The Poetry of Prediction: Musical Time, Rhythm, and Groove

Professor Milton Mermikides

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The River of Musical Time

Music is a temporal art. It unfolds in time, created, and delivered to us over a specific duration. Unlike a piece of visual art, which can be appraised in the order and length of time the viewer wishes, music takes as long as it takes, and its elements are fed to us in a carefully timed choreography. On the one hand, music needs time as its principal delivery system, but music also changes radically how we *experience* time itself. Why and how this happens will be revealed, but we should first unpack what we mean exactly by musical time and rhythm.

Since all aspects of music must involve a time component, we might ask if all music is rhythmic, and if not, what portion is? To better define rhythm, let’s consider a gradient of time starting at the shortest possible sliver of time, in other words the highest frequency (incidentally a unit of *Plank time* ≈ 5.39 x 10-44 seconds) down to larger portions of time (lower frequencies), where we meet the frequency spectrum of Gamma waves, X-rays. And ultraviolet light. Below this, we can perceive the colour spectrum of violet to red. Of course (vision is employed in music but it's not considered its primary canvas). Below visible light are infrared waves, microwaves and the radio waves upon which sound might hitchhike for broadcast and light-speed travel. It’s only when we get down to 20kHz (a twenty-thousandth of a second) that we enter the *audible spectrum*, which we can perceive as sound. This region is surprisingly wide, spanning down to 20Hz (a 20th of a second), and within these extremes lives everything we can hear, the sonic material of music: timbre to the full sweep of pitches. If we go below this region, we cannot hear this time component itself, but we can recognise these time slices as milliseconds to minutes, ordering and durational components of sonic objects. If the audio spectrum gives us *what* of music (pitches, chords, and timbre) this middle ground gives us when if music. Some pieces may last for hours or far longer as in the case of John Cage’s *Organ^{2}As Slow as Possible* - which is currently in year 23 of its 639-year performance. Rhythm is usually defined however we tend to constrain to elements of time which are perceptible (from about 10ms) to a reasonable short-term working memory of a minute or so. Slower than this *rhythmic spectrum* might be considered *sectional* or *compositional* time. Followed by historical and geological eras, until we approach the age of the universe, and the lure of infinity but these we will leave for Lecture 6.

For now, we might accept that the rhythmic domain (the milliseconds-minute range) is the playground of musical timing. It requires at the very least that we can hear and recognize sonic objects (notes, chords, sounds and their timbral quality), what order they appear in time and how long they last. Why this range is felt as the *when* of music (and the audible range of pitches and chords and timbres as the *what* of music) may be due to the fact that it correlates with many aspects of our physical engagement and activity with the world and each other’s. Our reaction times, stride rates, heart rates, short term memory all fit neatly within this zone of time, and we have developed sharp perceptual and predictive skills in this millisecond-minutes range.

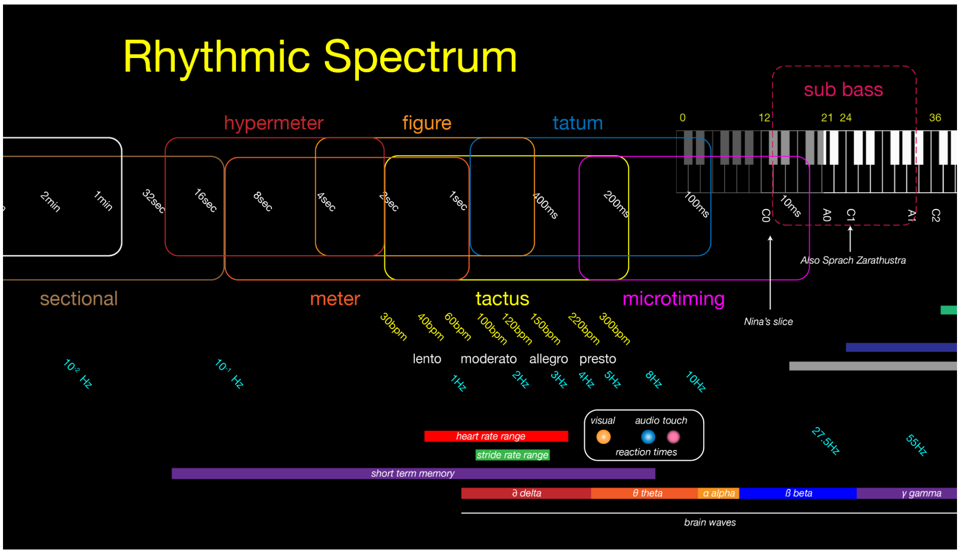

Figure 1. The central portion of the rhythmic spectrum in time duration (white), frequency (turquoise), and beats per minute (yellow). Indicative ranges for the tactus (beat), tatum (subdivision), meter and other rhythmic strata are shown alongside human physical activities including heart rate, stride rate, reaction times. Higher frequencies (shorter time spans) are shown on the right morphing in the audible pitch and timbral spectrum.

Within You and Without You: Sound and Movement in the Environmental and Social World

Sound and movement are closely linked in our evolution as a species, as well as our development from child to adult. Every breath, movement and step we take is accompanied by a sound, and we use this tight link between movement and sound to refine our physical connection to the world. Furthermore, the ability to use sound to learn about the behaviour of other entities is essential to our survival. Hearing helps us refine our actions, be alert to dangers and opportunities and crucially coordinate our movements with others. Sound is somehow able to link a movement in space (a series of steps and a jump) to a movement in time (a durational ordering), and it's perfectly natural for us to consider music as a *movement* through time. Movement and sound are so intuitively linked, that a piece of music might be heard as static, gradually moving or in rapid motion, even when devoid of any spatial component. And this connection between the temporal – a movement through time – and the physical movement of our bodies in the world is echoed in the time scales – and even language – we use in music. A traditional metronome runs from around 40 to 200 beats per minute, remarkably close to the range of human heart rates from an athlete at rest to the limit of stress. Embedded in this heart rate range also sits the tempo of human strides through a leisurely stroll around 60bpm, to moderate and more *andante* walking speeds up to around 110bpm up to an athletic sprint around 140bpm. A walk through the world is – through sound – linked to a walk through time.

The upper range of 'local' rhythmic perception (around half a minute) also aligns well with our capacity for short term memory. At our shortest perceptual capacity for time (typically in the 10-200ms range) we find our reaction times, and fine-tuned capacity for language decoding (in the word "pill" for example there is a ≈50ms between the 'p–' and '–ill' sounds). It seems we have calibrated our temporal appreciation of sound to a practical physical engagement in the world.

This linking of sound to movement offers the opportunity for social cohesion through play and dance, and the efficient accomplishment of labour all involve rhythmic coordination: an interlocking of movement aided by sonic signals and a symbiotic choreography of action. These all invite (if not describe) a naturally evolved music form, where coordinated sounds help us time activities, raising spirits while accomplishing necessary tasks. Again, the abundance of music on our planet (introduced in Lecture 1) means we find countless examples of such music emerging from work or play coordination. Take the nomadic *Bayaka* tribe of the Central African Republic and Republic of the Congo. Among their hugely rich and sophisticated musical practices is *liquindi* – water drumming. While bathing, children indulge in a musical game, drumming, sloshing, and slapping the water in complex interlocking patterns until the adults reward them with praise and by singing to their liquid rhythms. It seems this activity associates an essential task with play, increases bonds between the children, parents and children, the present to the past, and develops perceptual and physical skills in all. Often music is more than entertainment: Alan Lomax's 1948 recording of 'Rosie' – prisoner field workers in Mississippi coordinating axe strokes with powerful call and response blues phrases, aids and cajoles the brutal labour and perhaps imbues enough hope and stamina for the next stroke. Sea shanties emerged in different forms, (short-haul, halyard, and capstan shanties) each requiring the direction of a skilled task (and musical) leader, and a series of actions to complete the task - music emerging from specific necessity. Not only do work songs provide rhythmic frameworks to accomplish critical tasks with efficiency and coordination, but they are also a bonding exercise – a way to gain trust and a sense of unity between individuals – qualities which themselves aid survival.

