossible." Out of this necessity the academic exercise of writing a thesis is born. The assumption is that by articulating the thought process that has driven the (last two years of) work we make another step in the evolution of future ideas.

In a sense, much of what is going to be discussed in this thesis could be conceptualized as a form of writing. At the heart of the work is the idea of a program - the code that is forever striving to approximate the natural order of a written sentence. John Maeda has injected this seed of Computer Science into the discipline of graphic design, providing the original inspiration for the likes of my own to embrace the engineer's approach. The thesis is particularly concerned with the concept of writing as a physical inscription. This has to do with abstract marks printed on paper, which had been used to generate electronic signals that make chips and microprocessors tick. The voltage signal itself is but a linear trace in time, twisted into forms that we call digital and analog. At the level of the signal, the line between speech and writing is finally blurred as the ear is able to pick out the undulation, making a sensible imprint in the mind. Thus it is around letters, symbols and codes that the subject of this work (literally) revolves. The final results are visible to the eye and audible to the ear, and so music, image and text are the three components that circumscribe the area where I've chosen to locate the discussion that follows.

1.1 Motivation (or how I got to write a "musical" thesis)

One must abandon the arrogance characteristic of an understanding of 'serious' music which believes it can completely ignore the music which today constitutes the only musical material consumed by the vast majority of the people. [2]

- Theodore Adorno (1929)

First came the idea, which somehow preceded a logical thought process. In fact, it was one of the first concepts that I pitched to my advisor in the fall of my first year at the Media Lab: "*wouldn't it be great if*... there was an optical turntable that could play visual records?" It seemed like an "in" enough thing, and we were the Aesthetics & Computation Group, trying to push the boundaries of what is interesting to look at. A week and a half later, Chris Csikszentmihályi came to the lab to show his *DJ, I Robot*. Maybe Golan was right with his initial words of advice: "turntable has been done." Truth be told, at that time I hardly possessed the skills to implement either the hardware or software aspects of the project.

A year and a half later, a unique confluence of events had me pitching the turntable concept all over again, this time as none other than a thesis project. Chris' first reaction was as to be expected: "don't tell me you're going to do a DJ thing!" However, in half an hour we agreed that there was some room for a yet another mutant turntable. Then there was the encouraging positive reaction of Joe Paradiso, who saw an interesting potential in the thing. Hidden in the concept of wiring an optical turntable up to the computer for the purpose of programming graphics and sound was the antithesis of an earlier sentiment: "something quite like this hasn't been done."

My one concern with the project was that my own experience with music is so limited. I have never learned to play an instrument, or even memorized the musical notation. Then I found a different way to look at it: growing up in late 20th Century it was impossible for me not to be surrounded by music. Even in Soviet Russia one could own (some) music in the form of a recording and to obtain musical equipment. In my case, this provided for an early experience of learning to thread a family reel-to-reel tape player and playing endless selections from what was then available in my parents' bootleg collection. Later in life, it was the exponentially growing collection of records, cassette tapes, then CDs that provided countless hours of entertainment. Since the MP3 format became popular a few years ago, the sheer amount of music accumulated on my hard drive easily surpassed the size of the largest collection I could ever own in tangible form. In short, I would call myself an avid music listener, opinionated about the kind of music I like and interested in the directions of contemporary music culture.

There are two contemporary forms of musical expression that I find very intriguing, particularly in view of their interrelationship. Like many of my peers, I think of the evolving culture of a DJ-musician as a cool

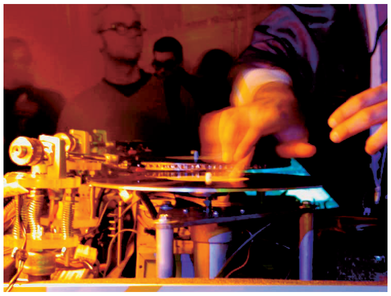


Fig 1.0
DJ, I Robot - the original mutant turntable.

Fig 1.1
Author of this text, caught practicing his tape player skills at the age of three.

concept that fits right in to the post-everything mentality of this age. Another fascinating development in my view is the concept of electronic music.* This music is now made by programming machines to play entire compositions at the touch of a button, not unlike the mechanical playback turntable. In both electronic music and DJ performance, the musician is a (usually calm and expressionless) manipulator of sonic material that effectively generates itself. Moreover, it would seem that the two musics coexist in a kind of symbiotic relationship with each other. It may have all started when the Bronx DJ Afrika Bambaataa made his famous remix of "Trans Europe Express" by German electropop pioneers Kraftwerk. At the time the idea of such a tribute was less than welcome. As one Kraftwerk member wrote in his memoir: "a certain Afrika Bambaataa (whom I prefer to call "Bambus")... mixed parts of 'Numbers' and 'Trans Europe Express' for a single release, turning out an American-style piece of music... This is the nastiest kind of theft!" [4] Today, the lines between electronic music and DJ performance are less clear-cut. The contemporary Detroit Electronic Music Festival books popular DJs alongside electronic acts. Funkstörung are electronic musicians, as well as DJs, and listening to their recordings it is often hard to tell how the material was generated in the first place.

Yet, there is an element of fundamental difference at play. The turntable remains an instrument that is only able to reproduce and manipulate sound, not to create it. This is where I saw an opportunity to fit in. The idea is pretty simple: give the turntable some hooks into software, using a bit of electronics as a glue. Turntable as a software synthesizer, sequencer, or drum machine, and a visual end to boot - this seemed like a fun concept to follow. I take my pains to explain the rest of the details below...

* Here it is important to make the distinction between popular electronic music and what might be called 'serious' electronic music, defined by one musician as "the type of music made with computers by the sort of composers who read *Computer Music Journal*" (certainly, an unlikely feat for a synthesizer-wielding teenager). [3]

1.2 Methodology

Intelligence from another planet is expected to manifest itself in simple geometric shapes. As it happens, we have chosen the disk as our own envoy to the rest of the sapient universe, such as it may be. At the heart of the spacecraft Voyager II, as it hurries to its appointment unspecified light years away, is a phonograph with picture instructions that an alien child could understand. [5]

-Evan Eisenberg

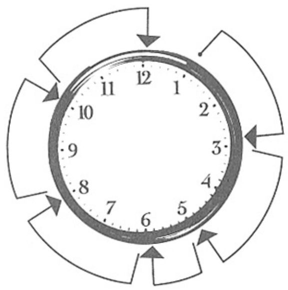
If I had one sentence to summarize what Aesthetics & Computation Group is about, perhaps it is the idea that through familiarity with programming we are able to take a firm hold of a computer and create visual expressions uninhibited by the limitations of pre-packaged tools and standard computer interfaces. The same idea extends just as effectively to music, the other great area of human expression. Paul Gredinger, who is one of the first composers to create music using a computer, provides a helpful definition:

"Closest to the typical idea of a program come structures in electronic music. Here the structural unity of the mental vision is realized by the projection into the musical experience. The elements of the composition are sound units (impulses). Composing with these units consists in regulating a single parameter: time. And the music is a structure of programmed impulses." [6]

Gredinger's explanation of musical structure evokes a mental image of a linear extension in time. In comparison, rhythmic composition is perhaps easier pictured as a circle that keeps the impulses coming back on themselves. In a book entitled *Digital Mantras*, author and musician Steven Holtzman uses a diagrammatic representation of twelve notes wrapped around a disk as an illustration of all kinds of musical structures, beginning with the Pythagorean Circle of Fifths all the way up to Serial compositions of the post-war avant-garde. With the metaphor of following pre-determined patterns around the disk, Holtzman suggests an intuitive way to think about the makeup of music generally. [7]

The concept of a disk also makes for a universal metaphor of data input and storage. By moving a single pickup head in a line across the surface of the disk, we get a near instant access to any portion of it. This structure still defines the most common method of information retrieval, as the random-access magnetic and optical storage media of today all function on this principle.

Taking the two metaphors together provides the basis of the idea explored in this thesis. The premise is that a turntable can function as a random access input device, anthropomorphic in scale and thus well suited for manipulation by hand. The large area of the disk-record is a means of storing information, but the concept of optical pickup turns the surface into a visual canvas as well. The disks become something one can print, draw, paint, assemble as collage, or even cut, rip, and fold. Each disk contains a set of instructions, data, or programs that are visually interpreted, then used as numeric data for computational processes on the machine. The whole setup incorporates the elements of visual representation together



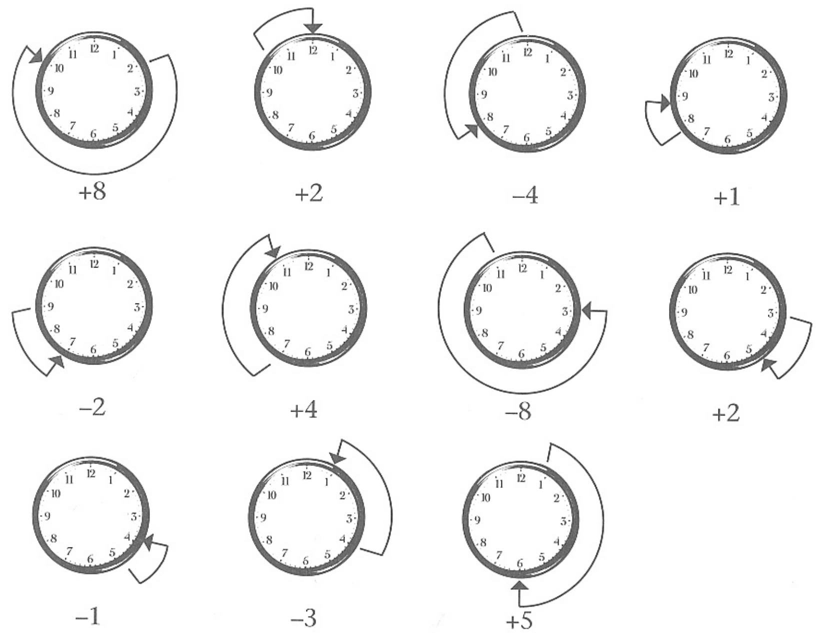


Fig 1.2 (above)
Holtzman's illustration of the structure of musical scale, C-D-E-F-G-A-B.

Fig 1.3 (right)
Clock metaphor as an illustration of the structure of Arnold Shoenberg's *Opus 23* series compositon.

with electronics, software, and sound generation in the final stage. In a curious way, the project seems to incorporate certain elements that ACG has been about, as well as the ones the group has been moving towards over the last couple of years. If that somehow translates to keeping things moving in a circle, perhaps I've managed to strike the right chord.

1.3 Overview of the thesis

The remainder of this thesis is divided into three chapters: background, implementation, and conclusion. The background chapter provides a historical foundation for the thesis. The chapter begins with a discussion of some theoretical implications of turntable technology, taken from the visual perspective. Specific examples are then covered, which outline numerous direct precedents for the idea of optical turntable as a musical tool, as well as a vehicle for visual expression. The second part of the chapter is devoted to computational models that provide a precedent for this work. Here I talk about some of the limitations of standard human-computer interaction metaphors and suggest a few alternatives, leading up to the discussion of the advantages afforded by the model of physical interaction. The chapter concludes with a formulation of a set of goals for the thesis project.

The implementation chapter provides a detailed explanation of the work provided in support of the thesis. I begin by introducing the interface components of the thesis project, accompanied by an explanation of their functionality and details of its technical implementation. Example applications of the system are then discussed as a way of illustrating some of its potentials. This is followed by an analysis of the system's successes and limitations in view of the goals that had been set out for it.

The final chapter begins by outlining a list of contributions that the thesis may be considered to have brought about. I then suggest some ideas for future development of the project, taken from the standpoint of its current limitations. This provides the conclusion of the discussion, followed by an appendix that highlights some of the pertinent details of project implementation.

2. BACKGROUND

If at some later point, instead of doing 'history of ideas' [Geistesgeschichte], one were to read the state of the cultural spirit [Geist] off of the sundial of human technology, then the prehistory of the gramophone could take on an importance that might eclipse that of many a famous composer. [8]

-T.W.Adorno (1934)

The introduction suggested a domain of inquiry for this thesis, which has to do with a desire to create a peculiar mix of possibilities by using a turntable as a physical interface for controlling musical and visual events on the computer. The aim of this chapter is to establish a historico-theoretical basis for, and to provide a comparative evaluation of issues and technologies that relate to, this work. The next section opens with a discussion of some general concepts that have come about with the advent of the phonograph. These issues provide the initial argument binding the concept of a turntable to the visual realm. For example, I discuss the similarities between the historic development of the phonograph and that of the photograph. I then extend the visual analogy and compare turntable compositions of the present day to cinematic montage. I also argue that the idea of recording has brought about a strong coupling of the musical to the visual by way of commercialization.

In the next section, I delve into specific historic examples that illustrate the potential of a turntable as a visual tool. First, examples of electronic music instruments that utilize the turntable interface in conjunction with optical pickup are cited. While these provide a very direct precedent for the thesis project from the technical standpoint, they do not stress the expressive visual possibility of the instrument, which is taken as a purely functional mechanism. On the other end of the spectrum are the instances of utilizing the turntable for purely expressive purposes. Several examples of work in this realm are provided, such as the use of the surface of the phonograph record as a visual medium, application of turntable technology as a vehicle for animated color projection/performance, as well as an instance of a conceptual application of a turntable in a contemporary gallery installation.

The second part of the background section brings up the subject of computation as it relates to the objective goals of the thesis project. Here I talk about the general limitations of common music and image making metaphors and introduce a few alternatives. I then discuss how the same issues have been addressed in some of the work done at ACG. The issue of physical interaction is addressed next. While software models allow us to create music, it is the tangible musical instruments that we have come to associate with music-making most strongly. The ability to hold an instrument in one's hands is an aspect of physical interaction, which provides a level of expressivity to musical performance that is hard to achieve otherwise. When physical interaction is used in conjunction with software, moreover, a new set of possibilities opens up. I provide an illustration of a Media Lab project that deals comprehensively with the issue of physical interaction in relation to sound and image generation on the computer, in effect establishing its own metaphor of a musical instrument. Finally, I discuss two physical interaction models based specifically around the turntable interface, providing an important case study for this thesis. The background chapter concludes with a comparative analysis of the projects discussed. Their successes and limitations are then used to formulate a set of goals for the thesis project, which is described in the next chapter.

2.1 Fragments for an overlooked history of the phonograph

And now, in this twentieth century, come these talking and playing machines, and offer again to reduce the expression of music to a mathematical system of megaphones, wheels, cogs, disks, cylinders, and all manner of revolving things, which are as like real art as the marble statue of Eve is like her beautiful, living, breathing daughters. [9]

- John Philip Sousa (composer of *Stars and Stripes Forever)*

In June 1878, *North American Review* published an article regarding the new “talking machine” thought up by the celebrated American inventor Thomas Edison. The magazine listed ten ways in which the phonograph could benefit mankind. Curiously, the list brought up the categories of “letter writing and all kinds of dictation without the aid of stenographer,” “phonographic books, which will speak to blind people without effort on their part” and “the teaching of elocution,” before it mentioned the subject of “music reproduction.” [10] Thus, at its birth the phonograph technology was thought to have applications beyond mere musical listening. The next few sections of this background chapter attempt to uncover additional potentials that were attributed to or seen/seem to have come about as a result of this technology. In particular, I make an attempt to formulate some ideas concerning the visual aspect of the phonograph, which might be considered another “overlooked” component of this technology. The theme for this portion of the discussion is effectively set by the following observation:

“Although traditional music history is constructed around the abstraction and idealization of music and art as consisting of musical periods, genres, movements and styles, it is possible to elaborate another set of histories. These would focus attention on those material objects deliberately overlooked in the production of standard musical history. As a blatant instance of such “overlooking,” we might invoke a scenario familiar to anyone who has studied music: imagine several partitioned cubicles, each of which contains a headphoned student who faces an amplifier and a turntable; on each platter spins a record of Bethoven’s Ninth Symphony. One student lifts his needle to run to the bathroom, another listens twenty times to a difficult passage, a third is frustrated by a skip in the record and proceeds directly to the next movement of the symphony, while yet another finds it difficult to concentrate due to the volume of her neighbor’s headphones. These students are required, even as they act in a way made possible only by the technology of recording, to develop a historico-theoretical interpretation as if the technical means through which the music is accessed - right there, staring at them in the face - were of no significance whatsoever.” [11]

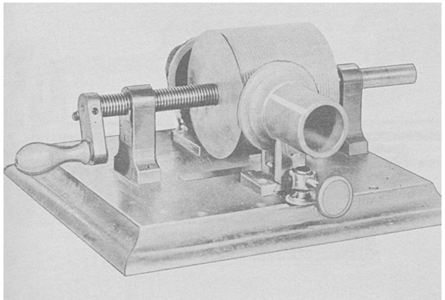
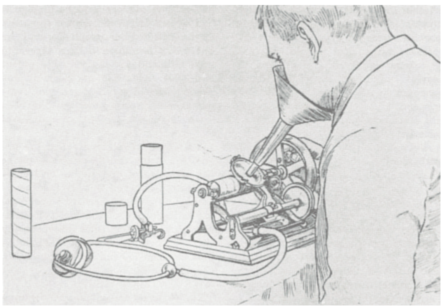


Fig 2.0
Edison's original tinfoil phonograph, 1877.

Fig 2.1
Advertisement of Edison's *Speaking Phonograph.*



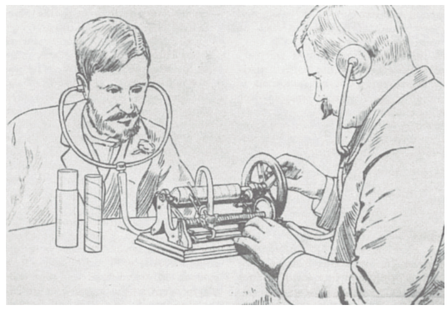


Fig 2.2-3
Harper's Weekly illustrations of phonograph use.

2.1.1 Phonograph as photograph

The inventor of the photograph, Louis Daguerre, speculated that one day an image of sound could be frozen in time in the same manner that the image of light could captured by his daguerreotypes. The connection he made is an appropriate one. We might say that, like a photograph, the phonograph record fixed an image that had been impossible to fix before. Sound could now be captured, played back at any moment and manipulated. Like a growing collection of images, sound recording enabled a new form of information to become available. Musics of world cultures, bird songs, recordings of distant past and lesser-known composers have since contributed to the multiplicity of events making up our cultural experience.

The analogy between photography and phonography extends further. For instance, as it had been the case with photography in relation to art, the early period of the phonograph saw this technology used as an extension of music as it has been up to that time. Much like painters of their day, early photographers made portraits, landscapes and dramatic scenes that were often exhibited in the galleries. Likewise, the phonograph was not initially seen as a way of creating something entirely new and it functioned instead as a substitute for concert. As time went on, rather than thinking of the camera a a means of extending what had already been done in art, photographers began doing things impossible to do any other way. Similarly, people began to see phonograph as a medium in its own right and as a means of creating entirely new expression. An example of such work is John Cage's piece entitled *Landscape No. 1* (1939), which

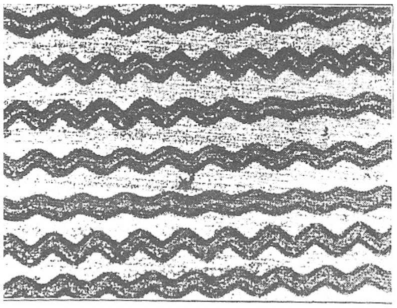


Fig 2.4
Curves of the needle in Adorno's time.

Fig 2.5
Francis Barraud's "His Master's Voice," which became a famous Victorola trademark.

was written specifically for the phonograph and used two variable-speed turntables to create as part of the composition a sound that had been impossible to produce before.

With time photography matured into an art form commanding its own critical audience and a corresponding body of discourse. For example, Walter Benjamin's seminal "Work of Art in the Age of Mechanical Reproduction," touches on the subject of phonography. In this essay, Benjamin laments is the loss of authenticity of the original performance as it is captured in a recording. He writes that the aura of the original, "its presence in time and space, its unique existence at the place where it happens to be... withers in the age of mechanical reproduction."   Benjamin turns our attention to the fact that the mechanical equipment of the recording studio has penetrated so deeply into reality that what is perceived by ourselves as its pure aspect is the result of a special procedure. According to Benjamin, the appearance of reality itself paradoxically became "the height of artifice." [12]

Like Walter Benjamin, Theodore Adorno was a critic-at-large who theorized the subject of Modernity with writings that often engaged the sphere of the arts. A few of Adorno's early essays deal specifically with the phonograph. His earliest essay on the subject, entitled "The Curves of the Needle," speculates on the psychological appeal of the phonograph by comparing its allure to the pleasure afforded by the photograph. The text begins with the question of how, like photography, the mechanical mediation of the gramophone* transforms in various and subtle way the events it records. Adorno writes: "in the aesthetic form of technological reproduction, (recorded) objects no longer possess their traditional reality." [13] In his later essay, "The Form of the Phonograph Record," Adorno further pursues this line of thought in arguing that the record is like an "acoustic photograph," intelligible even to the dog listening for his master.

