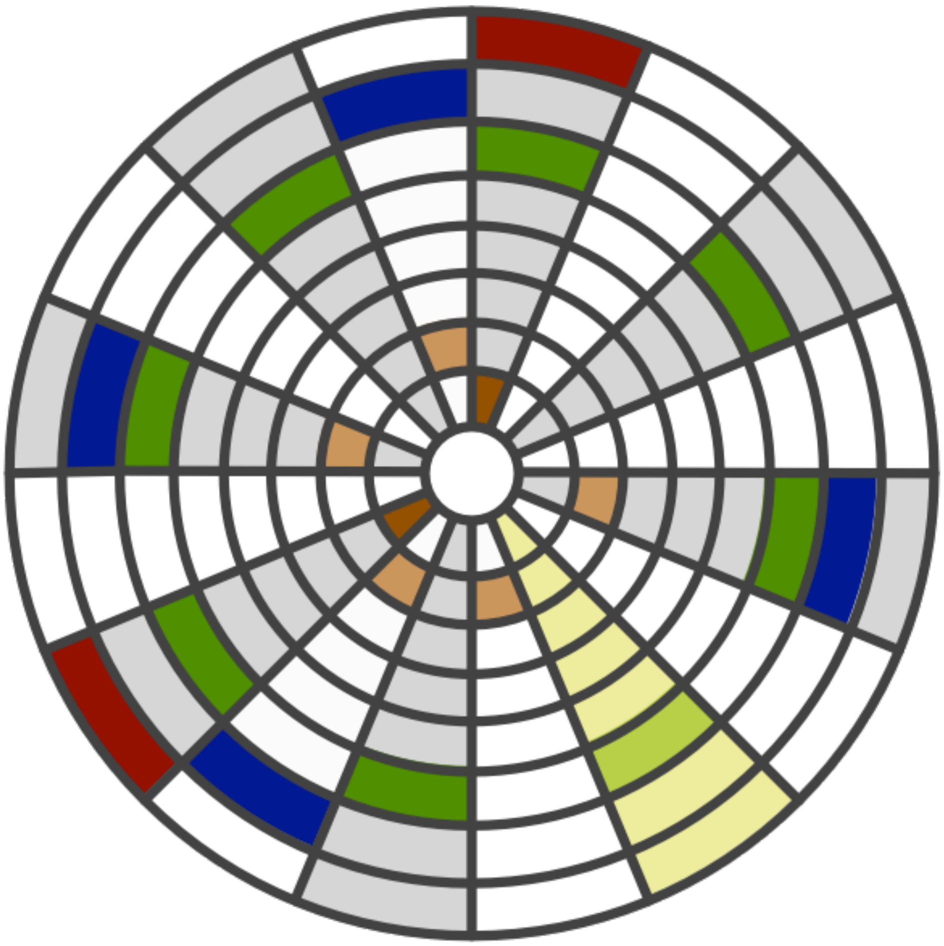
Designing the Drum Loop



A constructivist iOS rhythm tutorial system for beginners

by Ethan Hein

Submitted in partial fulfillment of the requirements for the Master of Music in Music Technology in the department of Music and Performing Arts Professions in the Steinhardt School of Culture, Education, and Human Development, New York University

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Dedicated to the memory of Michael Hein

Abstract

People wishing to learn dance music production are largely left to their own devices. Even those would-be producers who have access to formal music education are ill served by Eurocentric teaching methods and curricula. This is unfortunate, because learning how to create beats benefits all music students, not just electronic dance musicians. The ability to actively create and alter rhythms and to match their visual notation with the resulting sounds in real time can sharpen the rhythmic abilities of any musician.

Most dance musicians must self-teach, and they face some significant obstacles in doing so. Even "beginner-oriented" programs like Apple's Garageband presume significant musical knowledge. Nearly all music production tools are based on the keyboard/piano roll or multitrack tape paradigms. Beginners struggle to learn these visualization schemes on top of the musical concepts underlying them. A simplified and more intuitive interface would help to prevent frustration and abandonment of musical study.

A clock face metaphor is a more intuitive visualization scheme for the loops that form the basis of dance music drums. The present project consists of the design of The Drum Loop, a radial drum machine interface and a series of rhythm programming exercises following constructivist principles, teaching methods well-supported by psychological research.

Introduction

Global musical culture is dominated by music of the African diaspora as filtered through American pop. This music is beat-driven, cyclical and percussion-centered. However, music education in America is focused heavily on the European common-practice era classical tradition, which is focused more on linear melodies and harmonies. There is a wide disconnect between the music animating the inner and social lives of young people and the music they encounter in school and formal lessons. While this disconnect is typically framed in terms of "low" versus "high "culture, the true conflict is between two different conceptions of what the most important and salient components of music are: melody and harmony, or rhythm and groove. In western tradition, melody is broadly considered to be the fundamental basis of music. In the dance music derived from the African diaspora (including nearly all of American popular music), rhythm is the fundamental basis.

In our Eurocentric pedagogical tradition, rhythm is a neglected subject compared to melody and harmony. Dance music is generally considered to be insufficiently sophisticated or artistically legitimate to merit inclusion in the music classroom. Students who hold this music close to their hearts and want to create it for themselves must primarily learn to do so outside of school, on their own or in ad hoc peer settings. Music teachers who recognize the artistic significance of beat-driven dance music and wish to include it in the classroom similarly face a lack of good teaching materials. While other cultures have rich pedagogical traditions around drumming and rhythm generally, in America such pedagogical materials are specialized, and are not as accessible to musicians generally; certainly not to novices.

In the past decades, there has been an explosive growth in software both for producing and recording music, and for learning it. However, little of this software addresses rhythm in a way that is authentically connected to dance music. There has also been a proliferation of software tools for the production of dance music, but while these are highly culturally authentic, they can be as intimidating to the novice as standard music notation.

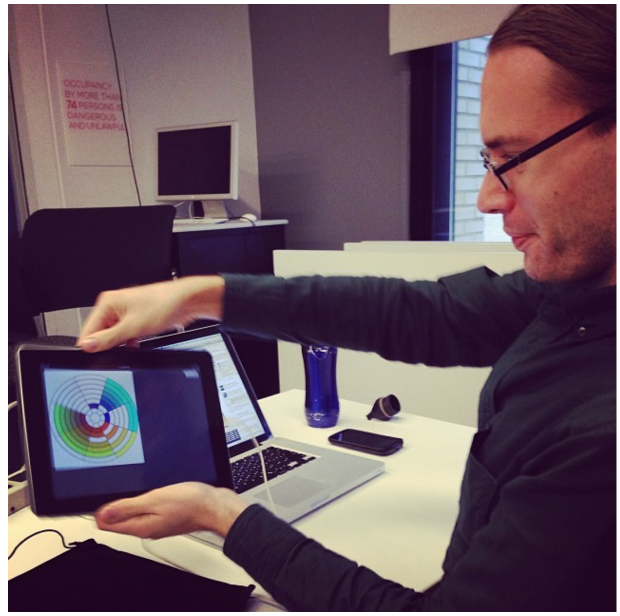
The Drum Loop is an iOS app that is designed to fill the vacuum in rhythm pedagogy. It uses a simple and intuitive interface to introduce complete novices to the creation of dance, rock, hip-hop and Afro-Cuban beats. Rather than presenting users with a daunting blank slate, each exercise in the app is centered around a pre-existing, culturally significant, “real world” beat. The user may then alter and customize this beat, within certain constraints that guarantee a musically satisfying and idiomatically appropriate result. The exercises do not proceed through a linear sequence with concrete goals and milestones; rather, they encourage a spirit of discovery, of experimentation through trial and error. Users are free to define success on their own terms according to their own tastes. More advanced users can also use the Drum Loop as an ordinary drum machine, without the constraints in the lessons.

The development of the Drum Loop has required a thorough examination of music visualization techniques and software interface paradigms. When examining any visual representation of music, we must ask whether it allows us to work with our figural and formal understandings (Ankney, 2012). Is the representation flexible enough to meet students' developing knowledge of musical structure? Does it connect to pre-existing musical knowledge, and does it facilitate the building of new knowledge? And on a more practical basis, can a good representation be implemented in code with a reasonable amount of effort?

As it details the background and development of the Drum Loop, this thesis addresses the following questions:

- What are the present limitations of music education practice in the area of beginner-level rhythm teaching?
- How can beginner-level music education be made more effective, more engaging and more inclusive?
- How can software support better music learning generally, and rhythmic learning in particular? Which visualization and notation methods are the most intuitive? Which beginner-level applications scaffold more advanced learning?
- How does the Drum Loop address the questions above? What vacuum does it fill in the present music education software landscape?
- What was the rationale behind the Drum Loop's design? How did the development process inform the final product? What future work remains to be done?
- Can the Drum Loop be of value in the learning of subjects other than music?

The Drum Loop development process



I collaborated closely on the technical aspects of the Drum Loop with my fellow masters student Christopher Jacoby. He graciously agreed to give me extensive assistance in exchange for jazz guitar lessons and music production tips.

Christopher's contributions to the project include substantial guidance with Max coding and a wide variety of specific feature implementation methods; implementation of the Max prototype's user interface in JavaScript UI; and considerable insight into the problem of maximizing target areas on the grid. He also learned Objective-C and the audio and MIDI functionality of iOS while simultaneously developing the back end of the app.

I created the user interface design, including all guidelines and requirements. I also developed all musical and pedagogical content. We received additional assistance on iOS audio implementation from NYU PhD student and programming instructor Oriel Nieto, as well as from the Stack Overflow community.

Before developing the iOS app, we first created a working prototype using Max/MSP/Jitter. This prototype was intended as a "minimal viable product" and implemented only the most basic functionality. After we completed the Max prototype and I performed some testing with it, we faced the choice of whether to continue to develop additional functionality in Max, or whether we should start over in iOS. We opted to move forward using iOS, even though that meant revisiting solved problems. Or so we thought—iOS turns out to be dramatically more difficult to work with than Max, and seemingly simple problems like polyphonic sample playback consumed considerable development time. It is our hope that this effort will have turned out to be worthwhile, for several reasons:

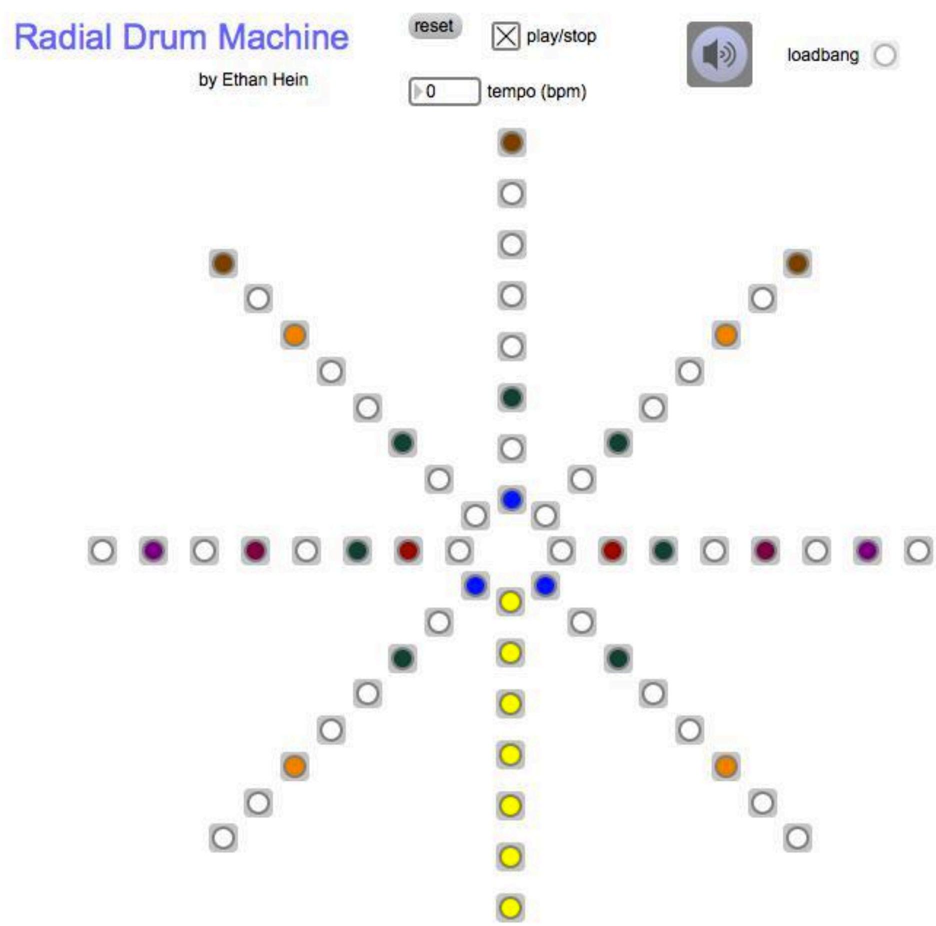
- Max is not suitable for robust commercial software releases. It is optimized for ease and accessibility while developing, not for producing well-optimized and stable code. Furthermore, each application created with it is platform and operating system specific. Of course, iOS apps are locked to a platform as well, but iPad usage continues to grow explosively, particularly in schools, so this limitation should prove less burdensome.
- Unlike the Max prototype, the iOS app sends and receives MIDI messages. This creates the possibility for having the Drum Loop communicate with other hardware and software via MIDI as well.

- There is a robust ecosystem of iOS music apps that can send and receive audio to one another in real time using inter-app audio. A user might set up a pattern in the Drum Loop, improvise a synth lead on top with Animoog, and record them both in Garageband.

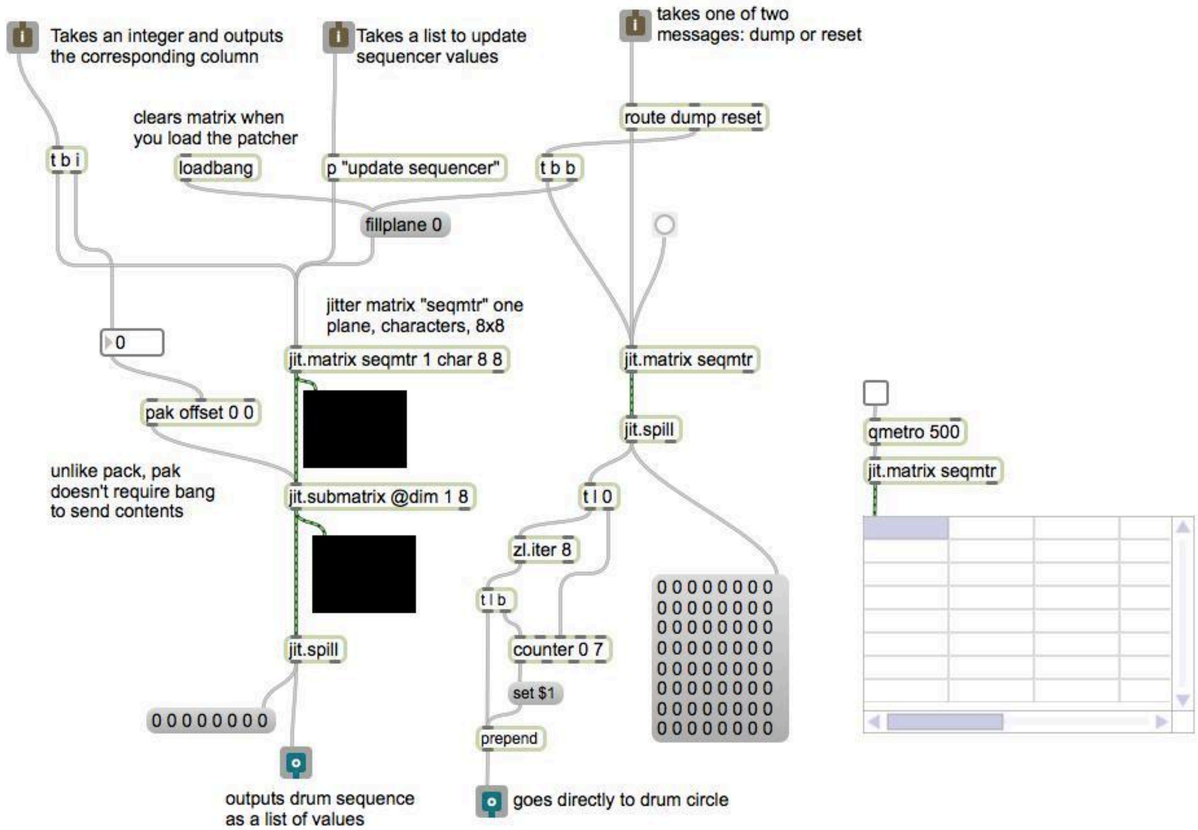
Over the long term, we also plan to adapt the Drum Loop into a web-based app running entirely within the browser, using the emerging HTML 5 web audio standard.

The Max prototype

We created two functioning prototypes with Max. The first is highly skeletal. It uses simple Button UI objects arrayed in wedges, that are themselves arrayed around a circle. The inner ring of buttons shows kick drum hits as blue dots; the second ring shows snare hits as red dots, and so on. By clicking each button, the drum hit in that slot can be toggled on and off. The downbeat is at twelve o'clock, and playback runs clockwise. The playback head is shown as a row of yellow dots sweeping the circle like a clock hand.

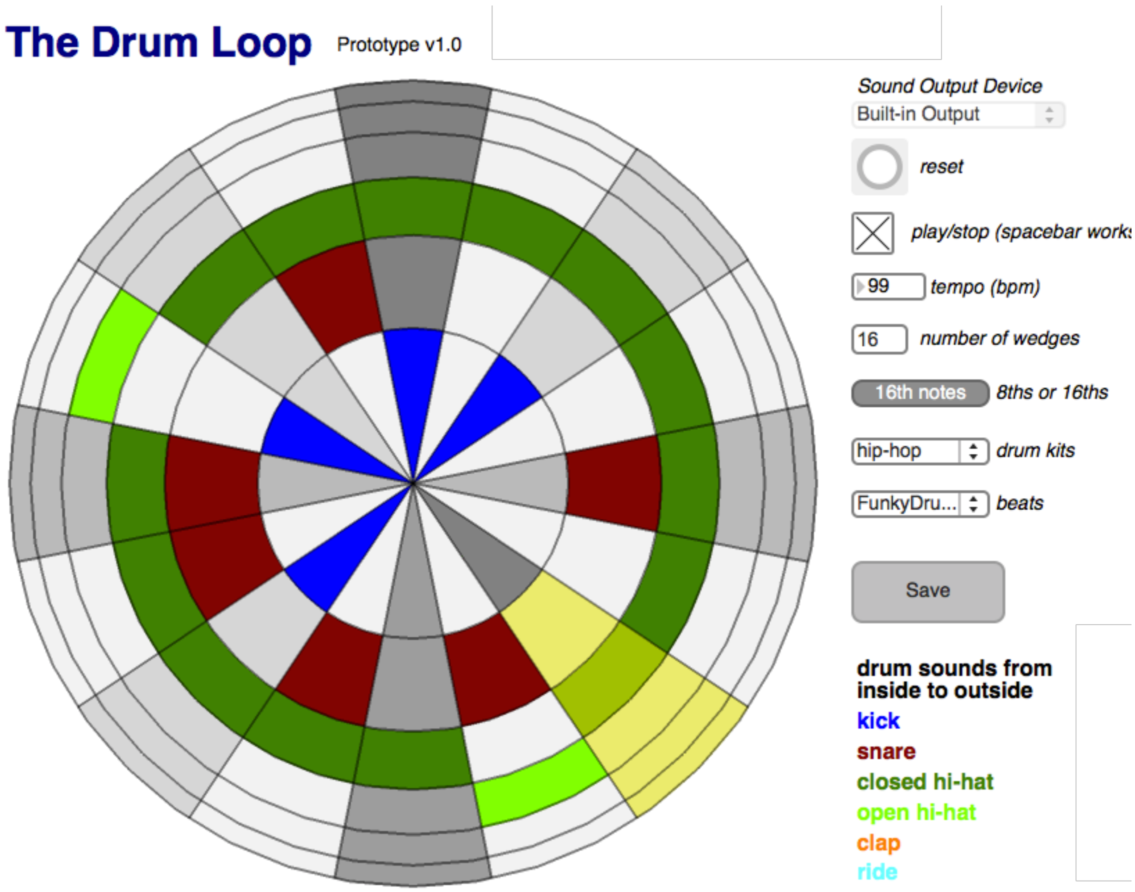


Drum patterns can be stored, retrieved and played back from a Jitter matrix.



The second, more full-featured Max prototype used the same back end, but had a more elegant user interface. In order to implement it, we had to find the best method for creating the radial grid. My initial plan was to simply create static PNG images for the empty grid, the filled cells, the playback head, and any additional graphics needed for animation. We would then display and hide these images as needed, and map regions of the screen for hit detection. This method had the advantage of superficial expediency, since I would have been able to produce the necessary images myself very easily. However, it would have been a cumbersome and inflexible system, requiring new sets of images for every possible number of wedges or alteration to the design scheme.

The alternative to static images was to render the grid, filled cells and animation entirely in code. Christopher advocated for this approach, since it is better programming practice and offered the greatest flexibility for design changes. Christopher suggested using JSUI, a Max object enabling interactive graphics using JavaScript. He was able to learn the syntax in a matter of hours, and I was not far behind. We were able to create a working user interface in a few weeks.



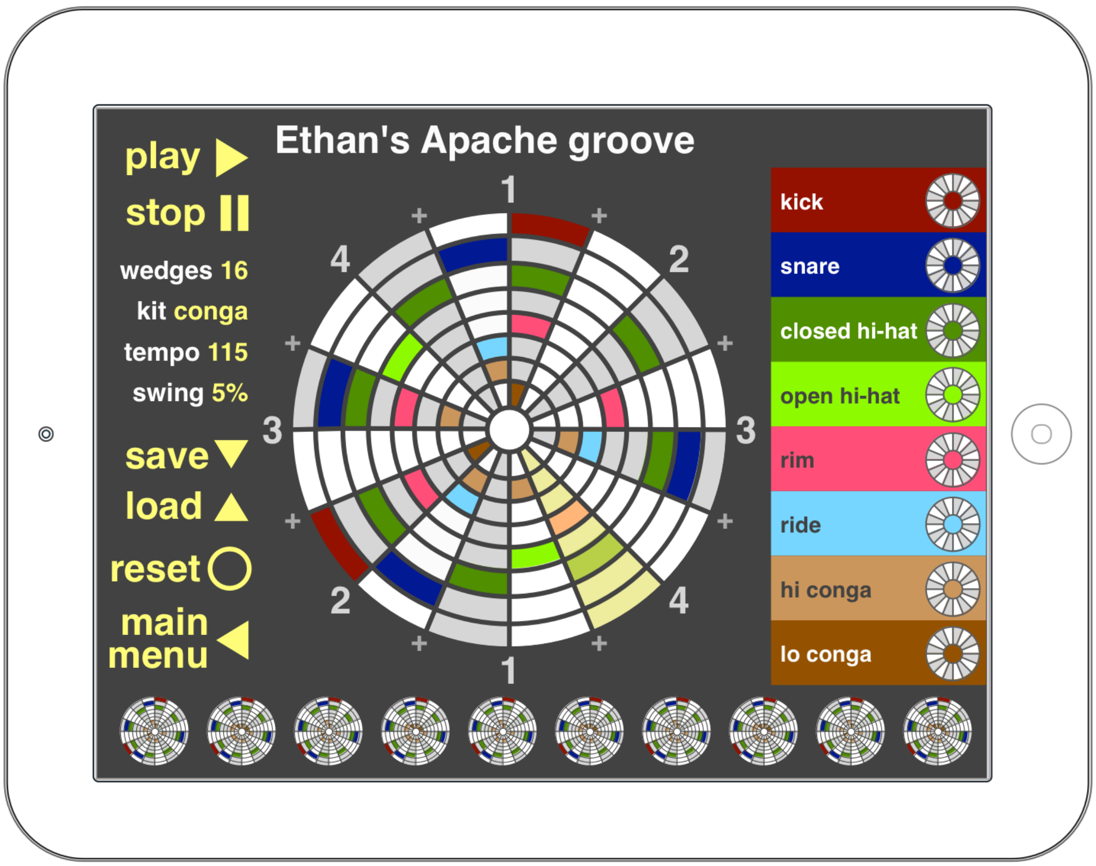
Accessible though it was, the combination of Max and JSUI had significant performance disadvantages. Max is optimized for ease of programming, not performance; the standalone apps it produces are notoriously slow. To make matters worse, JavaScript is a single-threaded language, placing a severe bottleneck on the app's throughput. While the prototype loaded and ran on the various computers I tested it on, it was quickly overwhelmed by the demands of polyphonic audio playback and continuous screen redrawing. Within a few minutes, the prototype became slow to respond, with lags of several seconds between mouse clicks and corresponding action. Thirty-two step patterns and faster tempos overwhelmed the prototype instantly.

While performance limitations were to be expected, the Max prototype suffered additional problems from our less-than-optimal algorithm for drawing the grid. JavaScript lacks a good method for drawing complex shapes using Bézier curves, so we were forced to generate the interface using simple wedges. The outermost ring of cells was actually a set of wedges originating at the center of the grid. The next ring inwards was a set of wedges extending not quite as far from the center. Each ring was its own complete set of wedges, all of which were redrawn every time the screen refreshed. This method would have performed poorly regardless of the language in which it was implemented.

The iOS app

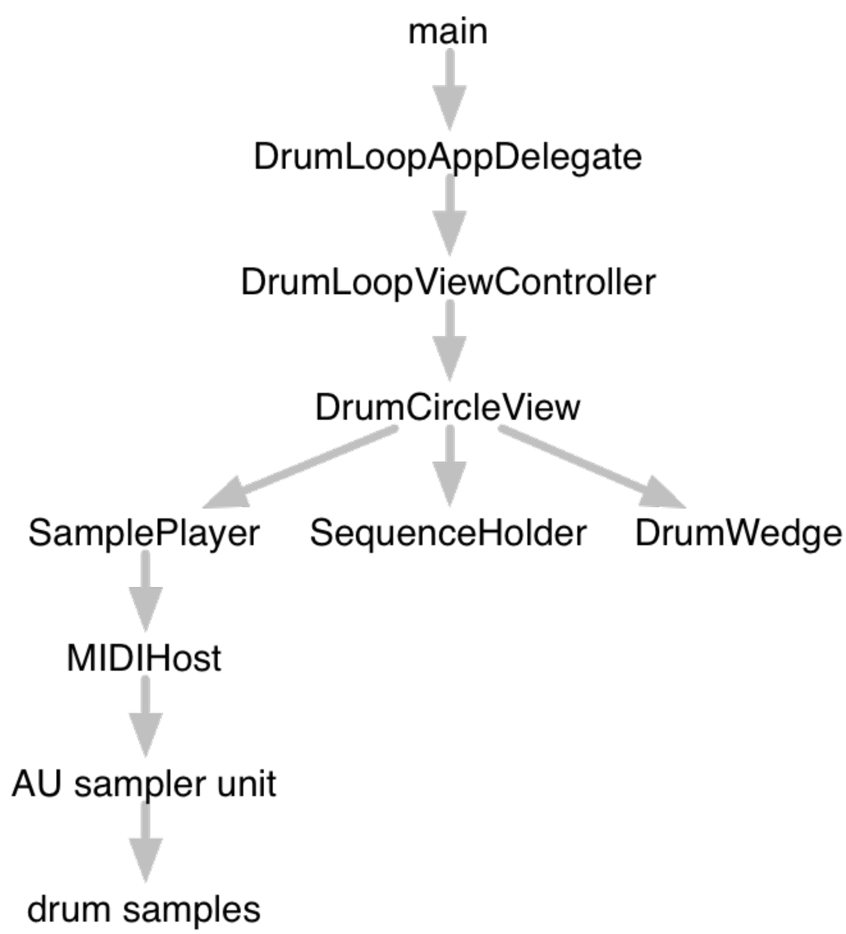
It was always my intention to create the Drum Loop in iOS. While there is no logical distinction between clicking on a grid cell with the mouse pointer versus tapping it with a fingertip, the latter has significantly greater intuitive appeal. Furthermore, iOS offers the possibility of multitouch control. However, iOS is also a significantly more challenging production environment than Max.

Below is an example screenshot of the iOS app. The functionality is much the same as in the Max prototype, though with several cosmetic differences.



The right side of the screen shows the list of buttons triggering the eight drum sounds in this kit. The icons on the right side of each button draw focus to that instrument within the grid—that functionality is discussed in depth below. The center shows the drum grid itself. Unlike the Max version, here the outer ring holds the snare drum. The next ring inwards holds the snare, then the closed hi-hat, and so on down the list. The left column contains mostly self-explanatory basic functions. The row of icons along the bottom of the screen are a sequencer for stringing multiple patterns together—this feature is still taking shape.

On the back end, the app is structured as follows. The DrumLoopViewController contains the main user interface: drum buttons, tempo, kit, swing, save, load and so on. It also contains the square DrumCircleView, which contains the radial grid itself. DrumCircleView communicates with three components. DrumWedge, as the name suggests, draws the individual wedges making up the grid. SequenceHolder is a matrix of values that stores drum patterns. SamplePlayer plays the AIFF drum samples themselves by sending messages to MIDIHost, which in turn communicates with an AU sampler unit.



The Drum Loop's approach

The goal of the Drum Loop is to bridge the gap between the rhythmic knowledge of a complete beginner and the skills required to make satisfactory use of intermediate tools like GarageBand. The Drum Loop should be simple enough to be learned easily without prior experience or formal training. But it must also have sufficient depth to teach substantial and transferable skills and concepts, including:

- Familiarity with the component instruments in a drum beat and the ability to pick them individually out of the sound mass.
- A repertoire of standard patterns and rhythmic motifs. Understanding of where to place the kick, snare, hi-hats and so on to produce satisfying beats.
- Awareness of different genres and styles and how they are distinguished by their different degrees of syncopation, customary kick drum patterns and claves, tempo ranges and so on.
- An intuitive understanding of the difference between strong and weak beats and the emotional effect of syncopation.
- Acquaintance with the concept of hemiola and other more complex rhythmic devices.

The user experience is predicated on the following constructivist principles:

- The user should engage with authentic cultural materials, and should be able to produce personally meaningful works.
- The difficulty level must be calibrated to the user's skill level, to steer a course between boredom and anxiety, thereby maximizing flow.

Methodology: design-based research

How does one evaluate the success or failure of a creative educational tool? Is it possible to conduct procedurally rigorous experiments that give reproducible results? Can we use random assignment and experimental control to avoid misinterpreting confounds or covariates? In the context of music learning experiences, it is doubtful that such rigor is possible. Experimental control is difficult in the complexity of real classrooms, and even more difficult in informal or ad-hoc learning situations. There is no good way to control for learners' prior experiences. Furthermore, double-blind studies are effectively impossible; how do we prevent teachers from knowing what treatment they are administering?

As detailed by Hoadley (2004), design-based researchers treat these problems as the basis for a different approach to rigor. Much as cultural anthropology cannot be conducted experimentally, design-based research must similarly embrace complexity and subjectivity. Outcomes are the culmination of interactions between designed interventions, individual and group psychology, personal histories or experiences, and situational contexts. Uncountably many factors interact to produce the measurable outcomes related to learning. In design-based research, the enacted intervention is a dependent, not an independent, variable. Design-based research, therefore, proceeds in a very different manner than experimental research:

- Studies involve a tight relationship between researchers and teachers or implementers, rendering total objectivity impossible.
- Generalization will be tentative at best.
- The research project can be altered in mid-stream by new discoveries and revelations, resulting in adjustment to both the intervention and its measurement.
- Design-based researches must document both the design and its evaluation as broadly as possible in order to catch unanticipated consequences and serendipitous discoveries.

Because researchers are both participants and observers who intervene deliberately in the settings they study, it is incumbent on them to document their own agenda and biases. Such introspection is usually undesirable in empirical research, but there is simply no better or more rigorous way to document design thinking or its effects in the world.

Software development as research

Brown's (2007) notion of software development as research, or SoDaR, is an attempt to restore rigor to the study of complex interactive software and its human users. SoDar uses qualitative, anthropological inquiry, involving a substantial amount of introspection on the part of the researcher, in order to encompass the complexity of messy real-life environments.

Software development is an excellent way to test educational concepts. The software itself is a concrete manifestation of the designer's theories and assumptions, stated and unstated. Brown describes software as "a mirror on researcher understanding." Seeing the software in action puts those theories and assumptions to the test, and gives the designer ample opportunity for ongoing reflection. Rather than waiting for the study to end before drawing conclusions, one can gather conclusions constantly and apply them to each iteration of the design.

Brown draws parallels between SoDar and ethnography, case study, and design-based research. All of these research methods deal with the messiness of people in real-world settings. Controlled laboratory environments are ideal for studying specific components of our cognition and social functioning, but we can only get the full picture from looking at the world. Unfortunately, that means going without control groups, clean separation of cause and effect, and other seemingly basic requirements for empirical objectivity. The results of SoDaR research are therefore difficult to generalize, since they are necessarily so dependent on context. Nevertheless, for people in natural settings, qualitative observations are the best data we have. Software development forces us to externalize our ideas, to do continual small-scale experiments, and to reflect on those experiences. As my collaborator Christopher and I struggle with each iteration of each function of the Drum Loop, we are in effect performing extensive user testing on ourselves.

The SoDaR approach has three stages. Each one includes description, data collection, and reflection. The first stage is to identify the learning opportunity, the gap to be filled. (For the Drum Loop, this gap is the paucity of good entry-level dance-oriented rhythm tutorials.) The second step is to design and produce the software. The third step, overlapping heavily with the second, is to test, iterate and repeat. The goal with the Drum Loop is to arrive at a minimum viable product that is robust enough for real-world classroom testing. The results will be the basis for future revision, followed by more testing, followed by further revision.

SoDaR draws on Activity Theory, the idea that our intelligence is distributed rather than purely individual. Our knowledge and skills are enacted through interactions between people, and between people and technology, all in social contexts. We can therefore only understand the effectiveness of learning technology in social contexts. We must ask of our tools:

- Are the learning activity and software mutually reinforcing?
- What are the differences between the expected and actual behavior of the students/users?
- How can the software and its use be improved?
- Are the students achieving the desired learning outcomes?
- Does the software open up new and unintended learning possibilities, or does it restrict them?

In Brown's own SoDaR research, he finds that most of the major findings occurred in the first few trials and iterations. The same has been true with the Drum Loop. Watching users interact with the prototypes, it is obvious within the first minute or two what makes sense to the users and what does not. Unpromising ideas get weeded out quickly.

Evaluating meaningful engagement

Dillon, Adkins, Brown and Hirche (2008) propose the Meaningful Engagement Matrix to evaluate creative pedagogical tools. The x-axis lists modes of creative engagement:

- Appreciating—Listening carefully to music and analyzing music representations.
- Selecting—Making decisions about musical value and relationships.
- Directing—Managing music making activities.
- Exploring—Searching through musical possibilities and assessing their value.
- Intuiting—Participating in intuitive music making.

The y-axis lists types of meaning:

- Personal—The extent to which the activity is intrinsically enjoyable.
- Social—How well the user is able to develop relationships with others through the activity.
- Cultural—The degree to which the student achieves a sense of self-worth by participating in (or succeeding at) activities valued by the community.

The activity under evaluation should address all combinations of the modes of creative engagement and types of meaning listed above. For the Drum Loop and similar software, we must ask what modes of creative engagement are enabled or discouraged, and what types of meaning can be created as a result. The Drum Loop attempts to fulfill the Meaningful Engagement Matrix in the following ways.

Modes of creative engagement:

- Appreciating—The user is given culturally authentic and aesthetically satisfying beats to study and manipulate.
- Selecting—The user chooses which exercises to engage in, and how much time to spend on each one.
- Directing—All exercises involve self-directed creative beatmaking on the user's part.
- Exploring—There is no single "correct" solution to a Drum Loop exercise; nor is there a linear path to search for one. Users proceed by trial and error, placing and removing beats and immediately hearing what works and what does not.
- Intuiting—Beyond the rudimentary "notation" implicit in the user interface, all pedagogical content in the Drum Loop is aural. The correct answers are the ones that sound good.