Though spatially fixed, we feel such societal and physical movement in music, and even when divorced from its dance and work function this motion persists in the dimension of time. Musicians share a sense of common pulse and movement with extraordinary precision and evidence even shows that audience members - when moved by the same music – synchronise their breathing and heart rates. As such the boundaries between music as a practical tool for coordination, group cohesion and pleasure are blurred, it seems that music can do all at once, aided by rhythm's precise choreography through time.

Necessarily in the Right Order

In music, as with text and language, the *ordering* of events matters – sometimes radically – in terms of meaning. "We are not friends" vs. "Friends, we are not." vs. "Friends, are we not?" vs. "Are we not friends?" hold different expressions, as do the ordering of a four-note melody. In addition to ordering, *relative duration*, the comparative size of sonic events (including silences) matters. Another form of language – Morse code – in fact reduces communication down to the simplest components of ordering and relative duration. There are only durational states (short *dots*, long *dashes,* and short and long silences), allowing the listener to reconstruct the letters of the message. Music is so reliant and hungry for even this basic engagement with time, that some composers use Morse code as an effective creative constraint or hidden reference (or 'Easter Egg') in their music. These include Delia Derbyshire's embedding of the morse code 'BBC' – through painstaking tape splicing – in her theme of *BBC Newsreel*. Other examples are Lalo Schifrin's harnessing of M (long-long) and I (short-short) in the iconic rhythm of the **M**ission **I**mpossible theme (1967) and Ronnie Hazlehust's 1973 complete Morse code spelling of "S-O-M-E-M-O-T-H-E-R-S-D-O-A-V-E-E-M" in the rhythm of its theme tune.

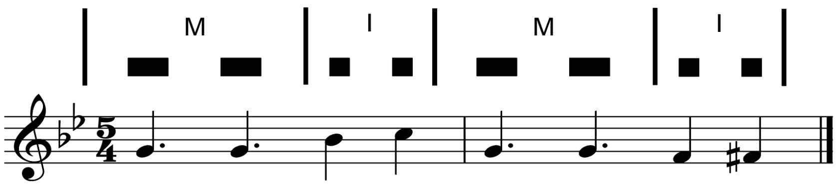

Figure 2: Morse coding of the initials of Mission Impossible in Lalo Schifrin's theme.

Musical rhythm, however, is inordinately more complex than a line of dots and dashes, but to understand it we need to explore our relationship with sound, movement, and time.

From the beatless to The Beatles

Our brains – as sophisticated as they are – have a simple goal, and that's to help us to survive and prosper (or at least our genes to do so). They constantly take in information from the external world and – using the resources of memory and reasoning – attempt to foresee the future so that we might take the most advantageous course of behaviour (to hide, follow, flee, fight, dodge, investigate and so on). In short, we are prediction machines, and our quite staggering thirst and skill for clairvoyance is deeply exploited by music. Rhythm exploits this evolved tendency to find patterns, "minds "wired" for expectation" (Huron 2006 p 7). For our survival, predicting future events was (and is still) vital, but these predictive faculties make no distinction between the movement of objects and animals in the wild, and musical objects over time. We are programmed to predict and be rewarded with dopamine doses in the hunt (or evasion) of rivals, prey, mates and events in the natural world.

However, these pattern-finding faculties come at the cost of cognitive stamina and distraction from other events and thus there is incentive to find the simplest, most likely, and most efficient predictions, and to continually update them, to maintain efficiency. For example, if we hear an isolated event, and a similar one a second later, a natural prediction is to expect another one at a similar interval later. An attentional window opens a second later (keeping attention open continuously is costly and so strategic 'snapshots' are essential). If we were to hear an event near to this, our prediction would be confirmed, our attentional peaks become more accurate and focused, building a trustworthy and efficient predictive framework to release cognitive attention for other (in this case musical) matters. Note that the reference structure that is built improves predictive efficiency, but also tolerates missing data. In Figure 3 a couple of predicted sonic events are missing but the predictive framework tolerates these. Frameworks are modified or discarded in light of new sonic information, and we build these predictive grids rapidly, intuitively and usually unconsciously. Our rhythmic experiences lie at the intersection of external sounding objects and these internal virtual reference structures, allowing the sense of satisfying reward from a well-made prediction, and surprise, delight or confusion from a forecasting error.

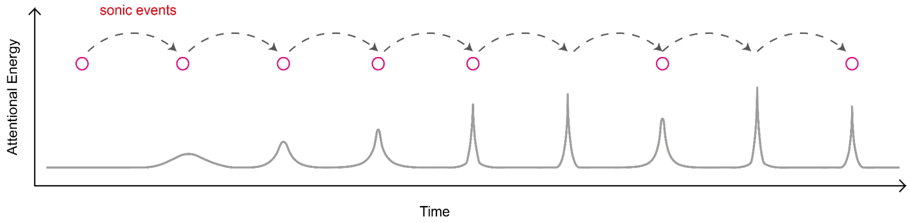

Figure 3: An illustration of the focusing of attentional energy in response to periodic sonic events. Note that some omissions, and 'near misses' of sonic events are tolerated by the predictive framework.

We are particularly attuned to – and accurate in predicting – repetition in the range of about half a second to 2 seconds - the domain of the beat (also known as pulse or *tactus*). This is the rate where most of us tap our feet, hands, or nod our heads to music and is a primary thread of rhythmic experience. This perception of pulse – demarcating time into a series of expectational nodes – transforms our experience of time as a continuous gradient (we might be called 'smooth' or 'clock' time) to a gridded or 'striated' ('striped') sequence were certain points of time have greater predictive weight (grid or musical time). We move from a description of time in absolute time intervals (in seconds and milliseconds etc.) to relative time duration (the world of 1/8th notes, crotchets, dotted minims etc. which all share a reference point). Not all music induces a sense of pulse however, some generally favour a smooth sense of time (such as Japanese traditional music or ambient electronica), while others enjoy the transition from smooth to gridded time such as in Hindustani *ragas* where there is a transition from the 'smooth' opening *alap* ('prayer') to the gridded rhythmic cycle of the *tala* – which quite aptly translates to 'measure', 'clap', or 'touch'.

Layers of Time

There is far more to musical rhythm than a series of equally spaced events, so let's carefully increase the complexity to gain some real world insight. Take Figure 4a which represents the *maqsuum* rhythm compelling found in Egyptian, Middle Eastern and Mediterranean folk music. This repeating cycle of five 'hits' inscribed with orange dots, is compelling and easy to absorb, but how does a listener 'entrain' to it? A listener could absorb the entire pattern, predicting each hit as it repeats (Figure 4b), however this is quite an involved pattern and inflexible to further information.

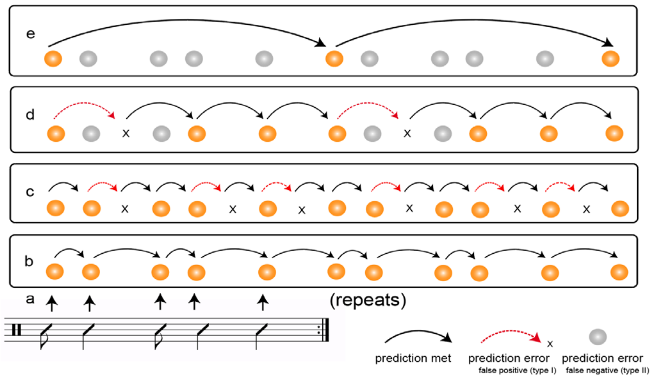

Figure 4. An example of prediction matching: the maqsuum rhythm (a) together with a selection of useful rhythmic frameworks. Prediction errors are annotated with red waves and Xs (for false positives) and grey dots (false negatives). Each of the predictive layers demonstrate trade-offs of these errors with cognitive simplicity.