* Although the terms "gramophone" and "phonograph" have long become synonymous, they referred to two competing technologies in the nineteenth century. Roland Gelatt explains that "Gramophone" then referred to a machine employing lateral-cut disks (Emil Berliner's invention), "Phonograph" to a machine employing vertical-cut cylinders. [10]

In comparing the phonographic inscription to the photograph, Adorno anticipates Benjamin's later discussion of "aura" by suggesting that the record changes the status of the acoustic event it captures in that "the latter cannot be turned on and repeated at will but is rather bound to its specific place and time." [8] In a sense, the record thus embodies the qualities of a documentary photograph whose appearance of reality is taken at face value. As a brief once prepared by the University of Toronto's Department of Musicology proposing a computer-controlled phonographic information system succinctly noted, "Whether we recognize it or not, the long-playing record has come to embody the very reality of music." [14]

2.1.2 Phonograph performance as cinematic montage

By the 1980's, the phonograph - known by this time simply as "turntable" - had come into its own as an expressive playback instrument within the popular music culture of urban youth. The turntable first came to be used live on stage with the (now) famous DJs such as Cool Herc, Grandmaster Flash and Afrika Bambaataa. These pioneers set out the idea of a performance "remix" made up of various records put together into a continuous montage, perhaps most famously with the forementioned Bambaataa's use of Kraftwerk's distinctive "Trans Europe Express" melody on his ground-breaking 1982 single *Planet Rock.* The tune was the first electro rap tune of it's kind and sold 620,000 copies in US. In Bambaataa's performances at that time, the futurist music from Dusseldorf, Germany found its way alongside African drumming, American soul, and British rock, often within the context of an open-air party held in the economically ravaged Bronx. Thus, from its inception the musical style that came to be known as hip-hop was plural, defined by an approach to sound and music-making rather than a single stylistic designation. Bambaataa himself comments in an interview with BBC: "(myself) and Grandmaster Flash... we could play house, hip hop, techno, electro all mixed together, ragga, there ain't no music on this planet that I can't jam too and that I can't play." [15]

Contemporary disk jockey Paul D. Miller (aka DJ Spooky) conceptualizes the mix culture of today as a "dynamic palimpsest... an electromagnetic canvas of a generation raised on and in electricity." In his words, all sounds have now become elements that can be mixed and it is the multiplicity of the sonic material, rather than the outdated notion of originality, that creates opportunity for individualization. Miller reminds us that "back in the early portion of the 20th century this kind of emotive fragmentation implied a crisis of representation, and it was filmmakers, not DJ's who were on the cutting edge of how to create a kind of subjective intercutting of narratives and times." [16] Perhaps the most extreme example of a very literal implementation of acoustic montage is the work of turntable artist Christian Marclay, who pastes slivers of different LP's together to form "composite" records that he would play in his public performances and installations.

The analogy between the concept of a remix and cinematic montage is also appropriate at the level of the recording process. In "The Form of the Phonograph Record," Adorno observed that the recording studio's sophisticated microphone techniques are analogous to the close-up and the jump cut in film, making a call for the establishment of a recording practice which takes these issues into account. He writes: "a renewal of the practice of technological recording of music could learn a lot from film. One need not, for example, be embarrassed to cut together the final tape out of a series of partial takes, selecting only the best out of 'shots' that were repeated ten or fifteen times." [8] Adorno argues that the practice of acoustic montage would enlist the elements of chance and expose the falsity of inspiration that is already incompatible with the iterated structure of traditional rehearsals.

2.1.3 Phonograph-become-image in a commercial product

Adorno reminds us that "records are possessed like photographs" and they were both collected in albums in the nineteenth century. [13] The phonograph allowed the image of sound to be fixed and made available in the form of cheap reusable objects that could be purchased, sold, traded and collected. This has enabled a network of commodity relations to arise within a newly formed body of massive musical audience and recording industries.

The idea of music as it relates to the combined machinery of record production, sale and distribution is the subject of an essay entitled "Free, Single and Disengaged: Listening Pleasure and the Popular Music Object" by culture theorist John Corbett. Corbett argues that music of today should be seen primarily as a commodity, which he defines as a "custom-cut straight jacket... tailored to the metaphorical body of consumer audience which constitutes the primary motivation behind its production and dissemination." The author's inspiration comes from the writing of economist Jacques Attali, who argued that "contrary to currently fashionable notions, the triumph of capitalism... is not that it was able to trap the desire to be different in the commodity, but rather it went far beyond that, making people accept identity in mass production as a collective refuge from powerlessness of isolation." [11]

Corbett identifies two general modes of consumption that exhibit this tendency, one of which he labels individualizing ("the desire to be different") and the other identificatory ("identity in mass production"). While in the former case people tend to individualize their consumption and associate themselves with the singular idiosyncratic object that has a certain "measured distance" from other objects of its kind, the identificatory mode of consumption breaks down this barrier and makes commodities appeal in their mass and proximity to each other. Such is the case with stuffed dolls of Garfield, Dilberts and other objects that people tend to identify with on the basis of their relation to the icons that these objects seem to represent.

Fig 2.6-7
Record consumption then (at Bloomingdale's in 1900's) and now.

According to Corbett, both of these modes coexist in the aural arena, and the apparatus of the music industry sets the basic terms of desire, pleasure, and interest that now encompass the notions of free choice, eclecticism and idiosyncrasy as well as the desire for "refuge" afforded by mutual consumption.*

The main gist of John Corbett's essay, as it is outlined above, is that the new conception of music as an object of public consumption stands in opposition to the pervasive characterization of music as an abstract and autonomous entity that appears in journals, guidebooks, and academic criticism. This conflict is well illustrated by the subject of audio-visual disjunction inherent in any musical package. Here Corbett once again takes inspiration from the writing of Jacques Attali, who characterizes items of popular consumption as "a set of objects that produce their own visual lack." Corbett identifies the lack of visual, endemic to recorded sound, as that which initiates desire in relation to the popular music object. "Since the second decade of the twentieth century," he writes, "the musical world has been driven by two conflicting quests: on the one hand, the direct attempt to disavow the cleavage of the image with sound and to restore the visual to the disembodied voice; and on the other, the desire to complete the break absolutely, once and for all - and further to naturalize the audio-visual split and interface the independence of recorded music with an already well-established musicological construction of music as autonomous." [11]

One attempt to reconstitute the lack of visual in a musical object takes place on its cover, which inevitably acts as the first link between the consumer and the consumed. While the album cover may have evolved simply as something to look at while you listen, it functions as a formative attempt to restore the visual

* Record consumption in this day has a peculiar aspect in that LPs would seem to have long been written off as a thing of the past. However, as vinyl enjoys continued popularity with disk jockeys and record aficionados, even major chains like Virgin Megastores stock new record releases. *Phonograph* magazine reported in May 2001 that British Phonographic Industry accounted for 3.2 million records sold that year, which made for a 40% increase over 1999. [17] At the same time CD sales rose by only 14% (but dwarfed records in comparison with 216 million sold). Perhaps we can attribute a degree of increased popularity of record shopping to the fact that there is no easy way to own an LP other than to buy it, whereas the increased availability of CD burners has made it easy to duplicate them. As usual, some collectors take their hobby to the extreme. Paul D. Miller aka DJ Spooky claims to have 20 to 30 thousand records in his collection, which he started at the tender age of three.

that is absent in a recording. A familiar saying advises us not to buy a book by its cover. This recommendation may be a little harder to follow when the matter comes to buying musical recordings, which are in most cases limited to exposing just their cover for direct inspection. While most stores provide at least a sampler of music they carry at listening booths, there is little doubt that a great number of recordings is bought on the basis of album cover alone. In *The Recording Angel,* Evan Eisenberg goes further to suggest that "pop fascination with album covers has given them a status as art objects independent of their contents." As the record itself fixes an image of sound, the picture on its album cover fixes a certain image in the mind of the consumer. One might think of bands like *Iron Maiden,* which relies on the image of skeletal zombie Eddie in order to establish a link to the audience and to provide the mental image of the music they hear. According to Eisenberg, "album art... finally renders the record unnecessary, as a perfect idol displaces the god it represents." [5]

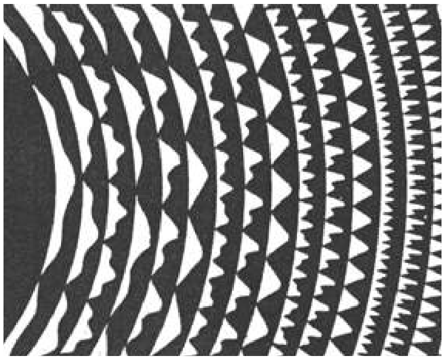
2.2 Historical Precedents

Having highlighted some of the visual metaphors that are bound up in the concept of turntable technology, I now turn attention to historical examples that illustrate this connection from a different perspective. The following two sections discuss specific illustrations of the visual potential of turntable technology, as it is used in the service of both music and art.

2.2.1 Turntable meets visual technology

The idea of utilizing the surface of the turntable/phonograph as a visual substrate is not new from the technological standpoint. In fact, some of the earliest experimental electronic instruments used a rotating turntable platter in conjunction with an optical photocell, since both technologies were among the earliest available in the categories of mechanical playback and electronic instrumentation, respectively.

For example, the first sample-playback synthesizers used glass or film disks, where a looped sound was encoded as an optical soundtrack, circling the disk in a series of concentric rings. A lamp above the disk provided illumination and a radial bank of photocells below generated the audio signals as the disk rotated. An example of the simplest instrument based on this technique is *Cellulophone* ("Cellule Photo-Èlectrique") invented by the French engineer Pierre Toulon in 1927. Cellulophone was an electro-optical tone generator instrument resembling an electronic organ, featuring two keyboards and a foot pedal board. The Cellulophone used rotating disks with a ring of up to 54 equidistant slits cut into them. A light source positioned above the disk flashed through the slits onto a photoelectric cell below, connected to a vacuum



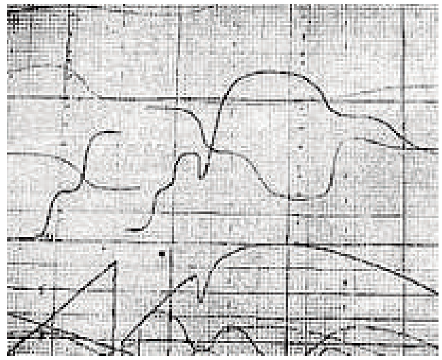


Fig 2.8
A detail of a glass disk used by the Welte Light-Tone organ.

Fig 2.9
A typical paper graph score by Percy Grainger.

tube oscillator. An inverse proportion of the number of slits on each disk thus determined the frequency of the sound produced by it. [18]

A slightly more sophisticated instrument used a picture of the actual waveform to generate sound. The *Welte Light-Tone* (1936), designed by E. Welte in Germany, utilized several optically controlled tone generators. A glass disk was printed with 18 different waveforms rotated over a series of photoelectric cells, filtering the light beam that controlled the sound timbre and pitch. [19] Ivan Eremeef and Leopold Stokowski used a comparable strategy in Syntronic Organ (1936), an instrument that was able to produce "one-hour of continuous variation" created by an optically generated tone using film disks. [20]

Another instrument credited to Australian composer Percy Grainger used paper graphs for continuous tone generation. Grainger had experimented with music by changing speeds of recorded sounds on phonograph disks and developed his own instruments since 1920. In 1948 he collaborated with the musician and singer Burnett Cross in the development of the *Free Music Machine* (or "The Electric Eye Tone Tool Cross-Grainger for Playing Grainger's Free Music"), which used 8 oscillators that were manipulated by paper graphs. Grainger saw the importance of the Free Music Machine and its unconventional notation in its potential to liberate music from scale, which he describes as "a tyrannical rhythmic pulse that holds the whole tonal fabric in a vice-like grasp and a set of harmonic procedures (whether key-bound or atonal) that are merely habits, and certainly do not deserve to be called laws." [21]

Perhaps the most complex instrument based around photocells coupled to the vacuum tube oscillators was the *RCA Synthesizer* (1952), invented by the electronic engineers Harry Olsen and Hebert Belar. The RCA Synthesizer featured a unique programmable sound controller in the form of a punch-paper roll. The system allowed the composer to predefine a complex set of parameters for sound and to mix and shape the result with dividers, filters, envelope filters, modulators and resonators. While this instrument didn't use optical disks, the turntable provided a different kind of functionality: the audio produced by the synthesizer was recorded by an internal lacquer disk cutter. By re-using and mixing the disk recordings a

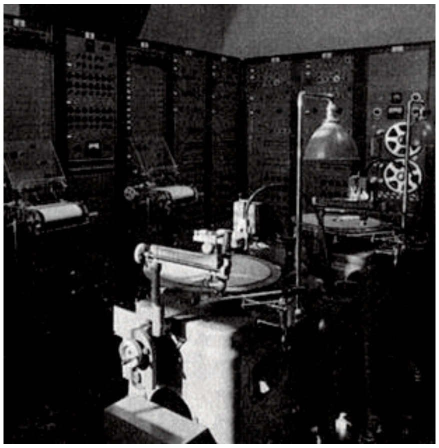


Fig 2.10
Photo of RCA Mark II synthesizer, showing the laquer disk lathe.

Fig 2.11
An Orchestron disk.

total of 216 sound tracks could be assembled together. Electronic composers such as Otto Luening, Vladimir Ussachevsky, Milton Babbit and others used the RCA Synthesizer to experiment with programming complex serial compositions which were previously too tricky for a composer to handle manually. As a result, the RCA synthesizer's novel features provided an inspiration for a number of electronic composers during the 1950's. [22]

The increased sophistication and reliability of electronic circuitry marked the decline of light based synthesis in the post-war era. Optical sample players did have a brief comeback in the early 70's with the aptly named optical-organ *Optigan*, however. This low-cost keyboard instrument was built and marketed by Optigan Corporation (a subsidiary of Mattel) in Compton, USA. Optigan played sounds generated from graphic representations of waveforms contained on interchangeable 12" celluloid discs, which were sold at department stores like Sears. In a manner similar to its predecessor optical systems, Optigan read the discs by passing a light beam through the transparent plastic. The beam was interrupted and transformed by the shape of the printed waveform and picked up by an array of photoelectric cells, causing a variable voltage which was then amplified and passed on to the speakers. The Optigan disks usually contained 57 loops of sounds, 37 of which were reserved for keyboard sounds (with individual loops for each key) while the other 20 were used for sound effects and rhythms. The most popular disks featured organ sounds, as the continually spinning loops had no beginning or end and it was impossible to create an attack or decay portions of the signal. Nevertheless, Optigan manufacturer hyped the instrument as a unique tool that could reproduce the sounds of real instruments:

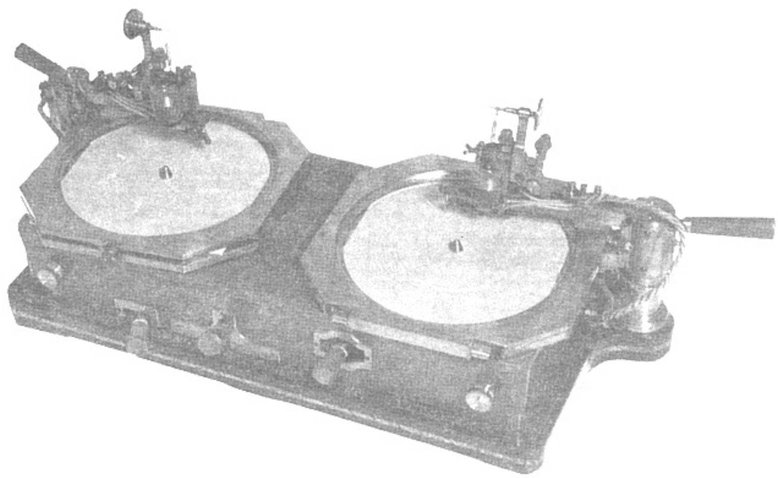
The Optigan Music Maker. The most revolutionary musical instrument ever. Because it's EVERY musical instrument. And every combination. You've never heard anything like it because there's never been anything like it... with the Optigan you actually play the real sounds of pianos, banjos, guitars, marimbas, drums and dozens more. You choose the sounds you want to play the songs you want on our piano-style keyboard and left-hand accompaniment panel. And you choose from Classic guitar to old time Banjo Sing-Along to Nashville Country to Rock and Roll. It all depends on the Program and there's a Program for every musical taste. [23]

Fig 2.12
Examples of 'phonovision' recordings.

The Optigan Corporation marketed the Optigan as a novelty home instrument for a number of years, selling it in street stores for as little as $150. Despite its mediocre sound quality, many Optigans were sold across the country, and the instruments are still prized for their camp appeal. The product license was eventually passed on the business to the Miner Company in New York (organ manufacturer) who continued to manufacture the instruments and discs under the company name of Opsonar. An unsuccessful 'professional' version of the machine was later marketed by a company called Vako under the name Orchestron, but only about 50 were built and the company soon folded. Among the musicians who utilized the Orchestron in peformance was Patrick Moraz, the keyboardist for the British progressive rock group Yes. Special note to their fans: it turns out that Kraftwerk also toyed around with the instrument. As the recent biography of a former band member Wolfgang Flür recounts, Kraftwerk bourght the Orchestron during their 1975 tour. Flür praises Orchestron for an unexpected reason, however: "the sound (of the Orchestron) was fantastic... The choir and string voices were the most fascinating, their droning and melancholy quality caused by the unstable drive across rubber bands, resulting in variations in synchronism. However, this didn't detract from their charm in the least." [4]

Orchestron represents one of the last vestiges of an era of visible-to-the-eye music. As optical technology moved down to microscale with lasers, there was no longer a need for the large format of turntable media. However, this form factor still held some potential for more data-intensive applications. For example, some of the early video technologies utilized the turntable and the familiar large disks. It might be a little known fact that the earliest known recordings of television exist on wax. Utilizing 'phonovision' technology patented in 1920's, experimenter John Logie Baird made recordings of the 30-line video signal less than two years after the first demonstrations of television. This early attempt to capture moving pictures relied on the old technology of the mechanical-contact needle, allowing only about four minutes of the video signal to be recorded. [46]

In 1970's, the first video disc system reached the consumer market. Developed in collaboration by Germany's Telefunken and England's Decca companies, the TED videodisk system used paper-thin records about 12 inches in diameter to reproduce both the audio and visual spectrums in color European TV standards from minute grooves off the surface of the disks. The authors of a comprehensive anthology



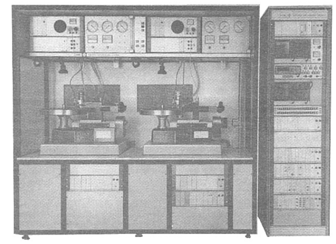


Fig 2.13 (top)
TED videodisk recording system, 1975.

Fig 2.14 *(left)*
Edison's *Embossing Telegraph*, 1877.

of phonograph technology entitled *From Tin Foil to Stereo*, Oliver Read and Walter Welch, use TED as an illustration of how far the turntable has advanced by the time of the book's publication in 1976. However, they also dig up a fascinating example that puts a truly ironic spin on things: As it turns out, the "father of the phonograph" (in inventor's own words) is Edison's *Embossing Telegraph* built in 1877. This instrument used paper disks to record and to repeat Morse code telegraphic messages that were encoded as indentations in the surface of the paper. Using an "ingenious hinged lever action," write the authors, the machine supported the weight of its mechanical parts in such a way that there was very little side pressure in embossing or reproducing the paper recordings - "analogical to the TED Videodisk practice 98 years later!" [46] Read and Welch point out that the Embossing Telegraph shows just how much of "an intuitive grasp on the shape of things to come" is in evidence in Edison's invention. I could only add: all the more so in 2002, when the mechanical beast immediately reminds one of the iconic two-turntable DJ setup.

Fig 2.15
Duchamp's Rotoreliefs.

2.2.2 Turntable as an expressive tool

Having captured the public imagination and made its ways into an increasing number of 20th Century households, it was a matter of time until the turntable generated its own response in the realm of the creative expression. Perhaps the most familiar example that utilized the turntable is a set of Marcel Duchamp's colorful disks called *Rotoreliefs*, which were meant to viewed on the revolving platter. As the disks spun around at the speed of the phonograph record, they created an impression of depth. Duchamp pointed out that the optical illusion became particularly intense if the disks were viewed with only one eye. In a joint venture with Henri Pierre Roche in 1935, Duchamp created 500 sets of six colored disks that were first shown at opening of the 33rd Salon des Inventions, at the Parc des Expositions on the outskirts of Paris. Situated between such exhibits as an incinerator, a rubbish-compressing machine and an instant vegetable chopper, Duchamp's invention went practically unnoticed by the public. It was, however, noted by the jury and awarded an "honorable mention" in the industrial art category.

A work that predated Duchamp's but went far deeper into the exploration of the visual potential afforded by the continuous motion of the spinning disk is a unique instrument for performance of animated color projection created by inventor Thomas Wilfred. Having given up a singing career in 1919, Wilfred set out to implement his own "fourteen-year dream" of building a color organ for the manipulation of light. This work was inspired in part by his involvement with Theosophism, which led Wilfred to investigate the possibility of absolute mapping between sound and color that would demonstrate the spiritual principles of the movement. Having come to the conclusion that such correspondence didn't exist, Wilfred concentrated instead on the silent exploration of the animated visual form he named "Lumia." Wilfred expressed a strong opinion regarding his new-found conviction: "an attempt to design Lumia instruments in imitation of musical ones will prove as futile as attempt to write Lumia composition by following the conventional rules laid down for music." [24]

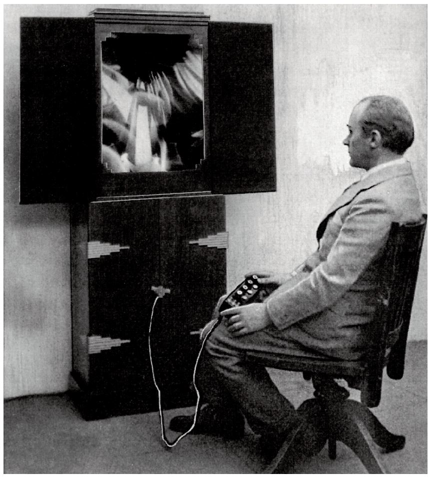


Fig 2.16
Wilfred in front of his Home Clavilux turntable-based system.

Fig 2.17
A set of hand-painted disks for Home Clavilux.