Types of meaning:

- Personal—Beyond the pleasure of producing the kinds of beats familiar to and enjoyed by the Drum Loop's intended young users, there is also the appeal of the visually complex and aesthetically pleasing radial grid.
- Social—Beat-driven music is intrinsically social, designed to be enjoyed in groups. The hope for the Drum Loop is that its users will be proud of their beats and will be eager to show them off.
- Cultural—Beatmaking is a highly regarded and much-desired skill among American adolescents. By offering an accessible introduction to this skill, the Drum Loop should prove to be quite compellingly and meaningfully engaging.

The problem: Why are so many young people alienated by music class?

Of those high school students in North America who have elective music programs available to them, only five percent choose to enroll. In the United Kingdom, the equivalent statistic is closer to two percent (Lowe, 2012). These low enrollment figures are startling when we consider the central role of music in the inner lives of adolescents. We should not blame students for voting with their feet if the music classes available to them do not offer what they want and need from music. Instead, we must ask why so many young people are so alienated by their music education experience.

Classroom music is alien

The music academy continually laments students' lack of interest in "legitimate" art music, and their preference for (supposedly) vacuous pop. From the student's perspective, however, there are valid reasons to find it difficult to connect to the music they encounter in most classrooms. The music education establishment draws its values and axiomatic assumptions from the European classical tradition, with its score-centrism, rigidly-defined canon of works that are often centuries old, and lack of improvisation and spontaneity. Casual pop listeners in America are immersed in a musical culture that lacks the melodic and harmonic richness of the European classical canon, but is considerably more rhythmically sophisticated, and delivers a much broader variety of timbres as well.

Students in the traditional music classroom are not just being challenged by the complexities of chord and scale theory and notation. They are also challenged to stay interested in spite of the absence of knowledge that is important to them: how do the songs on the radio work? Why are some of them so much more compelling than others? How are they made, creatively and technically?

There is a widespread fear among music educators that including pop music in the classroom necessarily entails pandering to students or "dumbing down" the curriculum. However, this does not necessarily follow. Bringing the level of rhythmic sophistication of classroom music up to the standard of African diasporic dance music would engage young people in a challenge that they might be a great deal more eager to take on.

Exercises are culturally inauthentic and musically unsatisfying

Beginner music students are rarely engaged with actual music beyond the simplest nursery rhymes and folk songs. It may be years before a beginner musician starts playing something that they would recognize as "real music." In the meantime, they study decontextualized fragments of scales, melodies and chord progressions. These fragments are designed for their pedagogical content, not their intrinsic musical value, and they rarely hold much interest in and of themselves.

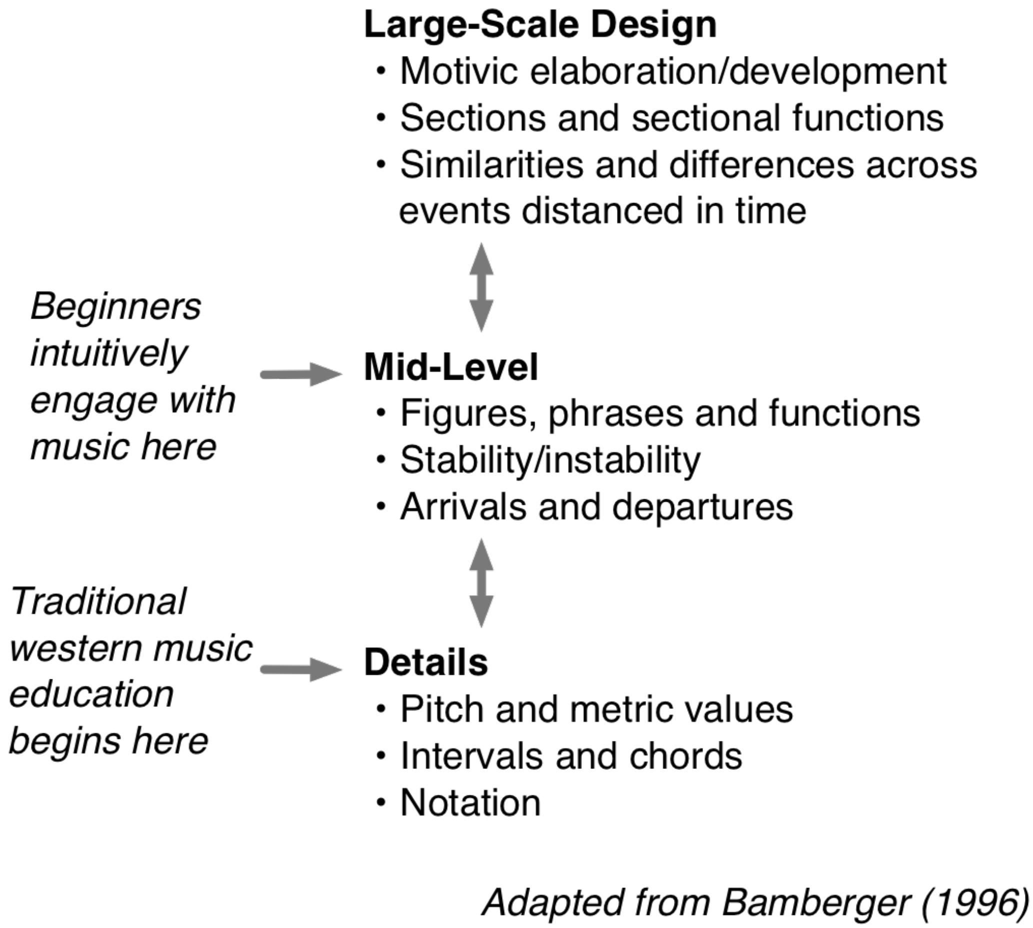
Software for music education has largely continued the traditional approach. The state of the art in interactive music learning software is well represented by My Note Games!, released by Appatta Ltd for iOS in 2011. The app comprises several distinct music theory, reading and ear training games:

- Hear It, Note It!—Hear a melody and use the game's notation editor to transcribe it.
- Tap That Note—Given a simple melody with a row of note names below, tap the note names in the sequence they are written on the score.
- Play That Note—Sight-read a short melody on your instrument into the iPad's built-in mic; the game tracks your accuracy note-by-note.
- Play-A-Day—perform more demanding sight-reading exercises, requiring more exact timing. You are given eight melodies, and when you can play all of them correctly, you advance to the next eight.

These games are self-paced, easy to understand, and presented with attractive graphics. But the examples are devoid of musical interest or cultural authenticity. Indeed, many of the melodies are generated randomly and are often barely even recognizable as music. Having to engage closely with emotionless and arbitrary strings of notes would be enough to demoralize any music student, especially those that may not be intrinsically motivated to begin with.

Beginners start at the wrong level of abstraction

Beginner music classes typically begin with the smallest units of music: beats, notes, and rests. However, beginner musicians are best served by learning what Bamberger (1994) calls "musical structural simples," the smallest *meaningful* units of music: motives, phrases and sequences. Bamberger draws an analogy between different levels of musical abstraction and the linguistic concept of phonemes and morphemes. Phonemes are the smallest sonic components of speech: individual vowels and consonants. Morphemes are the smallest grammatical components of speech: individual words and short phrases. In music, "phonemes" are individual notes, rests, and rhythmic values. "Morphemes" are motives, phrases and sequences. Young children and beginners intuitively understand music at the morpheme level. However, traditional musical education begins with the phonemes.



While the phonemes are the atomic units of music, working with them requires a nontrivial degree of musical sophistication: beginner students would need to understand and be able to dictate proportional rhythm, to conceptualize musical metadimensions such as key, scale, and meter, and to be able to grasp chromatic divisions of the octave. Unfortunately, too many beginning students are presented with decontextualized phonemes that they are unable to connect to their existing implicit musical understanding. At this early stage in their learning, students may understandably conclude that music is too abstract or difficult for them.

Most music production software also operates at the phoneme level of single notes and beats, whether these are represented in traditional music notation or otherwise. Users get some assistance from packages that include prefabricated loops, like Apple's Garageband. However, while the loops might be useful morphemes, they tend to be complex and compound, limiting their generality.

Musician Tor Bruce (personal communication, February 10 2013) draws a helpful analogy between music and graphics software. Blank-slate MIDI sequencers and audio recorders are like working at the pixel level. Loops are more like clip art—expedient but limited in their creative potential. Unlike music software, graphics software offers many tools in between the pixel level and the clip art level: geometric shapes, text, bezier curves and the like. Bruce asks, what are the equivalent tools in music? Where is the software that enables you to work with musical structural simples?

There have been some attempts to invite novice musicians to compose with meaningful structural elements, musical molecules rather than atoms. The composition program Hyperscore provides a visual analogue for structural events in diatonic music (Farbood, Pasztor & Jennings, 2004). It displays musical events as colorful shapes and lines, rather than in procedural notation or as a set of parameters, as is often the case with other graphical composition systems. Hyperscore's major virtue is the manner in which it modularizes compositional tasks, thereby keeping the complexity level manageable. It is much easier for naive composers to relate to the notion of making small bits of music and then assembling those bits into a larger work than it is to start with a completely unstructured task.

Steep barriers to entry

Anyone who has attempted to learn an instrument from scratch has experienced the discouragingly long time span between when study begins and when it becomes possible to produce musical sounds. The weeks or months of practice that come before the making of actual music are an obstacle that a great many students never overcome.

Music production software generally has much lower barriers to entry than acoustic instruments. Presuming familiarity with the conventions of computer operating systems, it is possible for a novice user to produce something that sounds reasonably good in a matter of hours. However, the beginner still faces obstacles to entry. Professional-level programs like Digidesign's Pro Tools and Apple's Logic are formidably complex. There is a more accessible "prosumer" level of product, promising professional capabilities with amateur-friendly interfaces and price points. Apple's GarageBand is the emblematic example. However, these programs still presume a considerable degree of implicit musical sophistication on the user's part.

Explicitly beginner-oriented programs do exist that strive to get their users making music immediately and effortlessly. Propellerhead Figure is an excellent example. While it succeeds in its goal of being learnable by a young child in a matter of minutes, however, it sacrifices a great deal of depth and variety. Figure is more of a toy than a tool, limited in its expressive capabilities, and it does little to scaffold learning of more complex tools. The same is true of most beginner-oriented tools.

Music technologies enable creativity

When schools do address music technology, they tend to focus on the nuts and bolts of the technology itself, rather than its creative applications. This is ironic, since common-practice notation and instrument design are themselves forms of technology. Dillon (2007) observes:

> The violin bow and the saxophone mouthpiece are perhaps the most expressive pieces of music technology in Western history yet composers and virtuoso performers did not undertake courses in these technologies. To understand them they actively explore what the expressive capabilities of these technology enable, what they revealed and concealed to us as musicians.

So it should be with electronic music production tools. But to truly engage such tools for creative music-making, we must address their most culturally significant context: electronic dance music and hip-hop. This music falls well outside the canon of what is widely considered suitable music for the classroom. I will argue that such music should nevertheless be included, and not simply because young people enjoy it. Rather than "dumbing down" music education, the inclusion of popular dance music would significantly enrich the curriculum, particularly in areas traditionally neglected: rhythm, timbre and space.

Expanding the idea of musicianship

Traditional music pedagogy takes a narrow view of what constitutes musicianship: instrumental technique, music reading, and some common-practice tonal theory. It is a rare American school music class that will incorporate composition, improvisation, or transcription from recordings. (The United Kingdom and Australia are moving to include these practices broadly in the classroom.) Still fewer classes venture into recording, production, publishing, reviewing, or applying metadata to music. It is vanishingly unusual for students to encounter DJs, sound designers, electronic composers, producers or engineers in schools; nor are students likely to have access to the tools of their trade: audio waveforms, the MIDI piano roll, graphic visualization, event lists and computer code.

Western classical tradition takes the linear narrative as its defining metaphor. Electronic dance and pop music are based on a very different basic image: the endless loop. Copy-and-paste is the defining gesture of digital editing tools, and infinitely looping playback their signature sound. The cyclic nature of pop, dance and hip-hop music unites the many styles and genres, and is much lamented by "sophisticated" musicians. However, repetitiveness is not coextensive with a lack of musical richness. Loop-centrism is ubiquitous in contemporary art music as well, with African-American dance music as its major vector of cultural transmission. McClary (2004) argues that the music of Missy Elliott, Steve Reich and John Adams are fundamentally more similar than different, united by their shared cyclic structures.

Why is repetitive music not boring to listen to? Why we can play repetitive music without getting bored? Butterfield (2010) argues that we do not hear each repetition as an instance of mechanical reproduction, even in looped electronic samples and sequences. Instead, we experience the groove as a process, with each iteration creating suspense. We are constantly asking ourselves: will this time through the pattern lead to another repetition, or will there be a break in the pattern?

Recognizing the aesthetic power of syncopated rhythms and breakbeats

What does the human brain find exciting about syncopated rhythm, even when repeated heavily? The answer is likely to be: predictable unpredictability. The brain is a pattern-recognition machine. We like repetition and symmetry because they engage our pattern-recognizers. But we only like patterns up to a point. Once we've recognized and memorized the pattern, we get bored and stop paying attention. If the pattern changes or breaks, it grabs our attention again. And if the pattern-breaking happens repetitively, recursively forming a new pattern, we find that extremely gratifying.

Good breakbeats and drum patterns are just complicated enough to challenge our pattern recognition ability without totally overwhelming us. Repeating a complex and unpredictable rhythm in a simple, predictable structure, and then sometimes breaking that structure, holds our attention without completely dominating it. A good groove ties the room's attention together while still leaving enough bandwidth for people to dance, rap, sing, socialize or daydream. Breakbeats are good for social music because listeners can let their attention wander, and then easily pick the thread back up at will.

Butterfield (2010) describes a groove as an experienced present that is "continually being created anew." Each repetition gains particularity from our memory of the immediate past and our expectations for the future. In live performances and recording played by live musicians, small deviations from the expected pattern add interest to a groove. There is tension between the expected identical repetition and the imperfections of the actual performance. This is why a hip-hop breakbeat sampled from a live performance can be so much more exciting than a drum machine pattern quantized exactly to the grid. The uncanny perfection of perfectly quantized synths and drum machines hold their own hypnotic pleasures, perhaps by relentlessly defeating our expectation of small imperfection. Each type of groove holds its own aesthetic power, and each is worthy of inquiry in its own right.

Looping and feedback support traditional music pedagogy

Beyond being a valuable method of musical expression in its own right, the open-ended loop has considerable value in support of more traditional instrumental and vocal pedagogy. Repetition is fundamental to all human learning, in the forms of drilling and rehearsal. Software is ideally suited to producing endless repetition in support of rehearsal.

The key to effective music learning is "chunking," breaking a long piece into short, tractable segments and then building those segments into larger meta-segments (Snyder 2001). Electronic dance music is built from loops of such chunks. Music learned on acoustic instruments or voice can be similarly broken into dance-music-style loops. Students can repeat loops in tempo until they are mastered. Then the loops can be chunked into ever larger loops of loops, without ever disrupting the underlying rhythmic groove.

Saville (2011) cites the music educator's truism that "accurate feedback may be the single greatest variable for improving learning." The longer the delay between the performance and the feedback, the less effective it is. It is best to give feedback in the moment, while the student plays along with the loop, "in the heat of battle." The loop can continue to run indefinitely, so students need not lose the flow when they drop a note or receive feedback. I have certainly found that having my students rehearse manageably-sized loops sustained by a steady groove can turn potentially tedious drilling into a satisfying and even joyous experience of real music-making. Even the most basic introductory exercises can sound like music and induce flow; the loop structure makes that possible.

A need for authentic music in the classroom

Ruthmann (2006) argues that the best curriculum activities derive from real-world activities, ideally retaining the essential values of the original. The objects and operations of the adapted activity should be genuine instances of the original activity, however simplified. Classroom music and "real" music should be one and the same whenever possible.

Martin (2012) concurs, advocating teaching "from within authentic music making contexts." However, he undermines his own argument, in a highly illuminating way. He believes that students should be able to explore electroacoustic music and sampling. However, while his desire for a more inclusive curriculum is admirable, his version of decanonization simply entails swapping in a different canon, the twentieth-century avant-garde. While Martin deserves credit for recommending teaching non-academic artists like Aphex Twin, he is unfortunately quick to dismiss popular music. He takes a dim view of "the repetitive ostinati of typical dance club pieces," preferring more abstract and challenging musical paradigms. However, Stockhausen and Varese are likely to alienate younger students even more than Mozart and Handel. Truly authentic practice should embrace the culture in which students live.

Why is a modernist like Stockhausen even less suitable for music classes with young students than Mozart? The answer can be found in a famous interview conducted by The Wire magazine in 1995, in which Stockhausen was asked to comment on some electronic music artists widely considered to be his musical descendants, including Aphex Twin, Plasticman and Scanner (Witts, 1995). These artists might be categorized as "pop" in the very broadest sense, but their music lies well outside the commercial mainstream. Nevertheless, Stockhausen voiced considerable contempt for their "permanent repetitive language," their "ice cream harmonies" and other "kitschy" indulgences. He advised Aphex Twin to "immediately stop with all these post-African repetitions," and "not allow to repeat any rhythm if it were [not] varied to some extent and if it did not have a direction in its sequence of variations." In other words, Stockhausen utterly rejects the very qualities of electronic dance music that give it such profound significance both in the lives of young students and in global popular culture.

The value of electronic music in the classroom is not in its abstraction and difficulty. Its value is in its absorption of African-American popular idioms, "converting our collective sense of time from tortured heroic narratives to cycles of kinetic pleasure" (McClary 2004). Prince (1990) drives home the point directly by singing:

> There's joy in repetition
> There's joy in repetition
> There's joy in repetition
> There's joy in repetition
> There's joy in repetition
> There's joy in repetition

Marshall (2009) wonders:

> How to argue for the aesthetic value of deeply repetitive music—a quality utterly taken for granted and celebrated by [electronic dance music] devotees—without falling into two common traps: (1) searching for the hidden complexities of seemingly simple sounds; (2) foregoing any sort of music analysis at all, in favor of socio-cultural exegesis, and thus implying that EDM does not need it (but also, perhaps, does not merit it). A great many journalists, cultural critics, ethnomusicologists, practitioners, and aficionados have been involved in the intertwined projects of explicating and celebrating EDM as social phenomenon, as cultural product and practice, and—if, ironically, less commonly—as music.

To truly come to appreciate the value of dance music in the classroom and in elevated cultural discourse in general, we must relinquish our present valorization of complexity, and instead, to investigate the aesthetic power of the loop.

Eurocentric music education undervalues rhythm

What value does dance music offer to the music curriculum? Certainly, its production techniques make wildly diverse use of timbre and space. For the present argument, however, the chief virtue of dance music is its oft-underestimated rhythmic sophistication, even compared to the furthest fringes of the classical avant-garde. McClary (1989), writing about "System of Survival" by Earth, Wind and Fire, observes that the groove is a foundational musical skill sorely undervalued by the gatekeepers of our culture:

> As is the case with most Afro-American music, the rhythm itself constitutes the most compelling yet most complex component of the song. I would argue that the skill required to achieve and maintain a groove with the degree of vitality characteristic of "System of Survival" is far greater than that which goes into the production of the self-denying, "difficult" rhythms derived by externally generated means. One need only observe professional classical performers

> attempting to capture anything approaching "swing" (forget about funk!) to appreciate how truly difficult this apparently immediate music is.

Groove offers the best of both worlds: it requires a depth of focus and discipline rivaling any other musical challenge, but it also offers young people intense and immediate gratification.

Riffs and loops: the building blocks of dance music

Monson (1999) proposes the riff as the fundamental unit of the musical African diaspora, the morpheme-level building block of much popular music. Since American popular and dance music dominates global musical culture, and African-Americans dominate American dance music, the riff deserves status as a foundational element of the music curriculum, alongside scales, chords and meters.

The riff faces some powerful intellectual opponents, however, Theodor Adorno prominent among them. Monson cites Adorno's oft-quoted stance equating the repetition in popular music with industrial standardization, loss of individuality, military marching, and fascism. Monson vigorously disagrees; he cites the "dynamic and open structure" of riff-based music as a liberating force for self-expression and community-building. Furthermore, because Afrocentric music has a high tolerance for imperfection ("participatory discrepancies" in Monson's terminology), the music opens up "the possibility of participation, sensuous immersion in sound." It is ideally suited to the goal of opening up legitimate participation in music to more students, not just the "talented" ones.

Changing consumers into producers

Even those educators open to including more African diasporic music into the classroom may balk at contemporary pop. What is it that makes the disposable ephemera of commercial culture worthy of serious study? Marshall (2010) invites us to consider that students need not passively absorb pop culture in the classroom the way they customarily do on their own. Digital audio editing makes it possible to actively engage the artifacts of our culture, to remix and recombine them, to personalize and mold them, and to use them as raw materials for entirely new work. The ability to claim creative ownership over pop culture is a tremendously empowering sensation, especially for young people who may not feel much empowerment otherwise.

Marshall advocates particularly strongly for the role of the mashup in music education. By deconstructing and recombining familiar pop texts, mashups open the door to broader critical thinking. As Marshall puts it, through mashups "we discover correspondences, connotations, and critical readings of performances that we may not have given a second thought—or even a first listen." Marshall also recommends that the study of the mashup go hand-in-hand with producing them, thus "folding musical analysis into musical experience." The same argument can be applied to the study of programming drums in popular dance styles.

Constructivist practice in music teaching

Music education will be most engaging and meaningful when the teaching strategies support students' agency in their own learning (Brennan, 2013). Agency, in this sense, refers to students' ability to define and pursue their learning goals, so that they can play a part in their self-development, adaptation, and self-renewal. While learner agency is often viewed as being incompatible with a structured learning environment, Brennan argues that structure and agency need not be in opposition. Ideally, we can create structures that support learner agency. Constructivist practice is designed to do just that.

Constructivist pedagogy operates by the following axiomatic assumptions:

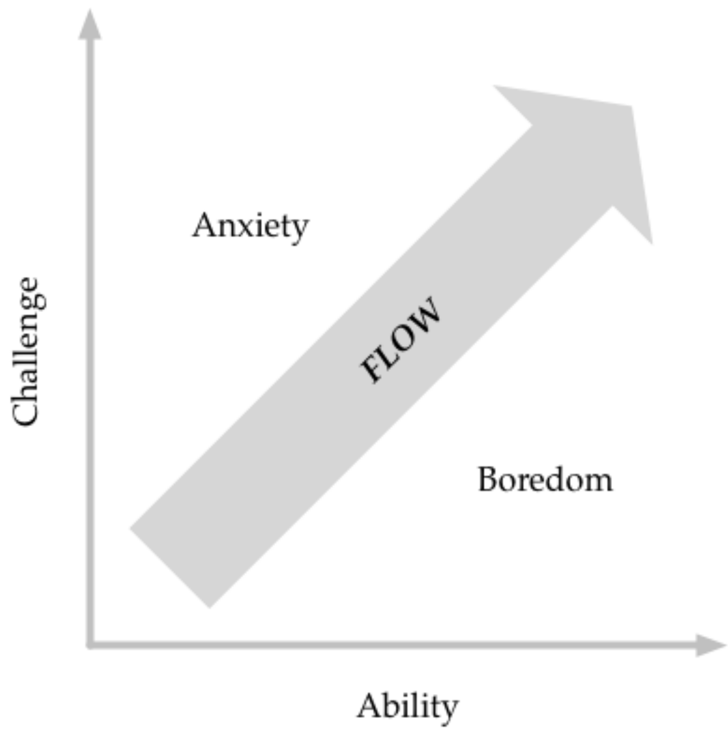
- Learning by doing is better than learning by being told.
- Learning is not something done to you, but rather something done by you.
- You do not get ideas; you make ideas. You are not a container that gets filled with knowledge and new ideas by the world around you; rather, you actively construct knowledge and ideas out of the materials at hand, building on top of your existing mental structures and models.
- The most effective learning experiences grow out of the active construction of all types of things, particularly things that are personally or socially meaningful, that you develop through interactions with others, and that support thinking about your own thinking.
- Learning takes place through four main activities: designing, personalizing, sharing and reflecting.

Music and flow

Before asking what types of music we should teach and how we should teach them, it is worth asking a deeper question: why teach music at all? People enjoy music, but there are plenty of other activities we enjoy that are not taught in school. What makes music so special that it is worth spending finite educational resources on? Dillon (2007) argues that the primary purpose of music is to create deeply gratifying flow states, for both performers and listeners. Csikszentmihalyi (1990) lists the elements of flow:

- Immediate feedback contributing to a balance between skill and challenge
- Merged action and awareness, completely occupying students' attention
- Deep, sustained concentration
- Control of the situation, and the freedom to generate possibilities
- Loss of self-consciousness

If an activity's challenge level is beyond than your ability, you experience anxiety. If your ability at the activity far exceeds the challenge, the result is boredom. Flow happens when challenge and ability are well-balanced, as seen in this diagram adapted from Csikszentmihalyi.



Dillon (2007) sees more at stake for music educators than just providing people pleasure. He proposes that flow is a matter of public health, calling it “a powerful weapon against depression.” Music-induced flow unifies the individual with the social. It draws out troubled, antisocial and developmentally disabled young people, and helps them integrate into the group. It gives voice to those who might find it difficult to express themselves otherwise. And flow is physiologically beneficial as well, though the precise workings of its support of physical well-being are not well understood.

Csikszentmihalyi (1990) observes that people with a self-motivated “autotelic” personality type have a predisposition to flow, an ability to seek and construct their own challenges. While some of us may be lucky enough to have been born autotelic, it is also a trait that can be learned, and taught. Autotelic people are better equipped for positive thinking and resilience. Studying music may help develop these qualities.

Flow experiences encourage autotelicism, a state that self-reinforces through pleasure. If you learn the ability to take satisfaction from self-challenge in a musical context, it is a tool you can carry with you into any other context. The challenge, then, is to create music learning experiences that encourage autotelicism. Dillon (2007) lists effective psychological motivators for music students:

- The image of successful achievement through playing
- Encouragement from one’s immediate cultural setting
- Internal and personal satisfaction
- Social relations and the reciprocal response of family and community
- Sharing in the teacher’s love of music
- Social meaning

Music has both analytic and intuitive aspects. The analytical components of music include technique, accuracy and clarity. The intuitive component includes music's expressive, aesthetic content. To induce flow, the sides have to be balanced, with a productive tension between the analytical (repetitive practice, studying theory) and the intuitive (playful experimentation and improvisation).

If we take a flow-centric view of music education, we are freed from the pressure of having to decide which kinds of music should be taught. The specific means by which the music creates flow is less important than the fact that it does it at all. Whatever the kind of music being played, and whatever instruments are being used to play it, if it induces flow, then it is a worthwhile pursuit. There are many roads up the proverbial mountain, and the right road for a given student will depend heavily on their inner life and their social context. The best strategy to serve all students is to offer a wide variety of musical experience.

There is social and aesthetic value in the experience of being part of an orchestra playing classical repertoire, of the sense of belonging that comes from subsuming one's ego into a complex machine under the conductor's control. There is a different kind of social and aesthetic value in being in a rock trio and having to figure out all of the music by ear, making musical decisions by consensus. And there is yet another in the experience of sequencing a hip-hop track in software. Dillon proposes that the correct approach is to choose "all of the above."

How popular musicians learn

Music educators use the term "popular music" to encompass such sundry styles as pop per se, rock, jazz, country, R&B, hip-hop, dance, and a great many other distinct styles that have widely varying degrees of actual popularity. I will use the term "popular" to refer to Afrocentric western dance music and hip-hop, though much of my argument applies to any of the styles referenced above.

Most practitioners of popular electronic dance music learned their craft informally outside of schools. Given the global reach of electronic dance musicians, their informal learning practices must be fairly effective. If we wish to introduce popular music into the classroom, we would do well to examine those practices.

Popular musicians are substantially self-taught, using ad-hoc methods cobbled together from peers, books, videos and simple trial and error. A great deal of this learning happens at the mid-level of musical morphemes—riffs, phrases, chord cycles, beat patterns and samples. Popular musicians may only approach the phoneme level of pitch and rhythm values late in their education, if ever. Typical pop music practice involves the study of specific songs that are meaningful to the student, rather than abstract chord/scale theory and technical exercises. In the absence of formal method books and courses, popular musicians must piece together information from recordings, books, online resources, word of mouth and whatever other sources are at hand.

Learning may occur in a “student-teacher” setting, but it is just as likely to take place among peer networks, or alone

Green (2002) proposes integrating the following informal, pop-oriented pedagogical practices into formal music education for young students:

- Allowing learners to choose the music.
- Learning by listening to and copying recordings.
- Learning in friendship groups with minimal adult guidance.
- Learning in personal, often haphazard ways.
- Integrating listening, playing, singing, improvising and composing.

Ideally, music class should be a genuine community of learning that speaks to students’ musical selves. We are all too familiar with students expressing social solidarity by resisting their teachers. It would be wonderful if social solidarity motivated students to participate instead.

Learner agency and motivation

Constructivist learning is closely linked to the idea of intrinsic motivation, also known by its more common name, enthusiasm. Papert (1976) sees a good example of constructivism in action in the Brazilian escola de samba. The literal translation is “samba school,” though that term might be a misleading one, as Papert explains: “It would be more likely to describe itself as a ‘club,’ for although it is a school in the sense that people do learn there, it is not a school in that learning is no more the primary reason for participation in the Samba School then it is for membership in a baseball team or for playing any game.” Papert (1993) continues:

> The samba school, although not ‘exportable’ to an alien culture, represents a set of attributes a learning environment should and could have. Learning is not separate from reality. The samba school has a purpose, and learning is integrated in the school for this purpose. Novice is not separated from expert and the experts are also learning.

Teachers need not be expert in the subject matter at hand in order to teach it using constructivist methodology. Learning alongside students is an excellent teaching method, provided that teachers exercise openness, curiosity, and vulnerability as learners.

It is a constructivist axiom that music students work best when they feel like they are making something of value. But it is a challenge to assess such creative practice in a school context. Constructivist practice is easily undermined by the pressure to “teach to the test.” A teacher in Brennan’s (2013) study puts the conflict succinctly: “How do you put a rubric on creativity?” Traditional testing methods are precisely the ones that frustrate intrinsic motivation.

Participatory music vs presentational music

Music teachers face two conflicting goals. On the one hand, they must maximize both the number of participants and those participants' level of engagement. On the one hand; teachers must also maximize the sound quality and individual virtuosity of student performers. The two goals are mutually contradictory; one prioritizes inclusion regardless of skill level; the other prioritizes exclusion of all but the most adept performers. Very different pedagogical strategies apply, depending on whether the goal is inclusion or quality. Music in schools is traditionally presentational—prepared by musicians for others to listen to. Informal music, like that practiced on the playground, is mostly participatory—not intended for listening except by the participants. The conflict between inclusion and quality is alleviated if music teachers work with participatory rather then presentational music.

Playground music has certain characteristics that make it suitable for keeping a large group of children of various skill levels together: internal repetition, short musical forms, predictability, and a level of rhythmic stability. Repetition of the rhythmic groove and predictable musical forms are essential to getting and staying in sync with others. Social synchrony is a crucial underpinning of feelings of social comfort, belonging, and identity. In participatory performance, "these aspects of being human come to the fore" (Harwood & Marsh, 2012).

Popular dance music is closer to playground music than the more "serious" music usually taught in schools. When we ask children to learn repertoire that is unfamiliar to them while simultaneously asking them to learn it in a way that is unfamiliar and unpracticed, we place our learners and ourselves at a double disadvantage. Having students work with familiar music in a participatory format might go a long way toward stemming the epidemic rates of abandonment of music study.

Communities of practice

The reproduction and evolution of knowledge happens most effectively within communities of practice (Hoadley 2012), structured groups that give learners a sense of membership, or at least aspiration to membership. The group should include expert practitioners to whom learners have access. And the community should create space for legitimate participation by the least expert, most peripheral members. Hoadley contrasts communities of practice against the traditional organizational scheme at work in schools, with students segmented into grades, levels or tracks. The community of practice is predicated on situated theories of knowledge. In these theories, "knowledge is a property enacted by groups of people over time in shared practices, rather than the idea that knowledge is a cognitive residue in the head of an individual learner."

Members of a community of practice need not be in close physical proximity, as long as they can communicate. The internet supports communities of practice by linking experts with learners, supporting platforms for storing and disseminating resources and tools, and enabling discussion. Communities of practice can and do coalesce around music production software. The software's affordances, presets and included sounds constitute a repository of resources and implicit instruction on the use of those resources. Documentation, user groups, online forums and informal peer-to-peer learning round out the community. In the best case scenario, the software and its surrounding community connects novice users to expert practitioners and real-world music.

The zone of proximal development and legitimate peripheral participation

A central tenet of constructivist pedagogy is that learning is most effective when it takes place within the "zone of proximal development" (Wiggins 2001). We understand new concepts and experiences in relation to our understanding of existing concepts and prior experience. To learn, we create meaning by making connections to understandings that we already hold. If we have no frame of reference from which to draw, new information and experience may be meaningless to us. We perform best within the zone of proximal development under guidance or in collaboration with more advanced peers, rather than operating on our own.

Schools generally draw a clear separation between observing or reading about an activity and actively engaging with it, with the former preceding the latter. However, the constructivists hold that the best learning occurs where there are opportunities for active participation from the outset. Consider the way that children learn playground games. There is no formal training; children simply hang on the edge of the circle and follow along until they feel confident enough to jump in and stumble through the activity. There is no clear separation between observer and participant; simply standing in the circle implies membership. Samba schools work along similar principles. Beginner drummers begin playing on day one, tapping out simple clave patterns. As they advance, drummers work their way up to more complex foreground drumming. Both the clave and the lead parts are valuable and intrinsic components of the music. Learning in these settings is coextensive with the social experience. Peripheral participation is a robust scaffolding that students can release as they no longer need it.

The Drum Loop not an intrinsically social experience; like most iOS apps, it presumes a single user. However, it is designed to offer the software equivalent of legitimate peripheral participation. Rather than being presented with a blank slate, beginners begin working with real drum patterns immediately. The quantized rhythmic grid makes it impossible to produce results that are completely unmusical. Since the included drum patterns are drawn from actual practice, they foster a sense of a community of advanced practitioners that the user can learn from. Since users progress through the Drum Loop's exercises at their own pace and in the order of their choosing, they are free to operate within their personal zone of proximal development. The goal is to create a learning experience so supportive and dynamically calibrated that it should hardly feel like "learning" at all.

Fighting option paralysis

Computers and synthesizers give musicians unprecedented control over the most minute parameters of audio. Nowhere is more detailed control possible than in audio programming environments like SuperCollider, Max/MSP and ChucK. These tools offer the skilled musician/programmer virtually unlimited sonic freedom. However, that freedom does not always result in richer creative output. The most sophisticated audio production tools can just as easily stifle creativity under the weight of option paralysis. For this reason, music made with the most advanced tools seldom makes it past the experimentation stage into fully-realized works, and performances too often take the form of technical demos.

Simple, limited interfaces have two major virtues. First, a small feature set can be learned quickly. Second, the most obvious uses will quickly become tiresome, forcing the user to push the tool's limits. Magnusson (2010) speaks approvingly of interfaces that "proscribe complexity in favor of a clear, explicit space of gestural trajectories and musical scope." If presented with a finite feature set, users are more likely to move quickly past the knob-twiddling stage into a search for musical expressiveness.

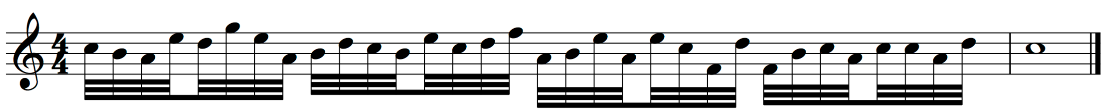
The virtues of tinkering

When we hear the word "tinkering," we typically think of aimless fiddling. Resnick and Rosenbaum (2013) would instead have us consider tinkering to be a valuable pedagogical method. They define tinkering as working without a clear goal or purpose, or without making noticeable progress. While classroom activities are usually highly planned and predictable, tinkering is a playful, exploratory, iterative style of engaging with a problem or project. Resnick and Rosenbaum advocate tinkering in the specific context of teaching of science, technology, engineering and math (STEM). While the popular image of these disciplines is one of meticulously structured planning, real-world STEM work is considerably more ad-hoc in practice. Expert practitioners in STEM disciplines typically employ much more tinkering in their work than is common in STEM classroom activities. The same is true for music.