Most listeners in fact will tap or nod along in even pulses (Figure 4d), this simple framework on the central *tactus* level requires minimal effort and catches three of the five hits. There is however a mismatch between the predictive pattern of beats in Figure 4d and the sounding events. One of the expected hits doesn't appear: This false positive - predicting something that didn't appear is marked with a red arrow and an X. It also misses the second and third of the 'hits'. These hits with type II errors (false negatives - unpredicted events) are marked in grey. The term 'error' suspects a weakness with the framework, but a slightly mismatched framework has distinct advantages:

a) Predictive frameworks built on a wealth of statistical learning, and even if one rhythm does not fit the grid, it leaves the possibility of hits appearing in those empty nodes. They are prepared for change. For example Figure 4a is a predictive framework which aligns with the beginning of each cycle, it ignores much of the detail within the cycle but forms of useful higher level grouping (which in this case might be called the measure or bar).

b) Information is gathered from the mismatches, for example the grey nodes suggest the existence of another rhythmic layer (4c) below the level of the beat which – although having more 'false positives' – catches every hit, and leaves open the possibility of further activity on this layer. This subdivision or *tatum* layer operates faster than the tactus and may be conceived as the largest time duration that manages to capture *all* salient rhythmic activity. 'Tatum' is in fact a contraction of 'temporal atom' and an homage to jazz pianist Art Tatum.

c) An element of surprise and challenge to prediction is central to rhythmic expression, the novel surprise and the missing expectations (or 'loud rest') can elicit a wealth of emotional responses from joy, delight, humour to bafflement.

Rhythmic listening rarely involves just one predictive layer; it exists on multiple simultaneous levels, each of these serving a useful function in 'explaining' the incoming rhythmic information, creating hierarchical groups, and preparing for new information. Some predictive layers are named and illustrated in Figure 5 along with some typical ranges of time durations. Each of these are felt differently, and predictions on any or all layers can be met, thwarted, challenged, made ambiguous, or modified to complex expressive effect. They can even transform identities as when beat groups become beats in *metric modulation.*

While the *tactus* may be seen as the central layer it is typically flanked by layers below the *tatum* (subdivisions) layer splitting beats into (usually 2, 3 or 4 partitions). Below this is the world of microtiming which commonly escapes standard notation. Above the tactus are the longer layers of beat groups, meters, groups of meters (hypermeters) and even larger sections. While music notation (and Digital Audio Workstations) acknowledges some of these layers, many are implicit, but all are present in the musical listening and making experience.

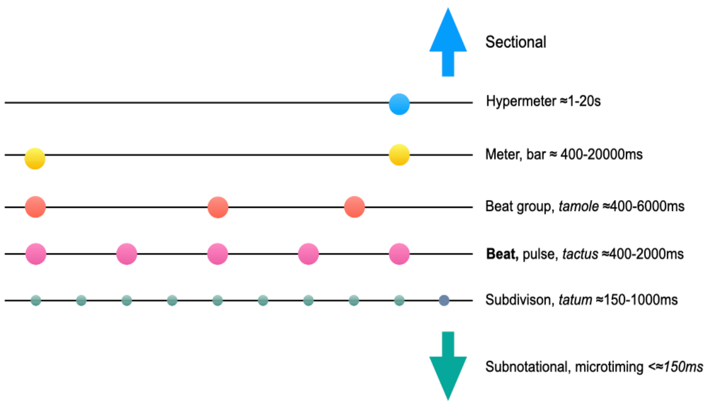

Figure 5. Common predictive layers in music listening and making, with indicative ranges of durations.

The Binary Default

Neurophysiological experimentation has revealed a predictive phenomenon that might be dubbed the 'binary default'. When listeners (from a wide range – but not all – cultures) are presented with a series of *identical and evenly-spaced* pulses devoid of any other context, they exhibit EEG responses that indicate a mental 'accenting' of the odd-numbered impulses also known as the 'tick-tock' effect. In other words, if we hear a string of identical isochronous beats we impose a 'binary' metric structure with stronger attentional biases on 'downbeats' 1, 3, 5, 7… and weaker on 2, 4, 6, 8. At this point, we need remind ourselves that prediction operates on multiple layers - so that not only the odd-numbered events are 'accented' but also the first two events over the next two, the first four over the next and so on. Thus, a binary metric profile emerges 'ground up' as a natural listening phenomenon.

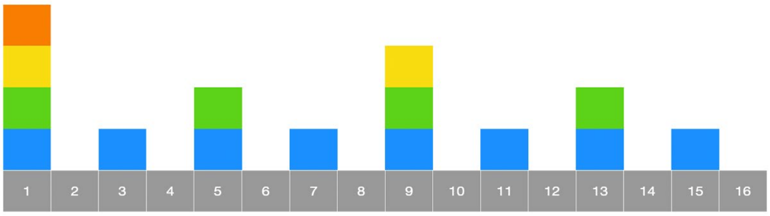

Figure 6. An illustration of the binary default. A series of identical pulses (in grey) are mentally grouped in pairs (blue). These pairs of pairs are similarly grouped (green) and so on. This leads to an expectational profile, where node 1 (which superimposes five expectational waves) feels stronger – more expected – than other metric positions.

This is illustrated in Figure 6, which demonstrates the profile formed from the superimposition of every 1, 2, 4, 8 and 16 events (these are 'pure binary' or multiples of two). Note how this model correlates with our concept of 'strong' and 'weak' beats. *When* a note is played in terms of metric position matters in terms of experience. We also see a remarkably similar pattern emerge in the *realization* of sounding objects across many styles so far tested, in the commonality of binary metric structures (2/4 and 4/4 etc.), the use of sections of 4, 8, 16 and 32 bars, as well the frequency of notes in metrical structures. Puerto Rican folk songs, Scott Joplin rags and Haydn's String Quartet no.1 all look stunningly similar to the hypothetical profile in Figure 6. There are variations from the binary profile of course (the last beat of a bar is more weighted for example), but given the diversity of music sampled, it is remarkable how – from the simple concept of 'pairs of pairs' – how ingrained such metric expectational profiles are in musical structure and experience. Such a profile explains the sense that in musical listening some moments feel more cathartic ('strong') than others, this sense of exceptional build results from the superimposition of multiple expectational ways, some on a beat to beat (or subdivision to subdivision) level, others at higher groupings of meters and hypermeters. Despite repetition, every point of time feels different. Listeners – and certainly musicians – learn to ride these waves of expectation, sensing intuitively these crests and troughs of prediction, and delivering or withholding predicted events to emotive effect.

Sweet Surprise

While we listen to music, we build expectational frameworks based on the incoming sounds, our innate predictive faculties, and previous listening experiences. We seem exceptionally good at predicting musical events, or conversely, we make music to match our predictive impulses. Both are likely true. It seems we make music based on what we expect to hear, and we build our expectations from listening to music. Our predictions when listening to music are usually shared: A whole crowd of people will quickly entrain, clap and move to a previously unheard rhythm. Furthermore, it seems we enjoy having our musical predictions met: Music uses a significant amount of repetition, and we enjoy relistening to our favorite pieces again and again. However, we are also delighted by the novel – a sprinkling of surprise – in music.

When listening to music, there is is a constant interaction between the sounding events, and a dynamic predictive framework, different metric positions feel different when played or omitted. One-way rhythmic surprise is introduced into our predictive frameworks (such as Figure 6), is by shifting emphasis in the music from the so-called strong beats (e.g. 1, 5 and 9) – where we most expect something to happen – to the less expected positions (e.g. 3, 4, 7 etc.). So by playing these weak nodes, or more crucially omitting stronger nodes, the listener is forced to rely on their own internal frameworks. This creates a dissonance, a mismatch of the expected and the heard, and to resolve this a virtual or bodily movement – refinding the beat – is enacted.