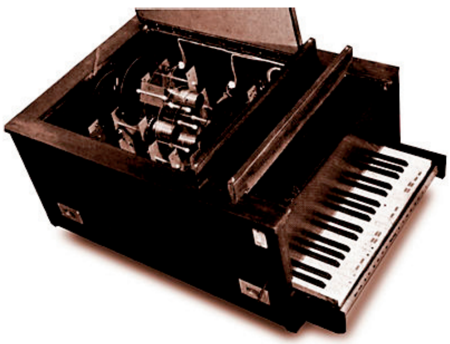
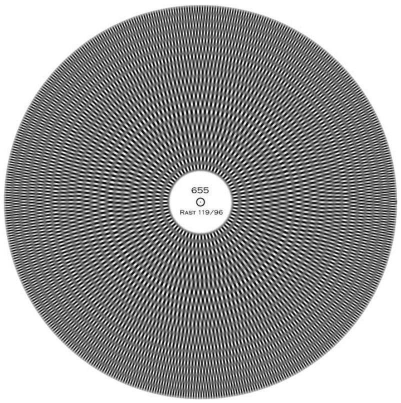
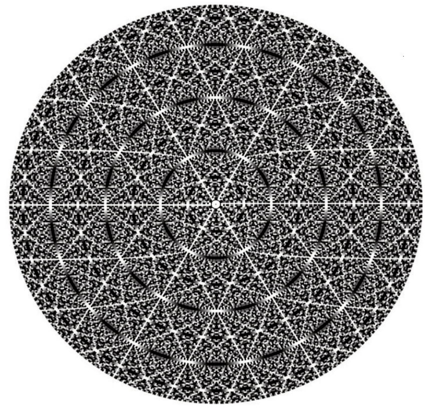


Fig 2.15-16
Baranoff-Rossine's piano optophonique, which used visual disks for color and sound effects.

In 1922, Wilfred finished work on the instrument he called *Clavilux,* which allowed him to perform on stage with projected images resembling a slowly metamorphosing, polymorphous streams of fluid that were compared by his audiences to the display of the Aurora Borealis. In 1925, a reviewer described Wilfred's work as a dream of "some unearthly aquarium where strange creatures float and writhe, and where a vegetation of supernatural loveliness grows visibly before the spectator." Building on the success of his instrument, Wilfred then constructed self-contained "Lumia box" units that could operate without performer's constant supervision. Lumia Boxes used hand-colored glass disks to produce a variety of light effects that would play for days without repeating the same imagery. What's even more fascinating, Wilfred eventually developed his concept into a "Home Clavilux" system, designed for performance by consumer instrumentalists. In 1930, sixteen of the first Home Clavilux models were conceived and built by Wilfred. Thus, with Clavilux we see a progression of a visual performance instrument from stage to the home by way of the familiar and consumer-friendly turntable metaphor. [25]

An instrument similar to Wilfred's Clavilux is *Piano Optophonique* created in 1916 by the Russian Futurist painter Vladimir Baranoff Rossine. As its name implies, the optophonic piano incorporates the element of sound into the visual mix. The instrument generated sounds and projected revolving patterns onto a wall or ceiling by directing a bright light through a series revolving painted glass disks, filters, mirrors





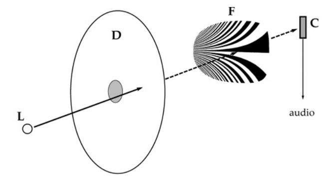
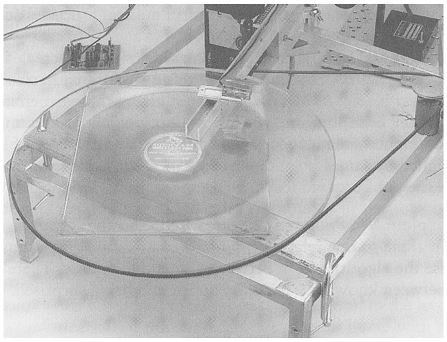


Fig 2.18 (above)
Principle of operation behind the photosonic instrument.

Fig 2.19 (left)
Examples of disks used by Dudon.

and lenses. As in the optical instruments discussed in the previous section, Rossine's disks were made audible as a result of the variations in opacity of the paint, which filtered a light source shining through the disk onto a photoelectric cell. The instrument contained a single oscillator that produced a continuous varying tone, accompanied by the rotating kaleidoscopic projections. Rossine saw the potential of Piano Optophonique in expanding the vocabulary of musical composition and performance with elements of light and color. He writes: "The day when a composer will compose music using notes that remain to be determined in terms of music and light, the interpreter's liberty will be curtailed, and that day, the artistic unity we were talking about will probably be closer to perfection." [26]

As the promise of optical technology started to fade in view of the advances made in other areas of electronics, a decline in experimental work utilizing the photocell followed. Similarly, the turntable began to be replaced by other technologies of sound reproduction that came onto the market. However, even to this day there remain occasional instances of work that explore the unique potential of the two technologies. A particularly poignant example of contemporary work in this realm is the photosonic instrument conceived and developed by the French musician Jacques Dudon. Like its predecessor systems, Dudon's instrument utilizes optical disks that filter a light falling onto a photocell, which produces the electric current that is amplified and fed to the speakers. Dudon's original contribution is to add an optical grating filter as an additional stage of light filtering. This results in a great complexity of timbral effects, explored by mixing the graphical representation of the waveform on the disk with various filters. In addition, Dudon plays his instrument by holding the light source in one hand and the filter in the other. Joe Paradiso suggests that by manipulating the sensor and filter in all dimensions, Dudon is able to achieve advanced forms of articulation and timbre shaping, switch between samples, and to blend and crossfade between various sounds. Notably, Dudon achieves all of this without the help of either analog or digital synthesis. Rather, it is the graphical representations of complex musical shapes, combined with manipulation of the light and filter by hand that give the instrument a "possibility of expert gesture." A paper submitted by



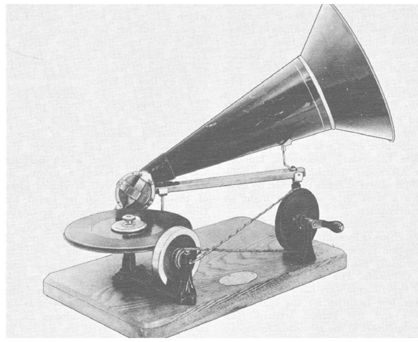


Fig 2.20
Paul DeMarinis' *Ich auch Berlin(er)* gallery installation uses a hologram of a record made audible with a laser.

Fig 2.21
Emil Berliner's original hand-driven gramophone, 1887.

Dudon and Daniel Arfin to the *Proceedings of the 2002 Conference on New Musical Expression* suggests that more than 900 different graphical representations had been devised for the disks used with the instrument. Authors suggest that this represents "only a small part of the possible material accessible to the optical disk technology." [47]

We can only speculate where the advancement of optical and electronic technology will take us next. At least, we can be reasonably sure that it will enable us to see what has been seen before. Joel Chadabe's encyclopedic *Electric Sound* provides a curious example of a contemporary artwork generated as a response to this condition. The piece entitled *Ich auch Berlin(er)* is a tribute to the inventor Emil Berliner, who was the first to patent the usage of a wax disk (as opposed to Edison's cylinder) as a recording medium. The author of the work Paul DeMarinis explains the idea behind the piece: "once I realized that only light reflections were needed to make the recorded grooves audible, it became apparent that a hologram (the memory of light reflecting from a surface) would suffice to play music." [27] What his gallery installation features, then, is a a gelatin dichromate hologram of a 78rpm record of the 'Beer Barrel Polka' rotated on a transparent turntable and played by a green laser. Here the idea of a musical inscription is finally conflated with the visible, which is itself but a trace of a reflection embedded in a holographic matrix.

DeMarinis' work offers a retrospective glimpse at the technology of the bygone age viewed from the lens of our own. We know that there is nothing more for the precision laser beam to see than what has been inscribed onto the original wax by the recording stylus, however. The technology of pre-computational era thus reaches its peak at the point where the unchanging nature of the physical material meets the limit of its own potentiality. In the next section, certain models of a new audiovisual paradigm made possible by the computer are introduced, which could be considered truly inexhaustible due to the nature of the software programs that has make these models possible. We know for sure that the computer programs will evolve at least as long as the machines do themselves. The task at hand, then, is to document the latest.

2.3 Computational models for graphics and/or sound programming

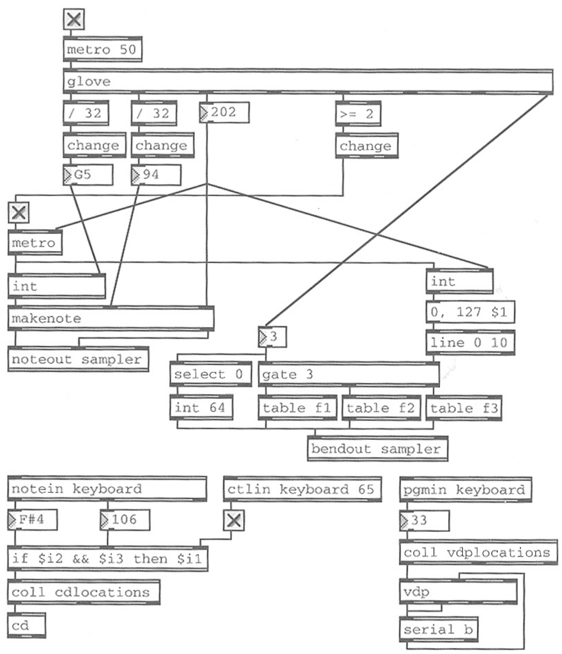
The first part of this chapter discussed the visual potential of turntable technology from a historic and theoretical points of view. The purpose of this section is to expand this idea in relation to the concept of computing. The aim is to show that the computational medium opens up a wholly new set of possibilities that could be explored with the chosen interface. By connecting a turntable to the computer, we can transform this tool into a flexible instrument for controlling virtual events, both visual and sonic. However, first it is important to show how this could be accomplished.

2.3.1 Software options for sound and graphics generation

In the realm of software, there is no necessary differentiation between audible and visual materials, as both are represented in a numerical fashion. The concept has not yet translated into an abundance of tools that explore this potential, however. In commercial software, there is a clear distinction between products targeted to different needs, as determined by specific market niches. For example, there are graphics programs for manipulating bit-mapped images, which are kept separate from graphic software based on the vector metaphor, or 3-D graphics programs. In audio software, similar divisions exist between programs that enable sound editing, synthesis, arrangement, etc. While we occasionally see some crossover between various programs within specific domains, I suspect it is a long time coming when we see Photoshop manipulating sound as well as pictures.

What's more, commercial software programs generally hide the true potential of the computational medium under the guise of usability. All that one is usually exposed to in using a modern day program is the functional facade, but none of the numerical underpinnings. Because there is an unwillingness to expose what is hidden under the visual cover, the degree of program's flexibility is often limited. In both graphics and audio, the most advanced idea is something like a frame-by-frame interaction metaphor: edit, push play, stop, then edit again. Notably, over the last few years we are starting to see a rise in popularity of programs incorporating hooks into the computational medium, such as the interactive tool Flash with its ActionScript technology.

In response to a general lack of tools enabling an advanced degree of control over the computational medium, a few software projects have come to fill in the void. Perhaps the most famous example is the Max/MSP environment, which was developed with the goal of enabling its users to "control anything by anything." The program utilizes a visual programming metaphor with a collection of 'external objects' which can be interconnected in various ways, enabling one to do things like use MIDI events to control a



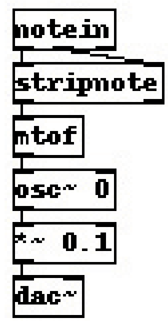


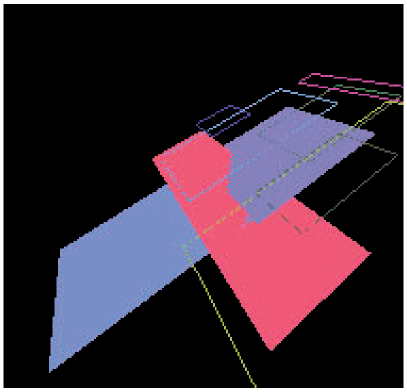
Fig 2.22
Sample program implemented in Max, allowing one to control a cd player and a laser disc player with MIDI data.

Fig 2.23
A simple synthesizer implemented with Pd.

laserdisc player, or mouse movement to control the playback of a Quicktime movie. Hundreds of different interfaces have been created using this basic framework, many of which cross the stubborn boundaries of audible and visual, as well as physical and virtual. [28]

While Max currently exists for MacOS 9 platform, a counterpart has also been developed that runs on Linux, PC and Mac OS X. Pd, which stands for “pure data,” is a program for real-time audio processing created by Miller Puckette, the original author of Max. The software is described as similar to Max/MSP system but “much simpler and more portable.” Like Max, Pd is based on the visual programming metaphor thereby a user manipulates iconic “patch” objects by connecting their inputs and outputs with mouse-drawn lines. “Using Pd,” states the program manual, “one can build audio patches which can synthesize musical sounds, analyze incoming sounds, process sound to produce transformed audio outputs, or integrate audio processing with other media.” [29]

Pd also incorporates some features that are not yet available in Max/MSP. Of particular interest is the GEM package by Mark Dank, which is now an integral part of the programming environment. [30] GEM is a collection of external wrappers that allow the user to create OpenGL graphics within Pd. As a result, Pd can be used for simultaneous computer animation and computer audio. For instance, *Pushit* is Dank’s own audiovisual composition created with GEM for the Pd environment in 1997. According to the author, Pushit “listens to the performer and generates new and processed sounds, as well as computer graphics, in real time.” [31]



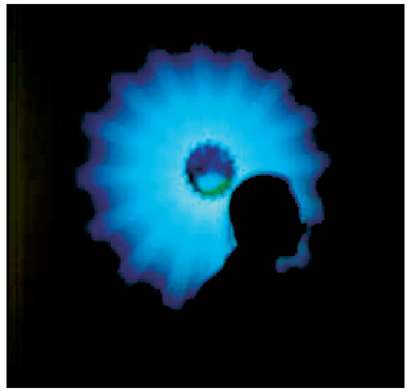
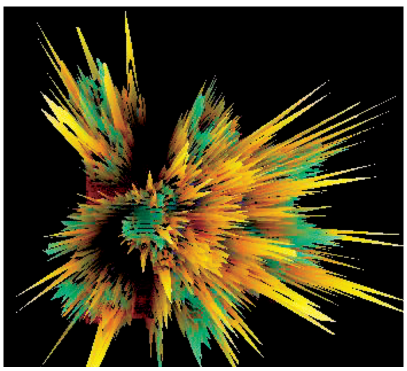


Fig 2.24
Segment from Mark Dank's Pushit composition for simultaneious performance of graphics and sound, implemented in Pd/GEM.

Fig 2.25
Biofeedback installation Autoregulative Spaces.



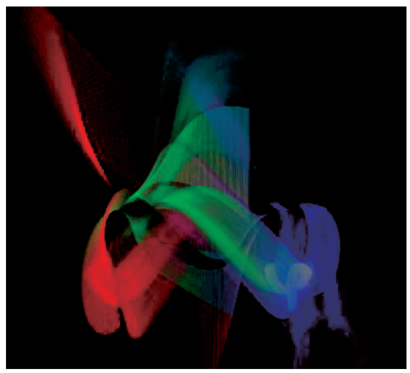
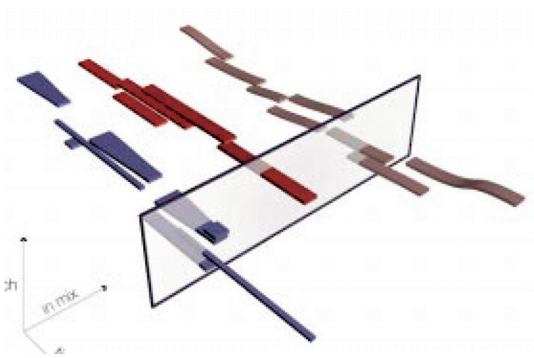


Fig 2.26-27
Video pieces implemented with Pd/GEM.

A more recent project utilizes the Pd environment to generate audio and graphics in response to physical interaction. *Autoregulative Spaces*, described by its authors as a "biofeedback installation," uses finger sensors measuring galvanic skin response of the human user/performer as an input to the computer. According to the project description, "the (sensor) data is converted into a MIDI-data stream, which can be used to control a wide range of machine-generated aesthetic events - such as sound, lighting, projections and digital images." In one implementation, the visitor's bio data controls the structural parameters of a granular synthesizer as well as the distribution of sound in space. [32]

2.3.2 Audiovisual investigations at ACG

The primary aim and contribution of visual environments like Max/MSP and Pd/GEM is that they allow one to assemble flexible software structures without the knowledge of programming. In a sense, the authors of these programs have chosen what might be the most useful programming blocks and packaged them up in a form that hides some of the uglier innerworkings of the real enabling technologies behind them, such as the OpenGL framework in the case of GEM. In contrast, the philosophy of ACG has been to embrace the systems that make advanced forms of expression on the computer possible at the lowest possible level, so as to avoid limitations imposed by higher level structures of available tools (even Open-



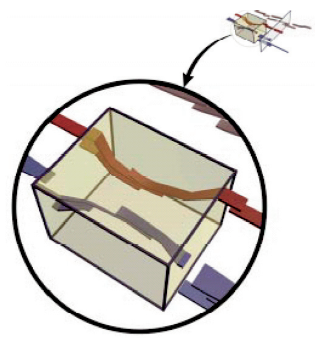


Fig 2.28
Reed Kram's MidiVis environment.

Fig 2.29
A closeup of an audio filter in MidiVis.

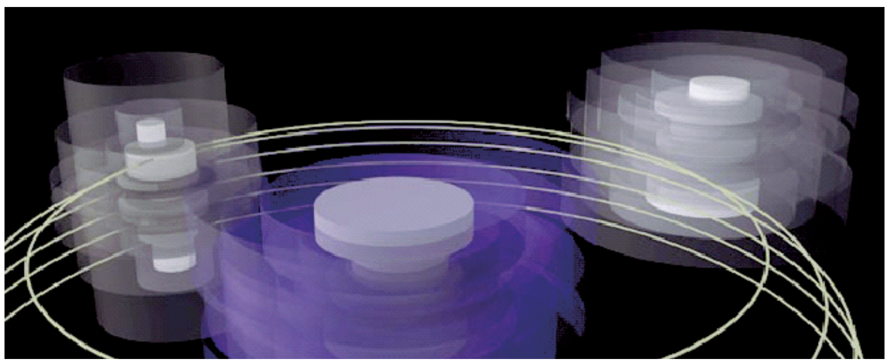


Fig 2.30
A screenshot of Reed Kram's Transducer application.

Inventor falls in this category). The work in the group over the past several years generally relied on the open-ended OpenGL framework programmed in C++. The following examples, chosen as an illustration of the lineage of work leading up to this thesis, show some of the possibilities that have been explored as a result.

Reed Kram '98 is a former ACG student whose research investigated several systems that combined aspects of performance with real time interaction, animated graphics and sound generation on the computer. For example, Kram's *MidiVis* program implements an interactive software MIDI sequencer that uses visual form to represent musical information. In the words of the author, "the *MidiVis* system seeks to unite the processes of playing musical instruments and editing the resultant midi tracks into a single, continuous performance." [33] The MidiVis environment is a three-dimensional space in which a given MIDI instrument is represented as flexible ribbons, one for each note. In this setup, the length of the note represents its duration, the width represents amplitude, and the position of the note in the vertical direction represents the pitch. A particularly interesting feature of the application is Kram's treatment of audio filters, which are represented by transparent three-dimensional shapes that exert a physical force on the moving ribbons. For instance, one audio filter is shown as a rectangular area inside of which MIDI ribbons are pulled together, making a very clear link between the visual aspect of the presentation and its sonic outcome.

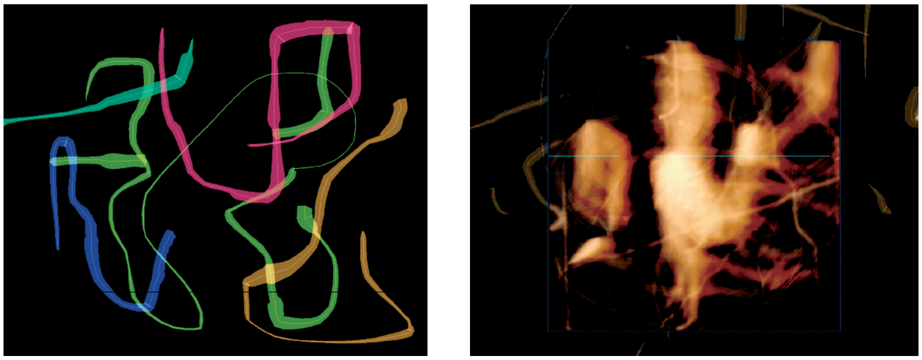


Fig 2.31-32
Golan Levin's freeform gestural marks in Loom and Yellowtail.

Kram's application *Transducer* is an audio-visual system that allows a performer to build constructions of sampled audio and computational three-dimensional form simultaneously. In this program, each sound clip is visualized as a cylinder of that can be manipulated both visually and aurally in real-time. Kram writes: "Transducer asks one to envision a space where the process of editing and creating on a computer becomes a dynamic performance which an audience can easily comprehend." He even compares the interactive functions of Transducer to those of a DJ's mixer, in that it encapsulates the "magic and freedom of disk-jockey performance with concise visuals that are clearly in tune with the music, though entirely unique to the medium with which the work is created." The performer acts within Transducer system by selecting sound objects and changing their visual (shape, transparency) and audible (frequency, amplitude) characteristics. According to Kram, a large number of sound objects can be previewed and manipulated at the same time, allowing a single user to build constructions examining interrelationships between multiple, diverse sound sources and a corresponding visual form.

Golan Levin '00 is another former ACG student, whose research investigated the design of systems which make possible simultaneous performance image and sound in response to real-time gestural inputs. The goals Levin sets out for himself deal comprehensively with the issues of software synthesis in the expanded domain of audible and visual. Specifically, he considers it a necessary feature of a successful audiovisual instrument that its results should be "inexhaustible and extremely variable," that the system's sonic and visual dimensions should be "commensurately malleable," while its interface should be "instantly knowable, but indefinitely masterable." Levin's answer to his own challenge is a new interface paradigm for audiovisual performance, which is based on the idea of an "inexhaustible, extremely variable, dynamic, audiovisual substance which can be freely 'painted,' manipulated and deleted in a free-form, non-diagrammatic context." [34] He derives the concept of a painterly substance from its real world equivalent. Levin's ultimate goal is to be able to create audiovisual compositions on the screen by building them up stroke by stroke much like an artist builds a composition on canvas. The advantage that a virtual environment affords him is the ability to breathe life into the brush strokes with animation, the possibility of sonifying the marks in a manner of his choosing, and the concept of 'inexhaustible' space that allows an unlimited amount of audiovisual material to be deposited on the screen-canvas.