How should we design pedagogical materials for tinkerability? Resnick and Rosenbaum list three qualities that such materials should offer: immediate feedback, fluid experimentation, and open exploration. These three descriptors also apply to ideal constructivist music teaching materials. The Drum Loop is designed for maximal tinkerability. All digital music production environments offer immediate feedback; the consequences of user actions can be heard instantaneously. The Drum Loop encourages a spirit of experimentation by giving users preprogrammed rhythms and inviting them to find out what happens if they add or remove drum hits, speed or slow the tempo, play it back on different drum kits, and so on. While the Drum Loop's expressive possibilities are limited by design, ideally users will graduate to more sophisticated and open-ended production environments.

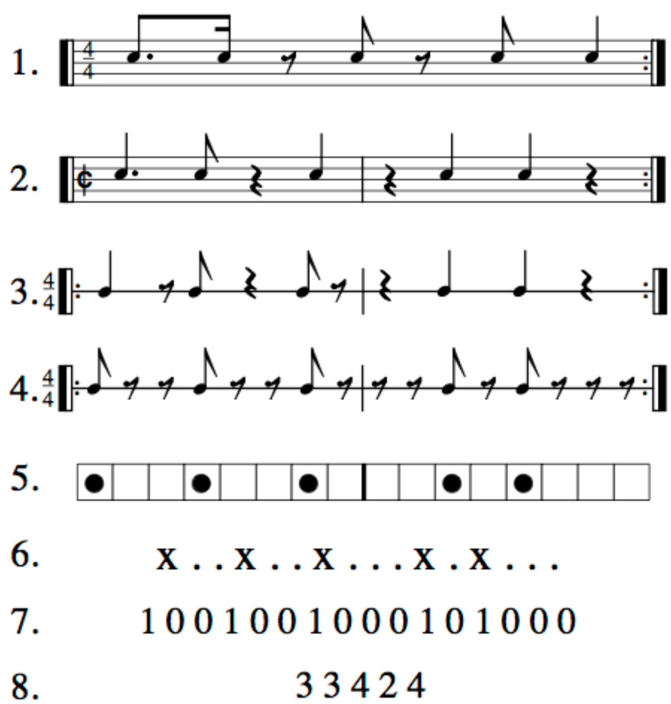
Visualizing rhythm

Standard music notation draws a simple and direct connection between pitch height and staff position. However, no such direct visual mapping exists between a note's duration and its length on the page. The illustration below shows two measures of 4/4 time. One might naively expect the measure on the left to be much longer than the one on the right, but they occupy precisely the same amount of musical time.



Asking beginner music students to simultaneously learn rhythmic concepts and a rather abstract system for representing them is asking a great deal. The MIDI piano roll is a better aid to comprehension for beginners, since it shows longer notes as being visually longer. The relationship between frequency of onsets and tempo is reinforced by the combination of the sight of the playback head sweeping across the piano and the resulting sounds.

Toussaint (2013) compares eight different visual representations of the Cuban rhythm son clave, known to American rock audiences as the Bo Diddley beat. The top four representations are variations on standard musical notation. The bottom four are simplified and abstracted visualizations, less culturally specific.

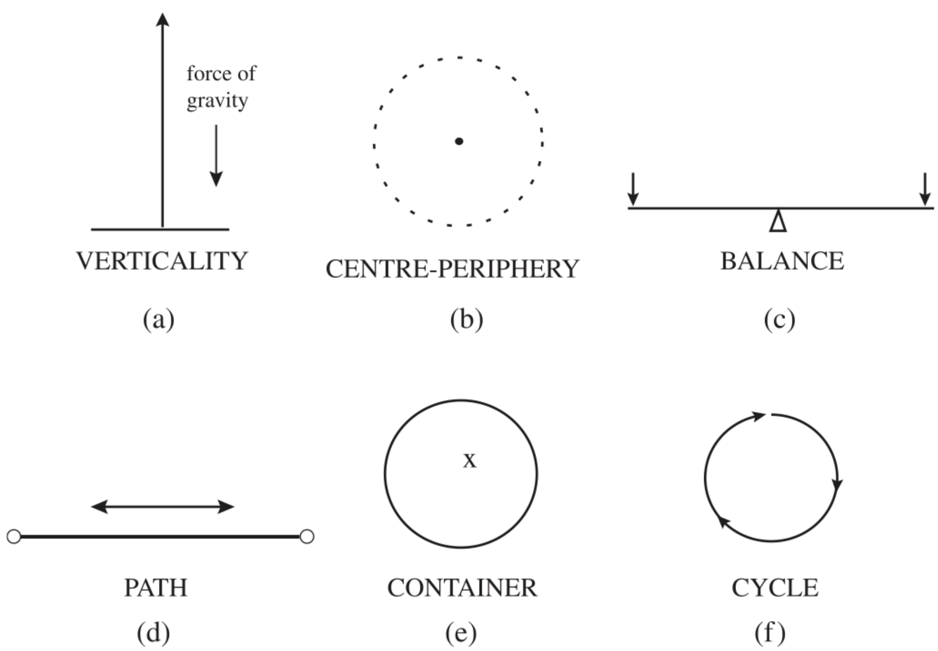


The fifth of these representations is called the Time-Unit Box System, and will already be familiar to producers of electronic music, who have encountered variations on it in their hardware and software. It is the Time-Unit Box System that forms the basis for the Drum Loop.

Bodily metaphors

We frame all abstract thought using metaphors relating back to states of our bodies. Indeed, body states are the only basis for abstract thought that we possess (Lakoff & Johnson, 2003). In music, we "climb up" a scale, we "ratchet up" tension and "release" it, we "land" on the tonic chord after a cadence. The closer a metaphor is to a state of the body, the shorter the chain of abstraction we must parse out, and the easier it is for us to understand. Metaphors that are several layers of abstraction removed from bodily states will be more difficult to learn and remember.

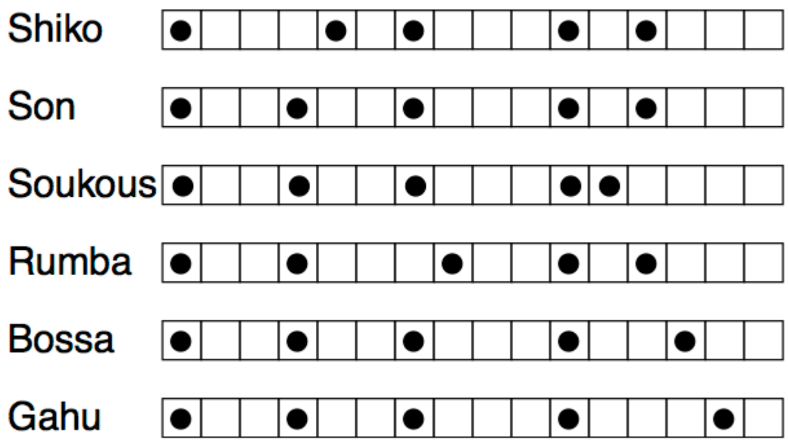
Musicians take bodily metaphors for granted, but it is worth pausing to reflect on the strangeness of finding visual expression for purely auditory phenomena. Music does not "look like" anything; it is remarkable that we have nevertheless evolved so many strongly felt ideas for how it looks. Brower (2008) lists the six most commonly used visual metaphors for music:



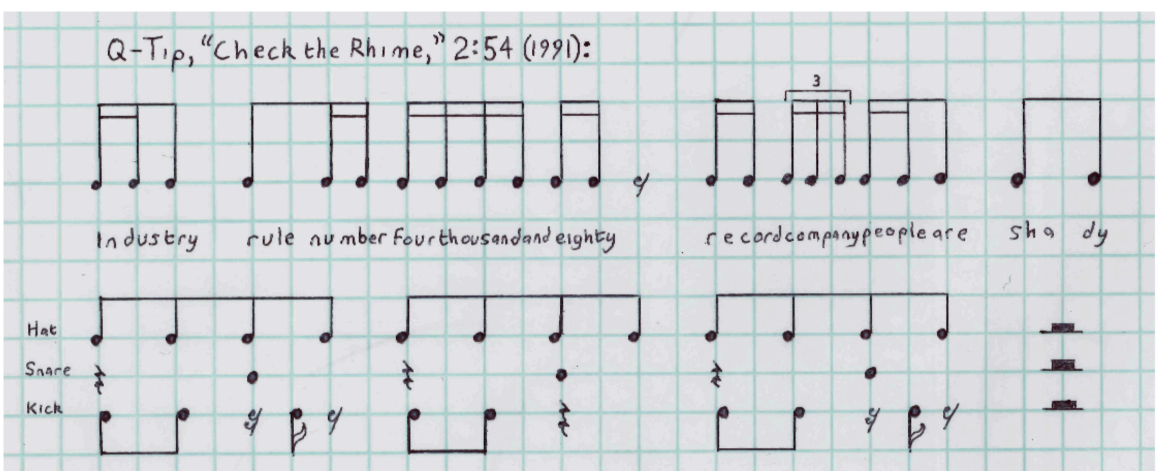
Wilkie, Holland and Mulholland (2010) demonstrate that the most effective bodily metaphors for aiding in musical understanding include containers, cycles, verticality, balance, the notion of center-periphery, and a narrative of source-path-goal. The music software should use these metaphors to create intuitive mappings between sound and image.

Time-Unit Box Systems

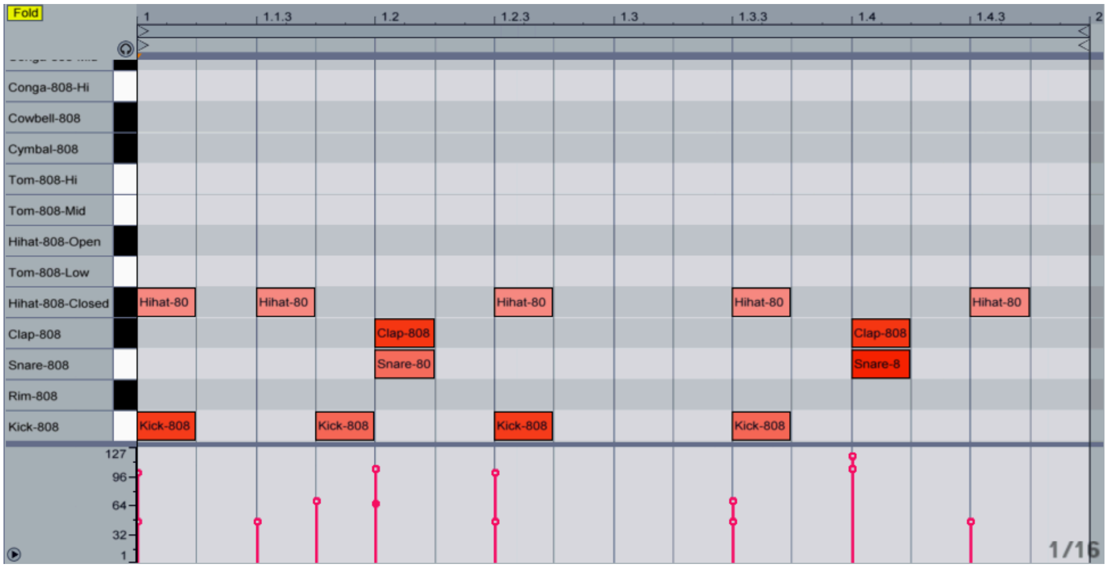
The Time-Unit Box System (TUBS) is a simple method for transcribing rhythm. Each time unit, usually an instance of the underlying beat or tactus, is represented by a box. If a box contains an onset, it is filled; otherwise, it is empty. The TUBS representation is popular among ethnomusicologists, especially when dealing with percussionists who are unfamiliar with Western notation. Toussaint (2013) shows the six fundamental 4/4 time clave and bell patterns in TUBS notation:



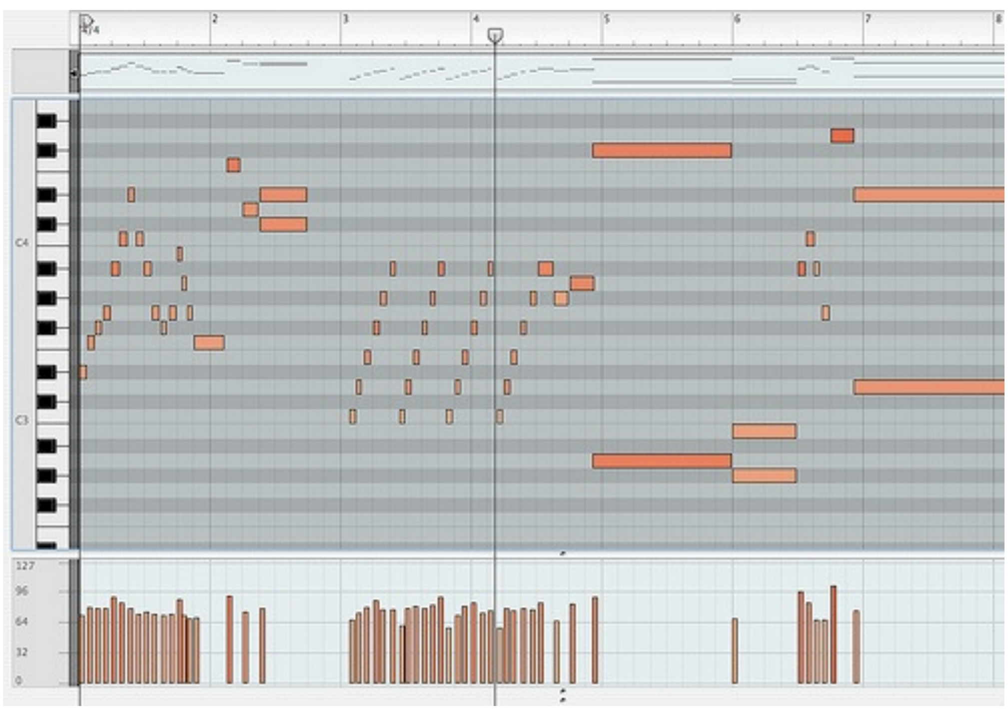
The hip-hop transcriptions created by Charlie Hely turn standard western notation into a TUBS by quantizing it spatially on graph paper.



Drum machine interfaces are almost always predicated on TUBS. For example, the image below shows a drum pattern in Ableton Live's MIDI clip editor. Time goes from left to right, and then circles back to the leftmost edge. The vertical axis lists different drum sounds: kick, rim shot, snare, clap, hi-hat and so on. The MIDI sequencer adds another axis to the basic TUBS, using both a color scheme and vertical lines below to show each hit's loudness (velocity).



The MIDI piano roll can be thought of as a kind of "super TUBS" with an infinite number of boxes that can represent arbitrarily large or small units of time. The image below shows part of "Four In One" by Thelonious Monk, as represented in Propellerhead Reason's MIDI piano roll. This time, the vertical axis represents pitch, as indexed by the piano keyboard on the left. The vertical line shows the playback position, which the user can manipulate at will.



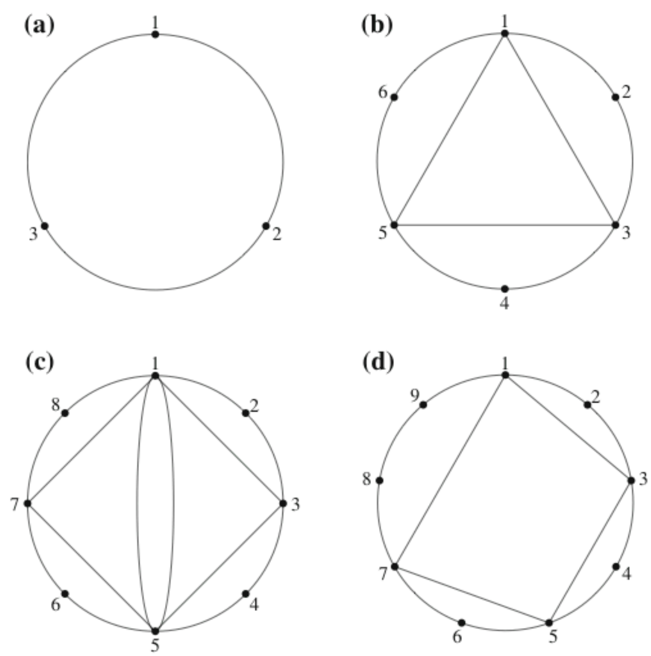
MIDI sequencers are a remarkable hybrid between music notation, recording and performance. There is no distinction between recording and notating a MIDI performance. Reading the "score" and hearing the playback are almost coextensive as well.

Appealingly intuitive though the MIDI piano roll may be, it still has some shortcomings as a music visualization system. It gives little indication as to the function of the musical events. While it is easy to see the short repeated whole-tone scale figure in the Thelonious Monk composition above, it is not so easy to grasp the broader metrical scheme without doing a great deal of meticulous counting. How might MIDI and other TUBS systems help us see the structure of the music beyond just a series of sequential events?

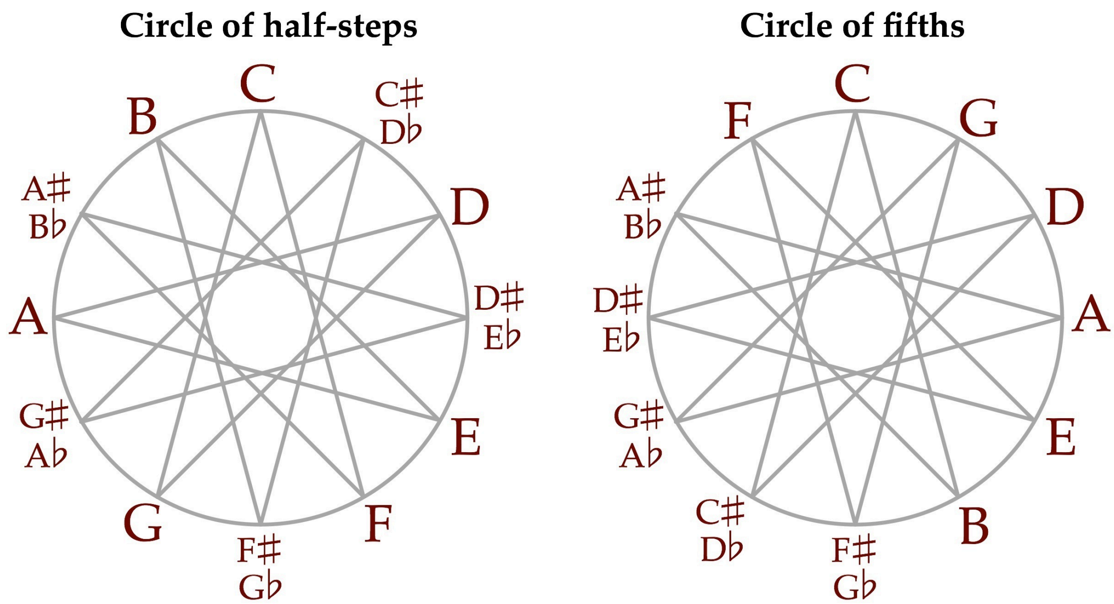
Meter relates non-adjacent musical events

Most music is organized into repeated rhythmic cycles, and cycles of cycles, and very often cycles of cycles of cycles. We make sense of these cycles using meter, "the grouping of perceived beats or pulses into equivalence classes" (Forth, Wiggin & McLean, 2010). Linear musical concepts like small-scale melodies depend mostly on relationships between adjacent events, or at least closely spaced events. But periodicity and meter depend on relationships between nonadjacent events. Linear representations of music show meter only indirectly. We must count grid lines (or implicit grid lines in standard western notation) in order to understand where in the cycle a particular event lies.

If we wrap the musical timeline into a circle, meter becomes much easier to parse. Metrically related events can be placed adjacently, and their position on the circle can represent their position within the meter. This system works especially well for repetitive, loop-oriented music. This graphic by Forth, Wiggin and McLean (2010) uses circular notation to show different subdivisions of triple meter:

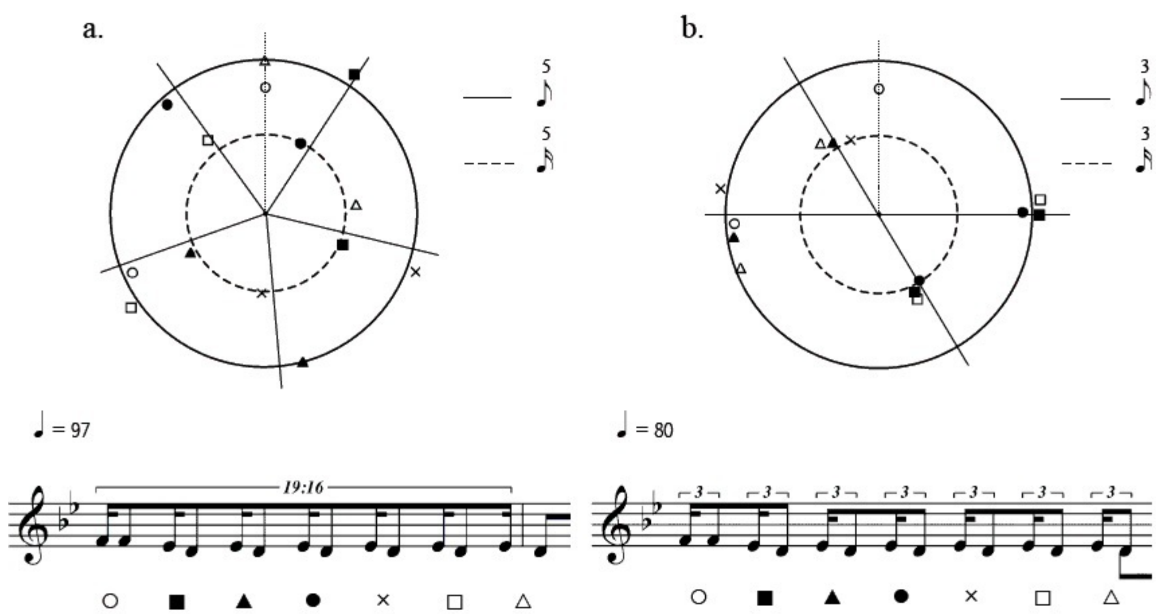


There is some precedent for circular representation of other cyclical music concepts. Pitch class is commonly represented as circular, organized either by semitones or fifths.



Representing cyclical music with a cyclical graph

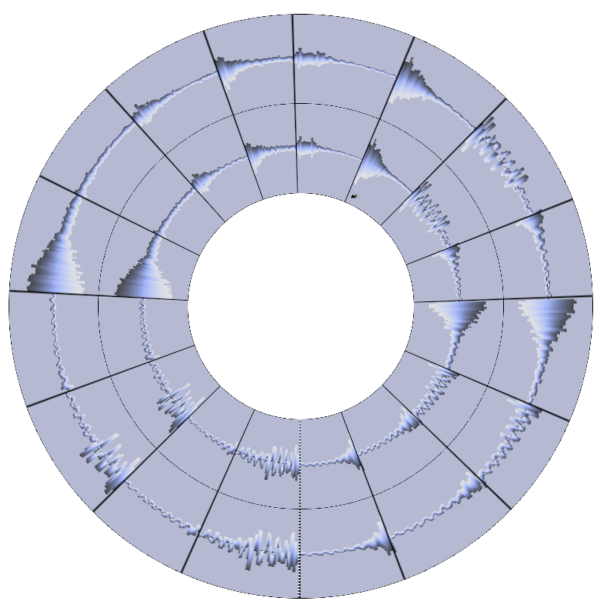
Benadon (2007) observes that a linear left-to-right orientation tends to conceal the recursive nature of beat-based patterns. He uses circular representations to describe the nuances of a performance's rhythm and pitch. For example, the graphic below represents Bubber Miley's trumpet solo on "Creole Love Call" by Duke Ellington:



There is a long historical precedent for radial depictions of rhythm. The Book of Cycles, an Arabic book about rhythm written by Safi al-Din al-Urmawi in 1252, depicts rhythms as circles divided into wedges. Shaded wedges show beat onsets, while unshaded wedges are rests (Toussaint 2004). This notation is remarkably similar to the system I arrived at independently for the Drum Loop.

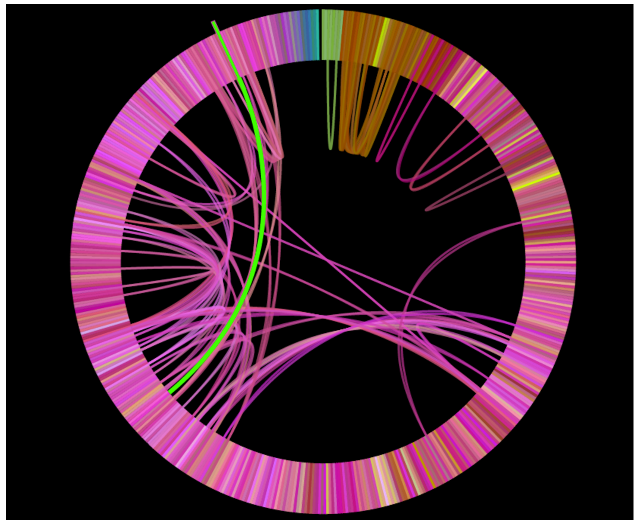
The fundamental unit of hip-hop and electronic dance music is the loop. This is nowhere more true than in the case of drums. Rhythm patterns in electronic music repeat with little to no variation throughout long passages of the music. In this idiom, a traditional linear visualization of the patterns is not the clearest representation; a circular visualization describes the music more intuitively. The Drum Loop's radial grid was inspired by circular visualizations of samples and breakbeats that I created using the Polar Coordinates filter in Adobe Photoshop. The image below shows the opening keyboard figure from Herbie Hancock's "Chameleon." The figure is repeated identically for a considerable length of time, and the circular representation feels appropriate.

The next image below is a screen capture of the loop from "The Funky Drummer (Bonus Beat Reprise)" by James Brown, loaded into Propellerhead Recycle, and given the same polar transform in Photoshop. As with the Hancock piece, the beat goes through an enormous number of identical repetitions over the course of the track, and again, the circular graphic feels like the most appropriate visualization.



While circular representation is rarely used at the level of entire songs or pieces, a few intriguing examples do exist. One such is the Infinite Jukebox by Paul Lamere (2013). The software uses the Echo Nest API to search for repeated musical elements within a song. Repeated segments are connected by colored arcs. The image below shows "Billie Jean" by Michael Jackson as visualized by the Infinite Jukebox. The software plays the song clockwise around the circle, sometimes jumping across arcs when it encounters them (as seen with the green arc below.) By seamlessly connecting repeated segments of a song, the software algorithmically creates an extended dance remix that, in theory, could go on forever.

Visualizing swing

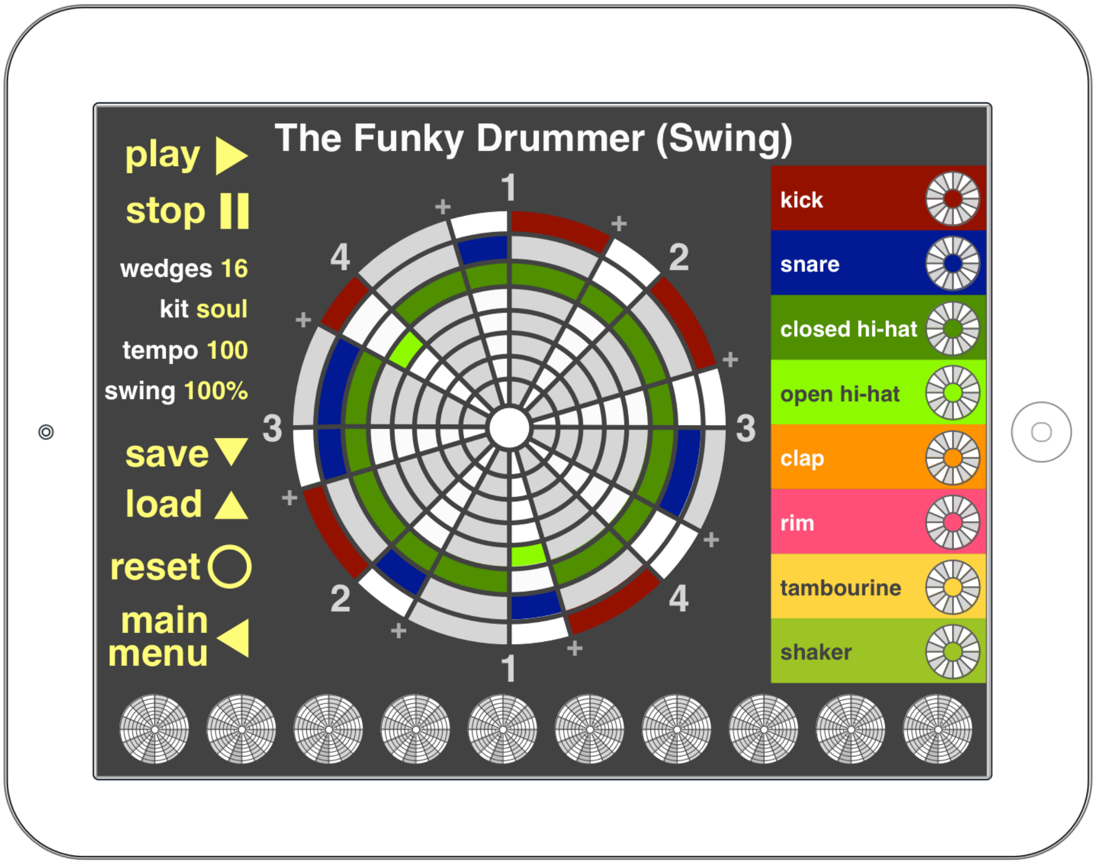


Swing is a subtle concept, not easily grasped by beginners, but it is an essential component in dance music drum programming. Drum machines typically represent swing with a knob ranging from 0% (straight eighth notes) to 100% (quarter note/eighth note triplet feel.) Some drum machines, like the Roland TR-808 and its various software emulators, refer to swing as "shuffle."

Jazz rhythms create a continual feeling of anacrusis (anticipation). Devices like the backbeat, syncopation and swing create metrical tension at multiple levels: the beat, the bar, the phrase, and the section. The continual flow of information provided by swung eighth notes draws focus to the quarter notes by perceptually grouping the shortened upbeat eighth both with its predecessor and the following on-beat. This device strengthens the tactus, making it easy to follow against the disruptive effects of the backbeat and other syncopations. Jazz musicians use rhythmic tension and release to motivate active and participatory listening (Butterfield, 2011).

Swing is rarely visualized in any explicit way. Sequencing software will sometimes show swing by displacing alternate eighth notes on the MIDI piano roll. Most drum machine interfaces do not show swing at all, except by reading a numerical value from the Shuffle knob. Swing is sometimes shown in classical music notation in exaggerated triplet form, but this is not an accurate representation. Jazz and country use more swing than any other idioms, but their practitioners do not notate swing at all; at most, they will make a terse verbal notation on the top of the lead sheet. By and large, swing is implicitly understood more than it is explicitly specified.

The Drum Loop uses a novel (and to my knowledge unprecedented) literal graphical representation of swing. The wedges alternately expand and contract in width according to the amount of swing specified. At 0% swing, the wedges are all of uniform width. At 100% swing, the first eighth note in each pair is twice as long as the second, so the first wedge is twice as wide as the second. As the user adjusts the swing slider, the wedges dynamically change their width accordingly.



Users who have difficulty understanding swing by ear can reinforce their learning visually.

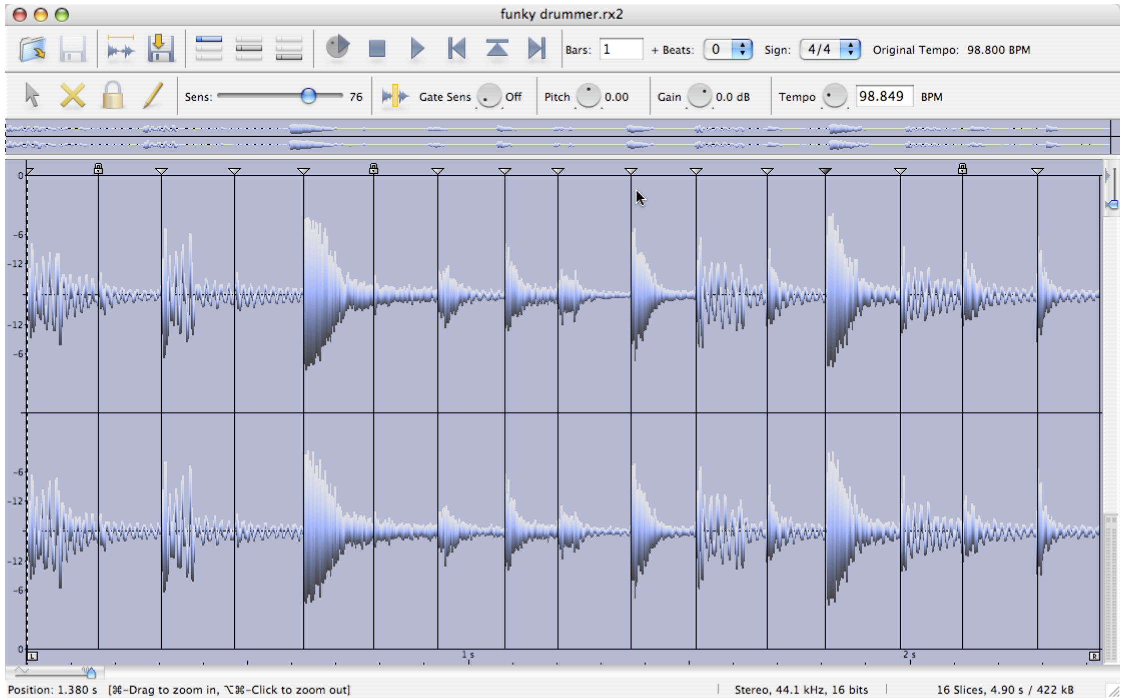
Visual metaphors for music in software

Levin (2000) lists the three most common metaphorical paradigms in music software: score displays, control panels, and “interactive widgets.”

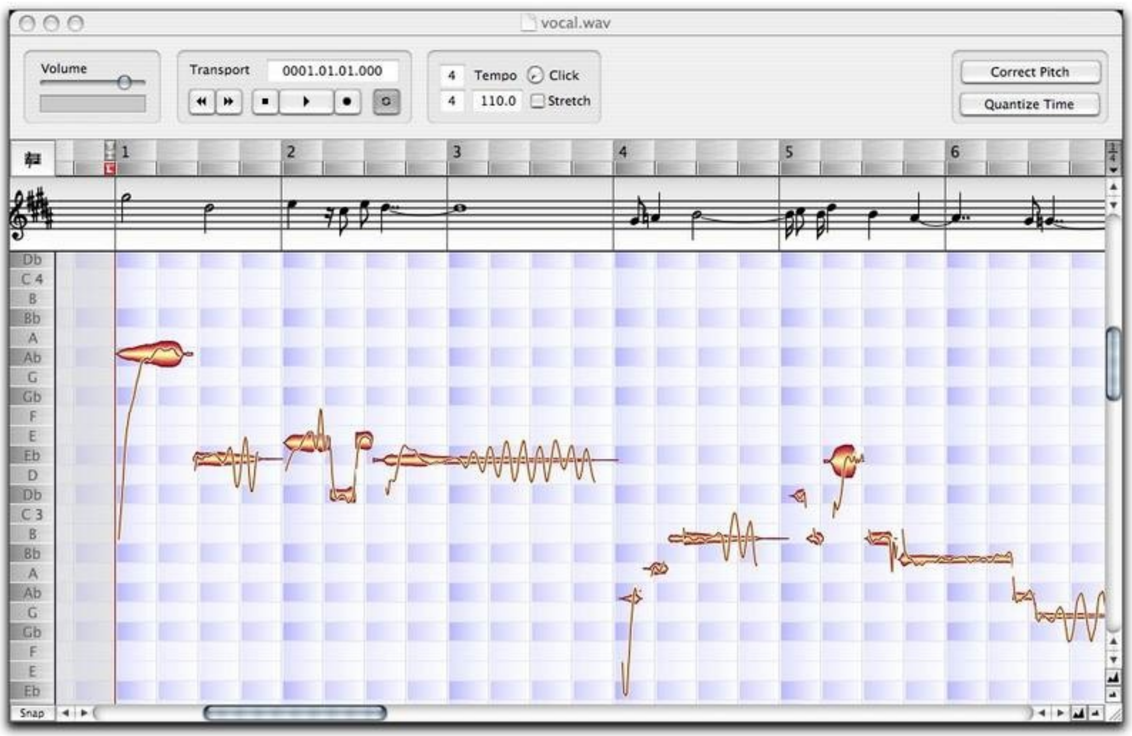
The **score metaphor** can be seen in sequencers and DAW editing windows. Sequencers and DAWs show parts or voices as stacks of horizontal bars scrolling from left to right. For example, the image below shows the Arrangement View in Ableton Live, a typical score-like representation.