Neuroscientific research shows that we gain pleasure – and in the case of a rhythm a desire to move – from the right level of surprise. The peak of our pleasure and desire to move appears somewhere between pure predictability, and complete bafflement. Figure 7 (from Witek at al 2015) demonstrates this 'inverted U', where the peak of pleasure and desire to move exists at this middle ground of surprise.

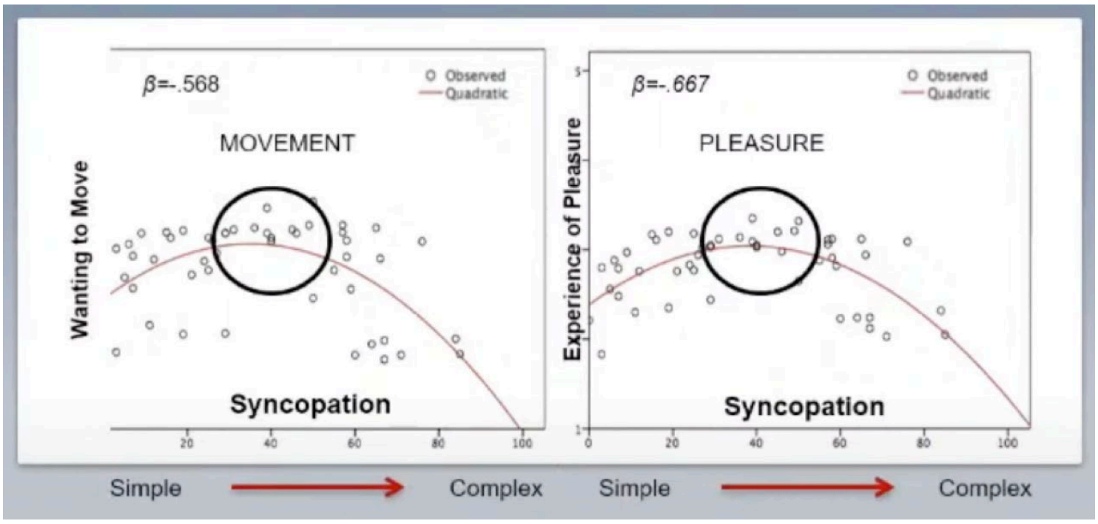

Figure 7: The 'inverted U' of syncopation, with pleasure and body-movement from Witek MAG, Clarke EF, Wallentin M, Kringelbach ML, Vuust P (2015) *Syncopation, Body-Movement and Pleasure in Groove Music.*

Music routinely contains small – or significant – surprises. You might think that relistening to the same piece would ruin the surprise, and thus the pleasure, but our predictive faculties are so automatic that we can experience the same confusion or delight with multiple listens. But what is the nature of a musical surprise?

Displacement Dissonance

Not all rhythmic structures are in duple meter (some contain 3, 6, 12 or other number so beats), and not all beats are subdivided into 2s or 4ths (3 is common also), but there is it seems a tendency towards binary structure on multiple levels – for example we still might expect to hear four bars of a repeating 'odd meter'. Rather than a limit to the musical experience, such tendencies – to expect pairs of pairs of patterns – provides countless opportunities for music expression, whether we meet the expectations or otherwise.

Musical surprises are not without structure, there is a logic of the unexpected. One such engine of surprise – perhaps universal in metric music – relies on the binary profile of expectation in Figure 6. Some metric positions are more expected (strong beats) than others (weak beats). By simply reducing the emphasis on strong beats, or omitting them entirely in favour of weaker beats, we create a sense of surprise in the listener, entrusting them to rely on their own internal grids to make sense of the rhythm. This *displacement dissonance* can create a pleasurable puzzle for our predictive faculties, but they also invite a physical movement, as our bodies gesture to fill in the missing rhythmic information. This mechanism is often called syncopation, but that is usually used just for playing 'off-beat', the perspective here is that every metric position has a different relative level of expectation, and opportunity for dissonance and expression. Figure 8 presents a collection of passages (of countless possible) showing how the exceptional profile is stripped away by the surface material. Figure 8a (the theme from Mozart's *Eine Kleine Nachtmusik*) – although containing gaps – is very rhythmically consonant emphasising (annotated with dots), the strongest beats (and tallest expectational towers). Figure 8b (*Spring Rounds* from Stravinky's *The Rite of Spring*) has a strong downbeat but emphasises the even number positions 4, 6 and 8) creating a lovely dissonance longing for a resolution. The subject of Bach's *Invention No.13* (Figure 8c) avoids entirely the first strong downbeat and features rhythmic 'pushes' anticipating the next meter group creating a sense of forward propulsion. Figure 8d (the distinctive two note guitar part in the verse of Nirvana's *Smells Like Teen Spirit*) sits on weak beats creating a compelling angular motif despite its simplicity.

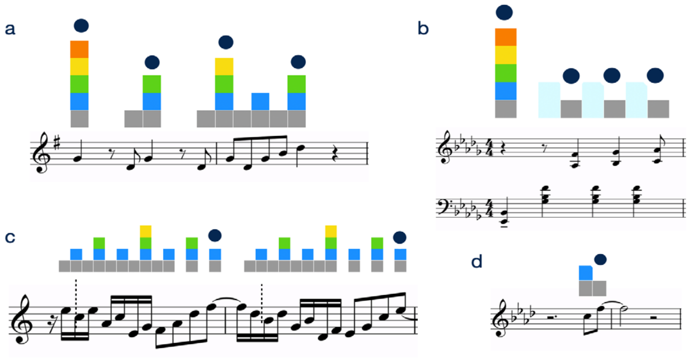

Figure 8: Four musical passages illustrating the level and nature of displacement dissonance in relation to the binary profile.

Displacement dissonance adds flavour to a musical passage, and some musical styles have that seasoning baked into the style. Take the 'back beat' which hits beats 2 and 4 in 4/4 meter (Figure 9a). The first recorded example of this is Elder Burch's 1927 *Love is a Wonderful Thing*, but its origins are undoubtedly West African. This simple displacement is hugely powerful, elevating a choir from dutiful singing to a community where the empty strong beats are felt together. The backbeat is so established in pop, rock, jazz and in its myriad related styles that it is now normative. In fact, in some situations clapping on 1 and 3 is as frowned upon as clapping between movements at a classical concert.

The backbeat is endlessly varied from its simplest form (with minor shifts or extra hits, but remains remarkably prevalent. It also appears in 'half-time' form (Figure 9b) hitting beat 3, and 'double-time' landing between every beat (Figure 9c) as in the guitar stabs of reggae and ska.

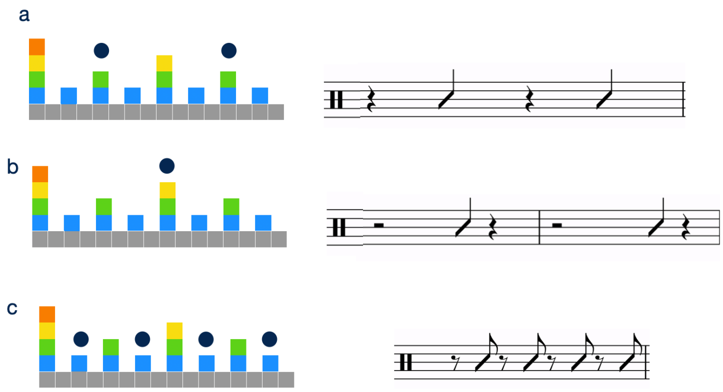

Figure 9: A backbeat pattern in regular (a), half-time (b) and double-time (c) forms.