In the course of his research, Levin created several applications which allow users to explore sonic landscapes by creating gestural, painterly marks using a tablet or mouse. For example, Levin's program entitled *Loom* allows its users to trace out visual marks that are used to control the parameters of an FM synthesis equation. Here, sonifications is based on the idea that a score or timeline could be wrapped around a gestural mark as it retraces its own motion over and over again moving along the screen. By mapping elements of the synthesis equation onto the visual properties of the mark, Loom generates musical tones whose sonic properties are continuously governed by its shape.

Levin's software piece *Yellowtail* uses the bit-mapped image of a gestural mark as a spectrogram, processing it through an inverse Fast Fourier Transform algorithm and feeding the output to the additive synthesis equation. Levin's innovation here is the fact his program permits the use of dynamically animated image, a feature that is missing in many applications that support reverse FFT. In *Yellowtail*, a gestural mark drawn on the screen is broken down into pixels, the values of which are treated as inputs to sinusoidal oscillators in such a way that the intensity of the color determines the amplitude of the oscillator. As the oscillators are arranged in order of increasing pitch horizontally, it is possible to make Yellowtail produce percussion-like sounds by drawing marks vertically, while a more "equal-tempered chromatic scale" will result from a horizontally drawn mark.

2.3.3 Physical interaction in audiovisual performance

The previous two sections outlined some of the options that enable musical and visual expression on the computer. It was shown that at the level of a computer program, the process of graphic and sound generation is equally accessible. The abstract nature of numerical representation of computer's processes allows us to mix any kind of data effectively. A project utilizing Pd/GEM framework, for example, illustrates how electronic sensor data could be incorporated as a part of an expressive composition. The issue of physical interaction is an important component of the thesis project, which aims to facilitate the process of sound creation and manipulation in the virtual realm through a physical interface. This section provides an illustration of a Media Lab project that shares the same goal, providing a direct precedent for the idea of a physical interface as basis of a virtual instrument.

The project entitled *Musical Navigatrics* is the subject of a recent thesis in the Responsive Environments Group. The author of the work, Laurel P. Smith, describes *Musical Navigatrics* as an "expressive and complex free space musical interaction for composition and performance." Her research builds on the previous work in developing an RF swept frequency tagged reader and a *Musical Trinkets* interface by Kai-Yuh Hsiao, [36] improving the technology and extending its feature set with the functionality of an

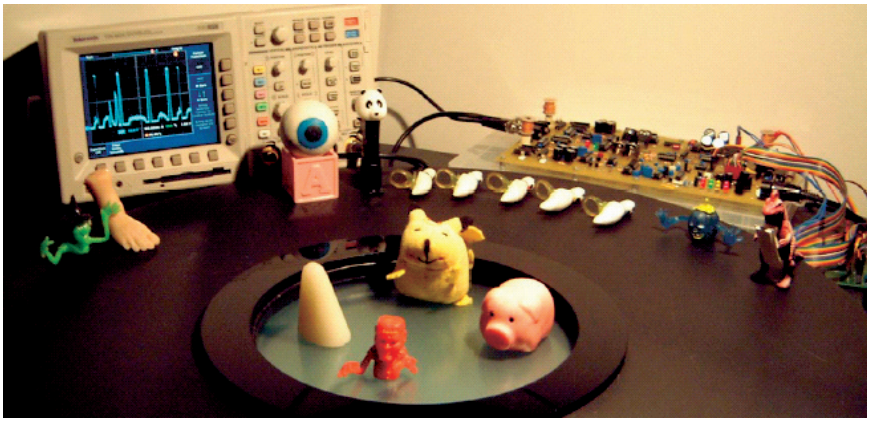


Fig 2.33
Musical Navigatrics setup.

Fig 2.34
Freeform interaction with the Musical Navigatrics instrument.

effects controller and a sequencer, enabling tracks to be recorded, overdubbed and accessed during a performance. The project has grown out as a response to the fact that, despite the growing popularity of electronic music, the interfaces for musical performance are still dominated by buttons, knobs, keyboards, or their virtual equivalents.

The basic operation in Musical Navigatrics is achieved by driving a wire coil at various frequencies to create a magnetic field and then introducing small magnetically-coupled resonators into the active region of the field. The change in coil inductance can be detected and matched with frequency of the resonant tags, allowing their identification. Both the tag's distance and orientation to the field can be detected in real time. Due to their small size resonance tags can be embedded into a wide range of objects, tangible interfaces and musical controllers. For example, the Tangible Media Group's *MusicalBottles* hide the tags in bottle corks, which seem to release sounds from the bottles as they are removed. Musical Navigatrics uses Halloween toys with tags embedded in them. The tags themselves are divided into three functional categories: note production tags, expressive effects tags and control tags. The note tags are used to trigger sounds, the effect tags to modify them, and control tags are used to store information about the movement of note and effect tags.

Fig 2.35
Ritchie Hawtin with his Final Scratch setup.

The combined functionality of Musical Navigatrics makes up a musical instrument that is used as a synthesizer and sequencer simultaneously, simply by moving various tagged objects in and out of the improvisational space defined by the sensing range of the magnetic coil. The hardware interface of the instrument provides raw numerical data, while computer software is used to generate musical and visual response. In the most recent implementation, the sensing coil data is mapped into MIDI notes in Max/MSP and internally redirected to Propellerheads Reason software, which takes care of sound generation. Graphics are generated with a program written in OpenGL. Smith points out that all prerecorded sounds in Musical Navigatrics are handled within Reason, while sequence coordination is performed in Max.

2.3.4 Turntable as a physical interface to software

Musical Navigatrics illustrates how a physical interface can augment the expressive element of human-computer interaction. The turntable offers its own model of physical interaction that could be used in a similar fashion. The aim of this section is to show that this idea has already been investigated to some degree. As of this writing, there exist at least two systems that utilize the turntable as an interface for controlling events on the computer. In fact, one implementation comes particularly close to the intended goals of this thesis in its use of optical pickup as a basis of input. However, as the next section of this chapter will argue, there is potential that hasn't been explored by the turntable-based interfaces presented here.

A product of Dutch company N2IT Development, *Final Scratch* is a system for manipulating digital music files on the computer using a standard turntable. The $3000 ProFS hardware-software package (a version without the laptop retails for $600) includes a software program and a Sony Vaio laptop computer,

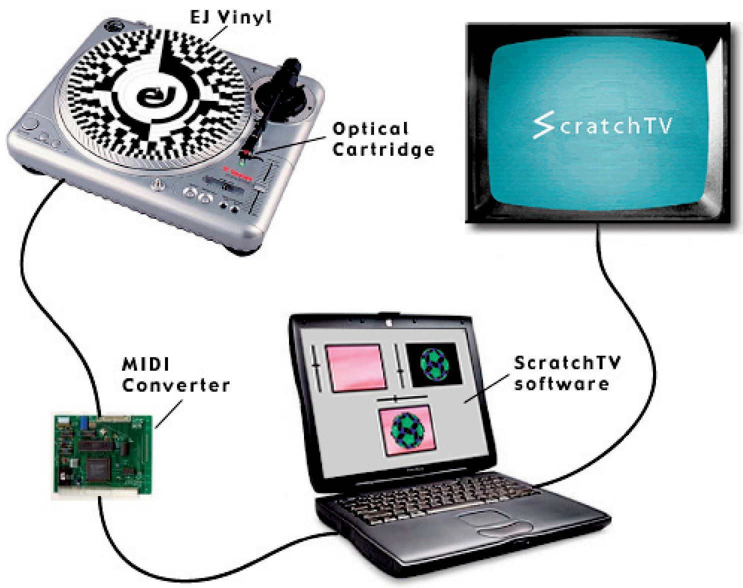


Fig 2.36
Justin Kent's Scratch TV system setup illustration.

which is connected to the turntables through a 'ScratchAmp' analog-to-digital processing box. Specially manufactured vinyl records containing time codes are then used to synchronize the activity of a DJ on the turntable with musical files residing on the computer. As a result, a user of the Final Scratch can play digital files as if they are contained on the record itself, placing a needle anywhere on the record to access various parts of a song, or scratching the digital file by manipulating the vinyl record. The company website suggests that "Final Scratch allows the mixing and scratching of virtually all formats of digital music to within a (12) millisecond of precision." [37]

A well known performer and spokesman for the company Ritchie Hawtin (aka Plastikman) explains why it is important that Final Scratch works through standard turntables: "It gives me the advantage of a physicality that not only I understand, but the crowd understands." [38] He also praises the ability of the software to store thousands of songs on a hard drive, to slice each song into dozens of discrete elements, and to edit and rearrange those songs. The capacity to store large amounts of music on the computer enabled Hawtin to do away with a huge amount of records that he'd normally have to bring to each performance. He suggests that he now carries only a single crate of records - ones he hasn't digitized yet. Hawtin says in an online interview: "My sets are ranging from a minimum of 30 to 40 percent FinalScratch up to 80 to 90 percent FinalScratch." [39]

Another instance of using the turntable as an interface for manipulating events on the computer is a system entitled *ScratchTV*, developed by MIT graduate student Justin Kent under the monicker eJ Enterprises Worldwide. The company webpage advertises the product, which is slated to start shipping by 2003, as something that allows one to hook existing DJ turntables up to a computer and then on to television with the intention of being able to ‘scratch’ the image on the TV screen. Kent points out that his system uses several “innovative constructions” to convert the rotation of a record into MIDI continuous controller values. Presumably he is referring to the photo transistors that are used to read the black and white paper records, imprinted with the quadrature encoding pattern one might find inside an optical encoder. Kent’s custom-written software for Mac and PC is used to map the MIDI information onto video and sound playback. [40]

As Ritchie Hawtin does in the case of Final Scratch, Kent sees the advantage of using the turntable as a way of manipulating video image in the familiarity of the interface. He argues that since a large community of users exists that already have a high degree of mastery of the turntable, users can expect to hear and feel with ScratchTV what they have come to expect from scratching a record. The unique contribution of the project is that the sonic output is accompanied by the visual track from which it is generated. Kent suggests that the goal of his system is socially determined: “by reversing the paradigm of static viewership, we may introduce a new level of social commentary into content, undermining the broadcast mentality fostered by radio, television, cinema, and print.” In the process, he aims to transform the turntable into an instrument taken on its own terms. He writes: “ScratchTV will revolutionize storytelling and music, allowing turntable virtuosos to operate in a new dimension. By doing so, the turntable will gain credibility as an instrument, its users will be validated as musicians, and our definition of music will be expanded - as it has been since the days of stone percussion in caves...”

2.3.5 Analysis of options and precedents

In the second portion of the background chapter, I’ve attempted to trace a lineage of concepts dealing with the issue of engaging the expressive potential of the computer. I started by discussing some of the common limitations in the standard metaphor of a software application and suggested some alternatives.

First, I discussed Max/MSP and Pd/GEM environments as two options that facilitate a much greater degree of expressive freedom in the virtual domain. These applications package some of the powerful tools available to the programmer in a more friendly visual metaphor, enabling novices to grasp the idea of organizing graphic and audio events on the computer intuitively. There isn’t a significant amount of abstraction that a program like GEM encapsulates, however. For example, just about the only difference between GEM and an exposed OpenGL framework (in what one could gather from Mark Dank’s own explanation) is that the former allows the control of graphics as objects, instead of as a sequence of vertices. In other words, beyond the visual facade of the application, the real foundation of GEM is OpenGL. Two research projects at ACG have been provided as illustrations of the potentials of the traditional programming metaphor coupled with OpenGL technology. For example, Reek Kram's work featured animated, interactive graphic and sound compositions generated in response to real time input. While Reed does run into some limitations with his application, they are dictated by the technology restraints imposed on him by the hardware of his day, rather than software. At the time Kram was working with real time sound and graphics, he had to rely on two powerful machines to handle the two streams of interactivity separately. I suspect that the graphic capabilities of 1997 hardware were stretched even by the relatively simple geometric elements that populate Kram's programs in large numbers.

In one of his projects, Kram successfully used the physical position and orientation sensing device *Flock of Birds* in order to instantiate a more direct mode of interactivity within the application. This instance of the use of a physical interface as a way of controlling software events represents an area in which the previous work at ACG could be most improved. The issue of alternative interfaces is pertinent to Levin's work, to take an example. In my view, Levin's otherwise finely tunable applications suffer from the lack of control parameters they are given. A mouse can at best provides just two, speed and directionality, multiplied by the number of buttons it contains. By evaluating these parameters over time, Levin extracts the curvature information of the mouse trace, the main component of his gesture analysis. With a Wacom tablet, he has the additional parameter of the pressure applied by the tip of the stylus. For instance, in Loom Levin quickly runs out of control parameters he is able to map, even onto the simple FM synthesis equation. As a result, certain parameters of the equation are not assigned the properties of the gestural mark at all. Instead, he relies on a slider interface that pops up with a click of a secondary mouse button, allowing the user to select a desired frequency by choosing among color coded squares that have a tenuous visual relationship to the rest of the composition.

One model that explores the issue of physical interface very effectively is Laurel P. Smith's *Musical Navigatrics*, which comes close to the goals of this thesis in that it combines the functionality of software synthesis and sequencing with graphic visualizations and an intuitive physical interface. This project suffers from its own set of interface limitations, however. Paradoxically, it is the excessive amount of freedom that a Musical Navigatrics user is given that detracts from the usability of the system. While the idea of a musical space in which objects can be freely manipulated by hand is extremely powerful, it makes it hard to get a feel for the relationship between the spatial positioning and orientation of the tagged objects and the sonic outcome of the system. The fact that the tags themselves are embedded in relatively undifferentiated toys also detriments the interaction model. Perhaps we can imagine tagged constructs that have a more limited range of motions and encourage a more discrete understanding of the system's musical space. Smith herself notes that Musical Navigatrics "suffers from direct haptical feedback... without the user being able to feel the distinction between notes or even have a visual reference, it becomes difficult to teach the body just where in space specific notes are." She writes: "in the end, Musical Navigatrics succeeds only somewhat as a pitched instrument." [35]

Smith sees a greater potential in the MIDI effects controller functionality of the system. According to her, effects rarely need to be precise as they relate more to exploring a certain musical feel. Musical Navigatrics offers the ability to pick from a variety of objects, move them about in simple and sensible manner and immediately hear the result of the interaction, making up a unique and engaging experience. Musical Navigatrics also succeeds well as a basic sequencer. Smith makes it clear that the system does not attempt to emulate the functionality of a thorough sequencer. Its strength lies in the unique interface for controlling major sequencing events along with an intuitive means for recording them. According to the author, "the tag reader's unique ability to understand and provide intuitive control of both discrete and continuous events presents a useful balance between expressivity and sequencing." The graphic display (albeit created with the more limited Musical Trinkets functionality in mind) offer the audience an additional visual context with which to follow the musical gesture.

In contrast to the novel interaction model of Musical Navigatrics, the turntable could be described as an interface that has already proven successful in musical use. Building on this idea, I introduced two projects that rely specifically on the turntable as an interface to the computer. Final Scratch is the first product of this kind, representing a successful marriage of the physical medium to the virtual. The strength of Final Scratch is the fact that it attempts to replicate the activity of playing real records with a computer-based interface, using vinyl records that look and feel just like any others. However, this also means that the user is completely bound to the specifics of the FinalScratch setup. There is no place to get the special records other than N2IT, and the system doesn't generally seem amenable to any form of expansion. In addition, due to the strict timing requirements, Final Scratch is currently bound to the BeOS platform and even when it is going to be released for Mac and PC this year, the product will require its users to switch to a specifically tailored Embedded Linux environment.

In contrast to Final Scratch, Justin Kent's ScratchTV takes advantage of the idea that there are alternative ways to translate the activity of the DJ and the turntable into instructions for the computer. By utilizing an optical sensor, ScratchTV enables the use of inexpensive/reusable paper records as a way of tracking the speed and location of the cartridge. However, as its name implies, ScratchTV system focuses solely on exploring the potential of scratching a digital file with a physical interface. His turntable platters are giant knobs that can tell the computer to move forward and back, but not much more. By attaching an optical sensor to the turntable tonearm, Kent provides his system with an electronic eye, yet he looks past the visual potential of the surface of the record itself. This is where I see an opportunity for this thesis to come in.

2.4 A set of goals for the thesis project

Simultaneous manipulation of visual and audio material in real time

The idea of interactive performance of graphics and sound has been explored by two previous research projects at ACG that were discussed in the earlier section. It is considered a necessary component of the thesis project, and a natural extension of the research pursued by the group. This idea is not a goal in and of itself, however. Rather, the ability to manipulate sonic and visual material interactively in real time should be taken for granted as an essential feature of an intuitive interface for creative expression on the computer, made possible by the unique nature of the computational medium.

Intuitive physical interface, designed for a target audience

A set of disk-jockey turntables has been chosen as a basis around which an interface for musical performance is to be developed. One of the primary goals of the thesis project, then, is to consider the objective features of the turntable in view of the patterns of familiarity which had been developed between the DJ/turtablist and his or her tool, as well as the audience of turntable music. In other words, there are certain expectations that the performance interface needs to fill in order to fit the interaction framework of a live disk jockey set. In order to address the challenge stated, in the next chapter I introduce the idea of a plug-in architecture that allows the optical turntable interface to fit the established setup of a DJ performance in an elegant and unobtrusive way,

Low-level control over events on the computer

The background section of this document looked at some exciting applications of the computer's creative potential which rely on new or innovative ways to engage the computational process. Examples like Max/MSP and Pd/GEM have been cited as illustrations of how one successful model could be extended to a range of applications once a flexible programming framework has been put in place. Some of the recent work at the Media Laboratory has also been used to showcase a unique potential of the computer as a computational medium, rather than a mere tool. The strength of the models cited lies in the degree of control and flexibility they offer within their application domains. I consider it imperative that the optical turntable interface should likewise establish a foundation for a low-level degree of control over its intended output, unhindered by some of the common limitations imposed by the hierarchy of modern operating systems and user interfaces. The project has thus come to rely on microprocessor architecture as a key component of its infrastructure. As a result, the primary element of musical structure - time - is accounted for at the level of a microsecond.

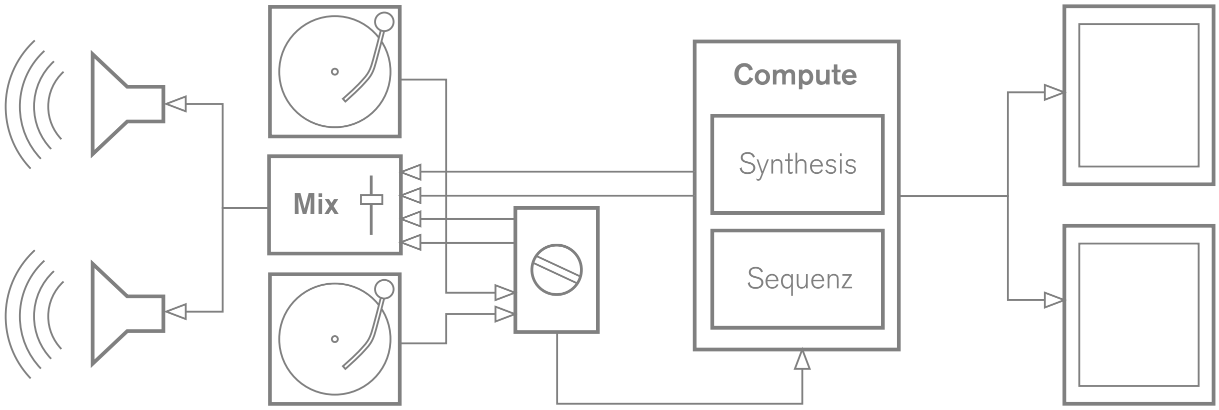
New paradigms for music-making and performance

The concept of a turntable as a physical interface with the ability to control events on the computer provides a unique framework for exploring issues of human-computer interaction. The optical pickup functionality also brings the visual aspect into the mix. This creates a potential to develop new models for expression based around the specific characteristics of this technology. For example, the idea of a visual score and its translation into virtual domain presents an interesting case study. The purpose of the next chapter is to describe in more specific terms the potentials that may be explored with the optical turntable.

Fig 3.1
Introducing *μoot* -- microprocessor
operated optical turntable.

3. IMPLEMENTATION

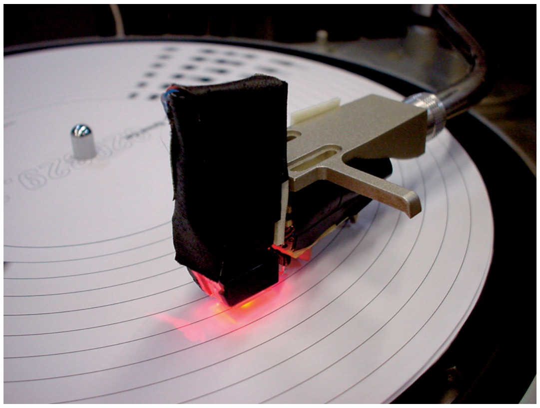
In the previous chapter I set out some goals for an audiovisual performance system utilizing the turntable as a physical interface. This section deals with the specifics of a system I had devised and implemented between the months of January and April 2002 as my best first-take response to the said goals. As stated, one of the primary motivations behind the project was to provide a flexible low-level framework for programming and manipulating audible and visual material on the computer. The result is a system that might be described as a reconfigurable visual programming environment wrapped around the blank canvas of a spinning disk. Markings that are drawn or printed on the disk and picked up by the optical reader take the form of meaningful codes that are interpreted in software and used to manipulate sonic events on the machine. Given the platform-independent and hardware-transparent makeup of the system, as it is described in more detail below, the optical turntable interface can be tailored to fit various modes of interaction and specific software or hardware configurations. In order to illustrate this idea, I provide a few exercises in creating software instruments that work in conjunction with the hardware interface and illustrate some of its potentials.