The plugins at the bottom of the screen are examples of simplified control panels.

Propellerhead’s Recycle is a significantly simpler score display, showing a single audio sample shown as a stereo waveform sliced at its transient points.



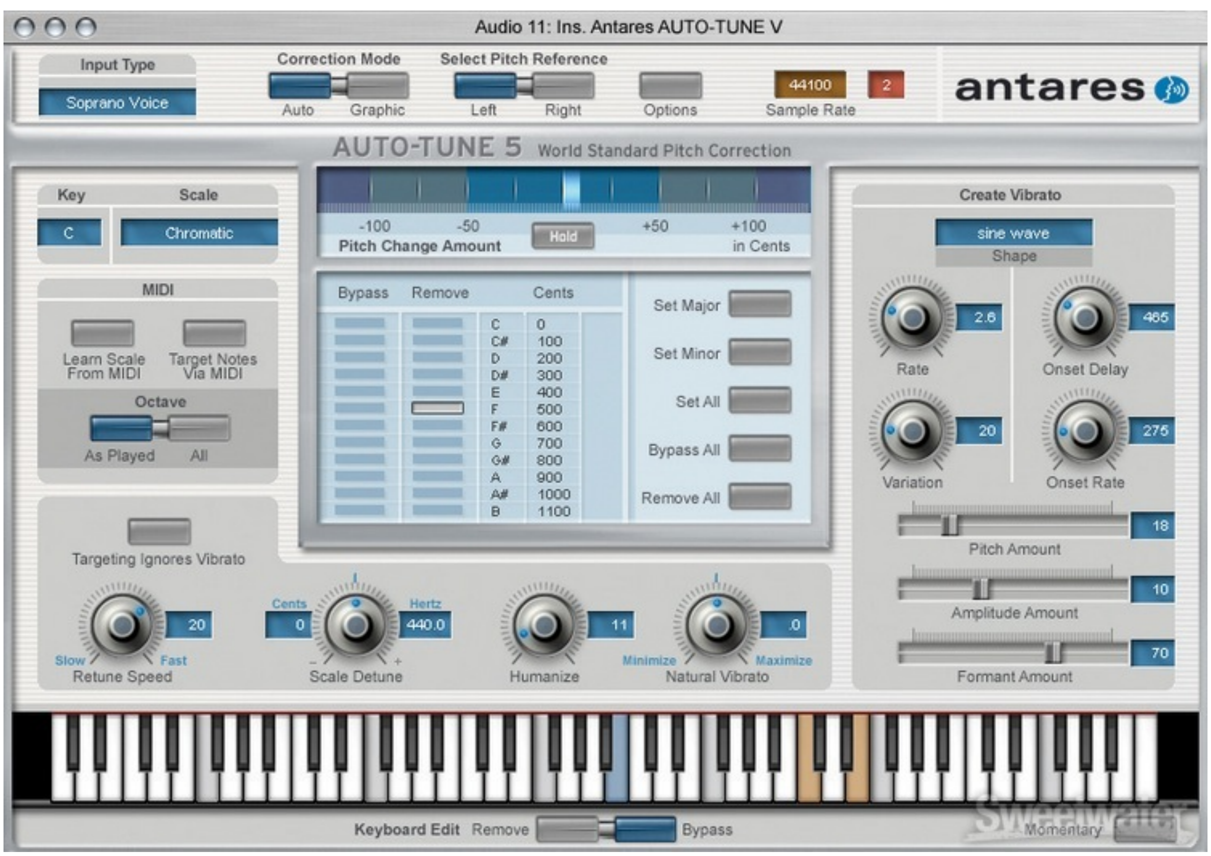
Celemony's Melodyne blends traditional notation and an audio waveform view.



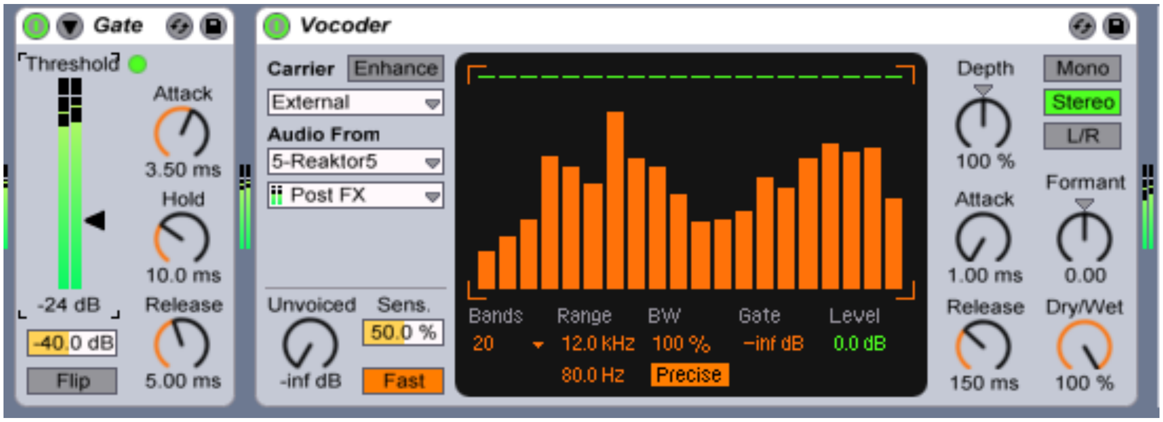
Control panel metaphors can be found in software instruments, plugins and hardware emulators. The most literally rendered control panels usually accompany software that emulates specific pieces of hardware, like Bomb Factory's BF76 compressor plugin, based on the hardware compressor of the same name.

Control panel metaphors are frequently skeuomorphic, using decorative elements meant to evoke the hardware object being simulated in software. The textured knobs and VU meter on the BF76 are examples of skeuomorphism.

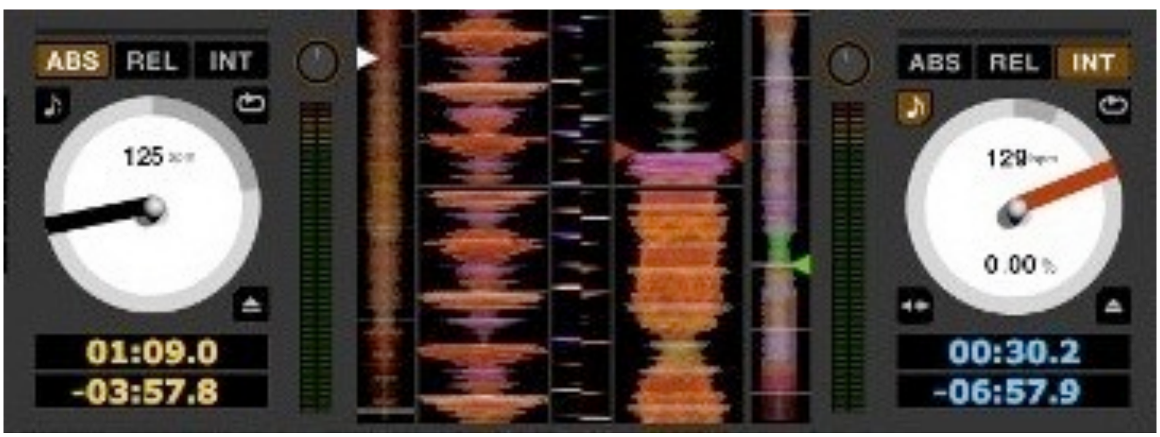
Antares' Auto-tune resembles the control panel of an analog piece of gear, even though it does not emulate any actual piece of hardware.



The least skeuomorphic control panels can be found in Ableton Live, which eliminates skeuomorphic "eye candy" in favor of geometric shapes rendered in flat colors.



DJ software like Serato uses rotating "turntables" to show the passage of musical time. The user can move forwards and backwards in time at any speed by rotating ("scratching") the turntables. This rotary metaphor is useful even to musicians who have never touched a vinyl record, by putting the cyclical nature of the music front and center. This idea will be discussed in greater depth below.



The **interactive widget model** is a catch-all for interfaces that involve the movement of semi-autonomous "objects" around the screen. The generative iOS electronic music app Nodebeat uses an elegant widget model.

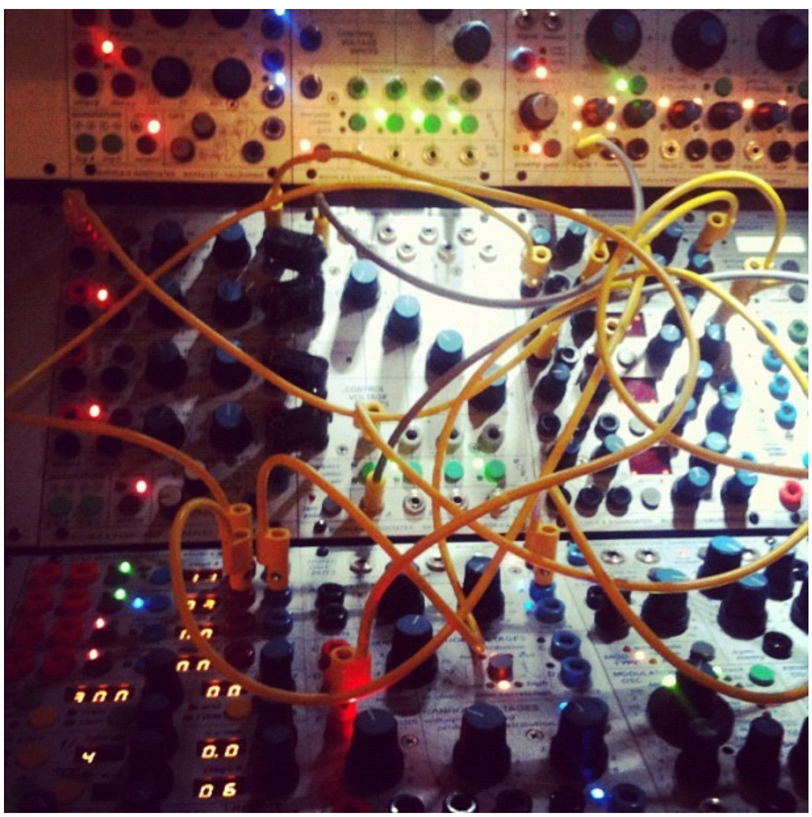
Levin's list of metaphors is by no means exhaustive. Ableton Live's Session View uses a spreadsheet metaphor to organize a collection of samples that the user can play improvisationally like the individual notes on a keyboard.

Regardless of the metaphorical scheme at work, interface designers all face the same challenge: offering users the widest possible variety of expressive techniques, but not overwhelming them with unmanageable complexity. Nodebeat sacrifices the former consideration in favor of the latter; while it is simple enough that my preschool-aged niece can express herself with it effortlessly, the range of sounds it produces are severely limited. Conversely, the possibilities within Ableton Live are effectively infinite, but novice users find it bewildering.

Liberating ourselves from the tyranny of the keyboard metaphor

The piano keyboard has dominated western conceptual understanding of music since its inception. Music notation evolved to serve the needs of the piano first and foremost, and it is implicit in all of our discussions of music theory. Software whose output is utterly un-piano-like is still likely to be controlled by MIDI, and the "piano roll" view of MIDI data preserves the keyboard metaphor intact.

Morton Subotnick (personal communication, December 2012) has struggled to find an electronic instrument interface that liberates the musician from the constraints of the keyboard metaphor. The Buchla synthesizer, for example, is controlled entirely with knobs, patch cords and other low-level electronic elements. A Buchla patch by the author is shown below.



Novel interfaces like the Buchla synth are full of possibility, but they all come with a built-in obstacle to creativity: musicians must now learn a new set of mappings from gesture to sound entirely from scratch. The past century has seen a variety of experiments in non-traditional control schemes, from the Theremin onward, but none of those schemes has found widespread use. The hegemony of the keyboard (and other acoustic instrument metaphors) remains substantially unchallenged. Software interface designers have struggled with this problem by turning to other metaphors from the physical world, as detailed in the following section.

Intuitive notation systems

Like the MIDI piano roll, music games are interactive graphical scores. They use accessible abstractions like time-unit box systems to create a symbiotic relationship between their notation systems and the corresponding sounds being triggered. The graphic below shows the TUBS system in Guitar Hero. Time progresses into the screen, like a train moving down a track (Schultz 2008).

While this notation system is necessarily simplified tremendously, it does succeed in conveying core musical concepts like metric hierarchy, subdivision, measurement and pattern identification.

Notable circular rhythm interfaces

There are few existing music software programs with circular interfaces. The following section analyzes three of the most prominent commercially available examples. It is significant that all three were released within the past year, demonstrating that this is a still largely under-explored interface paradigm.

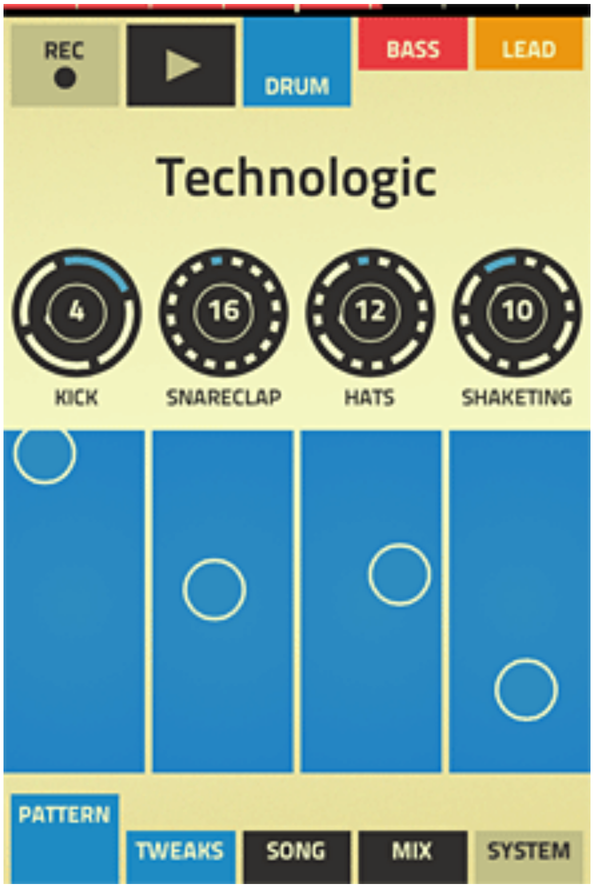
Propellerhead Figure

Propellerhead's electronic music production software represents both the worst and best of user interface design. Its flagship products, Rebirth and Reason, are heavily skeuomorphic, recreating the look of the hardware whose sound they are modeled on. Rebirth was designed to emulate the classic Roland TB-303 bass synth and the TR-808 and TR-909 drum machines, hardware popular with dance music producers. Propellerhead did an admirable job of reproducing the sound of these devices. Unfortunately, they also chose to reproduce the originals' impenetrable user interfaces. Users are forced to step-sequence drum patterns and basslines, without being able to see the entire pattern at once. This makes for a frustrating music-making experience, to say the least.

Reason is a substantial improvement on Rebirth because it includes a MIDI editor in addition to a fuller-featured step sequencer. Elsewhere, however, the interface continues to be excessively skeuomorphic. Reason is larded with nonfunctional "realistic" decoration evoking physical hardware: screws, labels, vents. The functional interface elements are modeled after the knobs and displays on rack-mounted gear. This aesthetic is attractive at first glance, but it swiftly becomes an obstacle to usage. You have to mentally struggle to distinguish functional onscreen elements from decorative ones. The skeuomorphisms occupy valuable screen space, making the usable elements smaller and harder to read. Turning fake knobs with the mouse is needlessly difficult and imprecise.

For users who started with software and have never even seen a vintage synth or analog compressor, the hardware metaphor is not helpful to begin with.

> Unfortunately, graphic synthesizers which use the control-panel schema replicate all of the undesirable aspects of multi-knob interfaces—such as their bewildering clutter, their confusing homogeneity, and their unobvious mapping from knobs to underlying sound parameters—and none of their positive aspects, such as their gratifying physical tactility, or their ability to be used by multiple hands simultaneously. Furthermore, because identical knobs are often assigned control of wholly dissimilar aspects of sound, control-panel graphics share a disadvantage with scores and diagrams: namely, that they must be "read" with the aid of a symbolic or textual key (Levin, 2000).



Propellerhead's mobile Figure app, shown in the image to the right, represents a clean break with the company's prevailing design aesthetic. It has no skeuomorphism whatsoever. The interface is comprised entirely of flat-colored polygons and large, legible text. Everything on the screen is functional; nothing is decorative. Mobile devices force minimalist design choices simply by virtue of their limited screen real estate. For this reason, mobile apps and web sites tend to be less cluttered than their desktop counterparts. Propellerhead appears to have made the limitations of mobile into a virtue.

Figure is aimed at the casual beginner, and its input methods are designed to be maximally intuitive and effortless. The interface for selecting rhythmic patterns is particularly successful. A musically meaningful pattern is pre-loaded by default. The user selects different patterns simply by swiping a finger up and down within the ring.

Most input in Figure is performed by dragging with a fingertip inside a rectangle. This paradigm works well for controlling the filters on the synths. Dragging left and right controls frequency, and dragging up and down controls resonance. The result invites playful exploration of the interplay between the two parameters. However, the rectangles are less effective for sequencing drum patterns. Drum hits fall on discrete rhythmic intervals, and it is quite difficult to hit a specific beat with the rectangles, because there is no indication as to which screen regions map to what beats.

In fairness, Propellerhead's goal with Figure is not pedagogical, and they are not trying to provide professional-level electronic music production capabilities. Interface designer Kalle Paulsson (personal communication, 2013) wanted to quickly move the user past sequencing and into the filters and effects, where most of the expressiveness of techno music lies. The clean aesthetic of Figure has been a major source of inspiration for the Drum Loop; a teaching tool with a similar look and feel would be invaluable.

O-Music O-Generator

The O-Generator aims to connect external representations of music like visualizations on the screen or standard notation to students' intuitive understanding of musical structure (Ankney, 2012).

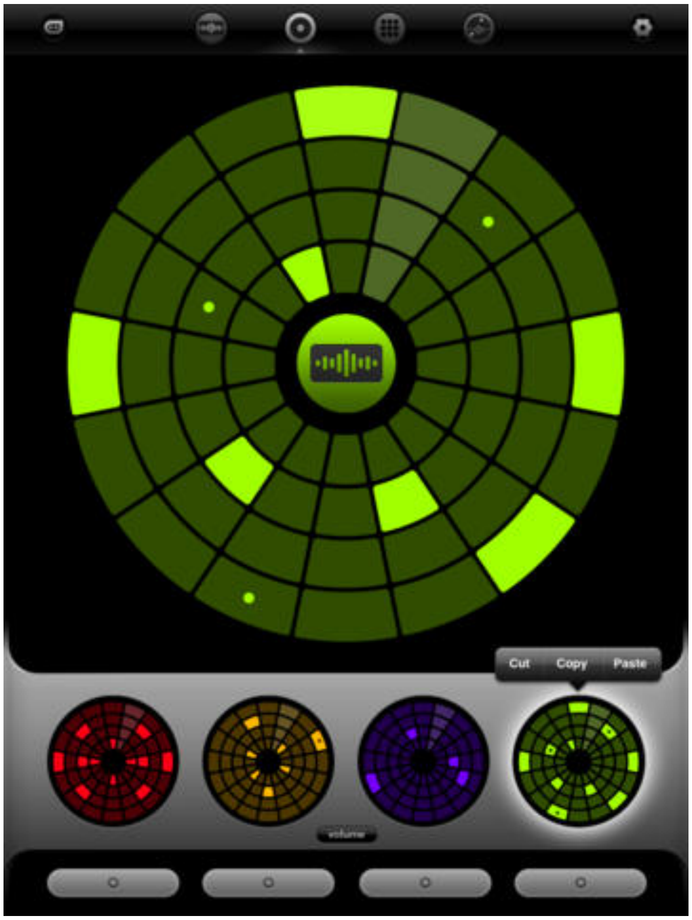
Like the Drum Loop, the O-Generator represents rhythmic events on a clock face. It uses common time, labeling both the quarter notes and sixteenth notes, though it does not quite explain what the distinction is between the two. Rather than having each ring contain an individual sound, the rings hold collections of sounds: bass and snare, or percussion, or assorted samples and sound effects. While the choice of sounds is limited, the available sounds are of good quality and are well representative of the timbres one might hear on pop radio. Each grid cell can hold one sound from a given collection, accessible from pull-down menus. Multiple loops can be sequenced to form complete phrases and songs.

The creators of O-Generator are quite explicit that the software is intended for the creation of popular dance music in 4/4 time. More specifically, "the objective is for students to compose back-up tracks to support lyrics they have written in dance music style” (Ankney, 2012). Alternative African and Latin sound collections are available for purchase separately, but none of the versions support any time signature other than 4/4. There is no way to output a track in standard notation; the software produces audio recordings only.

Users of O-Generator who wish to compose tracks using multiple loops cannot view the contents of more than one loop at a time. This is a severe shortcoming, since other programs are able to at least show simplified or miniaturized representations of the entire piece in addition to the section that is in immediate focus. For example, see the elegant solutions used in Loopseque, discussed below.

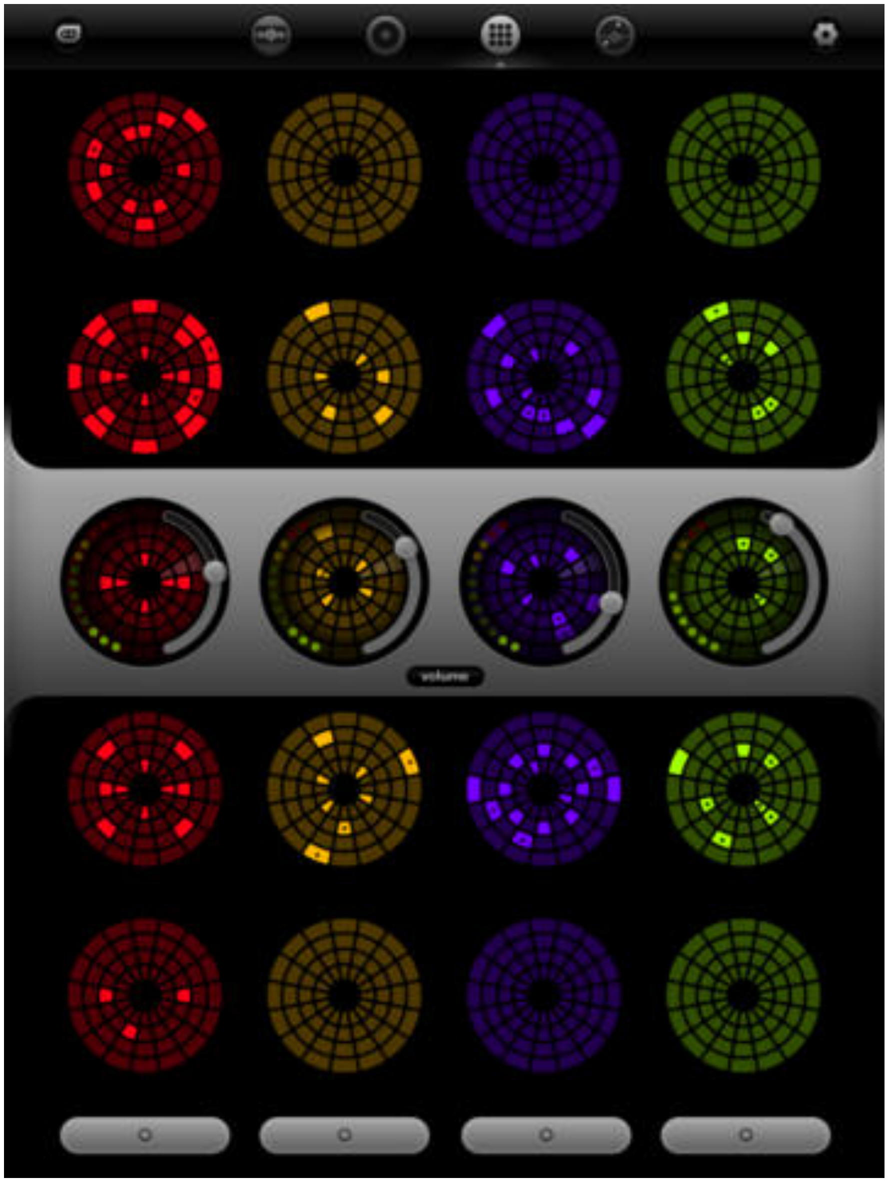
O-Generator’s developers deserve credit for attempting to include the ability to create melodies and basslines. However, the interface for doing so is awkward at best. Tapping a cell brings up an unwieldy pulldown menu of the chromatic scale spanning three octaves. Some pitches are flatted and others sharped, seemingly arbitrarily. The user receives no guidance whatsoever as to what pitches might sound good together. Perhaps the designers are expecting users to have learned music theory previously. Nevertheless, the O-Generator would be significantly more accessible if the user could select a key or mode and have the pitches from that mode be given some priority in the selection.

Casual Underground Loopseque



The strongest analogue to the Drum Loop presently on the market is Loopseque, an iPad app made by Casual Underground. The superficial similarities present themselves immediately: concentric rings divided into sixteen steps, wrapping a time-unit box system into a loop.

Loopseque handles the problem of visualizing multiple loops with considerable deftness. Four loops run simultaneously, two containing drums, two containing synthesizer patterns. My initial plan for a sequencer within the Drum Loop was to show miniature graphics of the loops lined up along the bottom of the screen. These loops would play sequentially by default, though the user could skip to a particular one by tapping it. Loopseque uses a similar paradigm, but it is more sophisticated. Instead of progressing through the sequence in a linear fashion, the loops are arranged into columns, and you can jump freely between them the way you would with clips in Ableton Live's Session View.



When a new loop is selected, the app waits to begin playing it until the current loop has completed, thus guaranteeing seamless transitions and making it impossible to produce jarring or unmusical sounds. The rhythmic “safety net” invites playful improvisation.

Loopseque has a pedagogical component in its “Master Class” mode. The lessons are enjoyable, but they do not delve very deeply into musical content. Users are given blank patterns with blinking boxes that they tap to activate. Like the Drum Loop, Loopseque introduces generic patterns in various dance music styles. However, there is no explanation as to what makes one style different from another. Text boxes pop up to explain the exercises, but they are not very illuminating, consisting of unhelpfully vague advice like “pay attention to the interaction of the bass and drums.” There is no real mention of musical terminology like strong beats and weak beats. There is some discussion of syncopation, but the text uses the words "symmetric" and "asymmetric" incorrectly in its explanations. There are no loops explicitly drawn from actual music, and the exercises have a "paint by numbers" quality, a linear structure that discourages tinkering and play

In spite of their visual similarities and beginner-friendliness, Loopseque and the Drum Loop diverge widely in their respective intended audiences. Loopseque is aimed at the casual market, would-be DJs, "non-musicians" and people seeking entertainment. To that end, perhaps to appease its investors, Casual Underground is attempting to "gamify" Loopseque. From the web site copy (http://loopseque.com/):

> Despite its apparent simplicity, Loopseque is a challenge to the musician. How fast you can change the patterns, which patterns you create, what effects you use – that's what makes the difference and determines the quality of music material… Loopseque is a game in which 'achievements' are measured by the richness of sound created by the musician on the fly, and 'high score' is the number of listeners who enjoy the music of the artist.

It makes sense for Casual Underground to build in a community aspect; they want users to keep coming back to the app, and not just toy briefly with it before forgetting it. A competitive game aspect seems a reasonable enough strategy. But does it make sense for a music tool like this? What is the win condition in Loopseque? On what basis are users competing with one another? The answer is unclear.

By contrast to Loopseque, the Drum Loop is primarily intended for the education market. It acts a music teacher, not a game. Loopseque wants to be a destination; the Drum Loop wants to be a gateway into broader musicianship.

Inspiration from the digital studio

While technology has revolutionized music production, music education has been slow to absorb the implications. Too frequently, computers in music classrooms are used as a more expensive platform for the same teaching materials that were formerly delivered on paper and the blackboard. Ruthmann (2012) criticizes bad technologically-mediated classroom tasks as being "information technology tasks applied in the context of learning about music, rather than engaging students directly in making, creating and responding to sound and music." For example, while having students research a composer on the internet is more expedient than doing so in the library, it is not profoundly different.

Teachers should find ways to leverage technology in support of active, social music making—*doing* music, rather than simply learning *about* music. However, getting students to do music can be easier said than done.

> Many traditional music and non-music software programs (e.g., notation, sequencing, looping, audio editing, word processing) are based on the metaphor of a blank canvas or void. When the program is launched the user is presented with a blank slate upon which to place notes, audio waveforms, images or words. For many students, it can be intimidating starting from scratch. In my own teaching I have seen many students who have been reluctant to add their first notes to the page, sometimes wondering if they have anything of value to say. Of course they do have something valuable to say, but starting from scratch is not always the best place for them to begin (Ruthmann, 2012).

One way to avert the terror of a blank slate is to use pre-existing materials, e.g., GarageBand loops. Rather than the usual process of having students place loops in a blank project, Ruthmann suggests making a game of a subtractive process. Students can be given a dense collage of loops, a "sound block," which they must transform into a new work by slicing and subtracting pieces only.

Studio as instrument, not documentation tool

As the cost of digital recording equipment falls within the reach of more schools, new teaching opportunities present themselves. Thibeault (2011) urges music teachers to think of the studio not just as a means of documenting "real" performances, but as a musical instrument in its own right, carrying with it an entire philosophy of music-making. The digital studio collapses composition, recording and editing into a single act. To meaningfully participate in the musical world, students must become familiar with the studio's particular demands and affordances. For example, the studio expands the definition of the word "musician" beyond traditional performers and composers to include anyone with the patience and the will to learn the software and explore its possibilities.

Within the context of interactive video game soundtracks and rhythm games, Herber (2008) argues that the traditional distinction between composition and performance is less meaningful than in traditional instrumental settings. The same is true for digital music production environments. When software is used both for conceptualizing ideas and realizing them, it erodes the creative distinction between the two acts. Herber focuses primarily on generative music like Terry Riley's In C, where the composer's role is to facilitate emergent and participatory interactive experiences. However, he might also have noted that prosaic dance music production software similarly gives the user the simultaneous experience of composer, performer and audience.

Dance music producers have a bad reputation in the broader music world. There is a widespread sense that simply playing loops and samples created by other people is not legitimate musicianship, that it is "just pushing buttons." This attitude is unfortunate, because dance musicians have a great deal to offer other musicians and composers. DJs and producers are looking for samples, loop points, sections—they are extracting the cyclical content from the linear auditory stream. The most important skill we can learn from dance musicians is to be able to listen closely at several different levels of detail: to songs, to phrases, and to individual beats or hits (Thompson, 2012). Rather than listening to recordings as complete and inviolable, dance music producers listen for the ways that the recordings could be altered, customized, or combined with other recordings. In other words, dance musicians treat recordings as the raw material, not simply the finished product.

Informal education in the home studio

In music pedagogical circles, the terms "popular musicians" and "informally trained musicians" are used interchangeably. While the situation is more complex than this casual linguistic equation would suggest, it is true that when it comes to education, popular musicians are substantially on their own.

> For nearly a century, formal music education has turned its back upon the learning practices of the musicians who produce most of the music that comes out of loudspeakers. But perhaps by constructively embracing those same technological developments which many people consider to have alienated music-making, and noticing how they are used as one of the main means of self-education for popular musicians, we can find one key to the re-invigoration of music-making in general (Bell, 2013).

For the first several decades of recording, the music was composed in its entirety before recording began. While some adjustments were made in the studio, composition and production were almost completely separate processes. In contemporary pop music practice, however, composition, arrangement, and recording are a single intertwined process. Popular musicians can hear sounds in a near-finished form and react to them, continually readjusting their approach as the track develops. In hip-hop and dance music in particular, there may be no plan whatsoever before the production process begins.

Music education has tended to treat composition and audio engineering as separate practices, but in the case of the solo bedroom producer, the distinction is no longer meaningful. There is precious little in the way of formal education for such musicians. In this context, software presets and default sounds become a critical educational resource. Bedroom producers may learn everything they know about EQ or reverb simply by scrolling through the built-in settings in their plugins. As Bell (2013) puts it, "purchasers of computers are purchasers of an education." How good an education are we buying? How could it be better?

Software as an active participant in the creative process

Electronic musicians tend to begin their work by playfully experimenting with a piece of equipment or software, a period of open-ended "knob-twiddling." The discoveries made during this period, particularly those not intended by the musician or the software's designers, are crucial raw materials for the more formal composition and editing that follows. One subject interviewed by Gelineck and Serafin (2009) described his tools as "having a life of their own."

Marrington (2011) draws a contrast between the computer as a musical tool and the computer as a musical medium. We use computers as musical tools when they make composition or recording easier or faster, in the service of realizing music that lives in the "real" world. An example of the computer as tool is a composer writing a string quartet with Sibelius, rather than with pencil and paper. By contrast, when we use the computer as a medium, it enables musical practices that would be impossible or inconceivable otherwise. An example of the computer as medium is a dance music producer manipulating an audio sample with Ableton Live.

It is not only the end result that is different when working with the computer as medium; a software tool's visualization system can change our entire conceptual imagining of music. Marrington observes that all DAWs enable the user to zoom in and out to view the music at any resolution. At one extreme, we can manipulate fragments less than a millisecond long; at the other, we can view the entire piece compressed to fit into a single screen. We can manipulate blocks of audio and MIDI of any arbitrary length, treating them as "things" rather than sequences of events. Rather than solely experiencing music as unfolding in time, we can also conceive it a group of objects in visual space.

Wise, Greenwood and Davis (2011) describe the way that students use Sibelius as a medium rather than a tool. Like all notation software, Sibelius is effectively a specialized MIDI sequencer, and younger students are likely to regard scores they create with it to be the finished product rather than an intermediate stage culminating in live performance. The software enables its users to create wildly complex patterns, copied and pasted into dense ostinati and played back on improbable instrument combinations.

Copy and paste is a forbiddingly tedious compositional strategy on paper, but it is so effortless on the computer as to constitute the de facto norm. Furthermore, software encourages naive and untrained experimentation in a way that paper-based composition does not. Formal theory need not be a prerequisite to such exploration, since students receive immediate auditory feedback of their every move and quickly discover on their own what works and what does not. The distinction between tool and medium may not even be a meaningful one when applied to music software.

Pedagogical goals of the Drum Loop

The Drum Loop aims to teach beginners with no drumming experience, or musical experience of any kind, to program beats in a variety of pop, dance and Afro-Cuban styles. The patterns that users learn with the Drum Loop can be used across a variety of drum machines and software—Pro Tools, Logic, Ableton Live, Garageband and the like. Patterns learned by ear (and eye) with the Drum Loop will also be easier to learn on physical drums and percussion instruments.

Users of the Drum Loop will practice connecting the experience of hearing beats to seeing corresponding visual patterns. The app thereby scaffolds the learning of the rhythmic axis of traditional music notation. The Drum Loop will be hopefully be of particular value to those students who suffer from dyslexia and other challenges to music reading. By connecting accurately-played authentic rhythms to a dynamically interactive notation system, the Drum Loop should lower the barrier to entry for more technically demanding musical skills and concepts.

More broadly, prolonged attention to the Drum Loop's included beats, and those created by users themselves, result in a great deal of practice of analytical listening and musical timekeeping. Users can experience for themselves which specific arrangements of rhythmic patterns and timbres create a satisfying groove after many repetitions, and which are unmusical or unsatisfying.

Target audience

The target audience for the Drum Loop is high school students. It is my hope that the app's simplicity also makes it accessible to younger children, and that its depth offers the opportunity for meaningful creative engagement by adult beginners. While the Drum Loop presumes no musical knowledge or experience of any kind, it may still be of some value to intermediate musicians, especially those without a background in drumming, percussion or dance music production.