Grouping Dissonance and the Hierarchy of Primes

Grouping dissonance occurs not just by displacing musical material from strong to weak beats, but by grouping rhythmic material in a way that causes a 'friction' – a contrasting predictive thread - against the underlying structure. Let's consider a repeating series of eight pulses (Figure 9 lowest line). In a binary structure, these might be felt as two groups of four, or four groups of two pulses. We can, however, create rhythmic interest in this binary structure by implying a grouping of three pulses. With a pattern of pulses of 3, 3 and 2, we are momentarily implying a grouping of 3 against the binary structure before resetting to the next group of 8. This rhythm – known as the *tresillo* – is depicted in Figure 9 in graphic and musical notational form. It is perhaps the simplest - and mildest - form of grouping dissonance but is extremely common around the globe forming important components to entire stylistic forms. It makes up the rhythmic heartbeat of the Argentinian tango, and throughout the music of Astor Piazzolla. It's found in West African drumming, South American clave patterns, and is ubiquitous in rock, pop and many other styles.

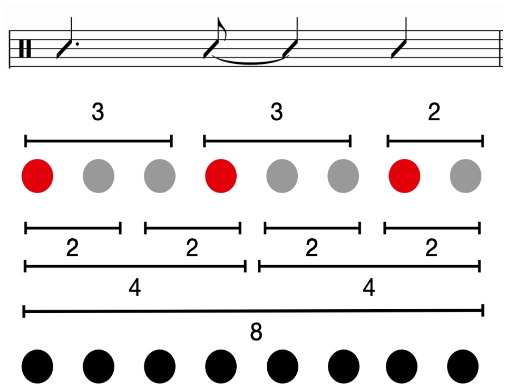

Figure 10: The tresillo pattern, demonstrating a 3-3-2 grouping dissonance.

It can appear in direct or subtle ways from clear stabs to the direction of notes in an arpeggio. Its underlying structure can be quite elaborated, while maintaining its rhythmic power. Take Figure 11 (sourced from the opening of Rage Against the Machine's *Wake Up*) where they played rhythm (a) is made up of hits (black dots with red at the beginning of each group) and silences (empty dots). This series of 6, 6 and 4 pulses can be reduced down to an underlying 3 - 3 - 2 *tresillo* pattern (b).

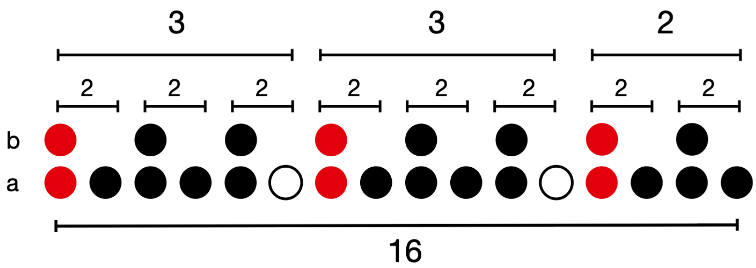

Figure 11: The implied tresillo pattern (b) of the opening guitar riff (a) in Rage Against the Machine's Wake Up.

The *tresillo* acts as a level of dissonance in many music forms, a seasoning of rhythmic flavour. But we can increase its level of spice: We can keep those groups of 3 beats going longer, until the next binary landmark of 16. This *double tresillo* pattern is made up of beat groups 3 3 3 3 2 2 creating a more prolonged grouping dissonance as the groups of 3 'phase' against the underlying binary structure, pulling at the listener's expectations. The opening of AC/DC's *for Those About to Rock,* the section from 0:53 of Led Zeppelin's *Kashmir* and the instrumental interludes (e.g. 0:24) of *Here Comes the Sun* by The Beatles are all examples of the *double tresillo* (Figure 12).

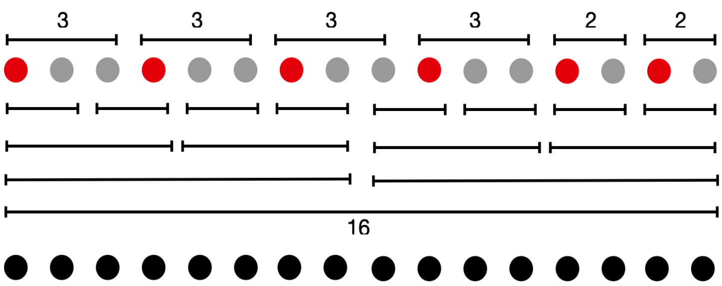

Figure 12: The double tresillo pattern. Here, 16 pulses are grouped in a pattern of 3-3-3-3-2-2, e.g. The Beatles Here Comes the Sun (0:24)

You may guess the next step we will take, and that is to let the groups of 3 run even further, without ever resetting them. If we consider how these groups of 3 pulses interact with a meter of 8 pulses, you will see that 8 groups of 3, match three groups of 8. The 3s will never line up with a 'pure binary' number of 8, 16, 32 or 64 etc., but this alignment of 24 pulses (that is 3 meters of 8 pulses) suggests a higher-level grouping - a 3-bar hypermeter. The effect of this is very evident in Radiohead's *Weird Fishes*. The endless 3s of arpeggiated guitar against the binary metric structure creates epiphanic moments at the 3-bar hypermeter. *Top Secret* by the Yellowjackets uses a very similar device, but here the guitar starts the track solo playing groups of 3, so when the band kicks in at the 'correct' grouping the listener must realign their internal framework, and when they do so, they get rewarded by the delicious dissonance.

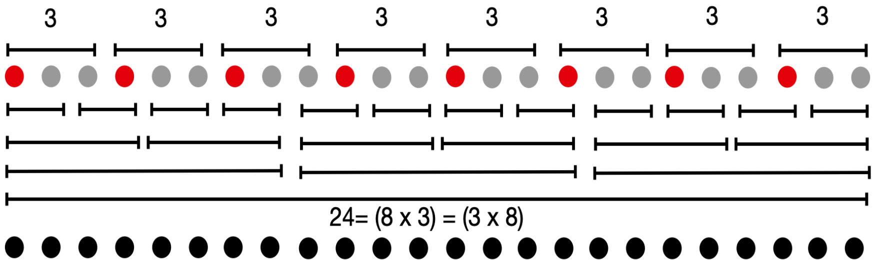

Figure 13: The *triple tresillo* pattern of Radiohead's *Weird Fishes*, the verses of Led Zeppelin's *Kashmir* and Yellowjackets' *Top Secret.* Repeating groups of 3 and 8 meet at the 24-pulse (3+bar hypermeter).

Grouping dissonance can be variously subtle, temporary, extreme and prolonged, and might involve multiple conflicting groupings such as a *passacaglia* passage in Benjamin Britten's *Peter Grimes* where a 13-beat bass ostinato accompanies a number of conflicting and changing groupings. Jazz saxophonist Steve Coleman, by instructing his bandmates, improvises live complex 'polymeters' - multiple simultaneous meters. 80s pop band The Cars in *Touch and Go* run 5/4 bass and drum pattern against keys and vocal in 4/4, and math-metal band Meshuga as a signature device employ long, uncompromising passages of grouping dissonance.

Fair Enough: Euclidean Rhythms

A range of musical cultures seem to converge on similar ideas independently, and one such concept is that of *Euclidean distribution.* The theory of this runs deep, the maths gets knotty and there is some conflicting terminology, but here is a simple introduction. Some musical contexts, particularly when associated with dance and/or fast tempos, seem to gravitate to rhythms where the duration of hits are quite similar. That is to say, given a number of hits in a repeating cycle, they are stretched quite evenly across the allotted time. In other words, rather than being scrunched up in some locations, they stretch over the entire span – like the courteous taking of seats in a train carriage. Incidentally, the same is generally true of musical scales which tend to be relatively spaced across the octave rather than confined to some regions. One might see why this, when playing at higher tempo, would make performance of such rhythms easier as it avoids close gaps between hits. Furthermore, it means the hits are of roughly similar length reducing cognitive load.