In composing the example applications I attempt to cover a range of requirements that might be expected of an expressive musical instrument. The goal is to show that a simple and intuitive physical interface, combined with the adaptable visual programming metaphor, enables it to mix the functionality of many different elements of the music-making process into a seamless interactive experience. The examples I provide begin with a simple demonstration of basic synthesis and sequencing functionality that enable the optical turntable to play notes and chords, to manipulate the sound being produced, and to arrange the order of musical events. In the first exercise, I construct a simple synthesizer that allows me to create sound and to experiment with various settings that effect its timbre. In the second, a sequencer that demonstrates the arrangement and layering of multiple voices in a composition simultaneously is described. The chapter later concludes with the analysis of the optical turntable system in relation to the example applications, its current limitations, as well as the potentials left to be explored.

3.1 Interface Components

The primary metaphor that guided the implementation of the thesis project is the idea of a plug-in, both from the standpoint of hardware and software. My desire was to create a system that could elegantly fit existing hardware and software so as to provide a maximum degree of familiarity through compatibility with functional interaction models. To this end, the hardware interface was designed to be as 'transparent' as possible. The elements of the interface are an optical cartridge that enables the pickup of printed records, a hardware switch box that connects the interface to the computer, musical synthesis and sequencing software, and custom written visualization/editing software that is used to read and generate the actual records. A universal MIDI protocol is chosen due to its popularity as a means of communication between the hardware and software systems. Most musical programs now come configured to receive MIDI from



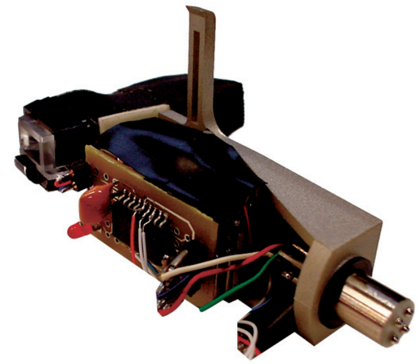


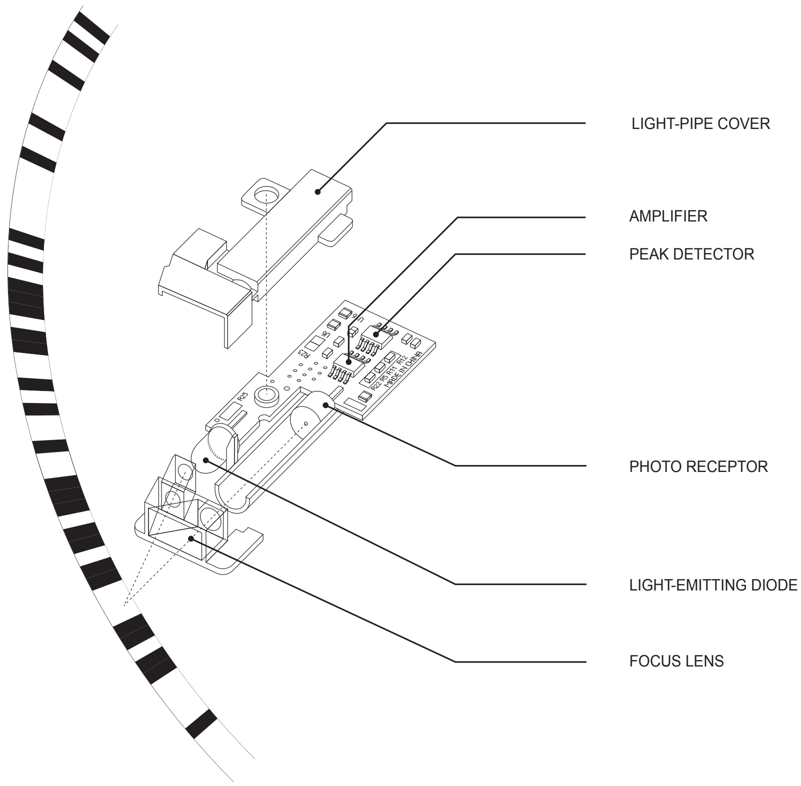
Fig 3.2-3
Optical pickup cartridge featuring a microprocessor board.

external devices or internally via a routing patch like MidiYoke for Windows PCs. The MIDI mapping is implemented in custom C code that is downloaded directly to the microprocessor embedded in the optical cartridge, enabling the turntable to output MIDI directly. The following sub-sections describe each of the interface components in detail.

3.1.1 Optical pickup cartridge

The primary component of the interface is the optical sensing cartridge. The cartridge plugs into a standard turntable tonearm and utilizes the four available lines (normally used by the two stereo channels) to draw power and to communicate with the computer. As a result, it can be easily disengaged from the tonearm in a matter of seconds and swapped in for a standard needle-based tonearm cartridge. The motivation behind this feature of the system is to enable the performer to switch from playing optical records to regular ones, or to mix the two media together during a live set.

The cartridge contains a high-resolution optical pickup module, its amplifier and signal conditioning circuitry, and a microprocessor that generates the digital output signals. The analog circuit design has been borrowed from a portion of a low cost barcode scanner :CueCat. This device was distributed by Dallas, Texas based company Digital Convergence as a free promotional item, most recently through the national electronics reseller Radioshack. The :CueCat scanner makes for an interesting case study because it was given away for free on such a massive scale. Over the course of its development, several generations of the barcode scanner saw this product designed to be cheaper and easier to produce. As a result, the optical portion of the scanner seemed like an appropriate model for the would-be inexpensive optical cartridge.



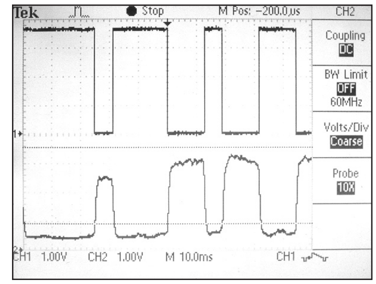


Fig 3.4 (top)
Digital and analog outputs of the optical module.

Fig 3.5 (left)
Optical module component diagram.

In the course of project development, several :CueCats provided ready-made circuits, optical elements of which I isolated and utilized as quick prototypes for the cartridge circuit board. The optical elements of the analog circuit are an Ultra-bright red LED (T1-3/4 clear lens packaging), a plastic lens system, and a Silicon Photodiode detector (T1-3/4 flat-top plastic packaging). The light of the LED is channeled through the lens, reflected off the surface of the material the cartridge is pointed at, focused by another lens and then picked up by the photo detector, which is itself covered by a metallic cap that has a pinhole opening at the top. The spectral response of the photodiode is within 400-1100 nm range, with a peak near the infrared region. The photodiode leads are connected to the operational amplifier that boosts the analog signal to 0-5V range. The signal is then fed through a peak detector (LM358 operational amplifier with a pair of diodes in the feedback loop) calibrated at 5 volts, adjustable with a variable resistance potentiometer.

The amplified analog signal and the peak detector output provide the inputs for the digital portion of the cartridge circuit. In the first iteration of the cartridge, a PIC16F84 microprocessor was used as the main element of the circuit. This re-programmable chip could process the peak detector output and provided the necessary means of generating serial and MIDI signals at a comparatively low cost. Due to the lack of analog-to-digital functionality and a small memory footprint, however, the more powerful PIC16F872 processor with 10bit A/D conversion and larger program memory was utilized in the final design. The microprocessor was programmed in C using Custom Computer Services C compiler. The code was

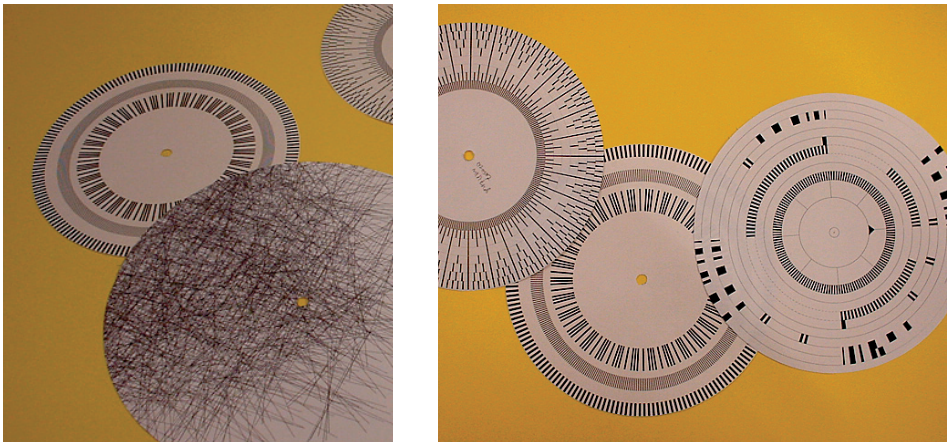


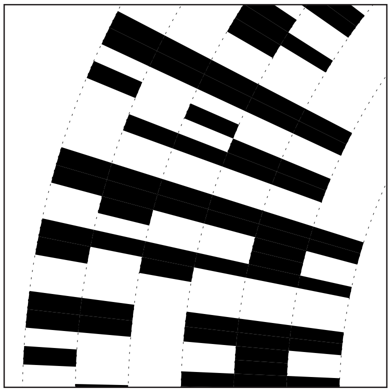
Fig 3.6-7
A few examples of optical records used.

then uploaded to the chip via an MPLab integrated environment using a PICStart Plus programmer from Microchip. The cartridge microprocessor program took care of generating MIDI and Serial Communications Protocol signals that are sent to the computer. The CCS compiler makes provisions for serial communications in the standard library includes, making it possible to send a stream of information with a simple printf command. MIDI mappings were implemented in C with custom methods for Note On and Note Off events, continuous controller values and other calls as needed.

3.1.2 Optical Records

The input to the optical pickup cartridge is provided by records that contain various visual markings or codes that designate meaningful information. The records themselves could be made from a variety of materials, most conveniently from something that is easily marked and cut into circles. Plain paper, cardboard and plastic are a few options that fit this criteria quite well. The markings are applied to the records by a printer, or they can be drawn or painted by hand. Paper in particular provides a very inexpensive and flexible substrate onto which any traditional means of visual imprinting is easily applied. Because the cartridge doesn't touch the surface of the record, layers of material can also be pasted together in the form of a collage.

What makes the markings on the surface of the record meaningful to the computer are software mappings implemented on the cartridge microprocessor. I have experimented with three different types of mappings in the course of thesis research. One approach is to use barcode-like binary patterns to represent numerical information. Several binary codes have been used in developing some of the example illustrations described in a later section. For example, there are codes that represent a direct translation of the 3-byte MIDI specification into the binary format. Codes of this type are used to



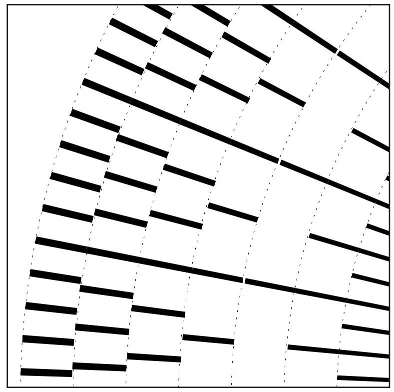


Fig 3.8
Example of digital (binary) codes.

Fig 3.9
Example of 'relative' marks.

represent notes with MIDI equivalents of Note On and Note Off events. The note codes are comprised of the status byte (MIDI channel and note on/off flag), a data byte specifying the note number, and a third data byte specifying the velocity of the note. The note codes are used in the most straightforward way to trigger corresponding tones within an application, much as the keys on the piano would be. The rotating record can be compared in this case to a piano roll that contains a recorded sequence of notes played sequentially as they pass under the tonearm sensor. Note codes can also be utilized by some software applications as control values for operations like turning a button on and off or flipping a switch. As a result, they can be used to start and stop an instrument, to route the signal flow, enable effects, etc. Another kind of binary code implements the MIDI control and mode change events. These codes are used to control various adjustable parameters of the virtual instrument, such as knobs, sliders or two dimensional controllers. Oscillator parameters, envelope generator settings, filter effects and any other values that span a continuous range can be controlled in this fashion. Finally, there are be binary codes custom-tailored to specific application domains. We can use binary sequences to represent instructions that the microprocessor will execute directly. For example, a specific code can be used to tell the chip that a sequence of codes that preceded it should be appended to the next sequence.

Another means to encode meaningful information in the visual marks is to use color. Any of the useful codes described above can be represented by individually chosen colors. As an illustration of the principle, we can imagine a set of different markers designated as musical notes or particular instrument sounds. The process of assembling a composition would consist of filling the appropriate spots on the record with a desired marker, making up a very intuitive visual notation process. Unfortunately, the optical cartridge as it is currently implemented allows only a limited range of grey values to be identified. The 10-bit a/d conversion theoretically provides a range of 1024 discrete values. However, in practice it has proven to be hard to differentiate between subtle shade differences on a rotating record. For this reason, most of the exercises presented in support of the thesis rely on the more reliable binary encoding. Nevertheless, the encoding-by-color method holds a valuable potential for the optical turntable system and represents a primary direction for its further development.

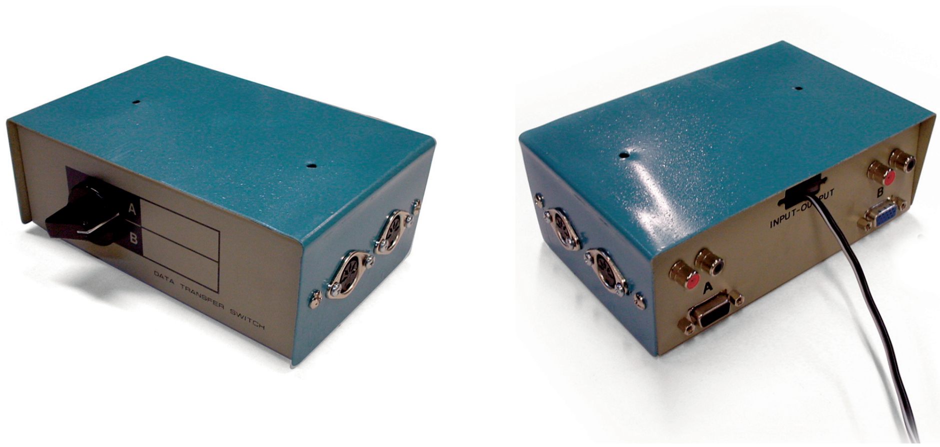


Fig 3.10-11
Hardware switch box.

In addition to codes that specify data in and of themselves, markings can be used to denote information in a relative, rather than discrete (digital) fashion. For example, the frequency of marks encountered by the cartridge can be mapped to a MIDI controller setting that the microprocessor sends out. In this case, a record with any visual representation at all could be used as an input to the computer. This represents an opportunity to use the surface of the record in a very flexible and creative way, and makes any visual material fodder for sonic experimentation.

Perhaps the most important feature of the optical turntable system is that various markings could be combined together on the surface of a record. It is possible make a record with an abstract visual pattern and then paste specific digital codes onto its surface in order to tell the microprocessor how to interpret the pattern below and what values to generate in response. Plastic transparencies could be used to overlay the codes in this fashion, and to effect their relationships by moving the sheets in relation to each other. There is virtually no end to the kinds of combinations that could be created in this fashion. Rather, it is the microprocessor speed and memory that determine the overall limits on the range of possible expressions.

3.1.3 Hardware Switch Box

The intermediary between the optical turntable and the computer is a modified switch box that contains the necessary communication and power ports. The box is connected to the turntable via two audio-in RCA jacks located at the back of it. These are used to channel audio signals when a standard needle cartridge is used or to provide two power lines and two communication lines for the optical cartridge.
A large mechanical switch on the front panel of the box determines whether the audio outputs are connected straight through the box to the audio-out jacks (the box becomes transparent and the turntable is connected straight to the mixer) in the former case. The serial and power adaptor connections are brought out at the back of the box, and two MIDI ports are embedded in the side.

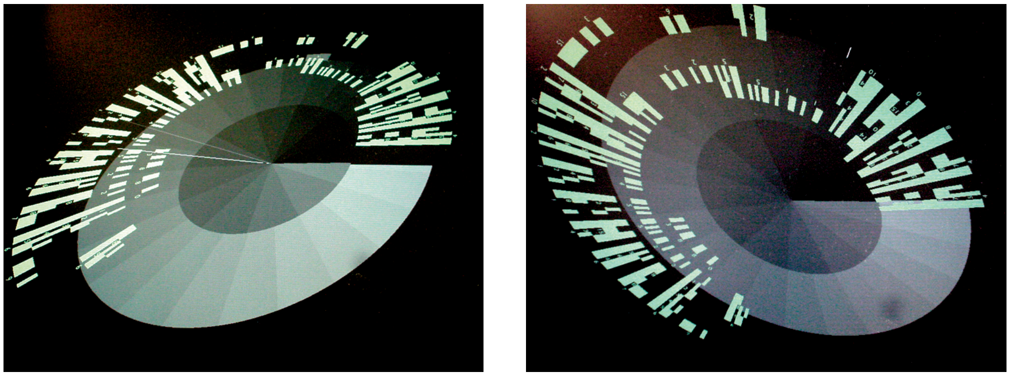


Fig 3.12-13
Software screenshots.

The plug-in cartridge and the switch box comprise the hardware elements of the optical turntable system. The system setup consists of the following steps: affix the optical cartridge to the tonearm, attach audio cables at the back of the switch box, attach MIDI cables to the side of the box, plug the MIDI cable into the joystick port, plug in the switch box power, then flip the box switch.

3.1.4 Visualization/Editing Software

In addition to custom hardware, a visual front end for the optical turntable has been implemented using a flexible C++/OpenGL framework. The software program receives the MIDI stream from the turntable and constructs a realtime virtual representation of the record spinning on the turntable platter. The software allows me to take an instant snapshot of the virtual record and to generate a PostScript file to be sent to a laser printer. The function of the software interface is to complete the feedback loop thereby a playing record is always recorded, so that whatever motion is applied to it could be recreated in printed form. In the simplest scenario, the software is used to generate a virtual copy of the paper record as it spins on the turntable without intervention at 33 rpm. If captured and sent to the printer at this point, an exact duplicate of the original is generated. As the performer manipulates the real record during playback by slowing it down or speeding it up, the changes are automatically reflected in the virtual record. In other words, if a paper record containing one score is manipulated in the hands of the performer, a new record is generated that contains a new score reflecting the trace of this manipulation. If the new record is printed and played at normal speed, the sound generated by it is equivalent to that produced by the original record while it was manipulated. Using the software feedback loop, a performer can experiment with sound timbre or arrangement, capture the result in transcribed form, print them onto a new record and use that to generate new levels of complexity. A virtual record can also be assembled from a collage of several printed records, or it can be generated from scratch without external input using a keyboard and a mouse or pre-programmed input.

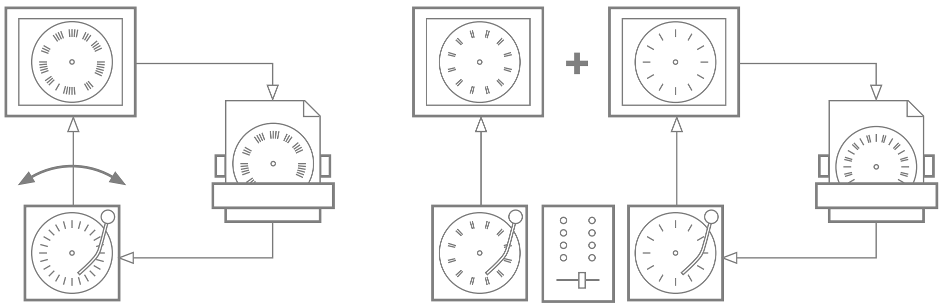


Fig 3.14-15
Two illustrations of software feedback functionality.

3.1.5 Sound Generation Software

The last link in the system I have outlined so far are the recipients of the messages sent by the optical turntables - the actual sound generation software. In the course of my research, while I worked with some sound algorithms programmed from scratch in C++, I also came to rely on a few commercial packages that took care of sound generation and helped me focus on developing other areas of the project. The range of options currently available to computer music hobbyists and professionals is wide and growing very quickly, with new players constantly entering the market. There are several competing products in the categories of drum machines, samplers, sequencers, synthesizers, waveform editors, and all-in-one tools, as well as advanced and experimental music programs that allow users to create, edit and manipulate sounds in just about every imaginable way. These tools range from free and inexpensive shareware programs and limited-function demos to expensive professional integrated environments optimized to work with certain hardware and running up in budget to thousands of dollars.

In this section, I will discuss two software packages that provide a set of features particularly appropriate to the goals of the thesis project. The two packages are a “modular sound design tool” Reaktor from Native Instruments and a “sequencing instrument” Live from Ableton, both products of German companies that have entered the music market in the last few years. These two applications provided the two main components of software sound-generation with their synthesis and sequencing functionalities, respectively.