Rhythm appreciation

Rhythm is much neglected in music education, unless you study drums or percussion specifically. Western musical pedagogy devotes enormous attention to harmony, but gives only the most cursory consideration to rhythm. There is a shortage of opportunity for students to consider the aesthetic and emotional meaning of rhythm, beyond simply the ability to follow and execute it correctly. For example, Temperley (2010) posits syncopation as a kind "rhythmic dissonance." The rhythms of common-practice classical music are organized hierarchically, with notes on weak beats conditional on the adjacent strong beat notes. Syncopation is the violation of this hierarchy, making weak beats more salient than strong beats.

All music contains structures of rhythmic tension and resolution as rich with metaphorical meaning as their harmonic equivalents. Indeed, the rhythmic structures of music can be considered to be more fundamental. A great deal of world music lacks triadic harmony, and is largely or entirely unpitched. By contrast, it is difficult to find music without any rhythmic structure. (I would debate whether completely rhythm-less music is even possible.)

The Drum Loop relates rhythmic dissonance to "angular dissonance." The strongest beats fall on the largest subdivisions of the circle: 180 degrees, then 90 and 270 degrees, then 45, 135, 225 and 315 degrees. The weakest beats fall on the smallest subdivision of the circle. For a sixteen-step pattern, those are 22.5 degrees, 67.5 degrees, 112.5 degrees, and so on. Students with no ear for rhythm whatsoever may nevertheless find the visual equivalent to be quite intuitive, with a sense that the cardinal angles are more "basic" somehow than oblique angles. Through extended exposure, such students should be able to translate their visual intuition into musical intuition.

The backbeat

The common feature of nearly all western dance music is the accented backbeat. A backbeat rhythm places percussive accents on the "back" half of the phrase, as opposed to the more metrically salient front half. In 4/4 time, the backbeats are beats two and four. Alternatively, in cut time, the backbeat is the third beat of each measure. The snare drum most commonly carries the backbeat, but it can be accented by any instrument. In early twentieth century American music, accented backbeats were quite common, but the term "backbeat" itself did not enter widespread use until the early 1950s (Baur, 2012). The backbeat originated in Dixieland jazz, country and gospel, and it became a defining characteristic of rock, funk, R&B and hip-hop. The backbeat and its associated music styles have been considered throughout their history to be disreputable, low-class, primitive and barbaric, even threatening to undermine the moral fabric of society entirely. This is unsurprising, given the backbeat's origins in marginalized groups: African-Americans, rural whites and immigrants.

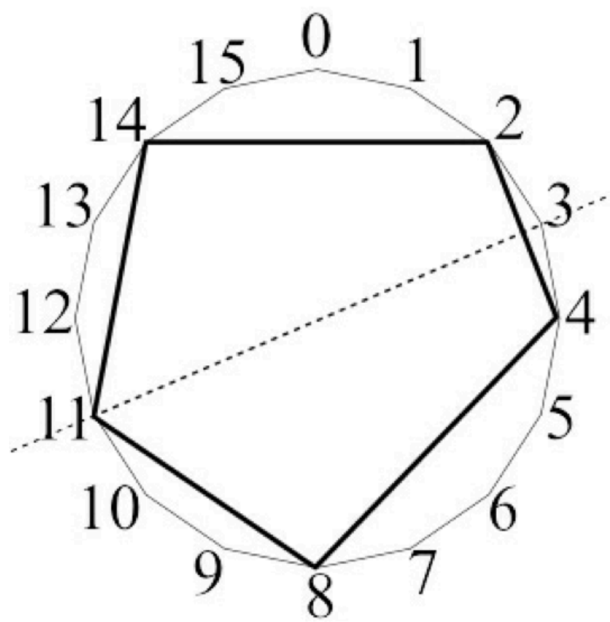
The backbeat arose independently from early jazz banjo and piano, climactic embellishments in "Chicago-style" jazz drumming, New Orleans processional drumming, handclaps and tambourine hits in sanctified gospel music, staccato guitar and mandolin accompaniment in country music, and slap bass techniques in both country and jazz (Tamlyn, 1998). The backbeat gradually expanded its role over the course of the twentieth century from an accent or embellishment to a foundational rhythmic gesture.

Why is the backbeat so compelling? Why has it come to dominate global popular music? The answer may be its balance between surprise and predictability. The backbeat is a form of syncopation, but it is the least destabilizing form of syncopation. We can define metric salience as the number of equally sized subdivisions of the musical pattern it takes to reach a given position. The more subdivisions it takes to reach a given event, the lower its metrical salience. The downbeat is the most salient position, while the backbeat is the second most salient. We understand syncopated patterns better when the syncopations happen in more metrically salient positions (Ladinig, Honing, Háaden & Winkler, 2009). The backbeat is syncopated enough to be interesting, while still being metrically salient enough to be understood.

Nearly all of the patterns included in the Drum Loop's exercises use a backbeat. Users will quickly come to appreciate how fundamental the snare hits on the east and west of each pattern are to creating the groove so familiar from the music around them.

Visualizing evenness and modularity

Why are traditional rhythms like clave patterns so compelling even after a great many repetitions? Perhaps we are reacting to symmetries that are challenging to detect on a one-dimensional timeline, but that are readily apparent on a two-dimensional circle. For example, this illustration of 2-3 son clave by Barth (2011) shows an axis of reflective symmetry between the fourth and twelfth beats of the pattern. This symmetry is considerably less obvious when viewed in more conventional notation. We may be responding to these symmetries without being able to easily parse them completely, which sustains our attention across long timescales.



Traditional rhythms have a tendency toward "evenness," a relatively equal distribution of beats across different regions of the metrical unit. This makes sense from an attentional standpoint; excessively long intervals of silence make us lose the thread of the beat, and undermine its "drive" (Toussaint, 2013). The most sophisticated rhythmic cultures use beats that are even, but not perfectly symmetrical. The drumming practices of Africa and the Caribbean balance a steadily predictable beat with destabilizing syncopation, to hold the listener's interest without confounding the sense of groove.

Claves often hold our attention by means of a rhythmic call-and-response structure. The first part of the pattern poses a "question" by creating rhythmic tension (syncopation), and the second part answers the question by releasing tension. The 3-2 form of son clave creates tension in its first half with three onsets spaced three pulses apart, in conflict with the underlying duple meter. The second half has two onsets spaced two pulses apart, with the second on the relatively strong backbeat.

> [I]n the most interesting rhythms with k onsets and timespan n, k and n are relatively prime (have no common divisor larger than 1). This property is natural because the rhythmic contradiction is easier to obtain if the onsets do not coincide with the strong beats of the meter (Demaine, Gomez-Martin, Meijer, Rappaport, Taslakian, Toussaint, Winograd & Wood, 2009).

Traditional rhythms also make use of modularity, rotating groupings of beats around the circle like beads on a necklace. The three-against-two hemiola common to Afro-Cuban patterns is easy to conceptualize once viewed on a circular graph; one simply skips around the circle in increments of three. This is quite similar to the way that we can use the circle of half steps or the circle of fifths to understand harmonic relationships and transpositions.

A planned feature of the Drum Loop will multitouch gestures to give users access to the expressive possibilities of rhythmic modularity. By twisting a ring with three fingers, the user will be able to rotate the drum hits in that ring any number of units earlier or later, during playback if they so choose. Rhythmic transformations that would normally require very sophisticated music-reading and performance skills to understand and execute will thereby be effortlessly accessible to beginners.

Teaching computational thinking

One could consider written music to be a method for "programming" human musicians. The analogy between programming and music composition becomes more direct when the musician is a computer. Drum and synthesizer programming makes the connection literal. A key concept in programming is that a particular activity or task is expressed as a series of individual steps or instructions that can be executed by the computer. Like a recipe, a sequence of programming instructions specifies the behavior or action that should be produced. In music, the behaviors and actions are notes and drum hits. The composer must specify various parameters for these events: when should they happen? What should be their pitches and durations? What sounds should they produce? What timbres should those sounds possess?

Music composition involves the computational concept of control flow. Loops are a fundamental organizing principle in both programming and music, particularly in dance music. Both domains make extensive use of the recursive nesting of loops within loops. The musical command "repeat until cue" is an exact parallel to the while loop.

Composers and programmers alike benefit from the ability to modularize and re-use units of code.

Beyond computational concepts, music also opens doors into the broader social context in which programmers operate. Building on other the work of others has been a longstanding practice in programming (Brennan & Resnick, 2012). It makes little sense to write commonplace code like sorting algorithms, database structures or device drivers from scratch when you have easy access to open source examples via the internet. The open-source ethic of programmers enables them to develop much more complex software than would be possible if everyone worked in complete isolation. Musicians similarly benefit from a culture of re-use and remixing, though we usually do not think in those terms explicitly. Why work through every possible note or chord combination by trial and error when you can use a standard scale, motif or chord progression?

Both in programming and music, reusing and remixing require critical code-reading capacities, and they provoke difficult questions about ownership and authorship. When is it reasonable to borrow from others? What constitutes appropriate credit and attribution? How should teachers assess cooperative and collaborative work? Is originality the chief virtue, or is the result the only important basis for judgment?

Students who learn through creative undertakings face a psychological obstacle around the notion of failure. In traditional schooling, being wrong is shameful. But programmers almost never get it right the first time. They fail, and iterate, and fail differently, and then iterate some more. A program is never totally finished; there is always another bug to chase down, another feature to implement, something that could be executed more elegantly. This is why the software we use every day is constantly being updated. A strong parallel exists with music. It is a truism among musicians that a piece is never finished; you simply stop working on it. The iterative nature of creative practice like programming and music can be at odds with the success/failure binary that predominates in schooling, as we will explore in the following section.

Creating a beginner-friendly environment

The electronic musician Tor Bruce (personal communication, February 10, 2013) offers an excellent set of criteria for a beginner-oriented music application:

> If someone who doesn't know the first thing about music, and never used the software before, sits down and tries it out for a couple of minutes, will they be able to make something that sounds like music? Or will the output just be random sounds, without even the most basic harmony or rhythm in place? Is this an app for making music, or just an app for making sounds (from which you can make music, if you already know how music is made)?

When studying an instrument, it can be weeks, months or even years before it is possible to produce a satisfyingly musical sound. Software is easier than acoustic instruments, but beginners can still be easily discouraged by the difficulty of producing something that sounds good. The Drum Loop imposes some limitations on the user that are designed to make it impossible to produce totally unmusical sounds. By giving the user “freedom from choice,” users are not overwhelmed with a rush of new concepts.

Avoiding skeuomorphism

There is a widespread tendency in musical interface designers toward skeuomorphism, the practice of retaining ornaments and metaphors from older technology that were necessary in the original, but are unnecessary in simulation. Graphical representations of “realistic” hardware like mixers, rack-mounted effects processors, amplifiers and so on are ubiquitous in music software. These visual cues are informative and helpful if the user is familiar with the original equipment. However, for a great many users, the software is their first experience of any kind of music production tool. They must learn hardware interfaces by clumsily manipulating onscreen graphics

The Drum Loop eschews skeuomorphism. Its visual vocabulary consists entirely of flat-colored geometric shapes and text. The graphics refer to no other experience except the Drum Loop itself. In addition to the lack of distracting or misleading visual metaphors, the flat design has the added virtue of being attractive in its own right, drawing the user in.

Enforcing 4/4 time

Nearly all electronic dance music is in 4/4 time. Very occasionally, one may encounter triple meter or more complex time signatures. The Drum Loop could easily be programmed to support any arbitrary time signature simply by changing the number of wedges. But it was decided that the user should be limited to time signatures that are idiomatic to dance music. The Max prototype allowed the user to select between loops of eight, twelve, sixteen or thirty-two steps in length. However, for the sake of simplicity, the iOS app is limited to eight or sixteen step patterns only. Perhaps a future version will offer "advanced mode" in which the user can select any number of steps.

Common time and cut time

Even when we are confined to 4/4, the tactus (the perceived underlying pulse) is a matter of some confusion. Martens (2011) demonstrates how tactus choices are ambiguous between individuals and within musical excerpts, demonstrating that they do not have a straightforward basis in tempo. Untrained listeners search for the tactus in surface features of the music, but if they do not detect a consistent pulse there, they will seek it at the next metrical level up. A single individual can hear the same piece of music as possessing a different tactus on different listenings.

Given the inherent ambiguity in the definition of a beat, labeling the steps in a time-unit box system poses a challenge. Should each step be an eighth note? A sixteenth note? A thirty-second note? Common 4/4 time uses a sixteenth-note pulse, placing snare backbeats on beats two and four. However, many musicians dislike having to read sixteenth notes, and prefer to use cut time. The pulse is counted twice as fast, so the snare backbeat is the third beat of each measure. In my experience, formally trained musicians tend to prefer common time, while informally trained musicians (like myself) tend to prefer cut time. For beginners, the distinction between the two is a major source of confusion.

The Roland TR-808 drum machine evades the common versus cut time issue by simply labeling the steps in the drum pattern one through sixteen. Users can choose to interpret those numbers how they see fit. One must simply learn that snare hits go on steps five and thirteen. The steps are grouped by color into sets of four, which helps visualize the metrical scheme, but it is far from a user-friendly system. Most software drum machine interfaces use a variation on the TR-808 paradigm.

The Drum Loop allows the user to choose between common time (each wedge is a sixteenth note) and cut time (each wedge is an eighth note.) The grid looks the same either way; only the labeling of the wedges changes. Rather than having to count steps, users can use visual cues to conceptualize the metrical scheme. Snare backbeats fall on right and left, or three o'clock and nine o'clock, or east and west, however you prefer to think. Beginners do not need to worry about the nomenclature; they can focus on the broader concept of time being subdivided equally. Users may toggle the common/cut time switch out of curiosity, which presents an opportunity for self-directed learning.

Sounds and drum kits

The number of sounds in each Drum Loop kit is limited by the spatial constraints of the user interface. It is practical to include at most eight sounds in a given kit; otherwise the grid rings become too narrow to be easily read and written to.

All kits have the same four basic sounds: kick, snare, and closed and open hi-hat. Many dance beats require no sounds beyond these four. Each kit also has four more ornamental sounds: clap, rim shot, ride cymbal, bells, congas, tambourine and so on. Due to onscreen space limitations, the Max prototype was only able to accommodate six sounds per kit, a significant limitation of the ring spacing scheme (see below.) In theory, using the current layout, any number of sounds could be included, but eight represents a reasonable compromise between variety and simplicity.

The initial three drum kits were acoustic, hip-hop and techno. All three were sampled from Ableton Live for expediency. The acoustic kit uses one of Ableton's rock drum kits; the hip-hop kit consists of Roland TR-808 samples; and the techno kit uses Roland TR-909. (If I release the Drum Loop commercially, I will need to create my own samples.) The problem is that these three kits were insufficient for all of the patterns I wished to include, especially the Afro-Cuban ones. So several more specialized kits needed to be developed to accommodate the different needed combinations of percussion sounds. Specific patterns are associated with certain kits by default, although the user is welcome to change them.

I struggled to find a set of eight drum sounds that could accommodate the stylistic range of the lessons. One possible solution would have been to use different drum instruments in the three kits, giving a possible twenty-four different sounds total. Practically, though, fewer drum sounds were possible because all kits needed to have basic sounds in common. The problem was that if, say, the cowbells were included in the Acoustic kit and the congas in the Techno kit, there would be no way to use those sounds in the techno and acoustic timbres respectively.

The ultimate solution was to expand the list of drum kits to have six different kits comprised of a total fourteen drum and percussion instruments: kick drum, snare drum, closed hi-hat, open hi-hat, handclap, rim shot, tambourine, shaker, ride cymbal, crash cymbal, high conga, low conga, high cowbell and low cowbell. All kits include kick, snare, and closed and open hi-hat. Each kit has four additional more specialized sounds, as follows:

- Soul kit: clap, rim, tambourine, shaker
- Rock kit: clap, rim, ride, crash
- Conga kit: rim, ride, high conga, low conga
- Bell kit: rim, ride, high bell, low bell

The Hip-Hop and Techno kits use the same set of instruments as the Soul kit. However, rather than using the Soul kit's acoustic samples, the Hip-Hop and Techno kits contain equivalent instruments sampled from drum machines.

A wider variety of sounds would present a wider variety of sonic choices. However, placing strict limits on the sounds available has its own creative advantage. It eliminates option paralysis and forces users to concentrate on creating interesting patterns rather than struggling to choose from a long list of sounds.

Tone, velocity and effects

In the current version, the Drum Loop does not offer any tone controls like duration, pitch, EQ and the like. This choice was due to a combination of expediency and the push to reduce option paralysis. However, velocity (loudness) control is a high-priority future feature. While nuanced velocity control is not necessary for the artificial aesthetic of electronic dance music, a basic loud/medium/soft toggle would make the Drum Loop a more useful production tool. For example, the "Ashley's Roachclip" break has a tambourine hit on every sixteenth note. When these hits played at a uniform velocity throughout, the result is exceptionally awkward; the pattern only sounds musical when each alternate hit is softer. The planned user interface design for velocity is to default all drum hits to medium. Users can then swipe upwards or downwards on a filled cell to toggle the velocity to loud or soft respectively. Velocity will be indicated with greater color saturation for loud and less color saturation for soft.

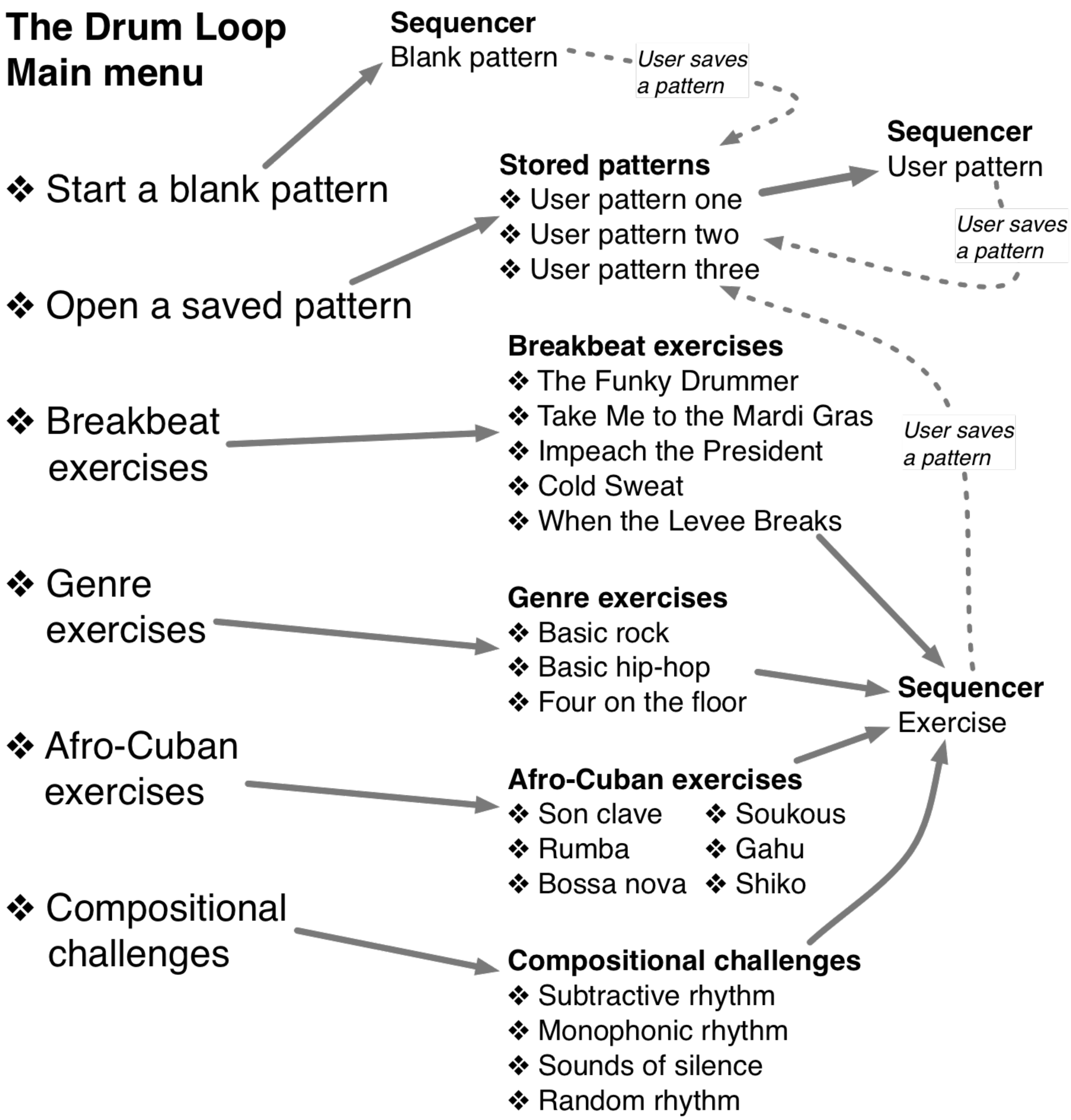
Color and typography

The goal with the color scheme is to make user interface elements maximally distinguishable, while still using an economy of colors, re-using wherever possible. Initial versions of the design, including the Max/MSP prototype, used a white background. This choice makes sense on a desktop or laptop screen, but is less satisfying on an iPad. Many iOS music apps use dark or black backgrounds, including GarageBand, O-Generator, Loopseque and (to a lesser extent) Figure. The dark background forced the use of light-colored text, the brighter the better for legibility.

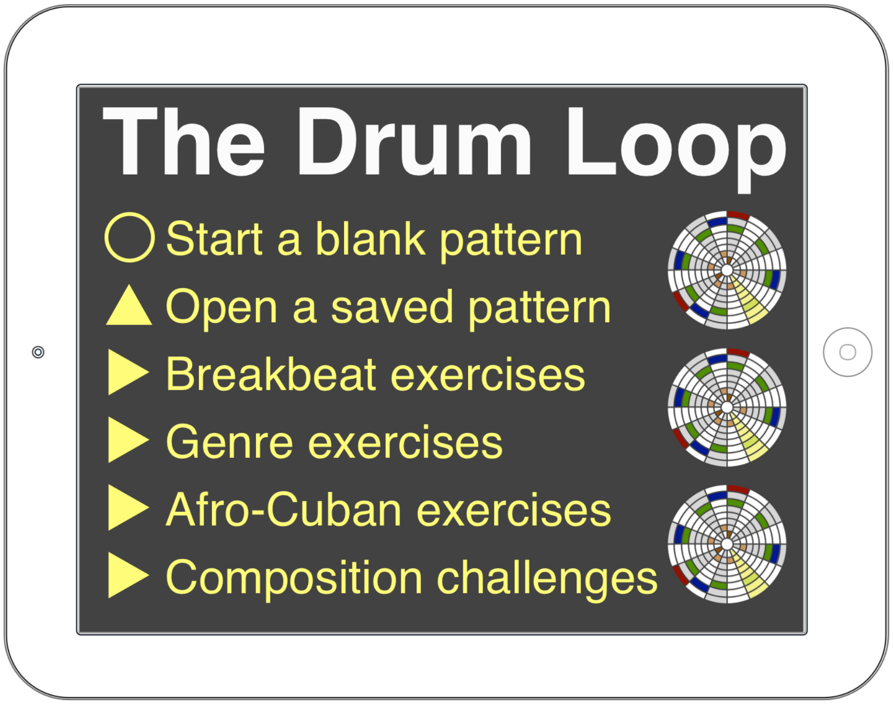
Nearly all text is Helvetica Bold, though text boxes and menu options are regular Helvetica for ease of legibility.

Menu structure

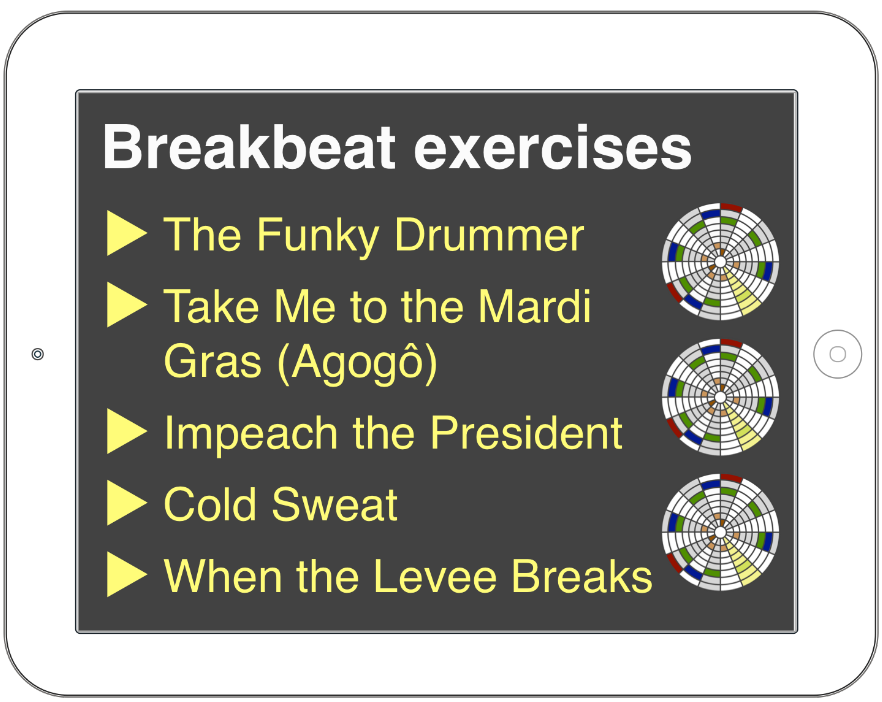
The menu structure is diagrammed below.


The Drum Loop
Main menu
❖ Start a blank pattern
❖ Open a saved pattern
❖ Breakbeat exercises
❖ Genre exercises
❖ Afro-Cuban exercises
❖ Compositional challenges
Sequencer
Blank pattern
User saves a pattern
Stored patterns
❖ User pattern one
❖ User pattern two
❖ User pattern three
Sequencer
User pattern
User saves a pattern
Breakbeat exercises
❖ The Funky Drummer
❖ Take Me to the Mardi Gras
❖ Impeach the President
❖ Cold Sweat
❖ When the Levee Breaks
User saves a pattern
Genre exercises
❖ Basic rock
❖ Basic hip-hop
❖ Four on the floor
Sequencer
Exercise
Afro-Cuban exercises
❖ Son clave
❖ Soukous
❖ Rumba
❖ Gahu
❖ Bossa nova
❖ Shiko
Compositional challenges
❖ Subtractive rhythm
❖ Monophonic rhythm
❖ Sounds of silence
❖ Random rhythm

The main menu is the first screen visible when the app loads.



The other menus follow an identical graphical presentation; for example, here is the screen listing the Breakbeat exercises.

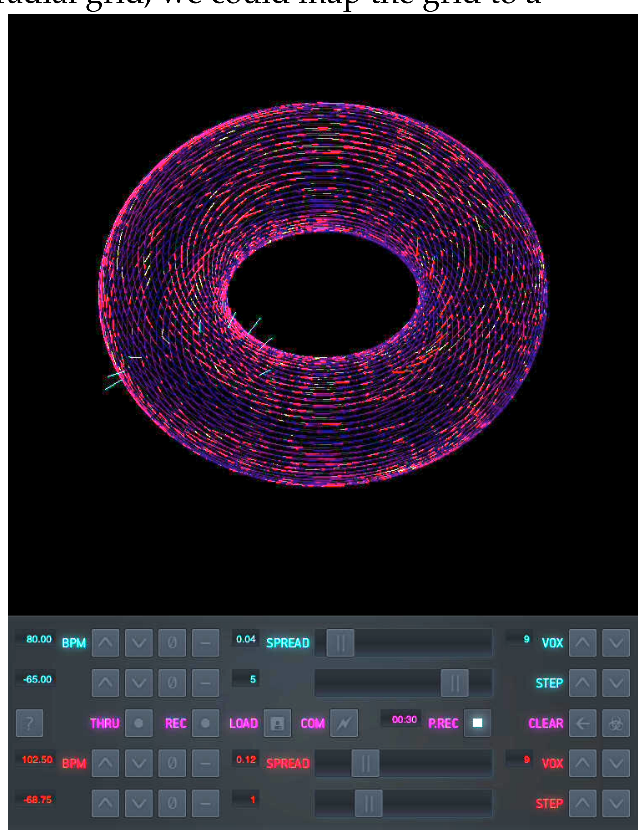


The major design challenge: maximizing the target area within the grid

As I began to make my first concept images, a practical difficulty of the radial grid presented itself immediately: the innermost grid cells were unusably small. I discovered this difficulty when I had trouble lining up the Photoshop paint bucket tool to fill in the cells. If I struggled to hit the targets with a one-pixel crosshair, how would users be able to accurately hit them with fingers on a touchscreen? This problem turned out to be the single greatest design conundrum of the project, and it took a series of iterations to solve.

The three-dimensional torus solution

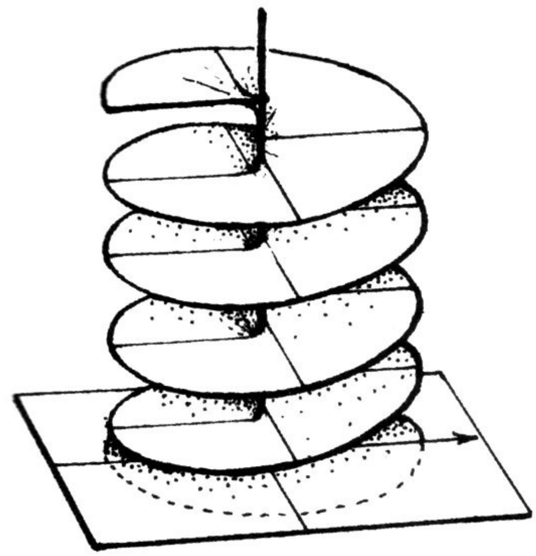
My fellow Music Technology student Don Bosley was interested in possibly collaborating on a commercial version of the Drum Loop, and convened a group of programmers and designers to discuss the idea. One solution to the target area problem was proposed: instead of a two-dimensional radial grid, we could map the grid to a three-dimensional torus. The advantage was that each grid cell could then be generously sized. However, only a few rings would be visible at a time; to access the others, the user would need to somehow twist the torus inside out. We nicknamed this solution “the groove donut.”



The idea continues to intrigue me, but it has two main difficulties. First, representing such a mathematical object is a significant programming challenge. Second, there is an existing rhythm app that uses a toroidal representation of time, The Donut by Strange Agency, shown at right. It is an appealing and futuristic looking interface, but after considerable effort, we were unable to make any sense of it. We therefore abandoned the “groove donut” idea quickly.

The spiral ramp solution

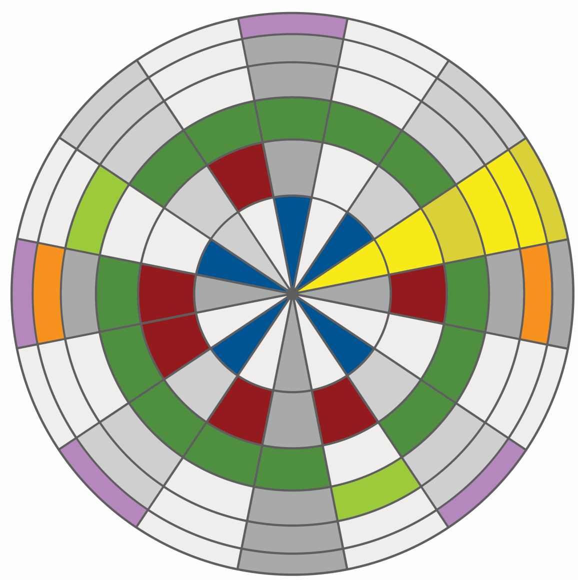
A drum loop unspooling in time has the topology of a spiral, not a circle. The drum patterns could be visualized using a spiral "parking garage" ramp, the Riemann surface $f(z) = \log z$. To the right is a hand-drawn rendering of such a spiral ramp by Penrose (2004).



However conceptually elegant this solution would be, however, it posed the same practical obstacle as the "groove donut," or really any three-dimensional object rendered on a two-dimensional screen: only a portion of the ramp would be visible at any one time. The user would have to continually rotate the ramp in three dimensions. This ran against my requirement of simplicity, in addition to the programming challenge it would have posed.

Logarithmic radii

By the time we created the Max prototype, I had arrived at a purely two-dimensional solution: to maximize the area of every grid cell by spacing the radii logarithmically. (In effect, this created a two-dimensional projection of a three-dimensional sphere bulging "outward" toward the user in the center.) We initially hoped to produce the radius values dynamically in code, but JavaScript lacked the necessary mathematical functionality. Instead, we used the logspace function in Matlab to generate a vector of logarithmically spaced values that we then hard-coded into an array in the JavaScript UI code.



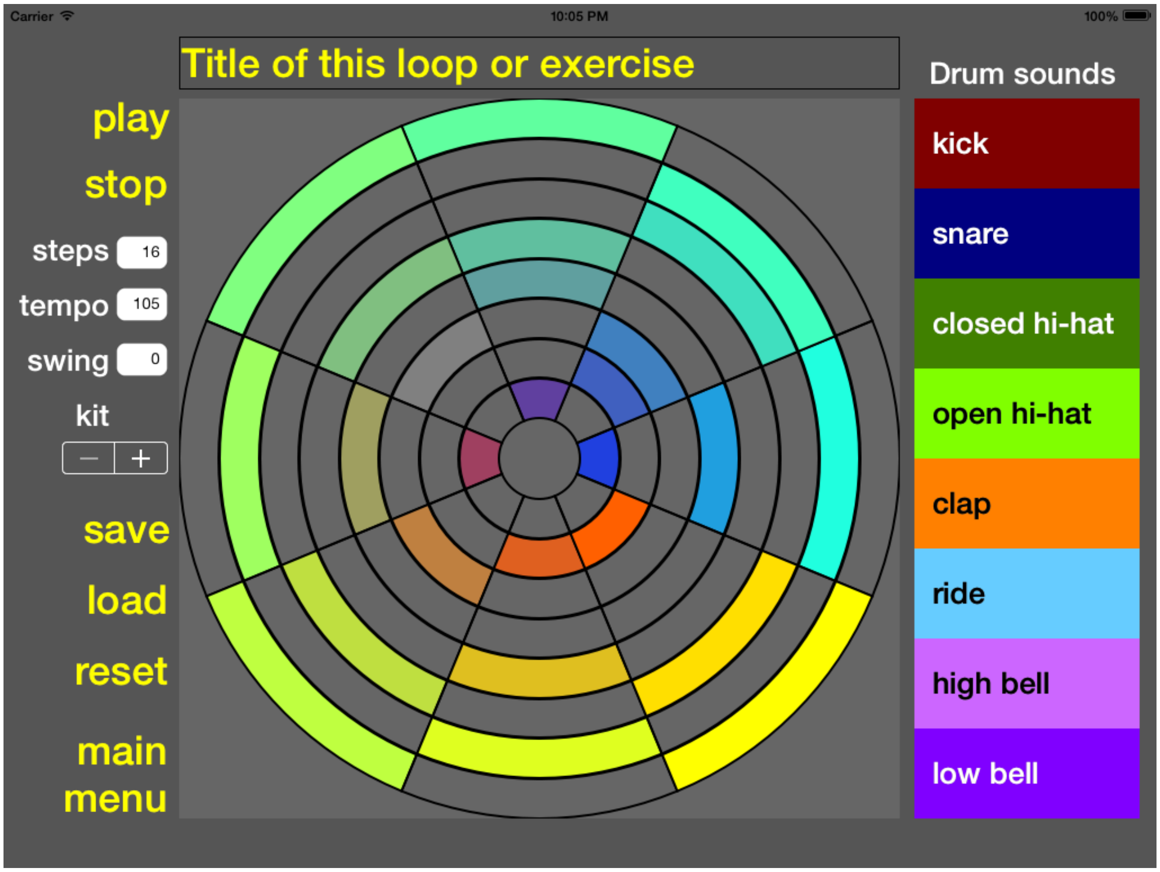
The logspace function takes in three values a, b and n, and generates n points between decades 10^a and 10^b. We generated seven points between decades 10 and 1 and normalized them to fit within the total size of the grid:

```
(1.0-((logspace(1.0, 0, 7))./10));
ans./max(ans);
ans*.97
```

This solution produced equally-sized cells throughout the grid and made for an attractive graphic, but it was still ultimately unsatisfactory. The innermost cells became long, narrow wedges, and the outermost cells became thin arcs. Both shapes were still difficult target areas.