So a Euclidean rhythm (as I'll define it here), is a rhythm where the beat groups are as similar as possible, the available time is distributed as fairly as possible among the hits. We encounter such 'maximally fair' distributions when dealing out cards. If the number of cards dealt does note divide evenly among the players, some people will get one more (or less) card than another player, but that is the limit of the unfairness. So too with Euclidean rhythms, the beat groups are either the same, or they differ only by one. So 3+3+2 (the tresillo) is Euclidean, so is 3+3+4+3+4+3. The pattern 2+4+1 however is not. It is too unfair, and the 3 groups of 7 elements are fairly distributed as 3+2+2. Here we will define Euclidean rhythms as rhythms where the beat groups only differ by 1 and can be in any order. So, 3+3+2, 2+3+2, 3+3+3+3+2+2, 2+3+2+3+2, 3+4 are all Euclidean.

We find such rhythms around the planet, so much so that if we take two different integers, say 3 and 7, there will be a Euclidean rhythm and musical form (with 3 hits in a 7-beat cycle) to match: 2+2+3 which is the *Ruchenitsa* of Bulgarian folk music. It is also found in Dave Brubeck's *Unsquare Dance* – inspired by a tour in Turkey. Note that this rhythm does not fit into our binary structure of regular beats, described from various perspectives as 'irregular', 'limping', 'odd' and non-sochronic, but their 'smoothness' makes sense of any rhythmic cycle. Euclidean rhythms are found in West Africa, South America, Blues, Jazz and now pop and rock music, but are particularly prevalent in Arabic music (there are 176 such rhythms in the *Muwashahat* a 1st Century encyclopedia of rhythms based on Arabic poetic forms). These rhythms made their way into Flamenco and Mediterranean, and in particular Bulgarian dance forms. Bartók transcribed and employed them extensively, see for example his *Six Dances in Bulgarian Rhythm*. In order to capture the essence of these beat groupings, he hacked standard music notation with 'additive' time signatures for example (3+2+3)/8 rather than the conventional 4/4. A small collection of Euclidean rhythms are presented below each showing the number of hits, the length of the cycle, the pattern of beats and an example musical form. For those in Bartók's *Six Dances in Bulgarian Rhythm*, the additive meter or grouping is shown (BR2 means the second of the six dances)

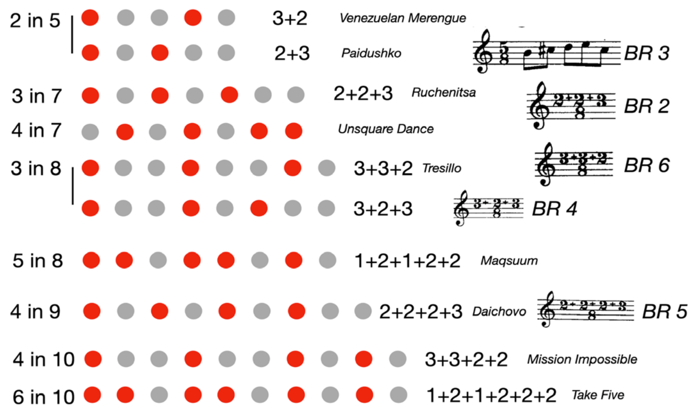

Figure 14: A collection of rhythms showing 'Euclidean' distribution, where a rhythmic cycle is divided into parts as evenly as possible. Example dances and pieces are shown.

We find examples of these running up to 35 beat cycles (the *Yovino Horo*), and an exhaustive list is a lifetime's work. In the popular sphere we find rhythms like these in film music, jazz (sparked perhaps by Dave Brubeck's *Take Five)*, prog rock (from Pink Floyd to King Crimson) and now more mainstream (less overtly 'muso') rock with Radiohead's extensive embrace of Euclidean rhythms. They are ubiquitous in electronic music (where infectious rhythmic cycles is the remit), and are now can be generated via software or hardware. After centuries, these rhythms are still going strong.

Multiplicity

Note that each of these rhythms in Figure 14 are very flexible, the beat groups can be re-ordered, and even 'inverted' so that hits become rests and vice versa (see *Ruchenitsa* vs *Unsquare Dance*). They can also be 'rotated' – started in any position to generate yet more rhythms, and even started *between* beat groups). Take the Flamenco *compás* a 12-beat rhythmic cycle divided in 5 parts (3+3+2+2+2). It is taught as positions on a 'clock' (12, 3, 6, 8 and 10 o'clock), with various dances starting from different positions on this clock. *Bulerias* starts as 12 o'clock 3+3+2+2+2, the *Siguiriyas at* 8 o'clock (2+2+3+3+2) and the *Soleares* family of rhythms at 1 o'clock - between hits, creating the pattern: 1 2 **3** 4 5 **6** 7 **8** 9 **10** 11 **12** and hugely important rhythmic backbone in Flamenco (see Figure 15).

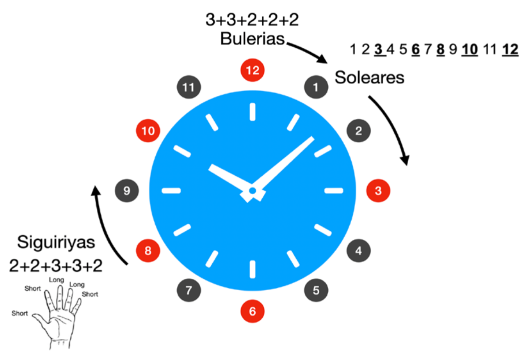

Figure 15: The Flamenco Clock - a pattern of 5 hits in a 12-beat cycle, with example rotations.

Such Euclidean rhythms in a 12-beat cycle are also embedded in West African music: The *Ewe* tribe (of the Ghana region of West Africa). One of their ancient dance songs, the *Agbekor*, involves rich interlocking percussion centred on a repeating rhythmic cycle - 'bell pattern' or 'timeline' – of 7 hits in 12. A 'card deal' solution would result in a pattern of 2+2+2+2+2+1+1, but this is not particularly memorable nor easy to play at high tempos. The *agbekor* separates the two short intervals as far as possible creating a *maximally even* 2+2+1+2+2+2+1. This mesmerising pattern has the property that it is different from any starting position (it is *maximally independent*) which invites multiple readings when played cyclically. The pattern is in fact the same as the diatonic scale – the 2+2+1+2+2+2+1 spells out the white and black keys on the piano, demonstrating how similar concepts can be found across musical parameters. This multiplicity in the rhythm is also apparent in the 12-beat cycle which can be heard in different groupings, such as 3 4s, 4 3s and 6 2s, again inventing a rich and flexible listening experience.

The minimalist composer Steve Reich owes much to this rhythm. He studied percussion in Ghana for five weeks in 1970 with an Ewe master drummer before contracting malaria and returning to New York. *Clapping*

Music is the Agbekor pattern (with one additional hit), starting in the lower left. His work employs the ideas of a movable barline, rotation of rhythms ('phasing') and regrouping of 12 beats as 4 3s or 3 4s – as in the last movement of *Electric Counterpoint* where a rhythm first heard in 3/2 is recast as 12/8 with stunning effect.

Steve Reich was considered a modernist, a musical revolutionary but these ideas are in fact insightful contemporary perspectives of ancient musical ideas.

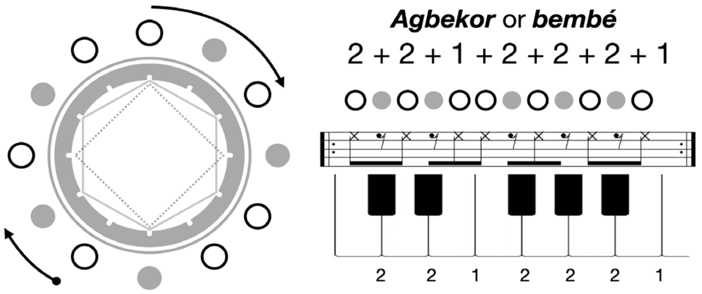

Figure 16: The *Flamenco Clock* - a pattern of 5 hits in a 12-beat cycle, with example rotations.