Ableton Live

The makers of Ableton Live describe their software as “the world’s first audio-sequencer conceived for live music.” The program is distinguished from other software sequencers in that it allows one not only to construct and edit samples, but to improvise with sample arrangements in the context of a live

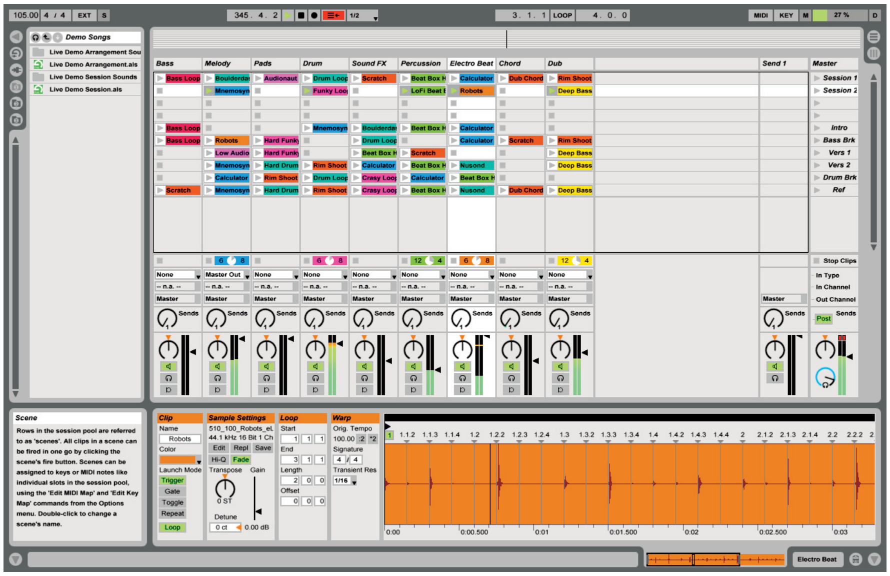


Fig 3.16
Screenshot of Ableton in “session” view.

performance. Ableton was started in 1999 by Berlin-based computer musicians Monolake, who were very specific about the features they wanted to see in their product: “we felt like there were no really good software solution for live performance, although thousands must have already thought of this: doing a whole gig with a notebook, instead of schlepping heavy and expensive hardware around... Until now, there was simply no reasonable solution for this.” [41]

Upon launching the program, a user is presented with a number of unobtrusive control buttons and knobs, a file browser panel and a large gridded ‘session’ space onto which audio clips can be dragged and dropped for editing. Once the clips are loaded into individual slots, they can be triggered with a click of a mouse, computer keyboard or MIDI notes coming from an external device. The samples can be launched one by one by one or in groups arranged by horizontal rows, making it possible to make rapid transitions between various arrangements. The program clock can quantized at various lengths of the measure so that the samples come in and out at the appropriate time given their length and time signature. A few buttons accessible at the bottom of the window determine whether a given sample will be looped, toggled or gated via external events. An important feature of Live is its automatic time-stretching capability. The program’s ‘time-warp engine’ temporally stretches and shrinks audio as it’s being read from the hard disk. As a result, loops, phrases and entire arrangements always play in sync with the set tempo or with external sync-sources. The time-stretching feature can also be adjusted by the user and applied towards more advanced audio manipulation techniques, like emulation of certain disk-jockey maneuvers. It is perhaps the most significant signature of Live, allowing its users to import samples of varying length and fit them within the time signature of the arrangement, which can itself be altered instantaneously at the click of a mouse.

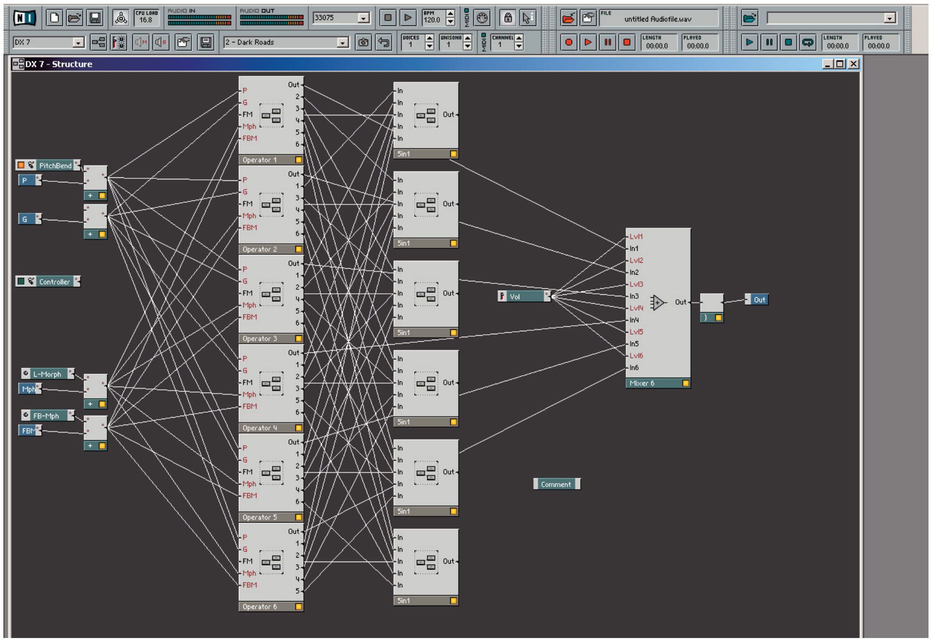


Fig 3.17
Screenshot of Reaktor, showing an ensemble that emulates the sound of the popular DX7 synthesizer.

Native Instruments Reaktor

Like Ableton, Native Instruments is a company that emerged in the vibrant entrepreneurial market of 1990's Germany, quickly gaining momentum and becoming a major player in the music software market. The company's line of products is constantly growing, encompassing several entries for each of the following categories: software synthesis, sampler, effects and vintage sound. Native Instruments was started with the idea for a modular synthesis program that eventually grew into Reaktor. A company representative Mate Galic talks about the beginnings of Native Instruments in an online interview:

"In the early '90s, Stephan Schmitt (the founder of NI) was an experienced user of hardware synthesizers and worked in the development of high-end studio mixing consoles. He realized that hardware synthesizers were limited in their characteristics: The principles of the synthesis with hardware synthesizers remain stable; the machines are very expensive and are difficult to operate... Stephan Schmitt developed a software vision of producing real-time sound, a synthesizer that would be easy to use, relatively inexpensive, flexible and open to modular developments of new synthesizers within one single software. It should be optimized for the use with standard processors, so-called "native processors." In 1996, together with Volker Hinz, he offered the first product, Generator (the predecessor of Reaktor), at the Musikmesse Frankfurt. It not only signified the beginning of NI but the beginning of a new technology of interactive real-time audio." [42]

The signature of Reaktor's modular approach is a visual programming model similar to that of Max/MSP, optimized for and limited to audio handling. Working with the application consists of creating and manipulating re-usable instruments and arrangements represented by rectangular icons, by connecting the inputs and outputs of the icons with lines representing signal flow. The highest structural level in

Reaktor is called 'Ensemble,' which is the level at which a user begins to assemble a project within the application. An ensemble is usually composed of several 'Instrument' blocks, which can contain such adjustable elements as switches, knobs and faders. An instrument in Reaktor is a module that has an internal structure, its own MIDI processing, and a separate control panel visible in the ensemble. Each instrument can itself be composed of other instruments and 'Macros,' which lack their own sound processing capabilities. As Reaktor manual explains, the main application for macros is the encapsulation of functional blocks to obtain a hierarchical and clearer layout of complex structures, making it convenient to build re-usable components. Finally, a 'Module' is the smallest hierarchical unit in Reaktor. An individual module is displayed as a graphical object represented by an icon containing all the necessary inputs and outputs. Reaktor modules encompass a range of functional blocks for sound generation and processing, such as oscillators, mixers, samplers, sequencers, logic gates, delay generators, modifiers, filters, etc. These blocks are used to compose every instrument made with Reaktor, including complicated ensembles that emulate the sounds of classic analog synthesizers. Since Reaktor offers a full degree of control over the instruments one can create, down to the lowest level of specifying the oscillators that feed into the sound modules, it provided a natural choice of a comprehensive software development platform for the thesis project.

3.2 Sound Experiments

In the preceding pages I outlined the basic components of the optical turntable system and discussed the software programs used in conjunction with it. The following sections present three exercises I devised as a way of illustrating the principle of system's operation within its current set of possibilities. The exercises build up from two simple demonstrations of synthesis and sequencing functions, accomplished with the help of Reaktor and Ableton Live. I then provide a more comprehensive illustration of using the optical turntable as a way to control a complicated Reaktor ensemble. The examples I cover do not circumscribe the possibilities afforded by the system, or comprise its essential components. Their purpose is rather to show that, with the help of a universal MIDI communications protocol, a physical interface is easily adapted to different performance modalities within one simple interaction metaphor.

3.2.1 Optical turntable as a synthesizer

In his *Computer Music Tutorial*, Curtis Roads suggests that the most significant development in the design of digital sound synthesis was the concept of unit generators.* According to his definition, unit generators are signal processing modules like oscillators, filters, and amplifiers, which can be interconnected to form

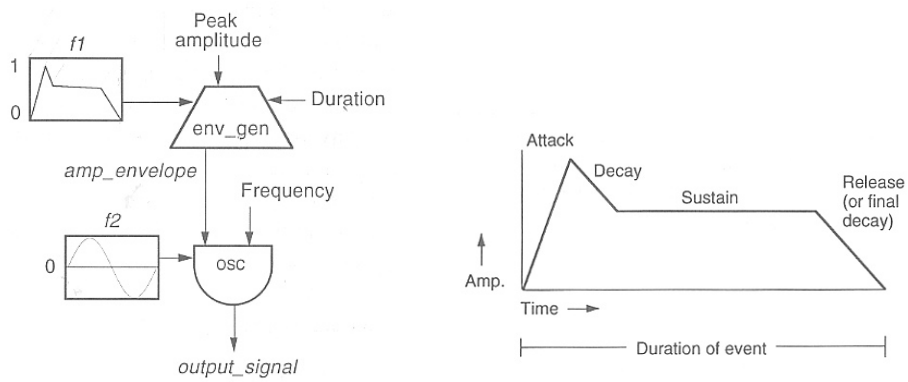


Fig 3.18-19
Unit generator and ADSR envelope diagrams.

synthesis instruments or patches that generate sound signals. “By passing signal through a series of such unit generators,” writes Roads, “a large variety of synthesis algorithms could be implemented relatively easily.” [43] He provides an illustration of the most essential unit generators in a synthesis instrument. The diagram shows an oscillator module which takes in frequency and amplitude values and generates a corresponding waveform (typically a sine, triangle or square wave, specified in advance). An envelope generator module shapes the amplitude of the oscillator. This unit generator is itself usually specified with several values. While the most flexible envelope editors of today allow musicians to trace arbitrary curves to define envelopes, analog synthesizers used to define amplitude envelopes in four stages: attack, decay, sustain and release, or ADSR for short. Over the duration of a musical note, an amplitude envelope is scanned from start to finish, shaping the amplitude input of the oscillator module appropriately.

The Reaktor application is clearly built with the concept of a unit generator in mind. The process of assembling instruments in Reaktor consists of interconnecting various modules together much like the model suggested by Roads prescribes. Even the iconic representations of generator units in Reaktor try follow universally adopted conventions. As a result, we can construct a basic oscillator cum envelope generator unit that resembles the diagrammatic representation used by Roads very closely. Once the generator units are put in place, it is possible to use Reaktor’s adjustable modules like knobs and sliders to control the module parameter values. For example, we use a slider to control the oscillator frequency and four knobs to account for each of the four envelope generator parameters. Figure 3.20 shows a screenshot of the corresponding Reaktor construct in diagrammatic ‘structure’ view as well as the instrument ‘panel’ view, complete with a visual representation of the envelope.

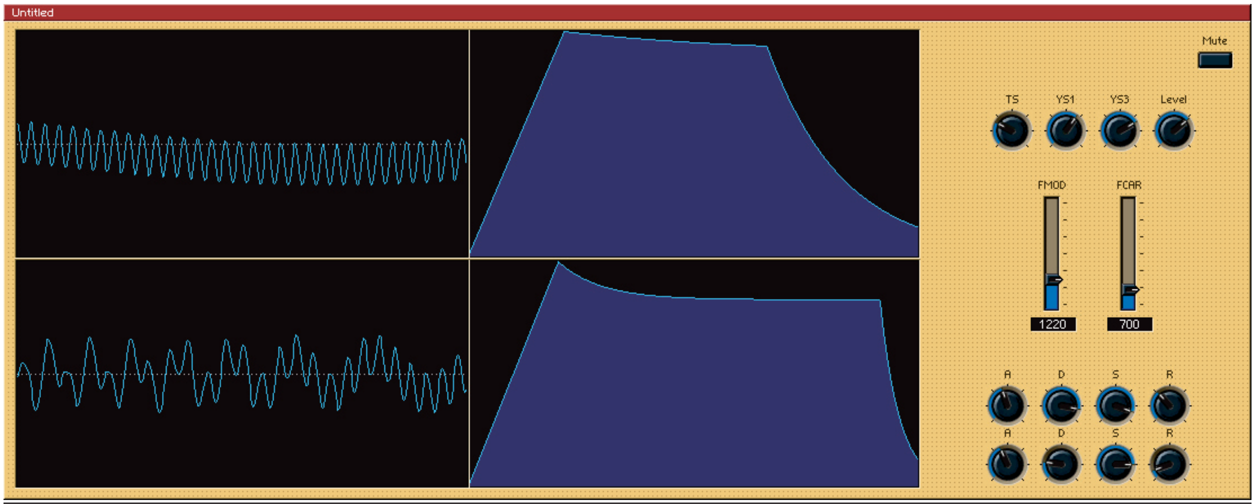
Every adjustable parameter in Reaktor is controllable remotely via MIDI. This provides the necessary foundation for utilizing the optical turntable interface as an input to a synthesizer of arbitrary complexity. The optical record contains MIDI continuous controller values and MIDI note events, both of which can be used to effect synthesis parameters. Commonly, notes are mapped to discrete oscillator frequency values when the synthesizer instrument is played with a keyboard. In the case of an optical record, continuous controller values are equally effective at setting this parameter as there is no necessary sequence which the controller values must follow (in contrast, a real knob turned from one setting to another sends the control values for all the positions in between, making it impossible to jump from one setting to another instantly). As an example illustration of this principle, I used Reaktor to construct an FM synthesizer in which two oscillators and corresponding amplitude envelopes are controllable by the optical turntable. Frequency modulation was chosen as this simple technique allows one to construct a wide range of sounds using just two or more oscillators.

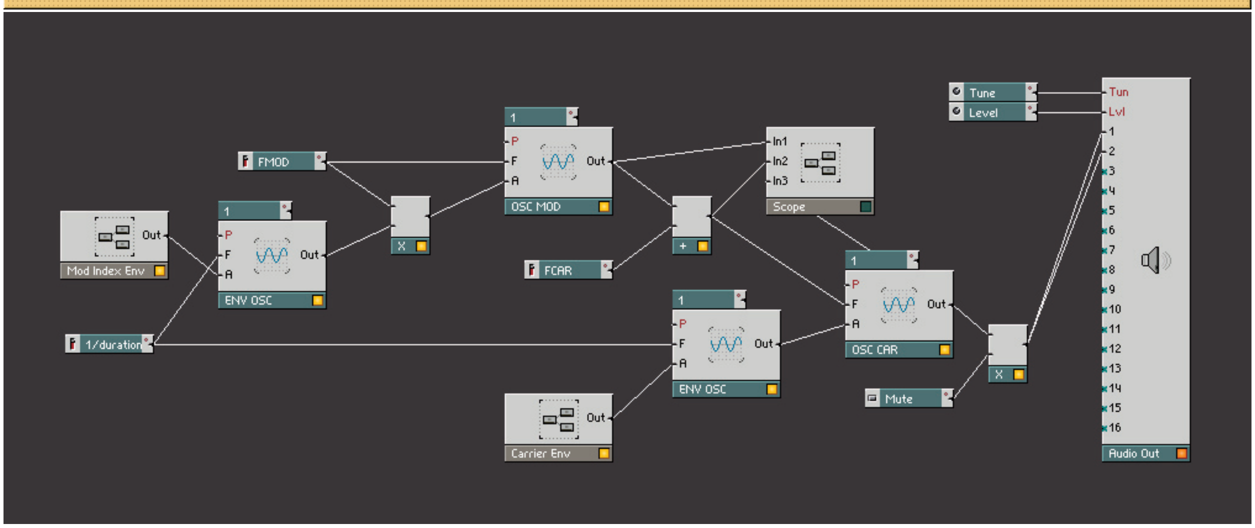
The earliest applications of FM date back to nineteenth and early twentieth century, when the theory behind FM of radioband frequencies was established. The musical potential of FM synthesis was first explored by John Chowning at Stanford University, who sought a way to generate synthetic sounds that had the animated frequency spectra characteristic of natural sounds, unlike the fixed spectrum techniques that have been in use up to that time. Chowning observed that using modulation synthesis he could use two simple sinusoids to generate a range of complex sounds that would otherwise require a very large number of oscillators. In 1975, Yamaha Corporation obtained a license on Chowning's patent, developed and extended his techniques further and introduced the new synthetic sound to hundreds of thousands of musicians and hobbyists with the highly successful DX synthesizer family.

In Chowning's original frequency modulation technique, also known as Simple FM, a carrier oscillator is modulated in frequency by a modulator oscillator according to the following equation (both oscillators are assumed to be sine waves):

$$FM = A \times Sin(C + (I \times Sin(M))$$

where A is the peak amplitude of the carrier, C is the frequency of carrier, M is the frequency of modulator, and I is the difference between C and M taken over M, referred to as 'index of modulation.' The synthesis of two sinusoids generates a series of sidebands spread around a carrier frequency at a distance equal to a multiple of the modulating frequency. The ratio of carrier frequency to modulator frequency determines the position of the frequency components generated by FM. When C:M is a simple integer ratio, the synthesis equation generates harmonic spectra in which the sidebands are integer multiples of the carrier and modulator frequencies. In the alternative case of non-integer C:M ratio, inharmonic spectrum is generated. The number of sidebands is controlled by the modulation index. Curtis Roads suggests that straightforward application of simple FM is generating brasslike tones (equation parameters C:M = 1; $0 < I < 7$), clarinet simulation (C:M = 1:2), percussive and bell-like sounds (C:M = irrational), as well as a variety of characteristically synthetic sounds. In addition, variations on the basic FM synthesis have





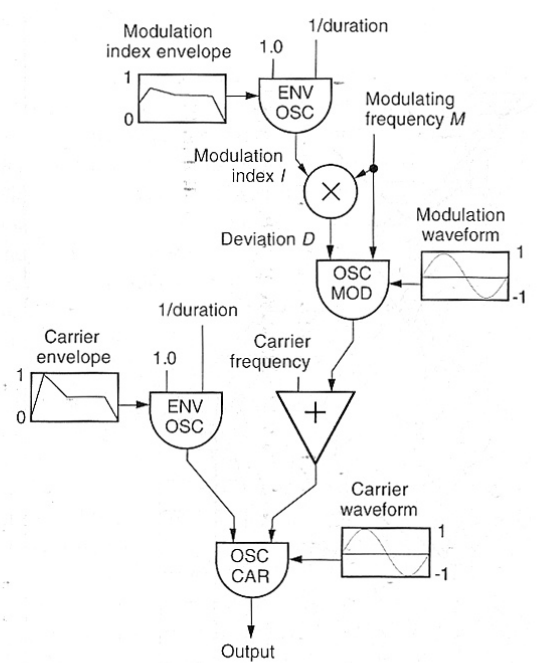


Fig 3.20 (left)
Simple FM synthesizer diagram with envelopes for amplitude and frequency (illustration from Curtis Roads' *Computer Music Tutorial*).

Fig 3.21 (above)
Reaktor ensemble implementing the Simple FM synthesizer. Note how the application blocks are almost identical to the conventional diagram.

Fig 3.22 (top)
Reaktor 'panel' for the Simple FM synthesizer, featuring two oscilloscope windows and visual ADSR envelope representations.

been used to simulate traditional instruments such as trumpet and brass tones (Multiple Carrier FM), piano and stringlike tones (Multiple Modulator FM), and many others. Louis and Bebe Barron's electronic music soundtrack for the science-fiction film *Forbidden Planet* (1956) is one innovative example of music composed using frequency modulation.

The Reaktor ensemble I constructed follows the illustration of a simple FM instrument provided by Curtis Roads. Here, the modulation index (I) is controlled by the output of a modulation index envelop and amplitude (A) by the carrier envelope, each with its own set of ADSR values. The modulation and carrier frequency are controlled by two individual sliders. The optical record contains codes that can affect any given value of the equation. For example, a series of continuous controller values might be sent that sweep through a frequency range on the carrier or modulator oscillator. In a similar fashion, four individual controller values sent in succession can instantaneously redefine one of the amplitude envelopes. The two turntables in effect become large knobs that control the virtual knobs of the Reaktor ensemble. The advantage of the physical turntable platters is the degree of expressivity they afford - one is literally able to 'scratch' with synthesis equation parameters. Any interface knob or slider can be reassigned to be controllable by either of the platters. For example, the turntables might be set up such that one determines the frequency of the carrier signal while the other one determines the modulator frequency. Alternatively, one could control the index of modulation and amplitude. In another scenario, one turntable could be set to control the knob parameters while the other would allow one to cycle through all the adjustable parameters in a given instrument (a slightly more tricky Reaktor arrangement, but nevertheless possible). A single turntable could also be used to control more than one parameter at a time, at different rates if desired.

Various visual representations on the records could provide input for the synthesis parameters. One straightforward scheme is to map parameter values linearly to the accumulated value of black marks that pass under the optical cartridge over a given period of time. In this scheme, the value of a given parameter would rise as the frequency of marks interrupting the light beam increases. If the cartridge is positioned over a white portion of the record, the value of the parameter would fall to zero. A similar mapping coupled with analog to digital conversion allows greyscale values to indicate parameter settings. Digital codes represent the most flexible system in that they can specify parameter values very specifically. A string of digital marks read off the surface of a record can be used to set several adjustable parameters of the instrument instantaneously. Alternatively, a binary code could be used to define the parameter is to be affected and then automatically switch the microprocessor routine into a direct mapping mode, until a new code is encountered.

Using two turntables and different visual recordings, one can experiment with a variety of settings that effect the sound produced by the software synthesizer. Reaktor allows one to connect the output of

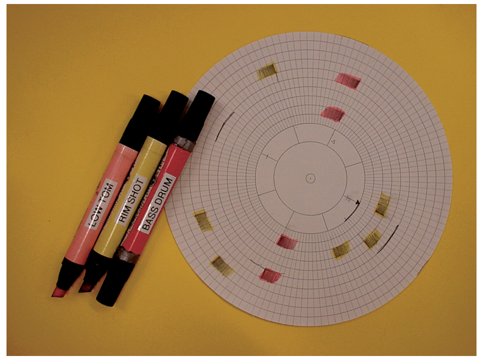


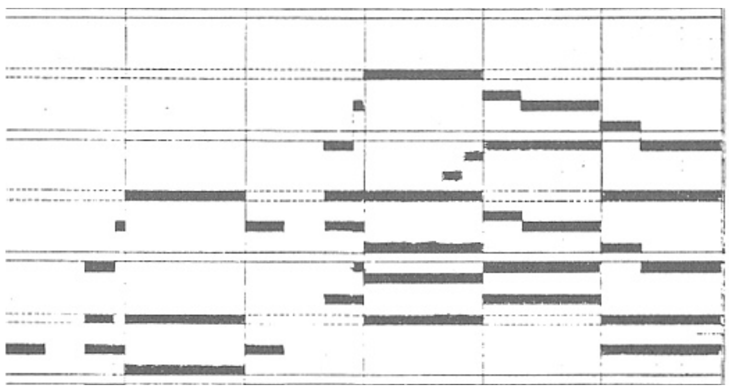
Fig 3.23-24
Concept sketch for a sequencer utilizing colored marks to represent sounds or instruments.

the signal produced to additional modules, such as a built-in recorder. The output of the synthesizer can thus be automatically captured, or recorded selectively using additional parameters to control the recorder module, which could itself be manipulated directly through the physical interface. The sound files produced this way could then be used in sequencing a composition, a process covered in the next section.