Radii at equal intervals

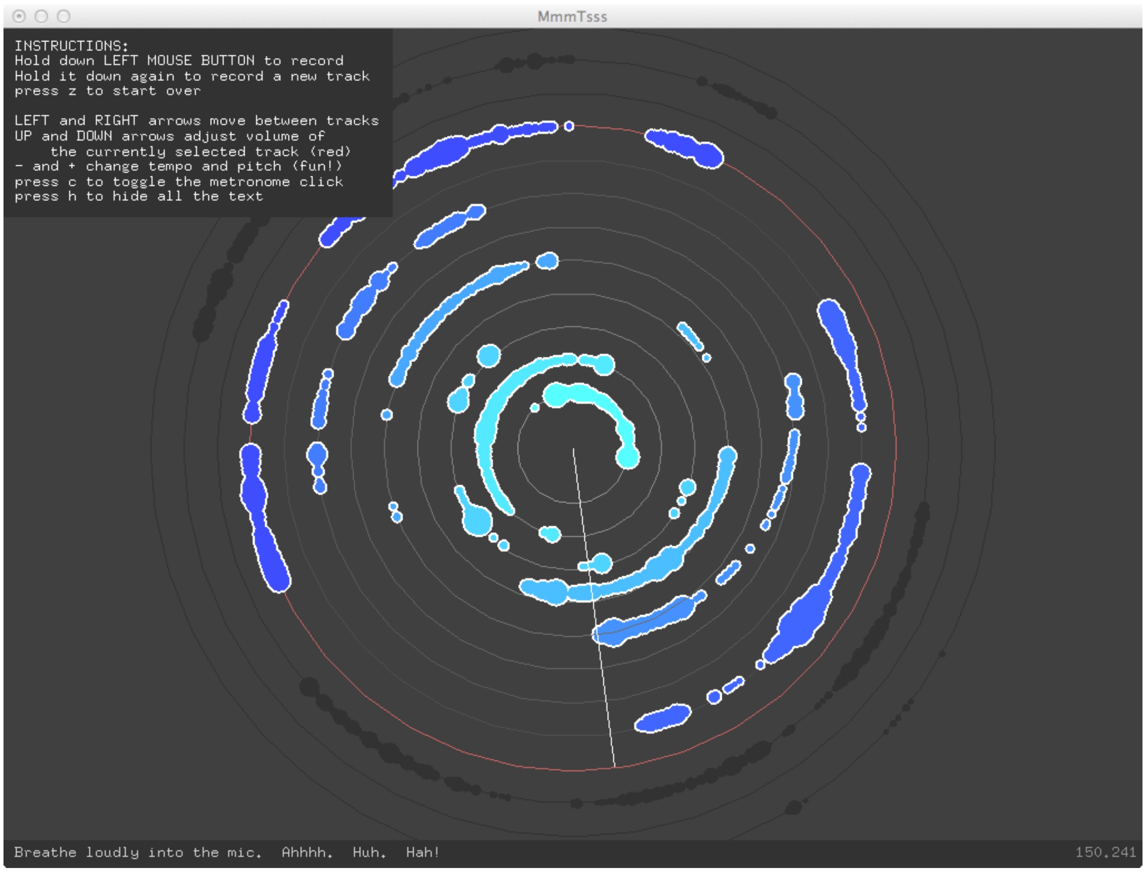
When we began the iOS version of the Drum Loop, Christopher quickly threw together a grid with equally spaced radii for expediency. We had this version under our eyes for several weeks, and during that time, its attractiveness grew on me. It is simple and clean-looking, and has the added virtue of being easy to represent algorithmically.



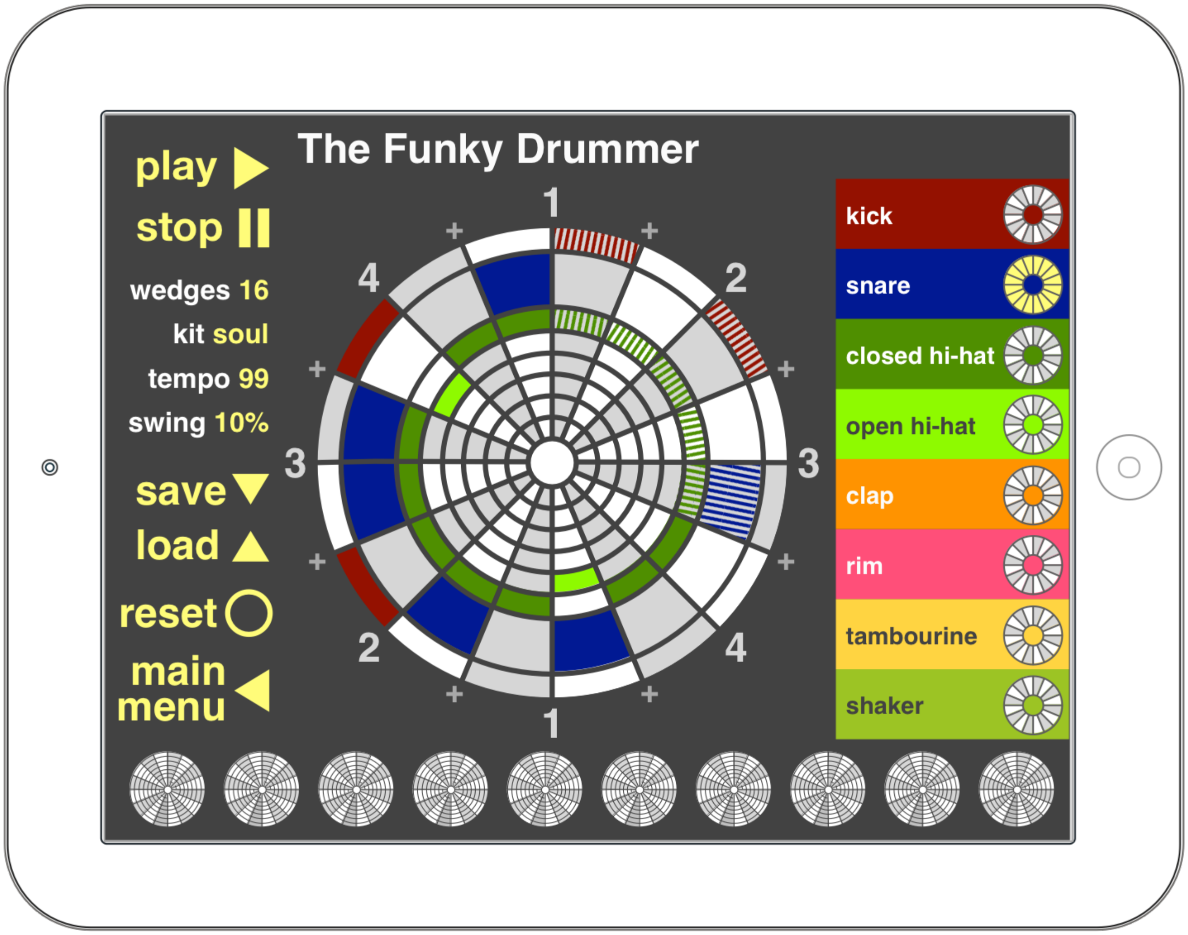
How, then, to reconcile these advantages with the problem of uneven cell size?

Variable radii

A new approach to the radius problem was inspired by Eric Rosenbaum's sampling application MmmTsss—the name refers to the sounds you make with your mouth and throat to simulate a techno beat. MmmTsss is a simple multitrack looping program, with each track represented by amplitude blobs around a circle. The circles are concentric, and each new track adds a circle on the outside, pushing the existing circles inwards. As the user selects a circle, it expands to fill most of the application window. This is as an exceptionally elegant solution to the problem of inner circles being unusably small, and inspired the ultimate solution to the ring sizing problem: varying their size dynamically.



In the Drum Loop, tapping the name of a drum sound while playback is stopped makes its home ring double in radius, while the other radii become proportionally smaller to accommodate it. (I misremembered MmmTsss as working this way, rather than simply zooming in and out.) The target area becomes reasonably sized, and also reinforces the connection between the name of the sound and its corresponding ring previously indicated only by color. The size cue also makes the app considerably more accessible to colorblind users, a requirement we discovered inadvertently during testing of the Max prototype. This image shows the Funky Drummer exercise with the snare drum ring selected:



The variable ring size also solves another problem that unexpectedly arose during testing of the Max/MSP prototype, that of visually indicating which ring plays which sound. An obvious solution would have been text labels within the rings themselves, but that proved to be an unworkable solution. Either the text paths would need to curved algorithmically or each label would need to be a static PNG. Either way, the text would layer awkwardly with the other information presented in the grid, and would become unreadably small toward the center of the circle.

The rings default to being equal in radius. This makes the area of the outermost ring much larger than the inner one. While this initially appeared to be a design deficiency, it became apparent that it had advantages as well. Placing more salient sounds on the outside rather than the inside gives visual reinforcement to their greater importance. The foundational kick and snare are larger than more "ornamental" sounds like tambourine and handclaps, and therefore seem more significant.

During playback, sounds can be entered live simply by tapping the name label. Some users will prefer entering sounds this way, especially if they have some percussion experience. This mode makes the target size within the grid irrelevant; now we need only be concerned with the size of the labels, which are quite generous.

Drum patterns and exercises

In keeping with the constructivist value of working with authentic cultural materials, the exercises in the Drum Loop are based on rhythms drawn from actual dance music. Most of the patterns are breakbeats—drums and percussion sampled from funk, rock and soul recordings that have been widely repurposed in electronic dance and hip-hop music. There are also generic rock, pop and dance rhythms, as well as an assortment of traditional Afro-Cuban patterns.

In each exercise, the users are presented with a pattern. They may alter this pattern as they see fit by adding and removing drum hits, and by rotating instrument parts within their respective rings. There are restraints of various kinds, to ensure that the results are appealing and musical-sounding. The restraints are tighter for more basic exercises, and looser for more advanced ones. For most exercises, the learning value is in the user's engagement with an influential or historic rhythm, and in the springboard for creativity that it provides. But in some instances, there is an additional pedagogical motivation, which is specified in the exercise description.

All descriptions of the following patterns are given in cut time. Unless otherwise specified, each pattern is sixteen steps long, two measures of cut time.

Classic Breakbeats

The cultural richness of hip-hop and dance beats lies not just in the rhythms themselves, but in their broader musical context. By tracing a breakbeat through the various songs that sample it, one can glimpse a small lineage within the broader musical genome. The web site WhoSampled.com is a crowdsourced repository of samples, interpolations and covers. It is possible to trace a sample through several generations of re-use and quotation.

What constitutes a "classic" breakbeat? I used two criteria: frequency with which the break has been sampled, signifying cultural significance, and musical distinctiveness, to give a diverse array of examples. The top ten most sampled breakbeats appearing in commercial recordings, according to Whosampled.com, are:

1. "Impeach the President" by the Honey Drippers (1973)
2. "Funky Drummer" by James Brown (1970)
3. "Synthetic Substitution" by Melvin Bliss (1973)
4. "Amen, Brother" by The Winstons (1969)
5. "It's a New Day" by Skull Snaps (1973)
6. "Apache" by the Incredible Bongo Band (1973)
7. "Papa Was Too" by Joe Tex (1966)
8. "Hihache" by the Lafayette Afro Rock Band (1973)
9. "The Big Beat" by Billy Squier (1980)
10. "Ashley's Roachclip" by The Soul Searchers (1971)

There is some musical redundancy in this list. For example, "Synthetic Substitution," "It's a New Day" and "Hihache" are all nearly identical patterns. So I chose to supplement the top ten with other well-known breakbeats in a broader variety of styles.

The Funky Drummer

"The Funky Drummer Parts One And Two" by James Brown and the JBs is one of the most-sampled recordings in history. It takes the form of open-ended groove, with extended solos traded back and forth between James Brown on organ and Maceo Parker on tenor saxophone. Four and a half minutes into the recording, James Brown tells the band: "Fellas, one more time I want to give the drummer some of this funky soul we got going here." He tells drummer Clyde Stubblefield, "You don't have to do no soloing, brother, just keep what you got… Don't turn it loose, 'cause it's a mother."

Though he was only eighteen years old at the time of the "Funky Drummer" session, Clyde Stubblefield was already a master drummer. On the recording, James Brown tells him not to cut loose and solo because it might break up the groove and let all the air out of the balloon. So when his cue comes, Stubblefield continues to play the main rhythm pattern, with more emphasis but not a lot of variation. James Brown does a short rap over the beat and then counts the band back into the original vamp. While the band plays, he names the tune on the spot:

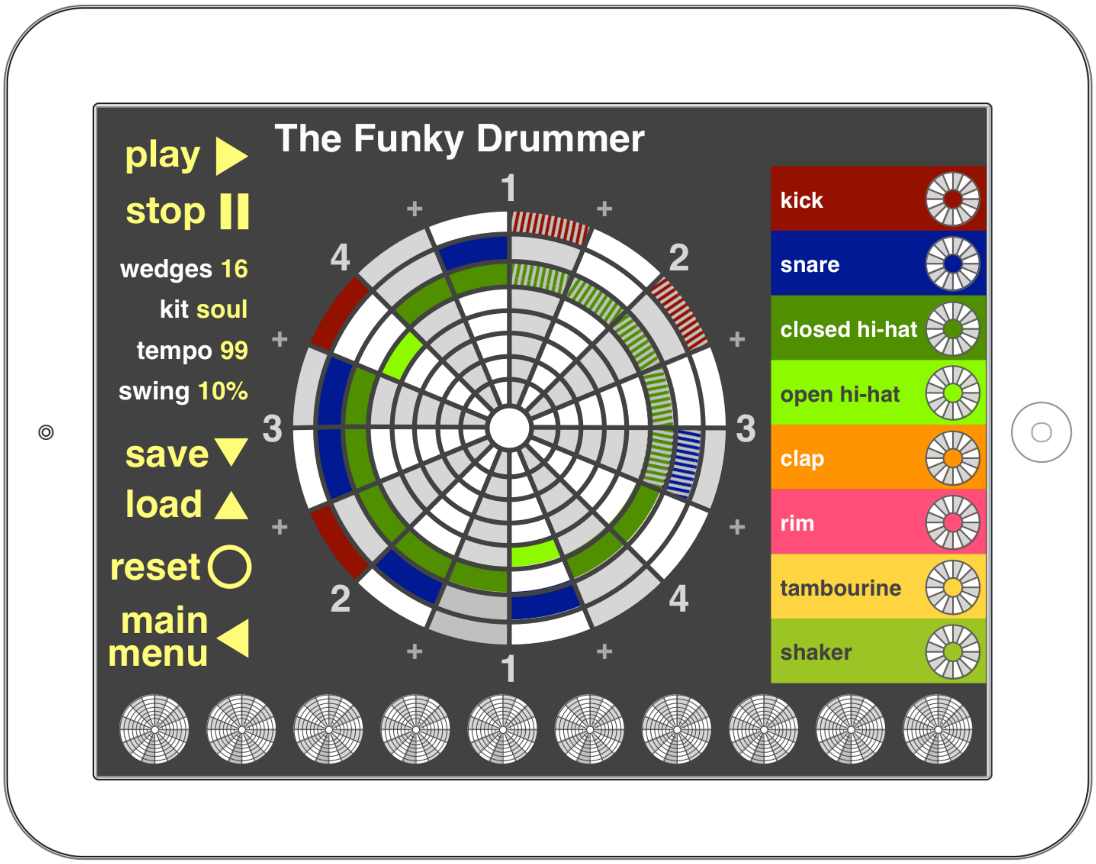
> The name of this tune is The Funky Drummer
> The Funky Drummer
> The Funky Drummer
> The Funky Drummer
> The Funky Drummer
> The Funky Drummer

The Funky Drummer drum break was much-loved by the first generation of hip-hop producers. They sampled it enthusiastically and repeatedly. In 1986, Polydor capitalized on James Brown's new-found cachet and released In The Jungle Groove, a compilation record of the hard-edged, open-ended funk grooves preferred by hip-hop listeners. This compilation was the first album release of "The Funky Drummer Parts One And Two." It also included a remix called the "Funky Drummer Bonus Beat Reprise," the Clyde Stubblefield drum break looped for three minutes with samples of James Brown's raps overlaid periodically.

The Funky Drummer break has been sampled in thousands of tracks, from hip-hop to pop to rock to every flavor of electronica. James Brown even sampled it himself, on "She Looks All Types A' Good." Public Enemy used the break on seven different tracks, and they refer to it by name in opening lines of "Fight The Power."

> 1989, the number, another summer
> Sound of the Funky Drummer

Stewart (2000) traces James Brown's rhythmic style to three major sources: African and Caribbean culture as filtered through New Orleans; a style of gospel singing and clapping known as "rocking and reeling;" and bluegrass and string band music. The Funky Drummer template is a cornerstone of hip-hop and many other American dance styles: a phrase beginning with an eighth-note/eighth-note/quarter-note figure ("boom-boom-cha") that then becomes more varied and syncopated (Greenwald 2002). While the bass drum states the pulse in most dance music, in hip-hop, it does so only rarely. Instead, after sounding the first downbeat in each hypermeasure, the bass drum often falls into a sparse syncopated pattern. The snare drum is most often placed on the backbeats, along with additional weak beats.

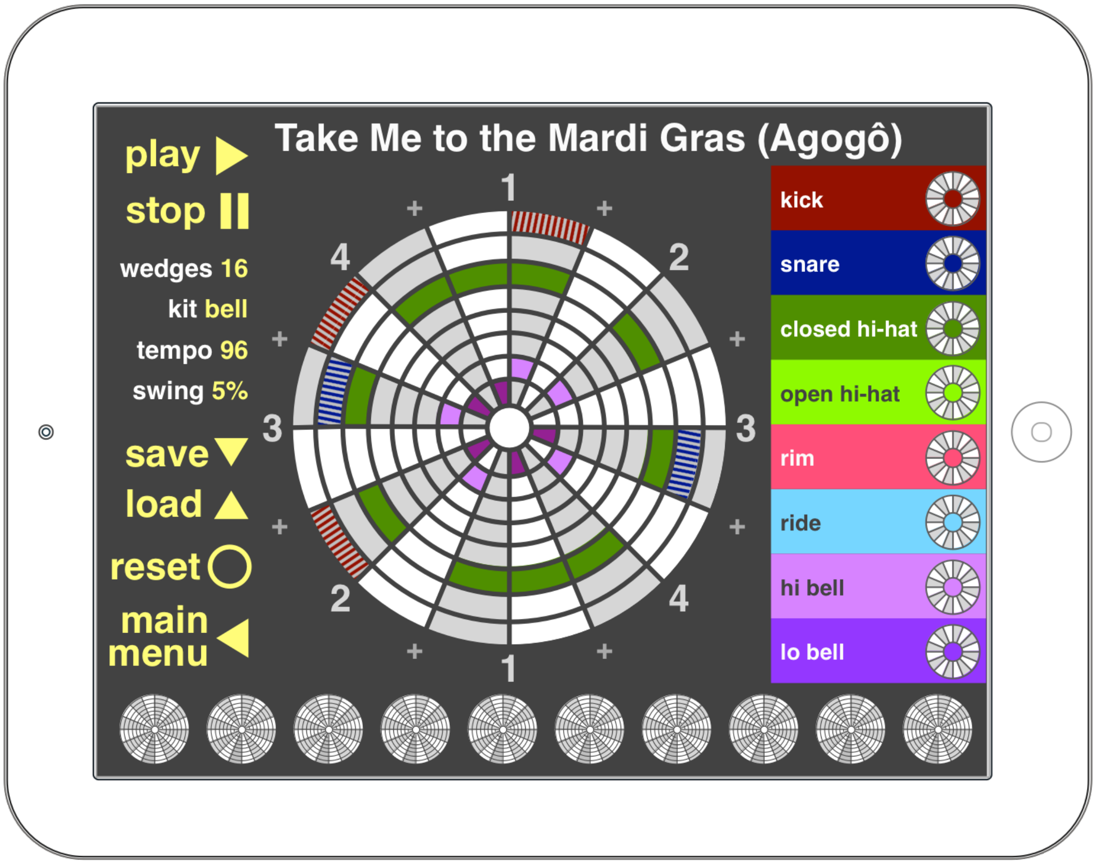


Exercise: the pattern is given, and steps one through five (the "boom-boom-cha") are locked. Users are free to alter the rest of the pattern as they see fit. The pedagogical goal is to demonstrate the versatility of the Funky Drummer template: a simple boom-boom-cha beginning followed by a more complex or unpredictable response.

Take Me to the Mardi Gras (Agogô)

Bob James' instrumental version of Paul Simon's song "Take Me to Mardi Gras" has a distinctive opening: a funk beat played on drum kit, an African bell pattern and samples of radio chatter and static. This introduction has been sampled in hundreds of hip-hop songs. Its most iconic usage is in "Peter Piper" by Run-DMC, which was itself sampled in "Work It" by Missy Elliott. The bell pattern is an example of Agogô, from a

Yoruba word meaning gong or bell. Agogô spread from West Africa to America via the Caribbean, where it also became one of the foundational sounds of samba.



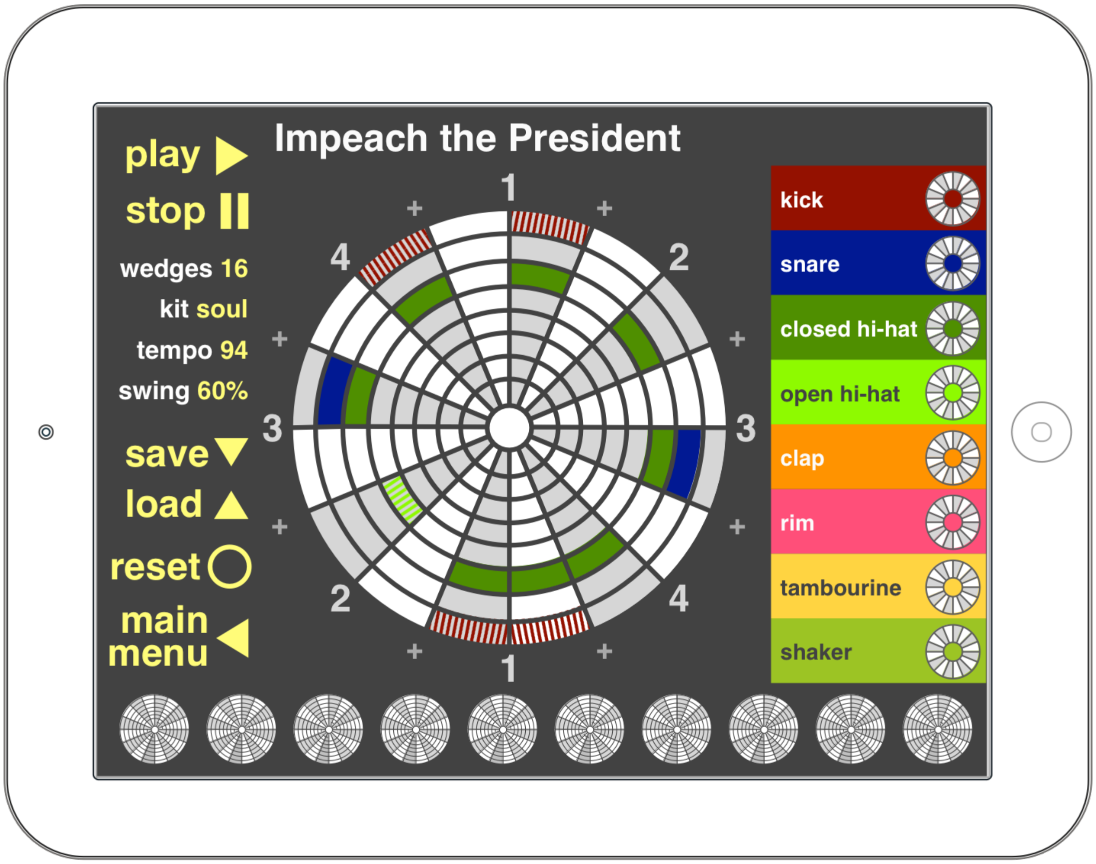
Exercise: The pattern is given. The kick, snare and hi-hat are locked. The user is free to alter the bell pattern and hi-hats, and to add rim and ride cymbal. This is in contrast to the Afro-Cuban exercises described below, where the bell patterns are locked and the user is free to create supporting rhythms around them.

Impeach the President

The opening seconds of "Impeach The President" by the Honey Drippers have become the most sampled breakbeat in history. Shields (2010) claims that about one hip-hop song in five samples "Impeach The President." That seems improbable, but according to Whosampled.com, the break has verifiably been sampled on at least one commercially released recording every year since 1987. Examples include:

- Audio Two – "Top Billin'" (which was, in turn, sampled in "Real Love" by Mary J Blige)
- De la Soul – "Ring Ring Ring (Hey Hey Hey)"
- Digable Planets – "Rebirth of Slick (Cool Like Dat)"
- Eric B and Rakim – "Move the Crowd"
- Nas – "I Can"

- Nice & Smooth – “Funky for You”
- Notorious B.I.G. – “Ready to Die” and “Unbelievable”
- Slick Rick – “It’s a Boy”
- Wu-Tang Clan – “Wu-Tang Clan Ain’t Nothin’ to F**k Wit’”

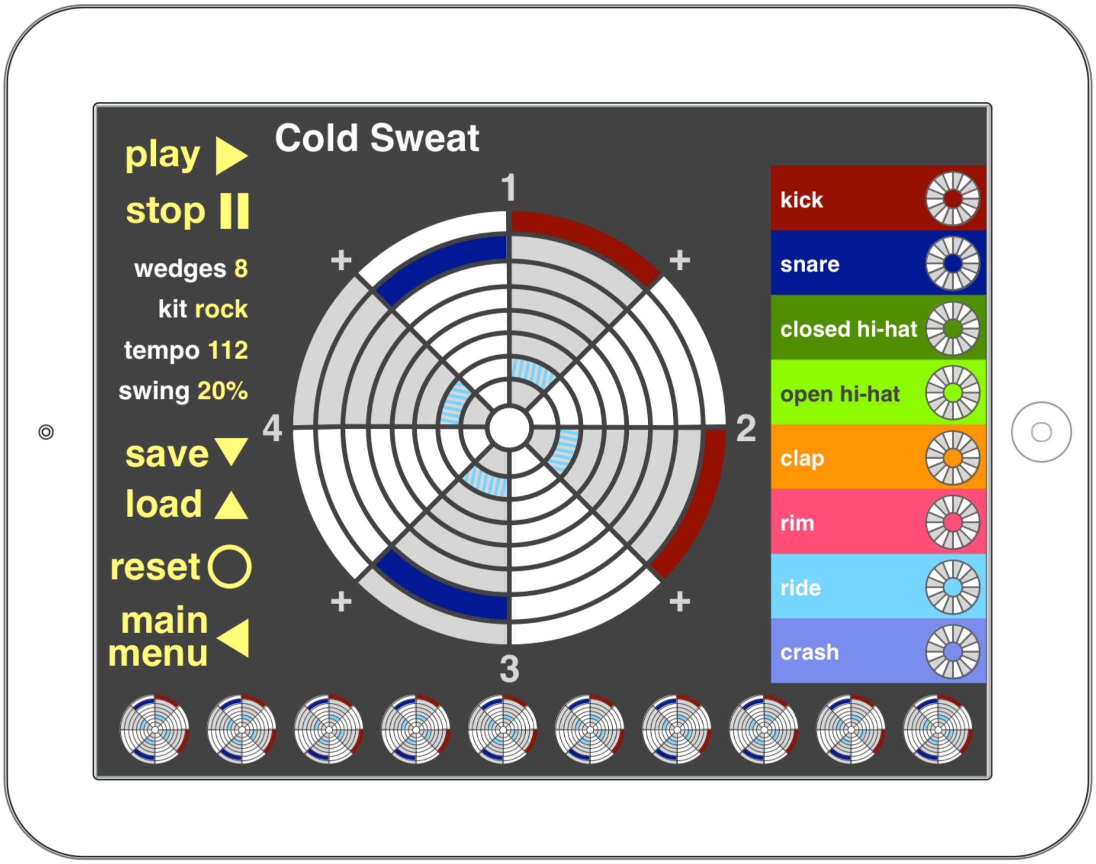


Exercise: the pattern is given. The two most distinctive features of the rhythm, the slightly asymmetric kick drum pattern and the open hi-hat accent, are locked. The user is free to create new patterns around them.

Cold Sweat

“Cold Sweat” by James Brown is a cornerstone both of hip-hop and more uptempo breakbeat-based music like drum n bass. On James Brown’s album of the same name, “Cold Sweat” sits alongside jazz standards like “Nature Boy” and run-of-the-mill blues and R&B. Compared to those more traditional songs, “Cold Sweat” sounds like it belongs in another era entirely. It has a radically simple two-chord structure and an African-influenced intricacy to its rhythmic groove, making it sound quite fresh more than thirty years after its release.

“Cold Sweat” has been a particularly rich source of inspiration for Public Enemy, who sample it on “How to Kill a Radio Consultant,” “Prophets of Rage” and “Welcome To The Terrordome.” The latter track has itself been sampled and quoted many times, by KRS-One, Non Phixion and Ice Cube, among others. Mongo Santamaria's cover version of "Cold Sweat" spawned a much-sampled breakbeat of its own.

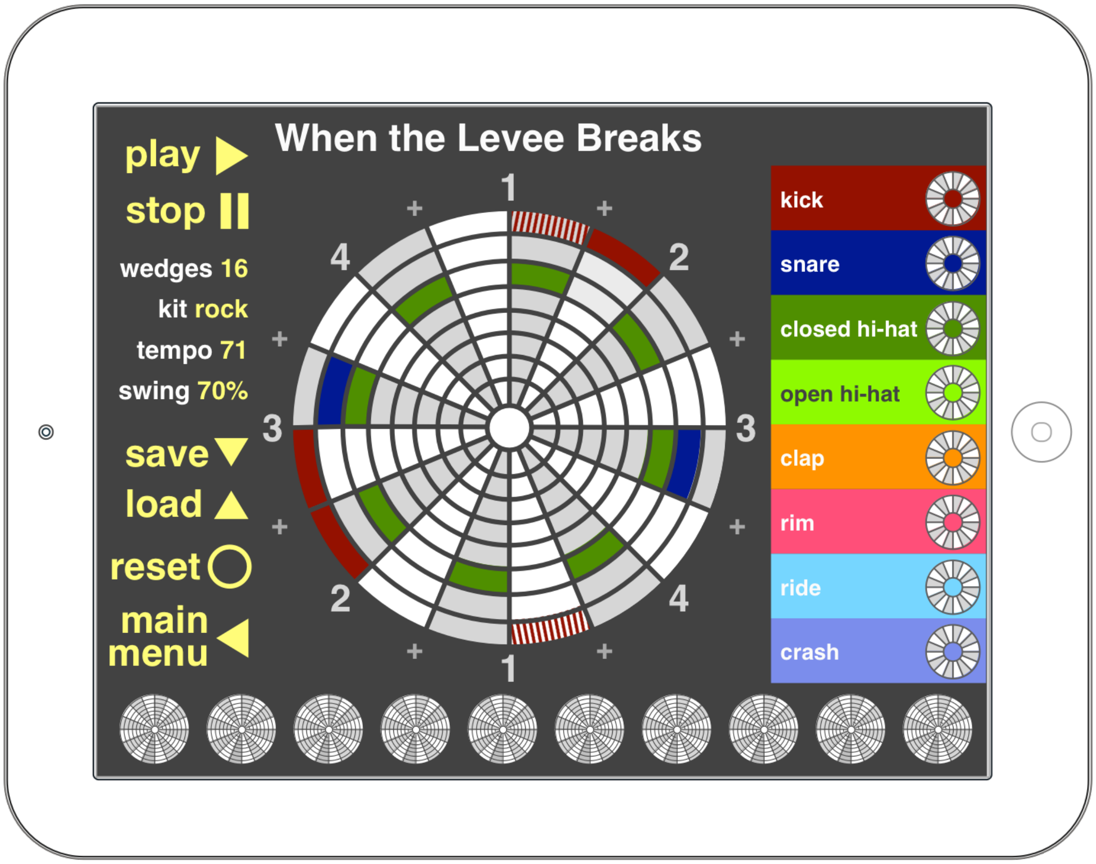


Exercise: the pattern is given, and the driving quarter-note ride cymbal pattern is locked. The user must find rhythms within the constraint of the single-bar pattern and with its quarter-note pulse.

When The Levee Breaks

John Bonham's drum intro from Led Zeppelin's "When The Levee Breaks" is irresistible to samplers for its stately grandeur and its arrestingly strange timbre. The song was recorded by engineer Andy Johns in Headley Grange, a Victorian-era poorhouse in England. Bonham's drum kit was placed at the bottom of a large stairwell, and the microphones were placed at the top of the stairs three stories above. The stairwell created a huge natural reverb. The tape was then slowed slightly, lowering the pitch and giving the sound a thick, sludgy quality.

The Levee break is popular in hip-hop not just for its timbre, but for its kick drum pattern. While a typical rock beat has a kick on every downbeat, the Levee break anticipates its second kick to the "and" of four, giving it a syncopated funk feel. Outside of hip-hop, high-profile uses of the Levee break include "Damn, I Wish I Was Your Lover" by Sophie B. Hawkins and "Army Of Me" by Björk.



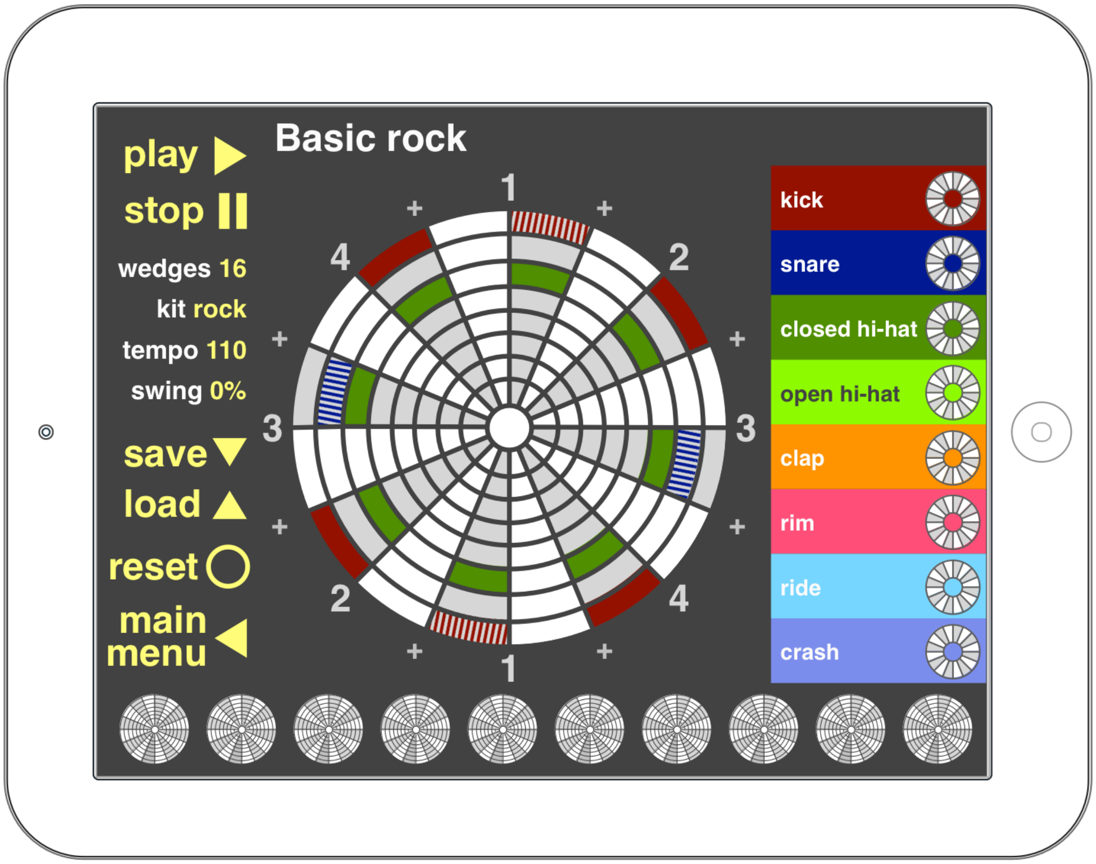
Exercise: The pattern is given. The kicks on the downbeat and the "and" of four are locked. The user must create a pattern that matches this asymmetry.