All the Feels

We have till now treated rhythm as precise dots in time. However, time is smooth (or at least has a staggering high resolution) so when rhythms are performed (even with technology) there is inevitable variation from these idealised infinitesimal points of time. This is the lowest level of Figure 5, below the tatum layer (the temporal atom) is that of micro-timing, the subatomic of rhythm, while such activity might be considered errors – tolerable (or otherwise) noise – we have long known that there is expressive value in this minute temporal scale, which somehow falls between the cracks of notation, and often beyond our conscious perception and terminology.

Early musicologists, armed with just a stopwatch, gathered 'temporal maps' of *rubato* (the elasticity of tempo) in recorded performances in the hopes of gleaning these hidden mechanisms of expression. Contemporary technology has revolutionised this area of micro-timing research, allowing us to analyse rhythms at and well beyond the limits of our perception.

Micro-timing research has revealed much about expressive rhythm in a range of styles, with large scale studies and in-depth analyses. There has – understandably – been a particular focus on jazz rhythm. Micro-timing (in jazz and popular styles) is of particular interest to me, and there is much to read and discover on the topic (a bibliography is included). However here we will look at just one topic and one example.

The most recognisable micro-timing characteristic of jazz rhythm is the 'swing-eighth note'. Although shorthanded in some 'fake sheets' as triplet eighths or dotted eighth or simply 'swing eighths' it has long been established that stylistic and individual occupies and traverses a continuum from 'straight eighths' (where the offbeat occurs exactly halfway between beats) to the 'hard swing' area up to and even beyond the dotted eighth. This tatum asymmetry might be considered a *micro*-grouping dissonance and is a component of the elusive 'time-feel' of jazz developed (Berliner 1996). It is however rarely explicitly communicated, and performers from outside of the tradition may be accused of employing a simplistic and mechanical triplet eighth swing feel as an easy placeholder for 'jazz-feel'.

If we use a circle now to denote a single beat (with time travelling clockwise from the top), 'swing' might be illustrated by the placement of a hit somewhere in the lower left quadrant. The view of time as a circle is ancient (including Arabic texts, and the circular canons of 15th century composer Baude Cordier). However, a circular view of a single beat we can perhaps trace to jazz composer and performer Charles Mingus's concept of *rotary perception*. A 'straight' note appears due south, and a dotted note (75% of a beat) due west. Swing is typically notated at the '2:1' mark, two thirds around the circle, however skilled performers can perceive and perform swing values around the whole continuum. These might stay approximately the same throughout a performance or change dynamically. Sometimes swing values are played collectively, and other times in 'friction' among the ensembles. This is by no means all of jazz feel – duration, articulation and shifts of the downbeat (displacement dissonance on the micro scale) – all contribute. However, this gives us an inroad to understanding, communicating, and developing the subtle but powerful micro-timing layer. Our expectational patterns are waves (not dots) and there is an emotive effect to slightly delaying or anticipating these attentional peaks.

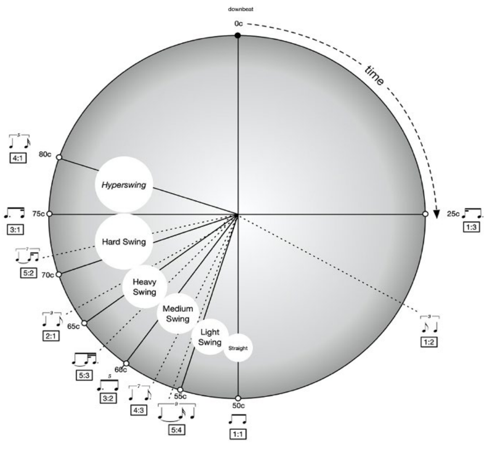

Figure 17: The ‘beat circle’. A typical range of swing values is marked up with rhythmic cents (in 5-cent intervals) alongside notated landmarks with ‘harmonic ratio’ labels. Subjective descriptive terms are also included.

Let’s put this model to the test using a well-known piece in the ‘pop jazz’ genre. *My Baby Just Cares for Me* by Nina Simone opens with a repeated swinging piano part. Most transcriptions notate this as either a triplet swing (66.7% of the beat) or a dotted-eighth (75%). Digital audio analysis, however, reveals that it sits between these two convenient landmarks. It is remarkably consistent, and yet has a feeling of looseness. Nina never sways from this zone, which at the bright tempo is less than 50ms. Let us understand how tight a sliver of time this represents. It is a shorter length of time than Olympic sprinters react to a starting pistol (typically over 85ms), the brain’s cognitive cycle is around 200ms, and when we say the word “pill”, there is a gap between the plosive “p” and the start of the vowel “i” of about 50ms. There is such quiet virtuosity shows how subtle rhythmic performance and perception is, and yet another expressive layer to our musical experience.

The Future of Rhythm

Technology (from player pianos to the latest digital technology) has contributed to our experience of rhythm in significant and subtle ways. Sequencers and drum machines bring an unparalleled virtuosity not just in terms of pure speed and stamina, but precision. They also have revealed otherwise hidden aspects of our own creativity. Nancarrow’s radical compositions, punching exotic geometric patterns into the reels of player-pianos challenged listeners with otherwise unimaginable rhythmic material. Frank Zappa (perhaps inspired by Charles Ives’ work) superimposed multiple recordings in different tempos into new compositions, an approach he aptly named ‘xenochrony’. Digital audio workstations (in the hands of musicians such as Squarepusher and J Dilla) have allowed unheard virtuosities. But they have also (fuelled by our understanding of human rhythm) afforded, a human even exaggerated expressivity. These not only include ‘recreations’ of human feel but precisely off-grid ‘wonkiness’ – sometimes charmingly referred to as ‘egg-shaped’ rhythms. What is ironic is that machines, technology, and progressive music notation, can now capture the ‘natural’ rhythms unhindered by the conceptual grid. These include speech, bouncing and interacting objects and other ‘aperiodic’ rhythmis. What is surprising is that humans have – in response – not only absorbed and accepted these rhythms as listeners, but also in conventional performance: Joanna Macgregor somehow managed to record and perform solo piano arrangements of Nancarrow’s mechanistic pieces. Dweezil Zappa (Frank’s son) performs his late father’s xenochronous solos live, and young musicians are able on conventional instruments to recreate the precise expressivity of technology-mediated rhythms. There is a co-evolution, a creative collaboration even, between human and machine.

Our rhythmic senses are astonishingly complex and fast, and still hold potential. I have made numerous pieces converting real-time processes (like voting patterns, or the movement of animals and physical objects) into rhythmic patterns. Even scaling up astronomical orbits, or scaling down the frequencies of colours, harnessing our evolved predictive faculties to experience rhythms beyond our time scale.

We spend much of our lives ignoring the passing of our most precious commodity of time. It is little wonder we avoid the thought. The idea of inevitable march through time leaving a trail of joys and pains to which we can never return, and heading goodness knows where, is both awesome and terrifying. Yet there is solace and beauty, in that we make this journey together, accompanied by music.

References and Further Reading

Recommended reading

Huron, David. *Sweet Anticipation: Music and the Psychology of Expectation*. MIT Press paperback ed. A Bradford Book. Cambridge, Mass.: MIT Press, 2007.

London, Justin. *Hearing in Time: Psychological Aspects of Musical Meter*. 2nd ed. New York: Oxford University Press, 2012.

Webography

Mermikides, M. (2022) The Art of Timing (video and audio examples of micro-timing) https://www.youtube.com/watch?v=PODzk-QBq2k

Website for John Cage's *As Slow As Possible* https://www.aslsp.org/

Bibliography

Ashley, Richard. 'Do[n't] Change a Hair for Me: The Art of Jazz Rubato'. Music Perception 19, no. 3 (March 2002): 311–32. https://doi.org/10.1525/mp.2002.19.3.311.

Benadon, Fernando. "A circular plot for rhythm visualization and analysis." Music Theory Online 13, no. 3 (2007).