3.2.2 Optical turntable as a sequencer

The basic function of a sequencer is to control the flow of MIDI information and to arrange the order of sonic events accordingly. A typical way to use a sequencer is to record the key presses of a synthesizer keyboard onto separate tracks that could be combined and edited at any point. Once a track is captured, the sequence can be cloned and copied onto itself, doubling the part, the musical key can be easily transposed, and the wrong notes can be fixed without having to redo the part. Using a recorded MIDI sequence, one can change the entire sound of a particular arrangement by swapping one instrument for another. Various effects and filters can also be easily applied to entire sequences. A common technique is to place MIDI program change messages, volume messages, various controller settings, or pitch bend messages on individual tracks so that the effect of these messages could be manipulated or disabled selectively. Sequencing has its roots in the tradition of pasting tracks of magnetic tape together in *musique concrete* in 1950's, but it really took over the music making business when software developers designed easy to use applications for the Macintosh in the middle 80's. Today, there are many software sequencers available for both Mac and PCs. Some of the popular choices include the products *Vision* by Opcode and *Performer* by Mark of the Unicorn for Mac OS, or *Cakewalk* by Twelve Tone Systems for Windows. Ableton Live is a new product available for both platforms.

Most sequencing software (including Live in its 'arrangement' mode) relies on the visual score metaphor to represent sequence structure. Rectangular bars are often used to denote the notes and sound samples, the length of which is determined by the horizontal extension of the bar. Usually, color or icons distinguish



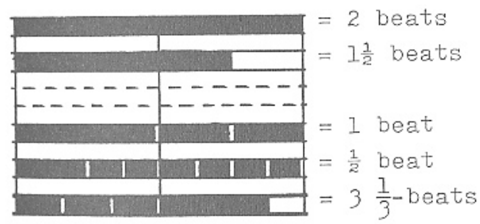


Fig 3.25-26
Adolph Decher's notation for
Graphical Chromatic Representation of Musical Sound.

between the various elements in the arrangement. The idea of this type of visual representation goes back at least to the year 1881, when German philosopher and mathematician Karl Krause wrote his essay "Concerning a notational improvement" (Uber eine verbesserte Tonschriftsprache). Krause was motivated by the principle that the eye should see what the ear hears. In his system for visual notation of music rectangular pitch bars represent the notes, the duration of which is shown by the proportional lengthening of the bar. The dynamics of the notation are also accounted for, as pitch symbols are shaded from light to dark to indicate soft and loud. According to the author of *Source Book of Proposed Music Notation Reforms* Gardner Read, Krause's was a "remarkable proposal for notational reform... that must have stunned his contemporaries." [44] Several systems later followed up on Krause's original proposal or came about independently. For example, *Graphical Chromatic Representation of Musical Sound* (Chromographische Darstellung der Tondichtungen, 1875) by Adolph Decher also advocates rectangular pitch bars that are elongated to show duration. Notably, Decher's suggested notation for orchestral scores featured each instrument as a differently colored or shaded part, much like the popular sequencing notations of today.

Following the simple visual notation, it is easy to picture an arrangement of notes specified by rectangular bars located in rings around the perimeter of a paper record. Each bar can be composed of a binary black and white pattern or a shade of grey to be interpreted through A/D conversion. As the optical sensor passes over a bar, a corresponding MIDI event is passed to the computer. The bars can represent notes, continuous controller values or other MIDI events that could be used by the sequencing software. For example, Ableton Live allows one to assign MIDI notes to individual samples or to arrangements of samples that should be played together. An optical record encoded with MIDI note events can thus be used to sequence samples in software by adding and layering them one by one, subtracting elements from a playing sequence, or triggering arrangements of samples to come in and out. At the same time, line and master effects can be manipulated through MIDI continuous controller values picked up off the surface of the record. Live comes several pre-built effects that could be used in this fashion, such as chorus, compressor, and erosion effects, grain and filter delay, and something called vinyl distortion.

Since the period of revolution of a record is about two seconds, a rhythmic pattern of that length is used as a sequence element. In order to extend the duration of the sequence, additional codes need to be introduced. One option is to use a code that determines the rate at which the microprocessor sends out the notes. A single ring of marks would be scanned by the cartridge in one revolution, but sent out at a rate encompassing two or more turns of the record. Sequences of different quantization rates can be mixed together by placing appropriate codes at the beginning of each one. Another approach is to create longer sequences by joining them. A special code can be used to designate a join operation thereby one sequence would be appended to the end of another. We can also imagine additional codes that would allow operations like subtraction of one sequence from another or rearrangement of elements within a single sequence. The limitation on what could be accomplished is placed by the limited memory footprint of the microprocessor used in the current implementation of the optical cartridge, however.

3.3 Project Evaluation

The optical turntable interface described in the preceding pages represents an accumulated effort of three months of research and development. While the project was approached with an eye towards developing a comprehensive solution to its stated goals, it was also conceived as a compromise between the variables of time, available materials and skills needed for its implementation. For example, I considered several potential configurations for the optical turntable in approaching the design problem initially. I also spent considerable time deciding on the technology of the system, both in terms of hardware and software. Subtle implementation details posed their own challenges as the project went along. In the following section, I discuss some of the issues that came about in the course of the design process. This will provide a segue to the conclusion of the thesis document, followed by informative appendices that document important specifics of the project in detail.

3.3.1 System Analysis

The current implementation of the optical turntable system features one optical sensor attached to the turntable tonearm. This provides the basic necessary means of reading visual information off the surface of a spinning disk. In order to interpret digital codes, the system relies on the consistent rotation speed of the platter at 33 revolutions per minute. As a result, it is not possible to scratch-manipulate these markings, although it is possible to manipulate the relative and greyscale marks. An improvement on the setup would be a two-sensor setup and a 'clock' track on each record. For example, the second sensor could be positioned at the edge of a record so that the first track always contains the timing information, facilitating correct pickup of digital codes at any rotational speed. Another approach is to place an array of sensors across the entire surface of the record. The attachment would have to be devised in such a way that it could it flip up so that records could be changed. This would enable the most quick and flexible optical pickup and create wholly new possibilities for visual expression, in effect adding another (longitudinal) dimension to representational possibilities. The disadvantages of both options is the fact that they detract from the elegance of the plug-in setup by necessiating a more complicated attachment with its own wire and physical connections. Perhaps the best compromise is to consider a smaller linear array of sensors that could still be attached to the tonearm cartridge. For instance, an eight-element array might allow one to read pixelated text, numbers or graphics off the surface of a record. These types of codes would expand the vocabulary of visual encoding considerably, especially in the way of making visual marks more readable to the human user.

Another limitation of the current system setup is that only circular tracks are processed as the tonearm remains stationary and there is no groove for the optical cartridge to follow. An obvious solution is to add a servo or a motor/encoder combination at the anchor of the tonearm. This setup could open up a whole new level of possibilities for the optical turntable system, some of which are suggested in the Future Directions section. However, while the current implementation of the project does not incorporate this functionality, the idea of a robotic tonearm has had an effect on the design of the optical turntable from another standpoint. Early on in the design process I experimented with spyrograph-like turntable drawings generated by a servo-controlled tonearm with a marker attached to it. We can imagine that such drawings could also be used as input to the optical cartridge. In other words, an automated turntable could both read visual markings and generate them. An extension of this possibility is the concept of a Turing machine that is able to carry out computational processes by reading visual input off paper and generating output on the same medium, which would then function as a replacement of the magnetic tape used in the classic computer science example. The idea of a feedback loop has been implemented to some degree in the current version of the optical turntable with the software application that processes the output of the turntable. By mapping the data sent by the optical cartridge onto a virtual record on the computer screen, a representation is generated that takes account of the manipulations applied by the performer's hand to the actual record. Once a snapshot of the virtual record is taken and output to a PostScript file, an interaction loop of sorts is created thereby the output of the optical sensor has been converted into a record that could be used as input to the system.

The issue of input brings up the subject of visual records themselves. By imprinting paper disks with binary information, I provide a flexible low-level framework for programming events on the microprocessor embedded in the optical cartridge. This method is very much akin to and no more intuitive than programming with punchcards, however. Nevertheless, I believe there are ways to make the programming process a little more user-friendly, or at least engaging. For example, the Appendix features a disk that has been partitioned into segments that could be filled with a marker using patterns that are specified on a separate lookup chart. Another approach is to create template sheets with many printed codes that could be cut out with scissors and then pasted onto the appropriate slots on the disk with tape or glue. In order to facilitate my own development process, I used a software program that allows me to type the desired codes with a keyboard and to move around the surface of the record on screen with cursor keys. As it had been discussed, the program writes out a PostScript file that is sent to a laser printer, which generates a ready-to-use record.

In the examples provided, the binary codes have been used to encode MIDI events like key presses and controller values. A critic might question the effectiveness of these values in controlling finely tunable synthesis parameters, as there are only 7 data bytes (128 discrete steps) contained in a given MIDI message. One possible solution is to connect several different knobs in Reaktor to set up a hierarchical control structures that are controlled by more than one MIDI event. However, this setup is somewhat inelegant from the standpoint of programming. In general, the limitation discussed here is not unique to the optical turntable system. Any MIDI controller, no matter what quality potentiometers are used in its manufacture, offers a limited discrete range. From this standpoint, the choice of the dated MIDI protocol is a necessary limitation of the entire system.

One suggested improvement over MIDI is OpenSound Control, a technology advocated by the Center for New Music and Audio Technologies at Berkeley. OpenSound Control is described as an "open, efficient, transport-independent, message-based protocol developed for communication among computers, sound synthesizers, and other multimedia devices." The protocol features an open-ended URL-style symbolic naming scheme, high-resolution time tags, the concept of "bundled" of messages whose effects occur simultaneously, as well as pattern matching mechanism to specify multiple recipients of a single message. [45] OpenSound Control has already been incorporated on the recipient end into such applications as CSound, Max/MSP, Supercollider, and even Reaktor beginning with the third generation of the product. In comparison to MIDI, however, the implementation of OpenSound Control on the sender end is a large undertaking that would necessitate a major technical revision of the thesis project.

Another option is to do away with a standardized musical communication protocol altogether. In the initial stages of the project I used a serial connection as a communications channel and experimented with creating sound by programming custom sound modules from scratch. Using this method, it was possible to specify any pre-programmed parameter. For instance, a stream of data could tell the program to create a new oscillator with given parameters. It was equally easy to adjust signal parameters to any desired degree. As a test application, I implemented an additive synthesizer composed of a large array of independently controlled oscillators. A similar design would have been prohibitively painstaking to implement in Reaktor, for example, as the great number of elements used would tend to crowd the visual programming environment. Unfortunately, as the project went along, I found it difficult to continue developing with custom programmed sound generation code. In particular, I encountered difficulties generating accurate timing results for the sequencer and sampled sound applications. As a result, the optical turntable gradually came to rely on professional audio software solutions.

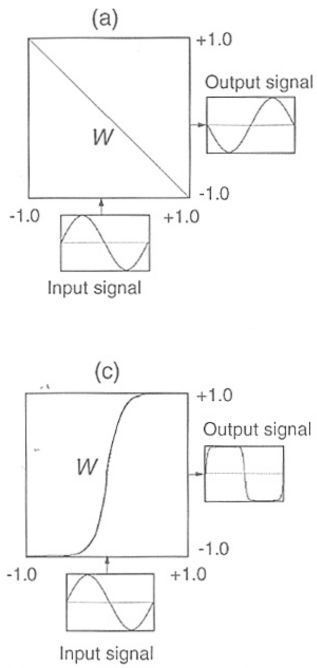
4. CONCLUSION

Despite the limitations and criticisms cited in the previous chapter, the optical turntable system nevertheless succeeded in fulfilling certain goals set out for it. The project was conceived as an attempt to engage the popular culture image of the disk-jockey turntable, which has the appeal of an intuitive interface that even a non-musician like myself could comprehend. This thesis set out a goal of connecting the turntable to the computer, so as to expand the vocabulary of its possibilities and turn it into a flexible interface for controlling events on the machine. The following section outlines the primary accomplishments that were achieved.

4.1 Summary of Contributions

A unique contribution of the thesis and its starting point was the idea of utilizing the surface of a turntable record as a visual means of input. The background section of the document outlined a set of issues and historical developments that point out the obvious, subtle and abstract connections of the turntable to the visual realm. Examples of early optical instruments that utilized the turntable have been provided, as well as illustrations of its use in the service of visual expression. Taken in isolation, the first part of the background chapter brought together a range of applications of turntable technology and its theoretical implications, making something of a fragmented anthology of turntable's curious appearances across the broad spectrum of cultural activity.

In addition, a functional framework for transforming a standard turntable into an optical instrument used in conjunction with a computer has been developed as a proof of concept for the thesis. The framework utilized inexpensive and accessible technology, suggesting an easy to implement solution. The practical aspect of the system was explored with the concept of a plug-in architecture that provides an elegant fit to the existing infrastructure(s). This concept had also been carried through with software, by showing potential uses of the system with examples constructed using widely available musical applications.



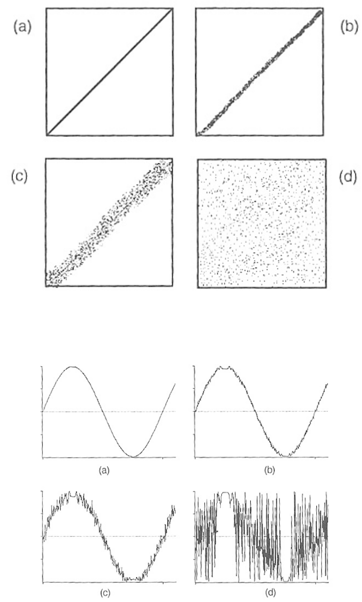


Fig 3.29
Diagrammatic representation of waveshaping functions.

Fig 3.30
Examples of four waveshaping functions applied to a sine wave.

4.2 Future Directions

The optical turntable interface as it is presented in this thesis is a simple solution that, to use Joe Paradiso's original pun, barely scratches the surface of its own potential. The system could stand many improvements in both hardware and software aspects.

For example, the software functionality of the system could be vastly expanded to incorporate a more advanced feature set for sound and/or graphics generation. This represents the primary direction for the future development of the project.

Equally, there are many potentials to explore in the range of representations for the visual records. In the preceding pages, I've suggested several 'mappings' that have been used to encapsulate meaningful information. There is a wide range of alternative representations that have not been explored, however. An illustration of a waveshaping function, above, is just one example of a linear mapping that seems very fitting for a two turntable setup.

There is yet another range of unexplored potential at the intersection of the virtual space and physical. Visual records function as iconic representations that could be substantially modified and extended in the virtual environment. For instance, we might be able to manipulate microscale events on the screen with macroscale gestures in the physical world. This could open the door to a whole new level of complexity and expressiveness for the optical turntable instrument.

Another level of complexity could be explored with the additon of an automatically-controlled tonearm. For example, the tonearm could be guided by the specific instructions contained on the paper record as well as the hand of the DJ. The tonearm could also be augmented with sensors for various interaction parameters, such as pressure or rotational torque. Perhaps the turntable instrument could add a level of expressivity by generating a response to having the tonearm pushed, twisted or squeezed.

In the meantime, the work stands its own as a contribution to the DJ culture that inspired it, hoping to encourage responses that are sure to improve on what has been accomplished or at least to call a challenge, so that the optical turntable too would have its adversaries to battle.

APPENDIX

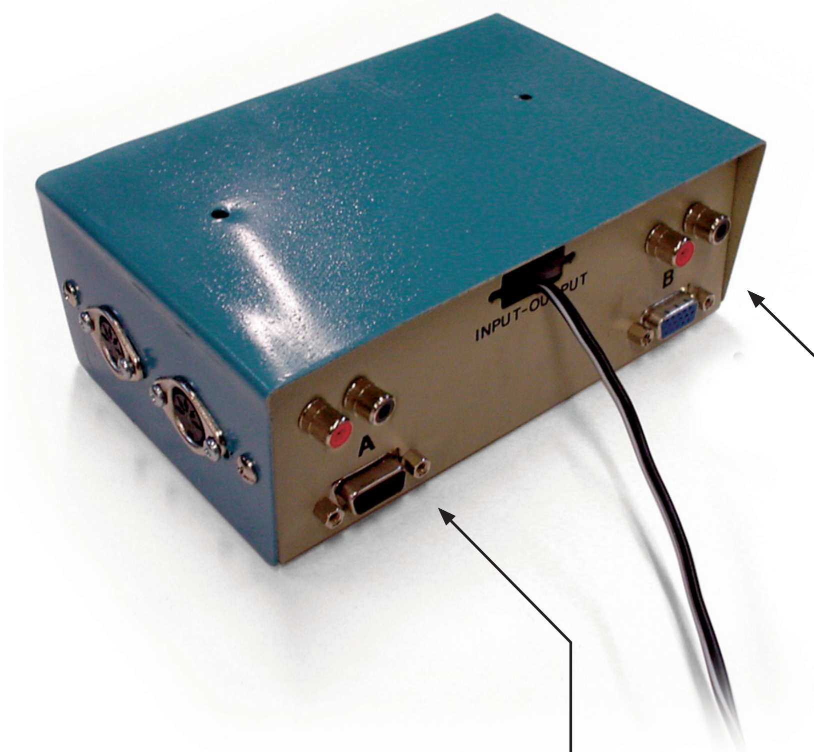
Generating MIDI with a microprocessor:

```
void sendMidiNote(long chan, long note, long vel)
{
	int i, j;

	chan = chan << 1;
	chan |= 0b0000001000000000;
	note = note << 1;
	note |= 0b0000001000000000;
	vel = vel << 1;
	vel |= 0b0000001000000000;

	for(mask=0x0001; mask<0x0400; mask=mask<<1)
	{
		if(chan & mask)
			output_high(MIDI_PIN);
		else
			output_low(MIDI_PIN);
		delay_us(23);
	}

	for(mask=0x0001; mask<0x0400; mask=mask<<1)
	{
		if(note & mask)
			output_high(MIDI_PIN);
		else
			output_low(MIDI_PIN);
		delay_us(23);
	}
	for(mask=0x0001; mask<0x0400; mask=mask<<1)
	{
		if(vel & mask)
			output_high(MIDI_PIN);
		else
			output_low(MIDI_PIN);
		delay_us(23);
	}
}
```

Hardware Switch Box

Switch between inputs: optical sensor or needle cartridge.

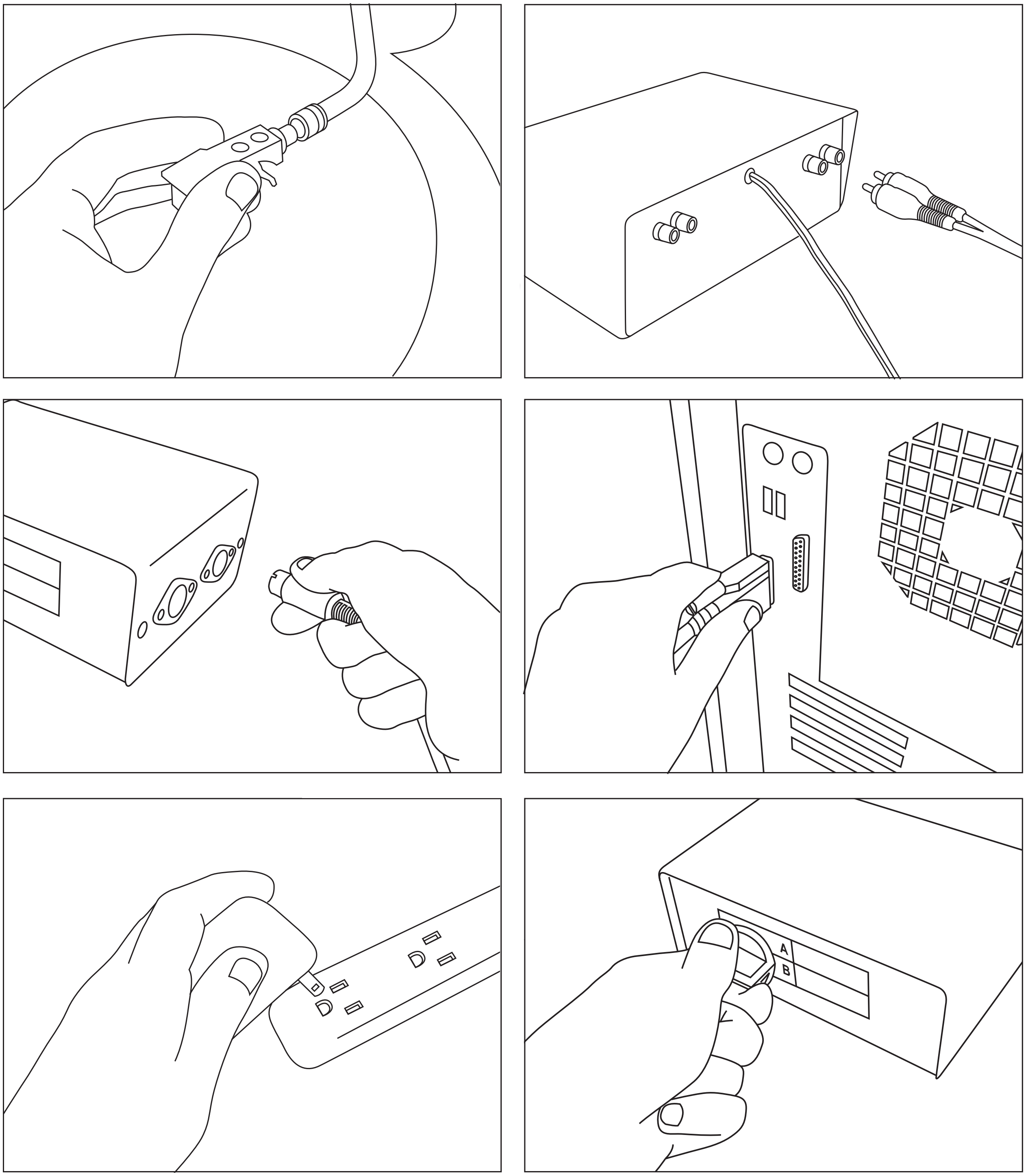
MIDI ports, cables connect to computer joystick port or to MIDI converter.