Genre templates

The central animating philosophy of the Drum Loop is to use real-world musical examples rather than artificially contrived ones. Nevertheless, there is some value in exploring generic examples of various major rhythm styles.

Basic rock

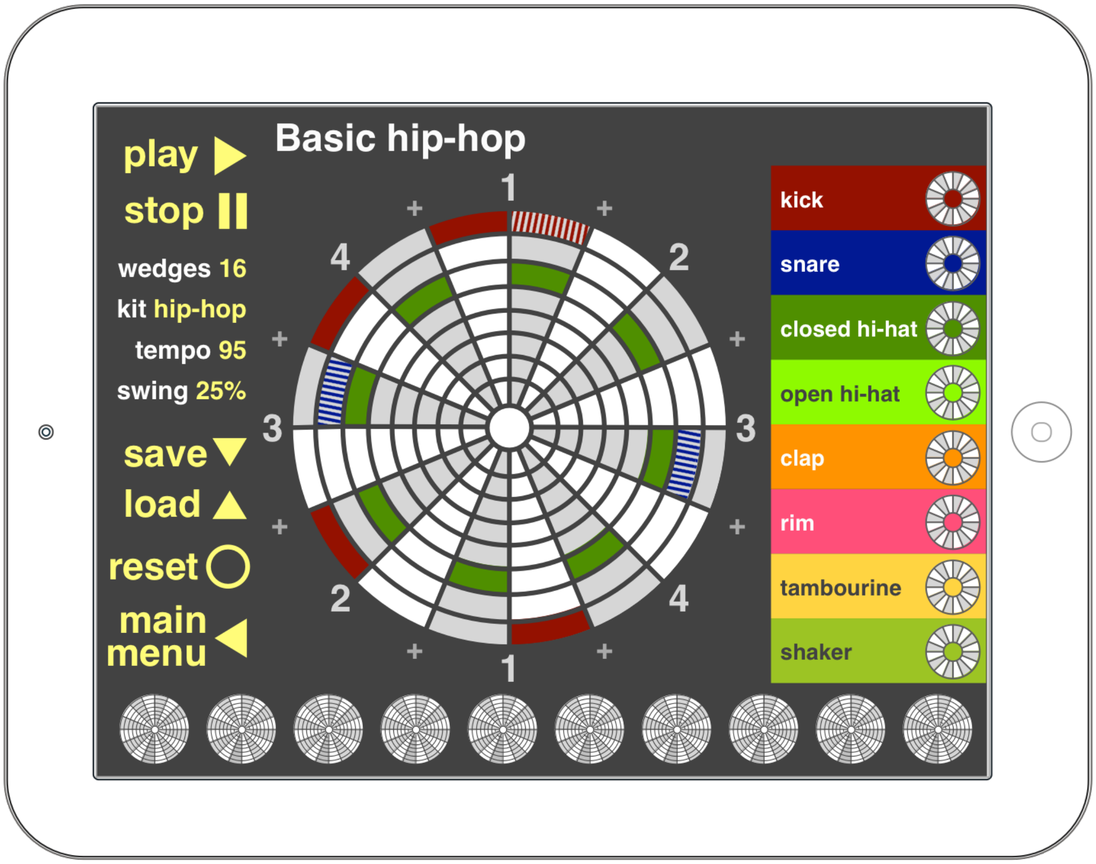
Rock beats are typically less rhythmically complex than those in dance or hip-hop. The vast majority of rock drum patterns feature kicks on each downbeat and snares on the backbeats. Aside from the backbeats, syncopation is limited to embellishments, or is entirely absent. Two conspicuous exceptions are found in “The Big Beat” by Billy Squier, which features a prominent kick drum anticipating the first backbeat, and “When the Levee Breaks” by Led Zeppelin, in which the kick anticipates the second backbeat rather than hitting it squarely. It is no accident that these two patterns are staple hip-hop samples, and they are addressed in other exercises. Here the purpose is to engage a more standard rock rhythm.



Exercise: The kick and snare are locked on the downbeats and backbeats respectively. There are unlocked closed hi-hats on each quarter note. The user is free to alter the hi-hat pattern and the unlocked kicks, and to layer on other drum hits.

Basic hip-hop

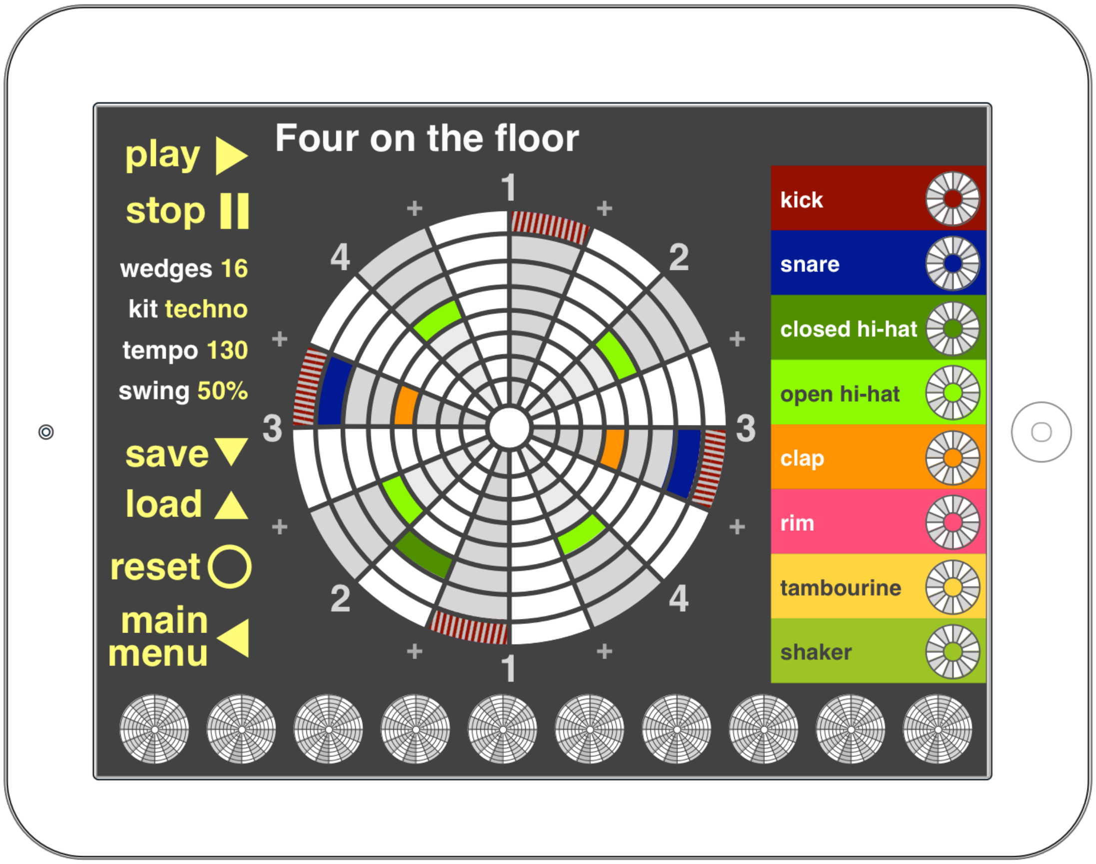
Like rock, hip-hop beats are anchored by snare backbeats. Also like rock, there are typically closed hi-hats on the strong beats, or on every beat. However, unlike rock, hip-hop kick drum patterns are highly syncopated after the initial downbeat. In fact, the kick is almost never found on the second downbeat in hip-hop beats.



Exercise: There is a locked kick on the first downbeat and locked snares on each backbeat. There are also unlocked closed hi-hats on the quarter notes and unlocked kicks playing syncopated accents. Users are free to change any of these; however, a popup text box encourages them to leave the kick off of the second downbeat.

Four on the floor

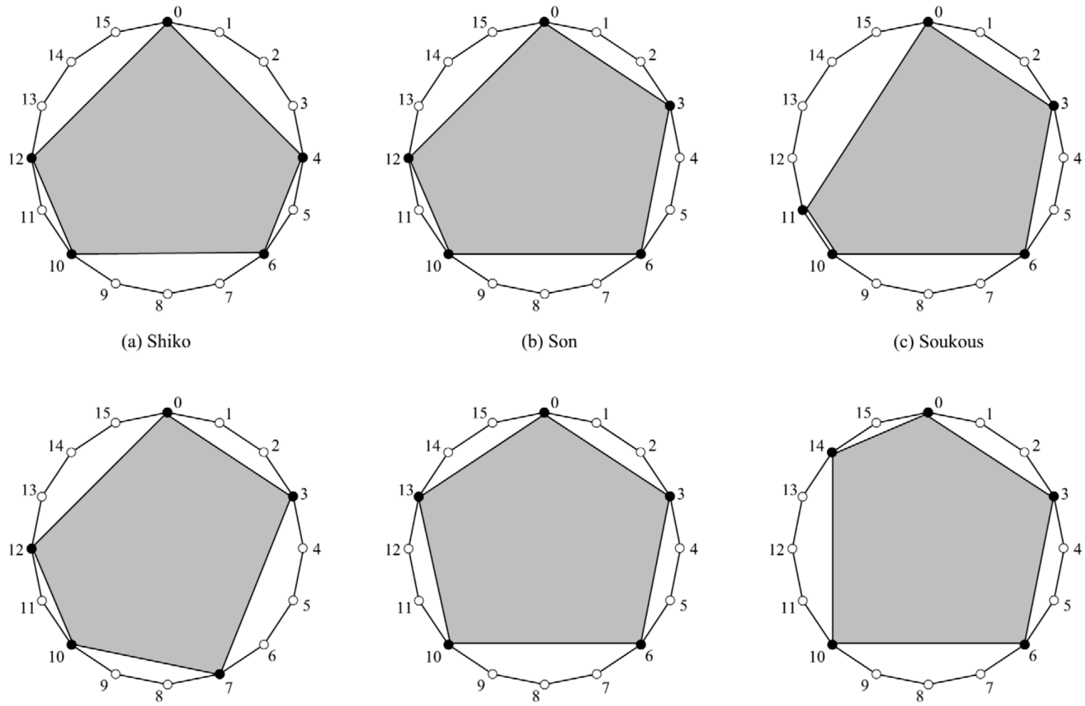
Disco, house, techno and a great many other dance styles are based on a "four on the floor" kick drum pattern, with kicks on all downbeats and backbeats. There may be snares or claps on the backbeats, but unlike in rock or hip-hop, these are optional. Closed hi-hats often appear on beats two and four of each measure, with further syncopation being commonplace. "Four on the floor" patterns are essentially defined by the tension between the kicks on the strongest beats and higher-pitched sounds on the weaker beats.



Exercise: There are locked kicks on the downbeats and backbeats, the "four on the floor" pattern . There are unlocked snares, claps and hi-hats filling out a typical house beat. The user is free add additional kicks, and to add or remove the other instruments, guaranteeing a result that is within the dance idiom.

Afro-Cuban exercises

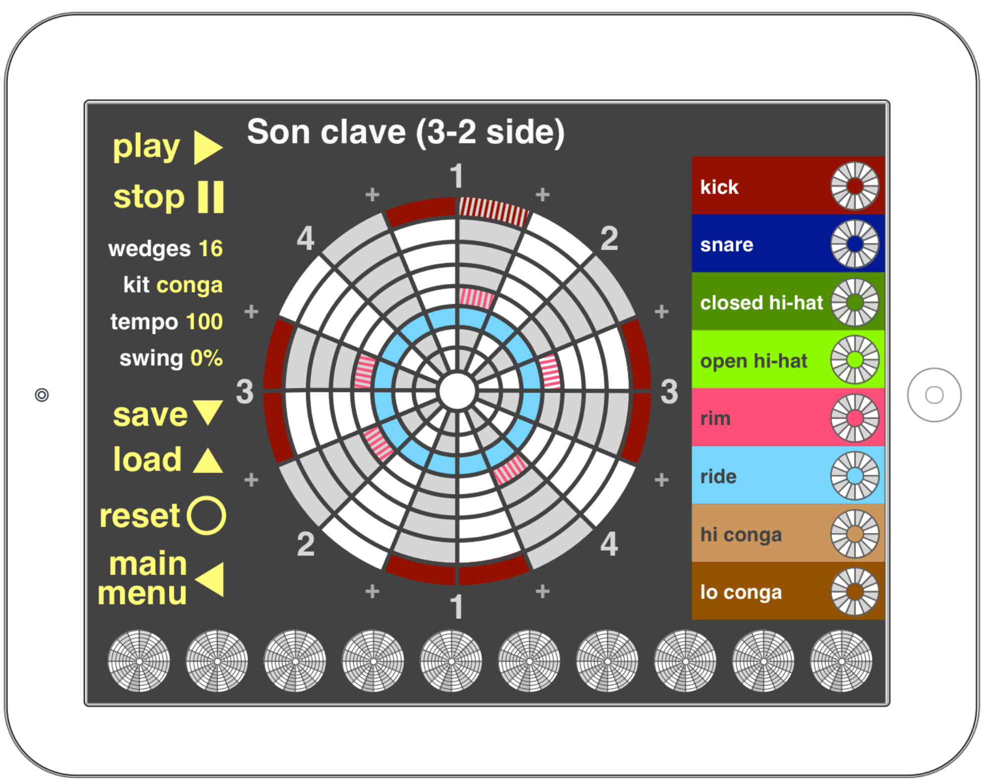
American popular music is saturated with Afro-Cuban rhythms, though we are frequently unaware of them. We may describe a piece of music as having a "Latin" or "tribal" feel, or we may simply unconsciously enjoy the extra syncopational richness. The Drum Loop includes six African and Latin American rhythms identified by Toussaint (2013) as "fundamental." When viewed in circular representations, these six patterns share an interesting property: the pairwise sums of their "geodesics" (distances between beats) are all equal (Demaine, Gomez-Martin, et al, 2009).

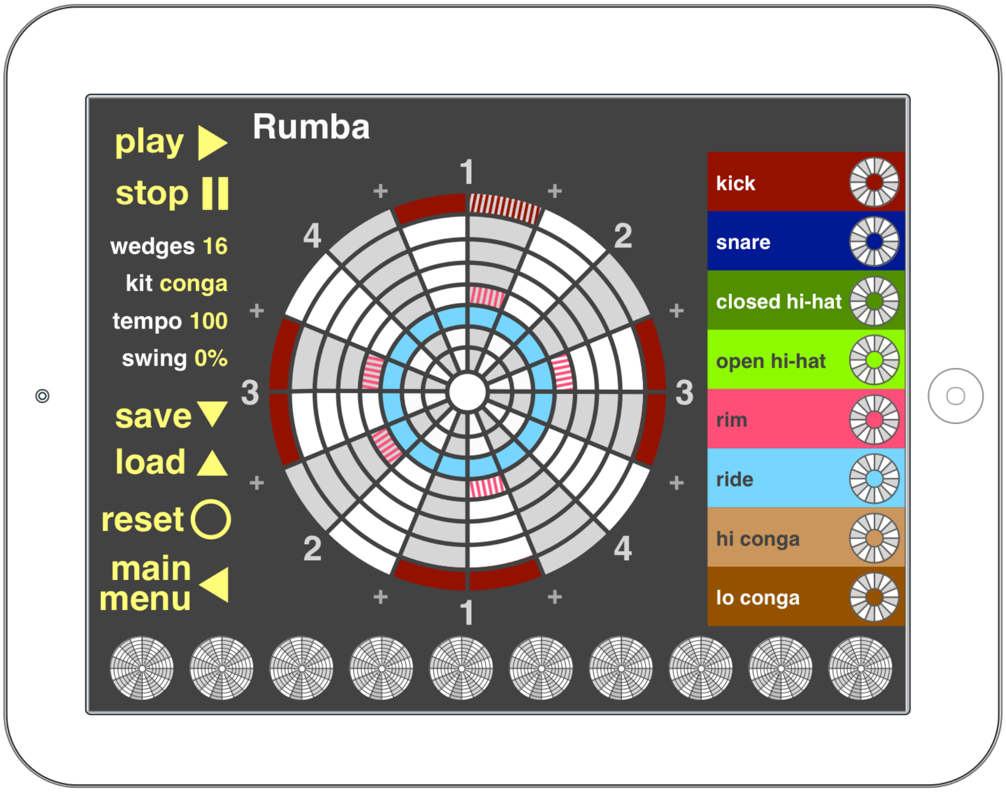


(a) Shiko (b) Son (c) Soukous

(d) Rumba (e) Bossa–Nova (f) Gahu

For the first three exercises, the rim pattern playing the clave is locked, as is the kick on the first downbeat.




Rumba
play
stop
wedges 16
kit conga
tempo 100
swing 0%
save
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main menu
1
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kick
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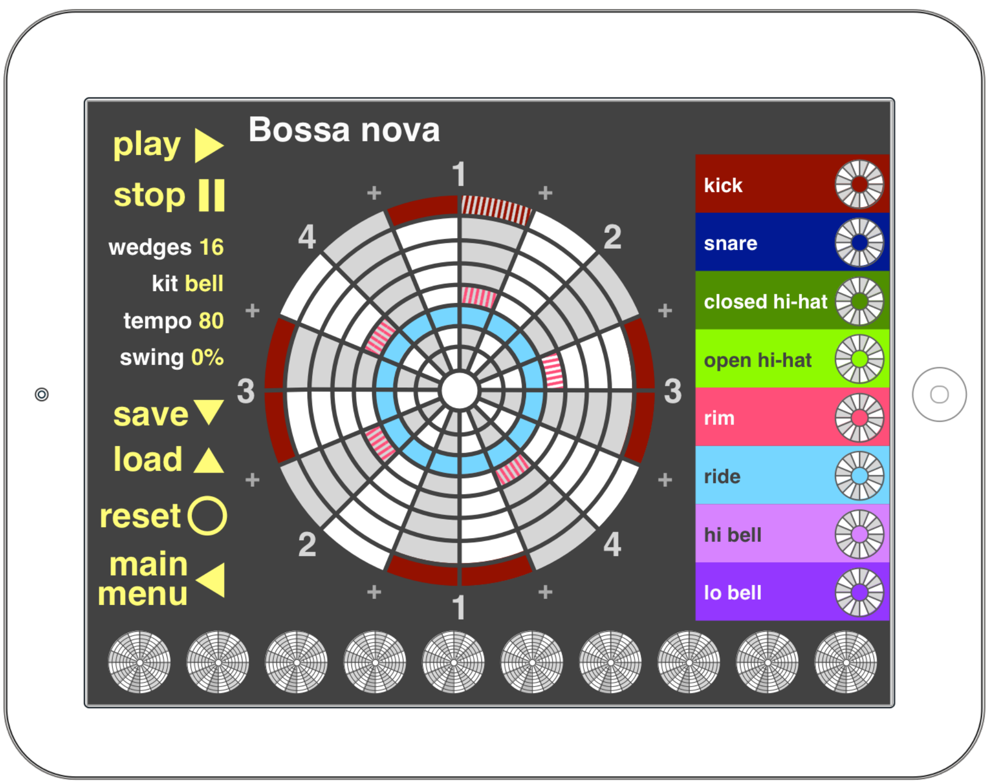
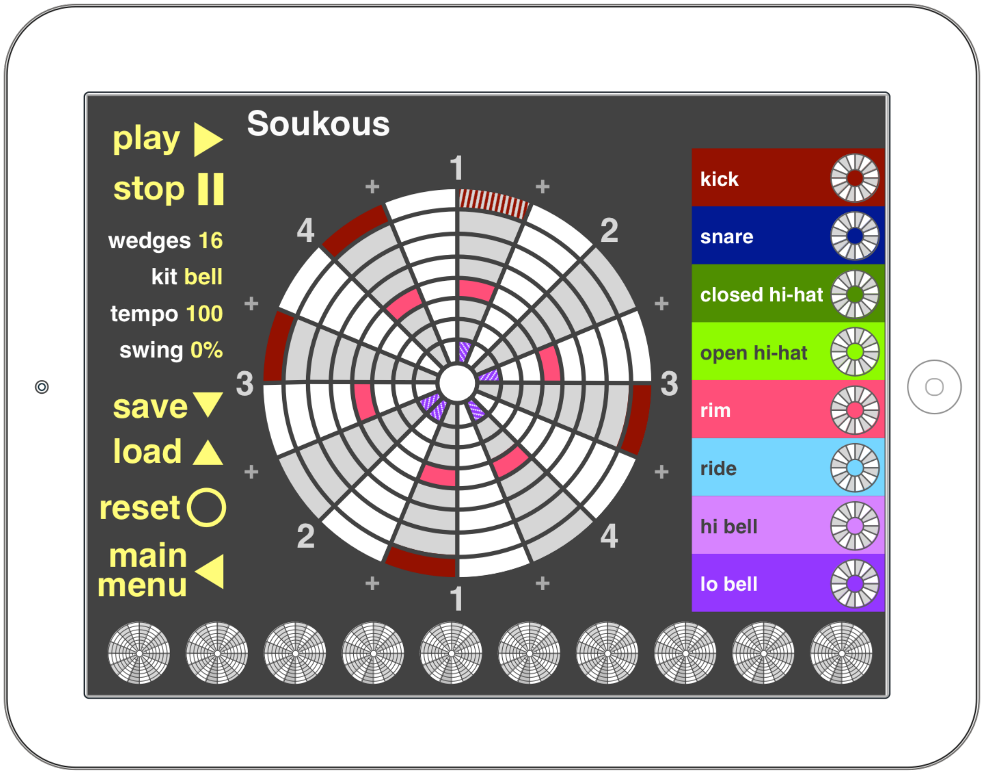
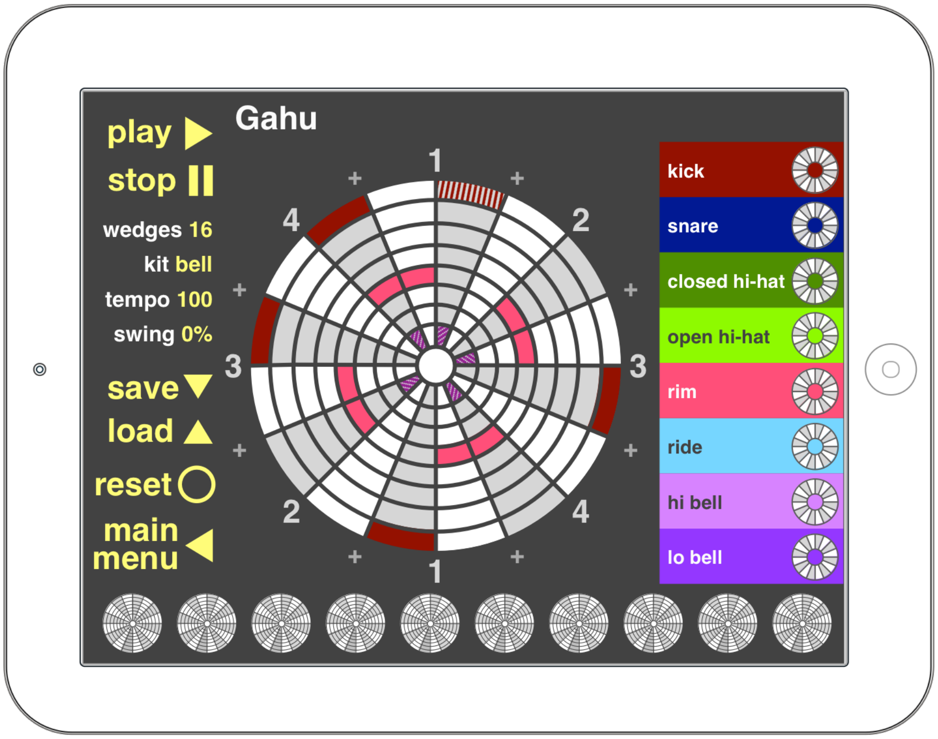
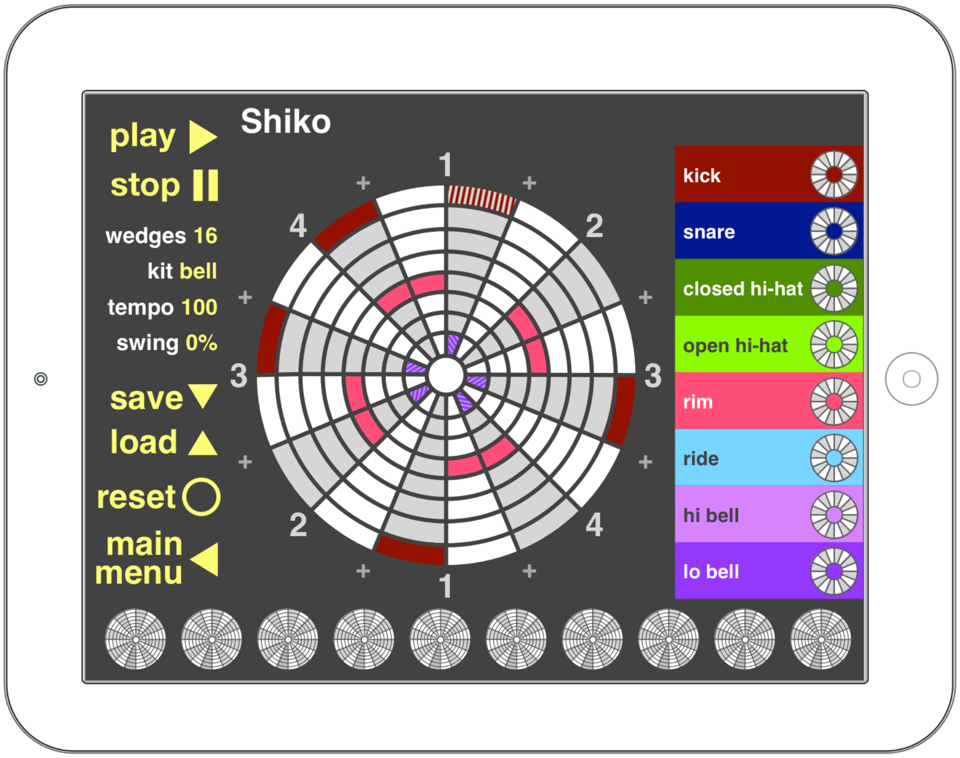
open hi-hat
rim
ride
hi conga
lo conga


Bossa nova
play
stop
wedges 16
kit bell
tempo 80
swing 0%
save
load
reset
main menu
1
2
3
4
kick
snare
closed hi-hat
open hi-hat
rim
ride
hi bell
lo bell

For the other three exercises, the locked clave pattern is played on bells.





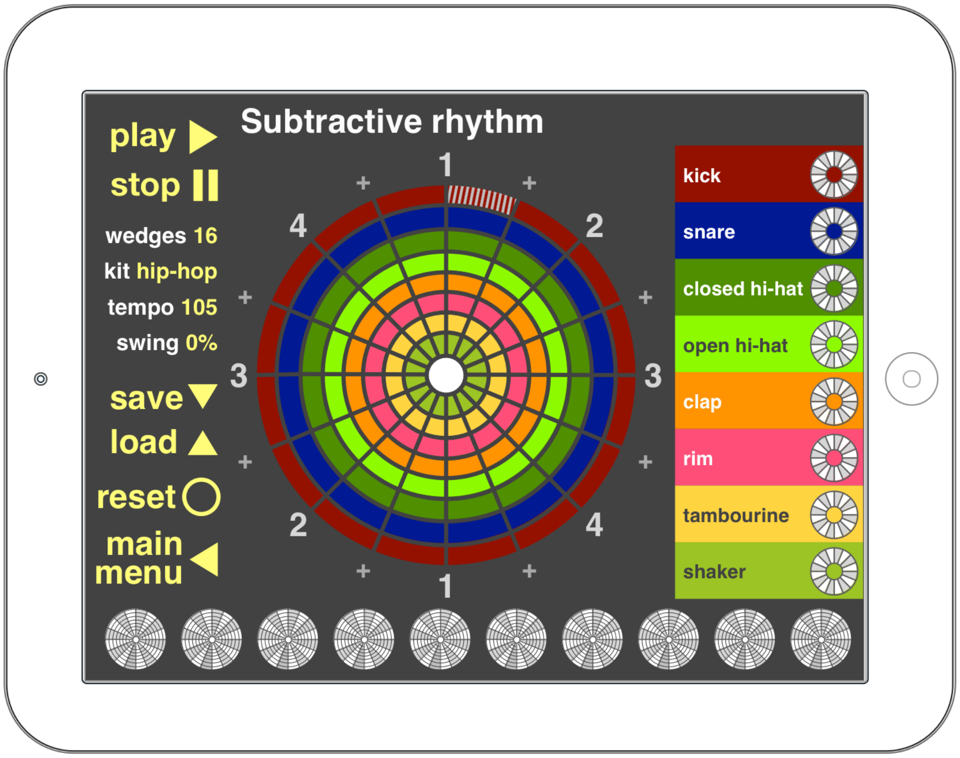


Compositional challenges

While the Drum Loop mostly adheres to the constructivist principle of working with authentic cultural artifacts, there are a few more abstract compositional exercises included as well. These are intended to serve more as “icebreakers” than as carrying any specific pedagogical or cultural content. Users who feel uncomfortable or uninspired working with the existing patterns may be liberated by the more abstract givens and constraints of these exercises.

Subtractive rhythm

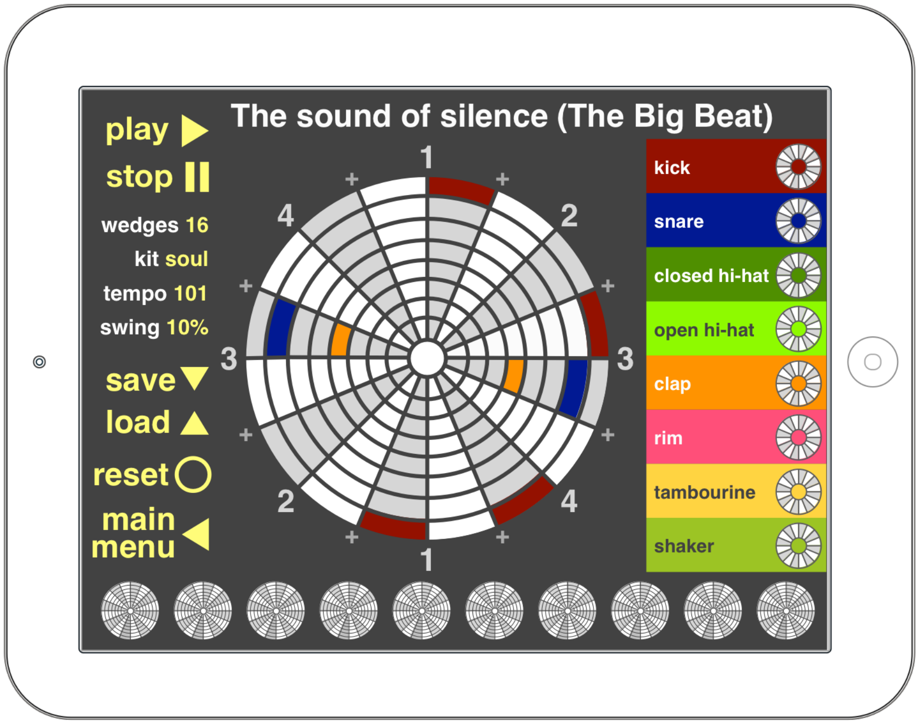
Inspired by Ruthmann’s notion of carving from a “sound block” (2012), every beat is initially activated. Needless to say, this sounds terrible. Deleting the “wrong” notes can be easier than identifying the “right” ones. This exercise also communicates the idea that silences are not simply the absence of sound, but rather are crucial rhythmic elements in their own right.



Exercise: Create a rhythm by removing drum hits only.

The sound of silence (The Big Beat)

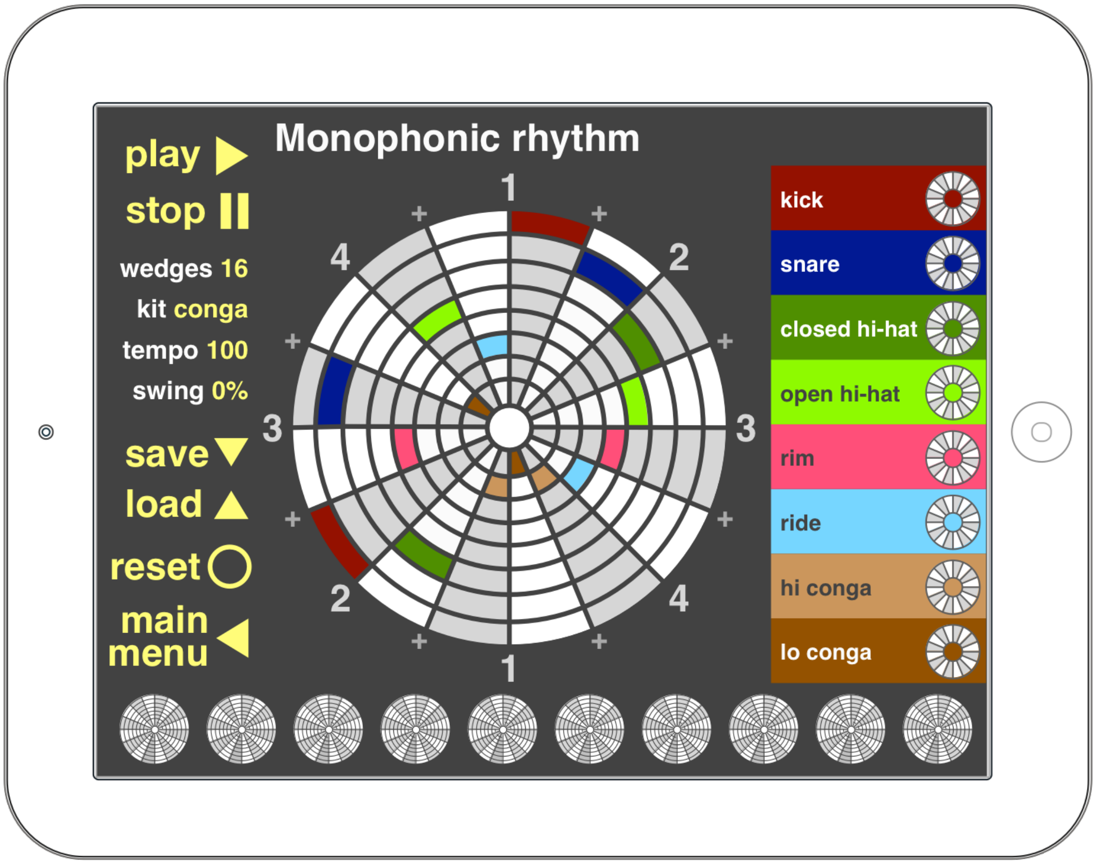
Beginner drum programmers have a natural tendency to want to make their beats more "interesting" by filling all of the available space with activity. It is a counterintuitive truth that simpler, less busy rhythms can be more attention-grabbing and compelling. Silences create anticipation and encourage the listener to imaginatively fill in the gaps, thus engaging them more actively with the beat. Some of the most effective patterns are composed mostly of silence. "The Big Beat" by Billy Squier is a classic example.



Exercise: The Big Beat pattern is given. Any hit can be turned on or off; however, no more than half the wedges can contain a drum hit at any one time.