Benadon, Fernando. "Gridless Beats." Perspectives of New Music47, no. 1 (2009): 135-64. Accessed May 18, 2020. www.jstor.org/stable/25652403.

Benadon, Fernando. "Slicing the Beat: Jazz Eighth-Notes as Expressive Microrhythm." Ethnomusicology 50, no. 1 (2006): 73-98. Accessed May 18, 2020. www.jstor.org/stable/20174424.

Benadon, Fernando. "Slicing the Beat: Jazz Eighth-Notes as Expressive Microrhythm." Ethnomusicology 50, no. 1 (2006): 73-98. Accessed May 18, 2020. www.jstor.org/stable/20174424.

Bergsagel, John. 'Cordier's Circular Canon'. The Musical Times 113, no. 1558 (December 1972): 1175. https://doi.org/10.2307/956587.

Berliner, Paul. Thinking in Jazz: The Infinite Art of Improvisation. Chicago Studies in Ethnomusicology. Chicago: University of Chicago Press, 1994.

Biamonte, Nicole. 2014. 'Formal Functions of Metric Dissonance in Rock Music'. Music Theory Online 20 (2). https://doi.org/10.30535/mto.20.2.1.

Bilmes, Jeffrey A. 1993. 'Timing Is of the Essence'. Washington University.

Brower, Candace. 1993. 'Memory and the Perception of Rhythm'. Music Theory Spectrum 15 (1): 19–35. https://doi.org/10.1525/mts.1993.15.1.02a00020.

Bruford, Bill. 2018. Uncharted: Creativity and the Expert Drummer. Tracking Pop. Ann Arbor: University of Michigan Press.

Butler, Mark J. 2006. Unlocking the Groove: Rhythm, Meter, and Musical Design in Electronic Dance Music. Profiles in Popular Music. Bloomington: Indiana University Press.

Chang, Denis. "The Secrets of Authentic Gypsy Jazz Rhythm", https://denischang.com/index.php/2015/08/11/the-secrets-of-authentic-gypsy-jazz-rhythm/

Cohn, R. 2016. A Platonic Model of Funky Rhythms, https://mtosmt.org/issues/mto.16.22.2/mto.16.22.2.cohn.html

Cowell, Henry, and David Nicholls. 1996. New Musical Resources. 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511597329.

Crook, Hal. 1991. How to Improvise: An Approach to Practicing Improvisation. Rottenburg N., Germany: Advance Music.

Danielsen, Anne, ed. 2010. Musical Rhythm in the Age of Digital Reproduction. Ashgate Popular and Folk Music Series. Farnham, Surrey, England ; Burlington, VT: Ashgate.

Dittmar, Christian, Martin Pfleiderer, Stefan Balke, and Meinard Müller. "A Swingogram Representation for Tracking Micro-Rhythmic Variation In Jazz Performances." Journal of New Music Research 47, no. 2 (2017): 97-113.

Hartenberger, R., & McClelland, R. (Eds.). (2020). The Cambridge Companion to Rhythm (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781108631730

Dunn, Michael. Django's Rhythm. DVD. Missouri: Mel Bay, 2000.

Ellis, Mark C. 1991. 'An Analysis of "Swing" Subdivision and Asynchronization in Three Jazz Saxophonists'. Perceptual and Motor Skills 73 (3): 707–13. https://doi.org/10.2466/pms.1991.73.3.707.

Friberg, Anders, and Andreas Sundström. 'Swing Ratios and Ensemble Timing in Jazz Performance: Evidence for a Common Rhythmic Pattern'. Music Perception 19, no. 3 (March 2002): 333–49. https://doi.org/10.1525/mp.2002.19.3.333.

Hargreaves, David, Dorothy Miell, and Raymond MacDonald. 2011. Musical Imaginations: Multidisciplinary Perspectives on Creativity, Performance and Perception. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199568086.001.0001.

Huron, David. Sweet Anticipation: Music and the Psychology of Expectation. 1. MIT Press paperb. ed. A Bradford Book. Cambridge, Mass.: MIT Press, 2007.

Ladinig, Olivia, Henkjan Honing, Gábor Háden, and István Winkler. 2009. ‘Probing Attentive and Preattentive Emergent Meter in Adult Listeners without Extensive Music Training’. Music Perception: An Interdisciplinary Journal 26 (4): 377–86. https://doi.org/10.1525/mp.2009.26.4.377.

London, Justin. Hearing in Time: Psychological Aspects of Musical Meter. 2nd ed. New York: Oxford University Press, 2012.

Mermikides, M. (2020) Monitored Freedom: Swing Rhythm in the Jazz Arrangements of Roland Dyens, Soundboard Scholar, no. 6, 36-54 Access

Mermikides, M. (2020) ‘Straight and Late’: Analytical Perspectives on Coltrane’s Time-feel, Jazz Perspectives, 12:1, 147-166 Access

Mermikides, Milton. 2010. ‘Changes Over TIme: Theory & Practice’. Guildford, UK: University of Surrey.

Meyer, Leonard B., Eugene Narmour, and Ruth A. Solie, eds. 1988. Explorations in Music, the Arts, and Ideas: Essays in Honor of Leonard B. Meyer. Festschrift Series, no. 7. Stuyvesant: Pendragon Press.

Meyer-Eppler, Werner. 1949. Elektronische Klangerzeugung: Elektronische Musik Und Synthetische Sprache. Bonn: Ferdinand Dümmlers.

Mingus, Charles. 2010. Beneath the Underdog. Edinburgh: Canongate.

Moulieras, Simon, and François Pachet. ‘Maximum Entropy Models for Generation of Expressive Music’. ArXiv:1610.03606 [Cs], 12 October 2016. http://arxiv.org/abs/1610.03606.

Osborn, B. (2014) Kid Algebra: Radiohead's Euclidean and Maximally Even Rhythms. Perspectives of New Music 52 (1), 81-105, 2014

Owen, Harold. 2000. Music Theory Resource Book. New York: Oxford University Press.

Peñalosa, David, and Peter Greenwood. 2012. The Clave Matrix: Afro-Cuban Rhythm : Its Principles and African Origins. Redway, CA: Bembe Books.

Potter, Douglas D., Maggi Fenwick, Donna Abecasis, and Renaud Brochard. 2009. ‘Perceiving Rhythm Where None Exists: Event-Related Potential (ERP) Correlates of Subjective Accenting’. Cortex 45 (1): 103–9. https://doi.org/10.1016/j.cortex.2008.01.004.

Progler, J. A. 1995. ‘Searching for Swing: Participatory Discrepancies in the Jazz Rhythm Section’. Ethnomusicology 39 (1): 21. https://doi.org/10.2307/852199.

Taruskin, Richard. 1996. Stravinsky and the Russian Traditions: A Biography of the Works through Mavra. Berkeley: University of California Press.

Titon, Jeff Todd, ed. 2009. Worlds of Music: An Introduction to the Music of the World’s Peoples. 5th ed. Belmont, CA: Schirmer Cengage Learning.

Tschacher, W., Greenwood, S., Ramakrishnan, S. et al. Audience synchronies in live concerts illustrate the embodiment of music experience.Sci Rep 13, 14843 (2023). https://doi.org/10.1038/s41598-023-41960-2

Waters, Keith. 1996. “Blurring the Barline: Metric Displacement in the Piano Solos of Herbie Hancock.” Annual Review of Jazz Studies 8: 19–3

Wishart, Trevor, and Simon Emmerson. 1996. On Sonic Art. New and rev. Ed. Contemporary Music Studies, v. 12. Amsterdam: Harwood Academic Publishers.

Witek MAG, Clarke EF, Wallentin M, Kringelbach ML, Vuust P (2015) Syncopation, Body-Movement and Pleasure in Groove Music.

Zappa, Frank, and Occhiogrosso, Peter. The Real Frank Zappa Book. New York, NY: Touchstone, 1999.