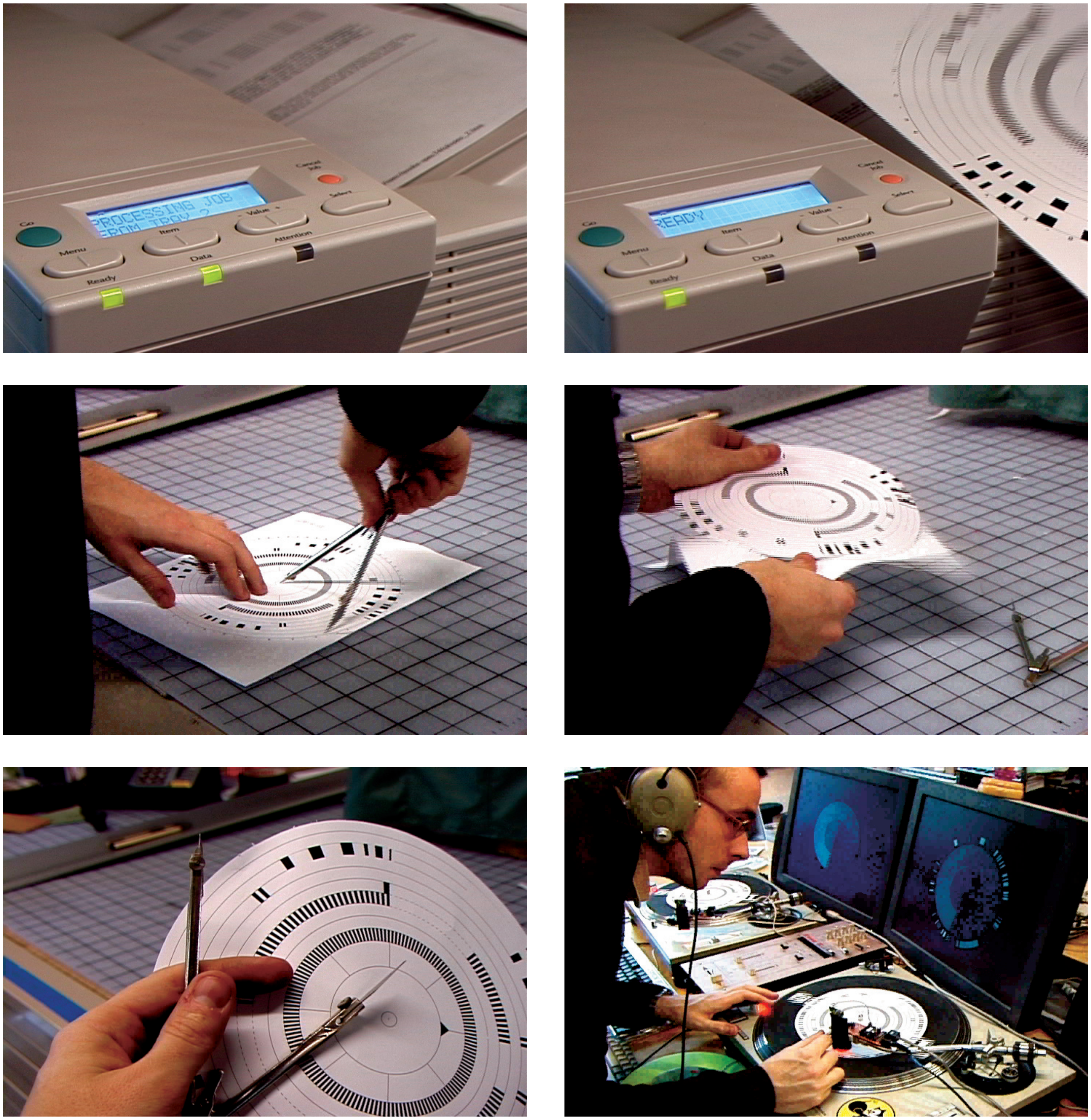
Audio-in ports double as power and signal lines for the optical cartridge.

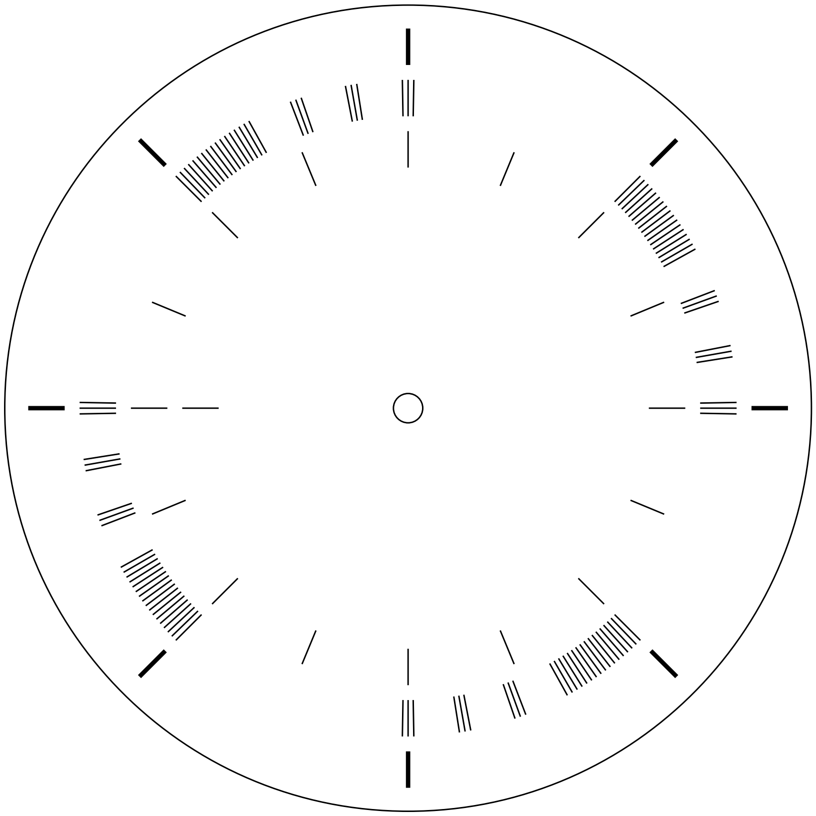
Audio-out ports, cables connect to the mixer.

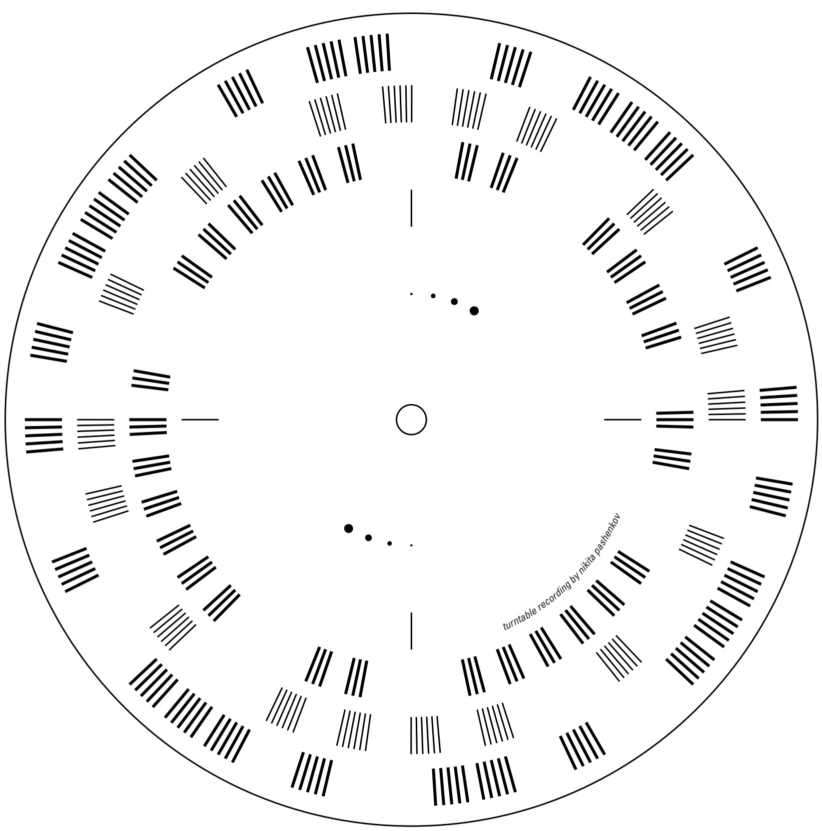
System Setup



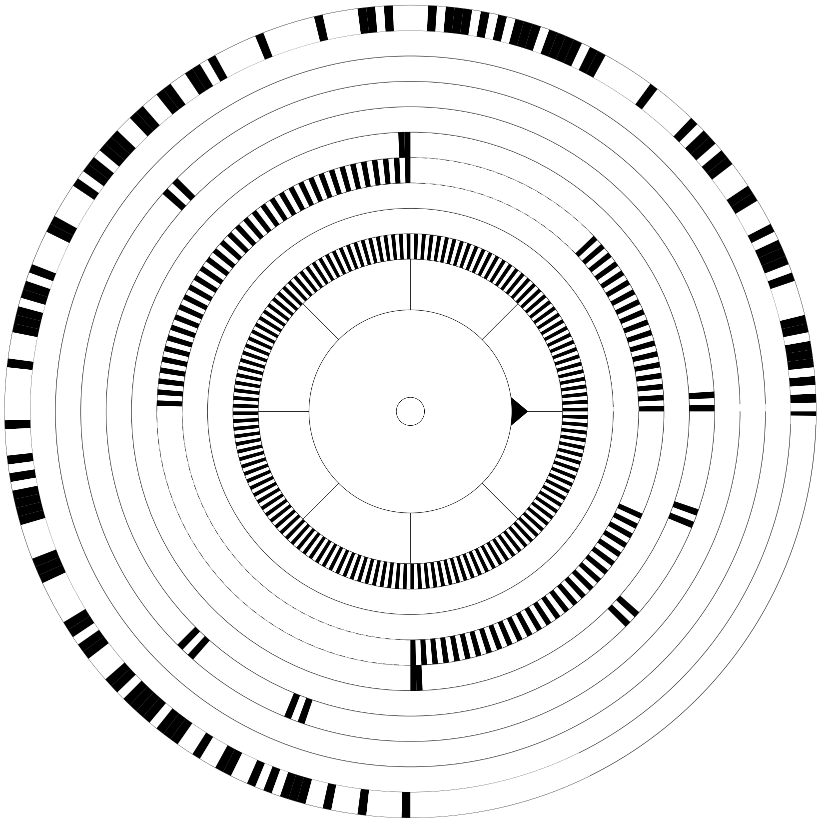
Development Process



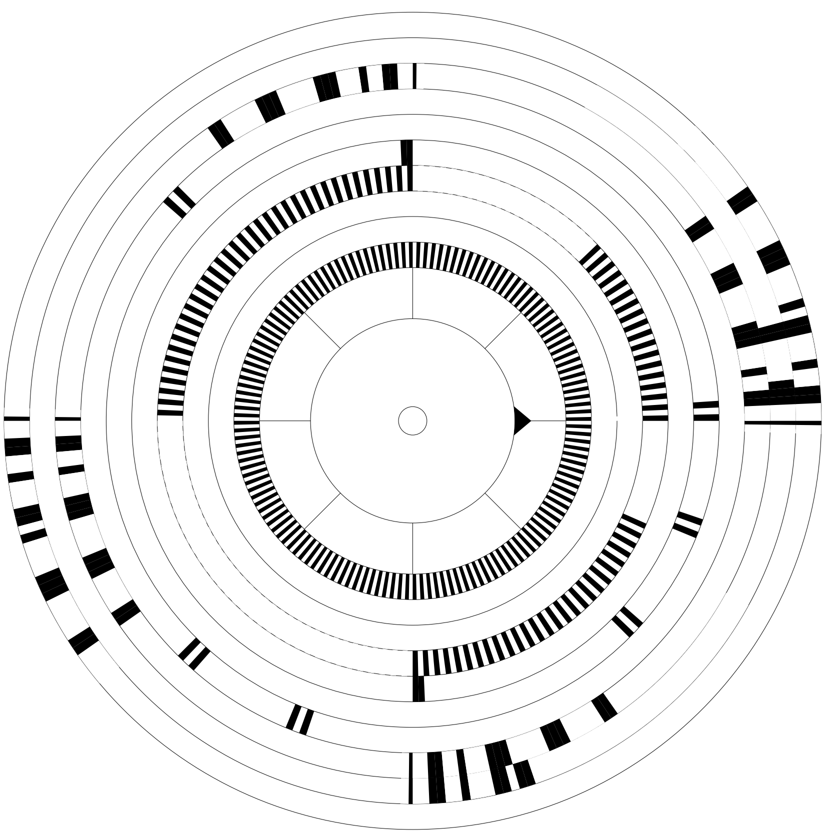




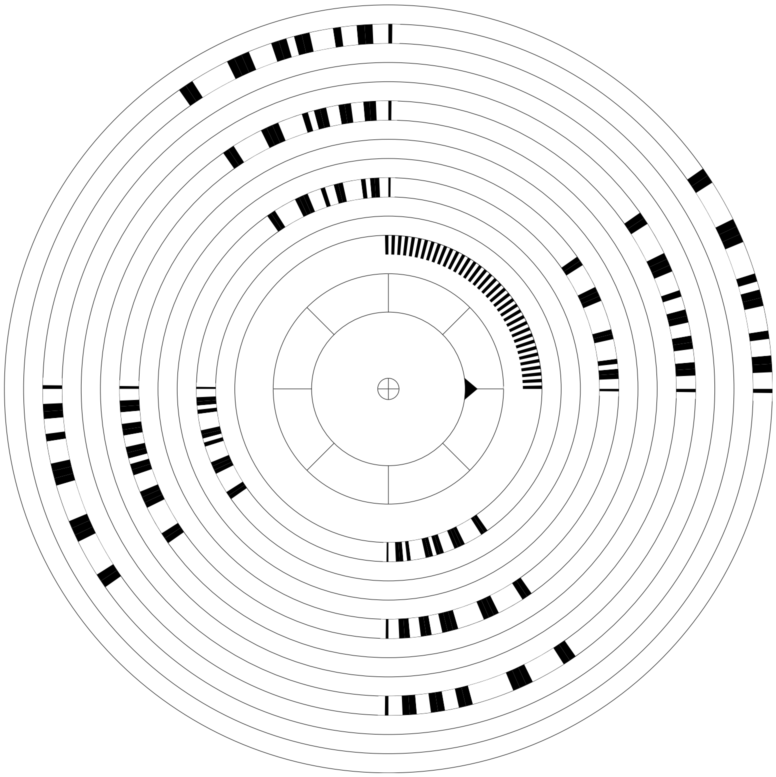
Some of the early test disks, containing various black and white patterns that were used to test timing for the microprocessor.



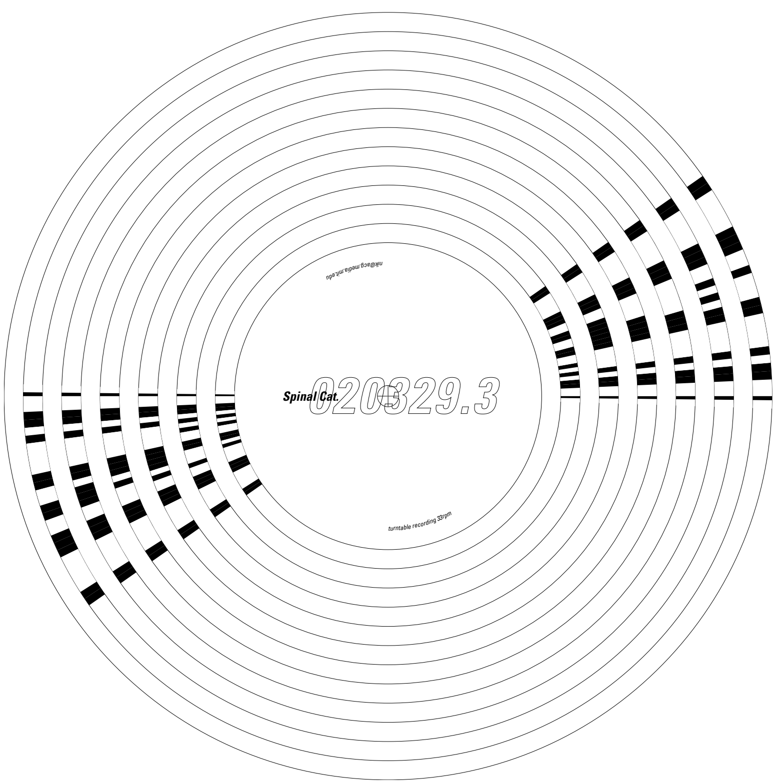
This early test disk contains binary-encoded ASCII text in the first track. Composed as a demo for Chris Csikszentmihályi, the disk reads: “Watch out, Afghan Explorer!” The data was sent as a serial stream that could be picked up in a communications application, like HyperTerminal.

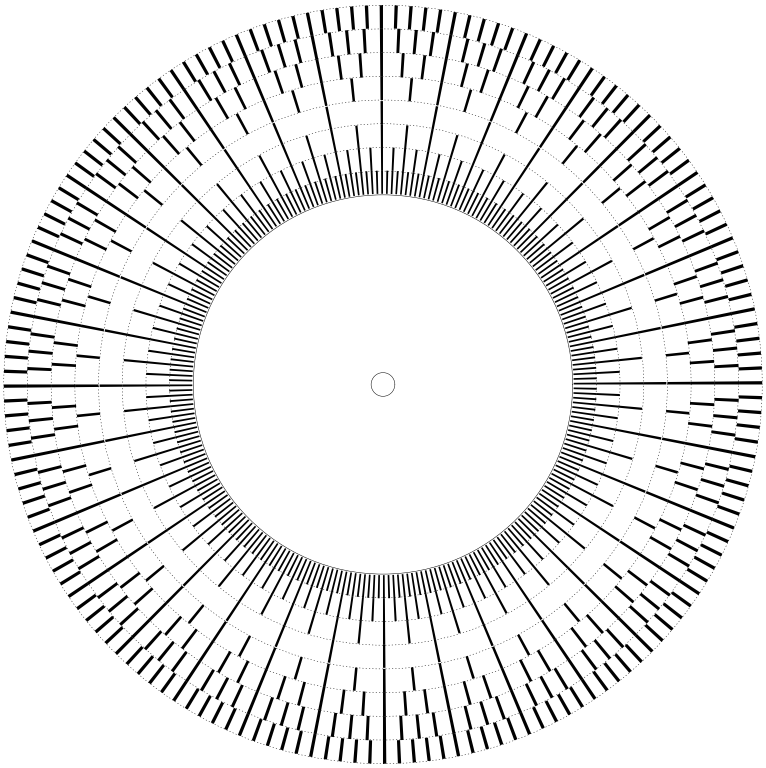


A binary test disk for MIDI signals. The tracks contain a few different variations for Note On and Off events using five notes.

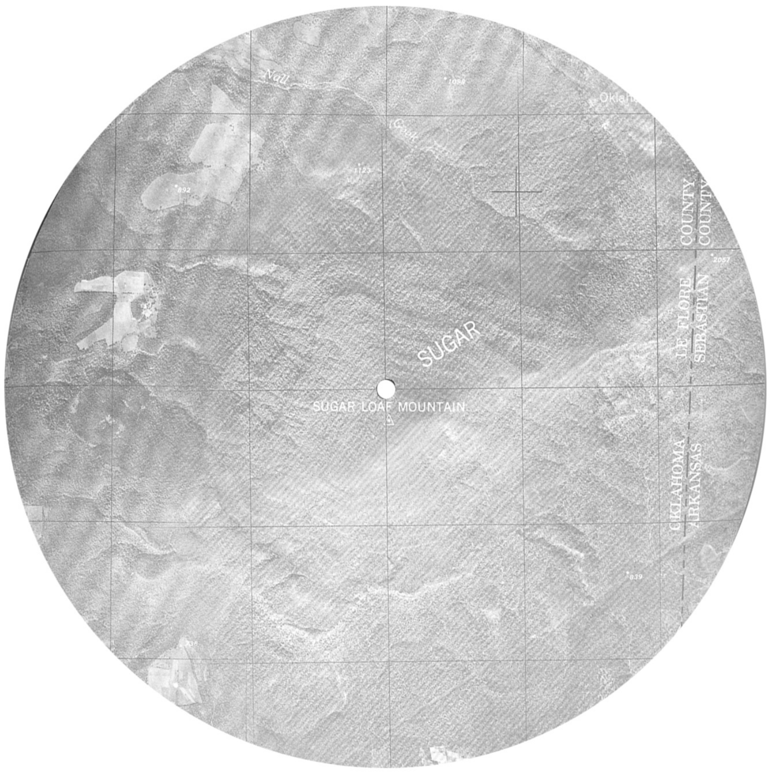


More variations of MIDI disks - each one of these contains 12 notes of an octave.





Both of these records represent an example of 'relative' mapping discussed in the text. The second record was cut out of a drawing made by a fellow student Afsheen Rais-Rohani, who wanted to hear what his work might sound like.



Any visual material could be played on the optical turntable. For instance, the records on the left are cut outs of a topographical map.

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