Monophonic rhythm

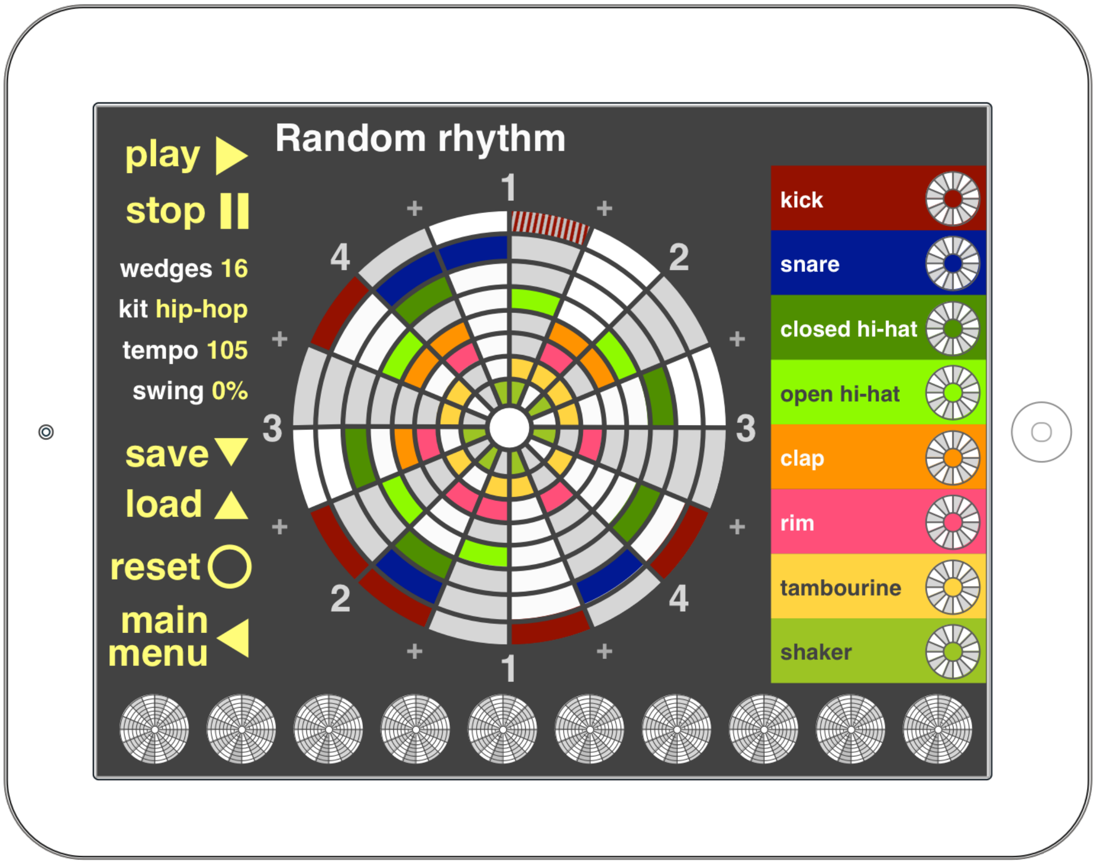
Over the course of implementing the iOS app, we have encountered some unexpected behaviors. While these have been mostly undesired, they sometimes stimulate new ideas. For example, while Christopher was able to make the app play monophonic sound quite effortlessly, polyphony turned out to be significantly more difficult. As a result, there was an extended period when the app could only play one drum sound at a time. While working to resolve this problem, Christopher created a series of monophonic drum loops, and these loops invariably sounded highly musical. This inspired me to create a new programming exercise: the user creates a monophonic loop in which no more than one sound plays in each wedge. Adding a sound to any wedge automatically disables all of the other slots in that wedge. As with the previous exercise, it reminds users that an economy of musical material can give the most compelling results.



Exercise: A monophonic pattern is given. The user may alter it freely, but each wedge can contain no more than one drum sound at a time. A more advanced exercise for future addition: constrain the user to use each sound exactly once.

Random rhythm

This challenge is simple: aside from a kick on the first downbeat, the grid is filled at random. The user must make musical sense of the result.



Exercise: The user adds or subtracts beats at will. In most exercises, the Reset button restores the pattern to its initial state; in this one, the Reset button generates a new random pattern.

Curriculum ideas

While the Drum Loop is well-suited to individual self-guided study, it is intended for use in a creative classroom environment. Its most obvious application is in general music class, but it can also be a useful basis for lessons and activities in cultural/social studies and mathematics.

Music

The Drum Loop has always been predicated on a role in the music classroom. There is some flexibility in what specifically that role would be. For teachers of drums and percussion, the answer is clear. I would hope that the Drum Loop could also find a place in the general music classroom, as a way to convey appreciation for the rich history of the rhythms of pop and dance. Furthermore, the Drum Loop offers a new and inviting doorway in for students who find it difficult to engage with music-making through more traditional routes.

The Drum Loop may be a tough sell for more traditionally-minded teachers, administrators and policy makers. The decades-long bitter struggle to include jazz in the classroom is still unfolding; it will be many more decades before hip-hop and techno follow suit. It is possible that the Afro-Cuban content may overcome some doubts. Furthermore, the Drum Loop need not be the focus of the class; if students are already writing and performing songs, the Drum Loop could be easily deployed as a convenient accompaniment tool. This is the intended use case for the O-Generator, which has found widespread classroom adoption in the United Kingdom. I hope for the Drum Loop to find a similar role in the United States.

Cultural/social studies

It is impossible to separate the study of music from the study of its social, historical and political context. Nowhere is this more true than in the music of the African diaspora in America. The Drum Loop would be valuable as an entry point into a contentious set of social and historical issues. By tracing son clave or the Funky Drummer beat from Africa, through the Caribbean and into the American mass culture, we can tell the stories of the people who played the beats, the people who danced to them, the people who sold and bought them. Specific social studies topics could include:

- The linearity of Eurocentric music versus the circularity of Afrocentric music—does this pattern extend to other art forms beyond music?
- What is the connection between repetition and dance? What makes a beat fill (or empty) the dance floor?

- Are drum machine beats "real" music? Are they authentic? Are electronic musicians "real" musicians? Are they practicing the same art form as violinists and pianists?
- Why is dance music so closely tied up with notions of sin, transgression and excess in America? Do all cultures regard dance music in this way? Why do we expect pop and hip-hop stars to behave in such conspicuously "antisocial" ways?

Mathematics

The Drum Loop may be an easier sell for math teachers than music teachers. Math teachers do not have a cultural canon to protect, and are eager to find ways to make their subject livelier. The Drum Loop could be used to teach or reinforce the following subjects:

- Fractions
- Ratios and proportional relationships
- Angles
- Polar vs Cartesian coordinates
- Symmetry: rotations, reflections
- Frequency vs duration
- Modular arithmetic
- The unit circle in the complex plane

Bamberger and DiSessa (2003) have an epigrammatic credo: "Music is embodied mathematics." They echo Gottfried Leibniz, who famously said in a letter to Christian Goldbach on April 17, 1712 that "Music is a hidden arithmetic exercise of the soul, which does not know that it is counting." The mathematical content of music has been appreciated since Pythagoras. Music has rich value for teaching symmetry, transformations and invariants. It is also an effective tool for helping elementary school students understand ratios, proportions, fractions, and common multiples, concepts which they frequently find difficult to master (Bamberger & DiSessa, 2003). It is significantly easier to learn standard notation once you are intuitively familiar with the concepts encoded by the symbols. The same is true of mathematical language.

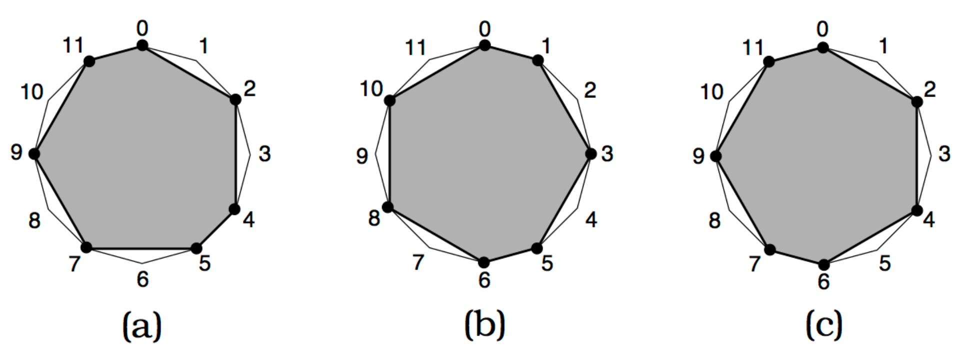
The mathematical term for a repetitive beat is periodicity. Music usually has several levels of beats operating simultaneously: quarter notes, eighth notes, sixteenth notes and so on. In mathematical language, there is a hierarchy of temporal periodicities. The ratios between different periodic frequencies are intuitive when heard in the context of a beat, but understanding them can be tricky and confusing when they are represented mathematically. Bamberger and diSessa (2003) ask what we mean when we say "faster" in a musical context. Trained musicians know that "faster" music refers to a faster tempo. But novice musicians listen for surface features, so if the feel goes from eighth notes to sixteenth notes, they will hear it as the music being "faster" even if the tempo does not change. Novices further stumble on the idea that a larger frequency or tempo means smaller beat durations, and vice versa.

Bamberger and DiSessa (2003) observe that graphic representations of music should help students come to attend to patterns such as symmetry, balance, grouping structures, orderly transformations, and structural functions. By "structural functions," the authors refer to medium-level musical entities like phrase boundaries, tension and resolution. Conventional notation does not show structural function, but to novice listeners, these are the most salient features of the music. Here, computer software can be an invaluable aid, with its ability to use dynamically interactive color-coding and spatial organization to convey meaning.

Specific kinds of music can help introduce particular mathematical concepts. For example, Afro-Cuban patterns and other grooves built on hemiola are useful for graphically illustrating the concept of least common multiples. If you have a kick drum pattern playing every four units and a cowbell playing every three units, you can both see and hear how they will line up every twelve units. Bamberger and diSessa (2003) describe the "aha" moment that students have when they grasp this concept in a music context. One student in their study is quoted as describing the twelve-beat cycle pulling the other two beats together. Once students grasp least common multiples in a musical context, they have a valuable new inroad into a variety of scientific and mathematical concepts: harmonics in sound analysis, gears, pendulums, tiling patterns and much else.

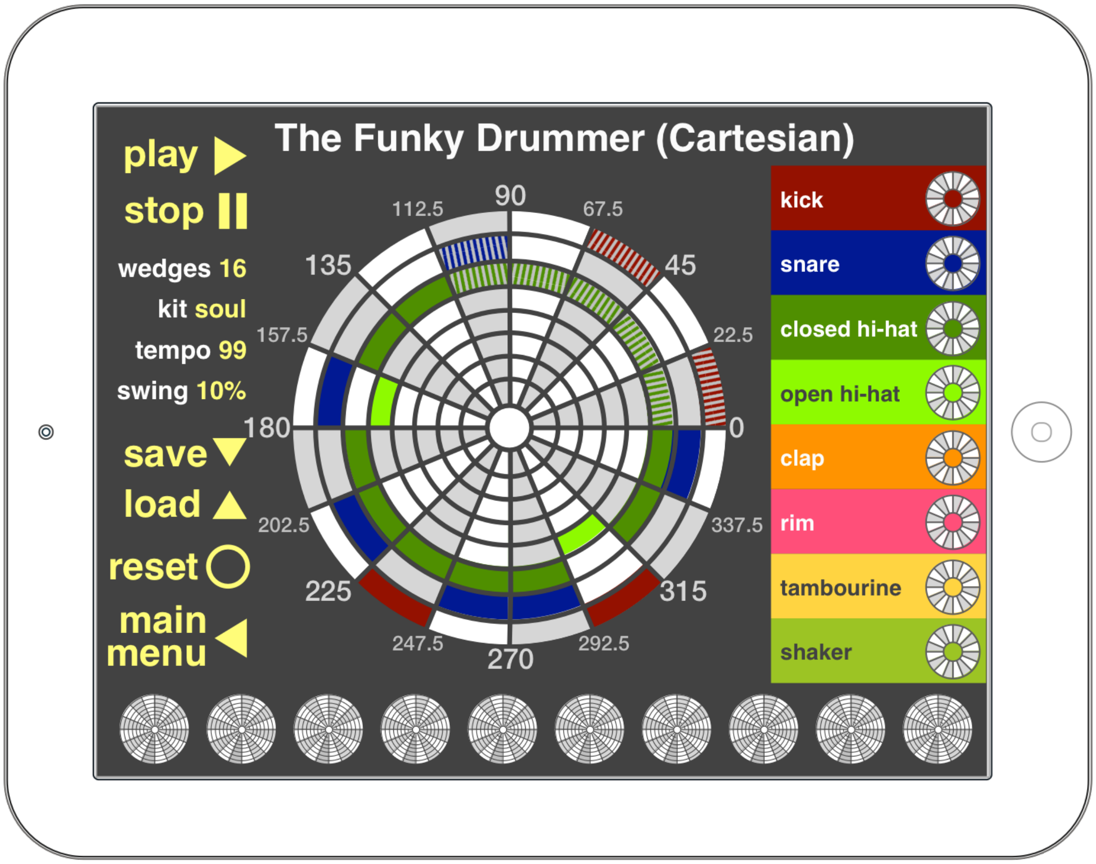
The Drum Loop is designed to take the best pedagogical features of the MIDI piano roll and enhance them. The spatial location of events helps reinforce their musical function. Users can see and hear for themselves the difference between a drum hit on a strong beat/cardinal point and weak beat/oblique angle. They can compare the duration of the wedges with the rate at which the playback head sweeps around the circle. They can double or halve the tempo, and compare that to doubling or halving the number of wedges in the pattern.

By rotating beat patterns, students can experience mathematical transformation, and hear its musical effect. This diagram from Toussaint (2005) shows (a) the Bembé rhythm, (b) Bembé rotated clockwise by one unit, and (c) Bembé rotated clockwise by seven units.

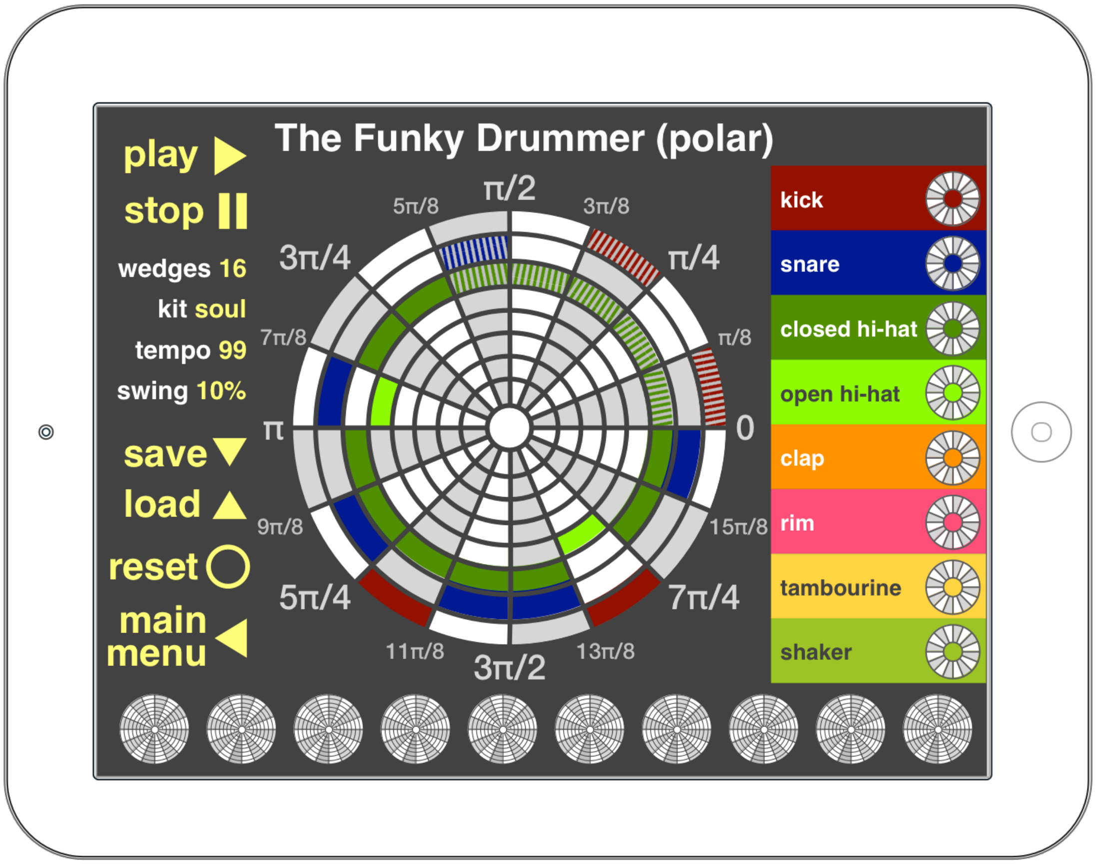


Symmetries and hierarchies of beat division are more apparent when reinforced by the rotational and reflectional symmetries of the circle. Furthermore, the Drum Loop can help students distinguish linear from rotational speed, and between linear speed and frequency.

The Drum Loop would be more useful for the purposes of trigonometry and circle geometry if it were presented slightly differently. Presently, the first beat of each pattern is at twelve o'clock, with playback running clockwise. However, angles are usually representing as originating at three o'clock and increasing in a counterclockwise direction. To create "math mode," the radial grid must be reflected left-to-right and rotated ninety degrees.



In this scheme, math students could describe beats in geometric terms. Snare drums usually fall on the backbeats, at 90 and 270 degrees. In the Funky Drummer beat, there are additional snare hits at 157.5, 202.5, 247.5 and 337.5 degrees. The "round" angles go with the strong beats, and the more "fractional" angles sound more syncopated. More advanced math students could perform a similar exercise using polar coordinates.



Now the relationship between simple/complex ratios and strong/weak beats is quite a bit more clear. Also, it is an intriguing coincidence that the angle $\pi/8$ represents an eighth note. One could go even further with polar mode and use it as the unit circle on the complex plane. From there, lessons could move into powers of *e*, the relationship between sine and cosine waves, and other more advanced topics. The Drum Loop could even be used to lay the ground work for concepts in electrical engineering, signal processing and wave mechanics.

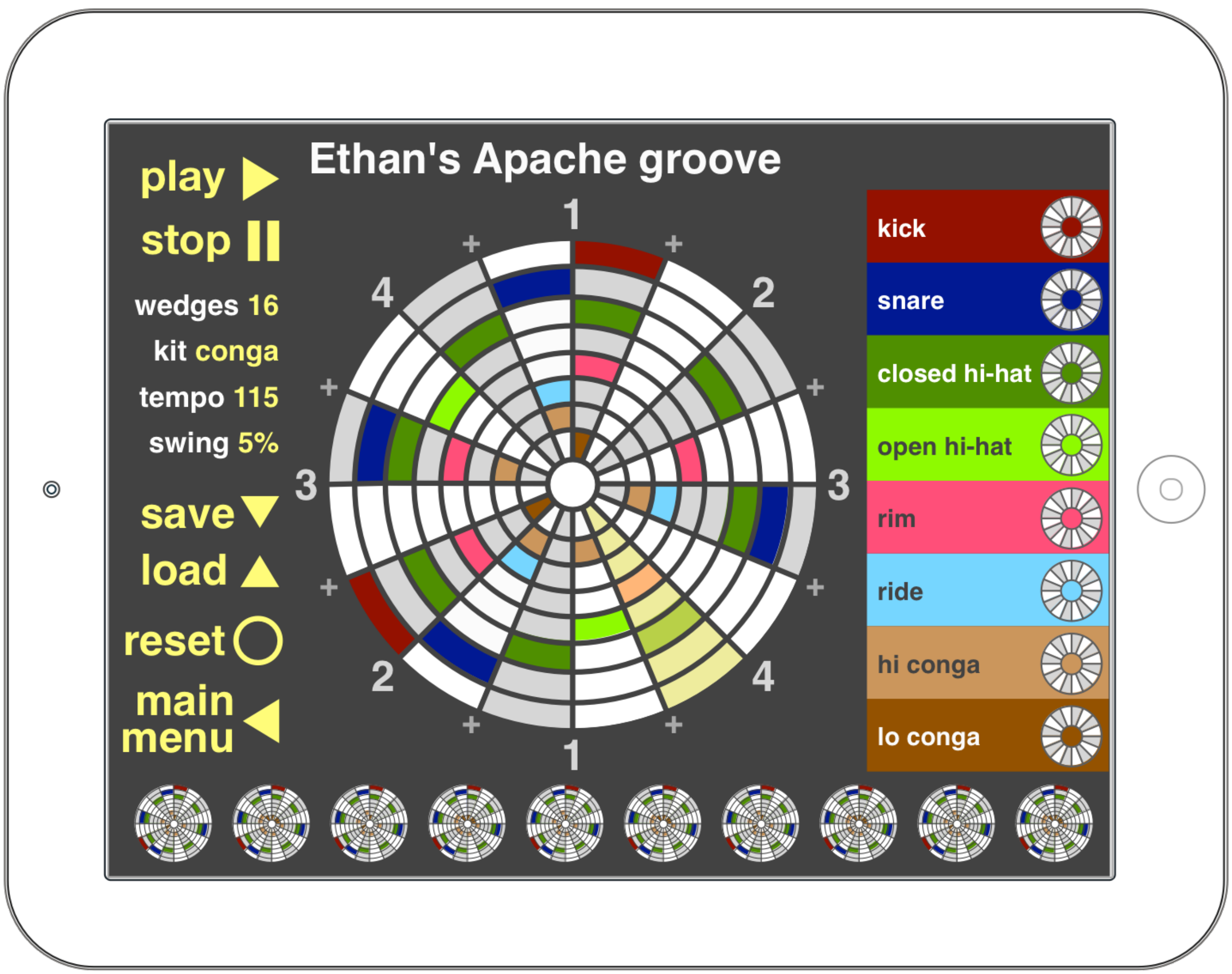
The New York State Learning Standards and Core Curriculum for Mathematics state as one of its objective that students "make mathematical connections, and model and represent mathematical ideas in a variety of ways." In an effort to make the Drum Loop maximally useful to public school teachers and students in meeting these goals, I have examined the state learning standards and identified some pertinent subject areas; these can be found in the Appendix.

Future work and feature wish list

Software development is extraordinarily time-consuming and labor intensive. As of this writing, development of the Drum Loop is still underway. There are a great many additional features we would like to include in the future that will make the app a dramatically more robust and versatile tool.

The pattern sequencer

Sequencing multiple patterns remains something of an unsolved problem. There is space across the bottom of the screen to store patterns in miniature form. Patterns stored there will simply play in order from left to right.



The unresolved questions are: how should patterns be stored and retrieved? Must they be played back in sequence, or should the user be able to jump among them at will, as in Ableton Live's Session View and Loopseque? The number of loops in the sequencer row is perfectly arbitrary, a function of the screen real estate available. Is ten the optimum number? Should it be more or fewer? If more, should the sequencer then occupy a screen view of its own? But in that case, how will the user see the current pattern and the larger sequence simultaneously? Considerable additional design, development and testing will be necessary to resolve these questions.

Two breakbeats of major historical significance had to be omitted from the Drum Loop's exercises because they are sixty-four steps long: the Amen break and the Apache break. Manipulating these breaks in the Drum Loop would require the ability to string at least four sixteen-step patterns together, and to able to effortlessly jump back and forth from one to another.

The Amen break

Gregory Cylvester Coleman is simultaneously one of the most influential and least known drummers in contemporary music. He was the drummer in a 1960s soul band, The Winstons. His claim to fame is a five and a half second break in an obscure song called "Amen, Brother," the B-side to the minor Winstons hit "Color Him Father." This short drum break rivals "Impeach The President" as the most-sampled breakbeat in history.

Ironically, it took several decades for "Amen, Brother" to come into any sort of prominence. Hip-hop producers started sampling the drum break in the 1980s after a pitched-down version was included on the first volume of Ultimate Breaks and Beats (Flores, 1986). Since then, the break has become ubiquitous not just in hip-hop, but in every style of dance music. It almost single-handedly spawned entire genres of electronica, particularly especially drum n bass and its various offshoots. It appears in TV theme songs and commercials. Casual music listeners have probably heard it in dozens, if not hundreds, of recordings. Given the ubiquity of the Amen break, its inclusion in the exercises would significantly enrich the Drum Loop's ability to put the genuine artifacts of our culture into the hands of students.

Apache

"Apache" was first written as ersatz Native American music by Jerry Lordan in the late 1950s, inspired by a cowboys-and-Indians movie. A group of studio musicians, Michael Viner's Incredible Bongo Band, recorded a funk version with an energetic drum and percussion break. This break was so ubiquitous in urban dance music of the 1980s that DJ Kool Herc describes it as "the national anthem of hip-hop" (Matos, 2005). As with the Amen break, Apache deserves a place in the list of classic breakbeats offered by the Drum Loop.

Exclusive open/closed hi-hat

On a real drum kit, it is not possible to play the hi-hat in open and closed positions simultaneously. Drum machines usually allow you to play both open and closed hi-hats simultaneously if you would like, though the resulting sound is quite awkward. I would like the Drum Loop to observe the real-life constraint, both to give users a sense of what is physically possible to play on a drum kit, and to constrain them into more aesthetically satisfying outcomes.

Durations greater than one rhythmic unit

Some sounds spill across the grid lines because of their long decay times, particularly ride and crash cymbals. Drum machines conventionally do not represent these sounds any differently than transient hits. Drum hit durations are most often controlled globally, for example with a single knob controlling the duration of all snare hits. MIDI sequencers will often enable control of duration by making the bars longer or shorter—if the drum sample is long enough, it simply cuts off when the MIDI event ends.

How might the Drum Loop give more control over duration? One possibility would be to have events able to occupy more than one grid cell. That would preclude other events occupying those cells, but it would mirror physical reality, since playing a drum usually terminates the previous hit's decay. For the time being, however, the present system is adequate. Having the duration of a sound be an inflexible parameter of that sound is just one of many constraints that force "drum machine" thinking.

Participatory discrepancies

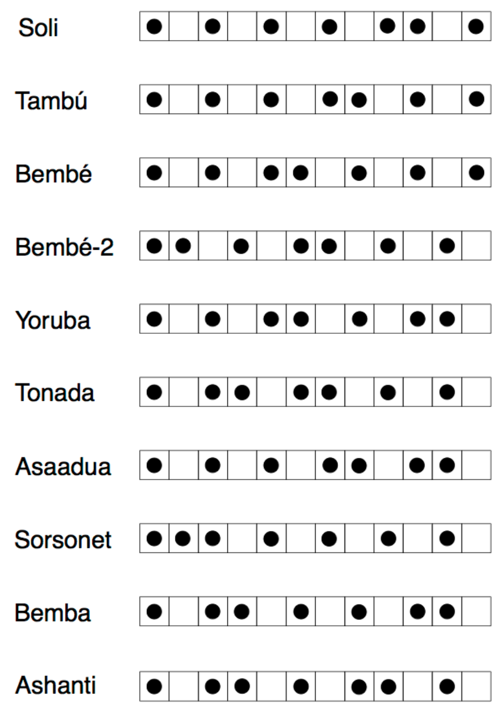
The Drum Loop is more like a hardware drum machine than a MIDI sequencer in that rhythmic events can only occur precisely on the grid lines. There is no possibility of introducing "humanized" imperfections, aside from the conspicuously artificial-sounding swing function.

Butterfield (2010) argues that repetitive music does not bore us because we do not hear each repetition as an instance of mechanical reproduction. Instead, we experience the groove as a process, with each iteration creating suspense. Will this time through the pattern lead to another repetition or a break in the pattern? Butterfield describes a groove as a present that is "continually being created anew." Each repetition gains particularity from our memory of the immediate past and our expectations for the future. The groove becomes more suspenseful if each iteration of the loop is slightly different due to participatory discrepancies. There is tension between the expected identical repetition and the imperfections of the actual performance. While the purely mechanical sound of quantized beats holds its own hypnotic charms, it would be wonderful to give Drum Loop users the option of using imperfectly quantized beats as well.

Some production software like Ableton Live and Propellerhead Reason enable the user to extract grooves from audio recordings. It is then possible to quantize MIDI events to the "live" groove, rather than the strict grid. Adding such "groove templates" to the Drum Loop would enrich its expressive possibilities significantly. There would be tremendous additional pedagogical value to visualizing the participatory discrepancies through slight resizing of the wedges, in a more complex version of the swing functionality.

Arbitrary time signatures

Because nearly all contemporary western dance music is in 4/4, there is no need to support other time signatures for the Drum Loop's pedagogical goals. Nevertheless, there is no technical reason why this must be so; in theory the Drum Loop could support any arbitrary number of beats per cycle. An early version of the Max prototype had a pulldown menu allowing the user to choose from a variety of meters. A future version of the iOS app might well support triple meter. Afro-Cuban tradition has a variety of patterns in 6/8 and 12/8 time that would make the basis for highly satisfying drum programming exercises. For example, to the right, Toussaint (2003) lists ten bell patterns in 12/8.



Similarly, there a variety of folk rhythms from eastern Europe and the middle east that can form the basis for exercises in 5/4, 7/4, 11/8 and other more complex time signatures. A more advanced version of the Drum Loop could include these rhythms as well.

The Drum Loop in the browser

Once the iPad version is complete and on the market, the next step will be to create a browser-based version. There are a number of advantages to software in the browser.

- Web-based apps are highly platform-agnostic.
- The user is not tied to a specific computer.
- Sharing and collaborating on work becomes effortless. This is especially valuable for classroom teachers who wish to use the software for assignments.
- It is easier to integrate a web-based app with an active user community.
- Web-based apps can connect together, in the same way that iOS apps can.

Specifically, I would like to be able to integrate the Drum Loop with the online notation tool Noteflight. Students struggling to learn the rhythmic aspects of notation would benefit greatly from being able to jump back and forth between Noteflight's formal representation and the Drum Loop's friendlier one. The two representations would reinforce one another, strengthening both. Furthermore, Noteflight itself integrates with a variety of other web services, most intriguingly YouTube. It is possible to use Noteflight to create a synchronized score or transcription to any YouTube video. I am quite attracted to the idea of finding a classic drum performance and scoring it with Noteflight, the Drum Loop or both.

Discussion/Conclusion

As I stated in the introduction, this thesis poses a series of questions about the present state of music education and software, and how the Drum Loop might contribute. We may now answer these questions.

Music education practice in the area of beginner-level rhythm teaching is limited by counterintuitive notation, a Eurocentric focus and disconnection from the culture of dance music. Beginner-level music education can be made more engaging and effective by incorporating constructivist methods: having students create music that is authentic and personally meaningful**.** When students are able to construct their own knowledge rather than passively receive it, they are more likely to experience flow, which carries a variety of secondary psychological and intellectual benefits.

Software can support better music learning generally, and rhythmic learning in particular, by supporting open-ended exploration and experimentation, and by appealing to the morpheme-level intuitive knowledge of music possessed even by beginners. The most intuitive rhythmic visualization and notation methods are the ones that represent music as patterns in space. Musical time should map onto physical space in a proportional way, so that longer musical events correspond to greater visual lengths. Rhythmic notation should make clear which events are metrically related, and how rhythm is built up recursively from cycles of cycles. It should also ideally show symmetries in the music that may not be immediately apparent to the ear.

The Drum Loop fills the vacuum of a beginner-friendly yet substantive rhythm tutorial app by combining an interface of toy-like simplicity with a wealth of real music to be engaged with and internalized. The Drum Loop uses a playful approach to rhythmic pedagogy. It encourages the user to tinker with the building blocks of dance music, using them as springboards to the user's own musical expression. Users can match challenge to ability by making their way through the exercises built into the Drum Loop at their own pace and in the order of their choosing. With the Drum Loop's beats in their ears and its visualization scheme in their mind's eye, students should be able to move more confidently into dance music production, classical notation and theory or any other field of musical pursuit.

The Drum Loop can support not only the broader learning of music, but also social and cultural studies and a numerous subjects in mathematics. It is my hope to develop the Drum Loop to the point where it can find its place in classrooms across different subject areas, or anywhere music is learned or played.

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Appendix: matching the Drum Loop to New York State's mathematics standards

Use of the Drum Loop by math teachers could support the following requirements from the New York State Learning Standards and Core Curriculum for Mathematics.

Fractions—Grade 3

- CCSS.Math.Content.3.NF.A.1 Understand a fraction 1/b as the quantity formed by 1 part when a whole is partitioned into b equal parts; understand a fraction a/b as the quantity formed by a parts of size 1/b.
- CCSS.Math.Content.3.NF.A.3 Explain equivalence of fractions in special cases, and compare fractions by reasoning about their size.
- CCSS.Math.Content.3.NF.A.3b Recognize and generate simple equivalent fractions, e.g., 1/2 = 2/4, 4/6 = 2/3. Explain why the fractions are equivalent, e.g., by using a visual fraction model.

Fractions—Grade 4

- CCSS.Math.Content.4.NF.B.3a Understand addition and subtraction of fractions as joining and separating parts referring to the same whole.
- CCSS.Math.Content.4.NF.B.3b Decompose a fraction into a sum of fractions with the same denominator in more than one way, recording each decomposition by an equation. Justify decompositions, e.g., by using a visual fraction model. Examples: 3/8 = 1/8 + 1/8 + 1/8 ; 3/8 = 1/8 + 2/8 ; 2 1/8 = 1 + 1 + 1/8 = 8/8 + 8/8 + 1/8.
- CCSS.Math.Content.4.NF.B.4 Apply and extend previous understandings of multiplication to multiply a fraction by a whole number.
- CCSS.Math.Content.4.NF.B.4a Understand a fraction a/b as a multiple of 1/b. For example, use a visual fraction model to represent 5/4 as the product 5 × (1/4), recording the conclusion by the equation 5/4 = 5 × (1/4).
- CCSS.Math.Content.4.NF.B.4b Understand a multiple of a/b as a multiple of 1/b, and use this understanding to multiply a fraction by a whole number. For example, use a visual fraction model to express 3 × (2/5) as 6 × (1/5), recognizing this product as 6/5. (In general, n × (a/b) = (n × a)/b.)

Ratios & Proportional Relationships—Grade 6

- CCSS.Math.Content.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."
- CCSS.Math.Content.6.RP.A.3b Solve unit rate problems including those involving unit pricing and constant speed. For example, if it took 7 hours to mow

4 lawns, then at that rate, how many lawns could be mowed in 35 hours? At what rate were lawns being mowed?

Ratios & Proportional Relationships—Grade 7

- CCSS.Math.Content.7.RP.A.2a Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin.
- CCSS.Math.Content.7.RP.A.2b Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.

Representation Strand—Grade Eight

- 8.R.1 Use physical objects, drawings, charts, tables, graphs, symbols, equations, or objects created using technology as representations
- 8.R.2 Explain, describe, and defend mathematical ideas using representations
- 8.R.3 Recognize, compare, and use an array of representational forms
- 8.R.4 Explain how different representations express the same relationship
- 8.R.5 Use standard and non-standard representations with accuracy and detail
- 8.R.6 Use representations to explore problem situations
- 8.R.9 Use mathematics to show and understand physical phenomena (e.g., make and interpret scale drawings of figures or scale models of objects)

Geometry

- G.PS.3 Use multiple representations to represent and explain problem situations (e.g., spatial, geometric, verbal, numeric, algebraic, and graphical representations)
- G.CM.2 Use mathematical representations to communicate with appropriate accuracy, including numerical tables, formulas, functions, equations, charts, graphs, and diagrams
- G.CN.1 Understand and make connections among multiple representations of the same mathematical idea
- G.CN.3 Model situations mathematically, using representations to draw conclusions and formulate new situations
- G.CN.6 Recognize and apply mathematics to situations in the outside world
- G.R.1 Use physical objects, diagrams, charts, tables, graphs, symbols, equations, or objects created using technology as representations of mathematical concepts
- G.R.2 Recognize, compare, and use an array of representational forms
- G.R.3 Use representation as a tool for exploring and understanding mathematical ideas
- G.R.5 Investigate relationships between different representations and their impact on a given problem
- G.G.21 Investigate and apply the concurrence of medians, altitudes, angle bisectors, and perpendicular bisectors of triangles
- G.G.54 Define, investigate, justify, and apply isometries in the plane (rotations, reflections, translations, glide reflections)

- G.G.55 Investigate, justify, and apply the properties that remain invariant under translations, rotations, reflections, and glide reflections
- G.G.56 Identify specific isometries by observing orientation, numbers of invariant points, and/or parallelism
- G.G.57 Justify geometric relationships (perpendicularity, parallelism, congruence) using transformational techniques (translations, rotations, reflections)
- G.G.60 Identify specific similarities by observing orientation, numbers of invariant points, and/or parallelism
- G.G.61 Investigate, justify, and apply the analytical representations for translations, rotations about the origin of 90º and 180º, reflections over the lines , and dilations centered at the origin

Algebra 2 and Trigonometry

- A2.R.6 Use mathematics to show and understand physical phenomena (e.g., investigate sound waves using the sine and cosine functions)
- A2.A.56 Know the exact and approximate values of the sine, cosine, and tangent of 0º, 30º, 45º, 60º, 90º, 180º, and 270º angles
- A2.A.60 Sketch the unit circle and represent angles in standard position
- A2.A.61 Determine the length of an arc of a circle, given its radius and the measure of its central angle
- A2.A.69 Determine amplitude, period, frequency, and phase shift, given the graph or equation of a periodic function
- A2.M.1 Define radian measure
- A2.M.2 Convert between radian and degree measures