Is Music Infinite?
Professor Milton Mermikides

16 May 2024

Everything (and Nothing New) Under the Sun

"All the good music has already been written by people with wigs and stuff"

Frank Zappa, (1986)

Every generation of musical progress seems to be accompanied not just by the optimists, hopeful about the present and future of the art form, but also by a voice of pessimism, a feeling that there is little if any new, good music, and that the music of today is a poor reflection, facsimile or recycling of yesteryear's 'real' stuff. This sentiment is likely amplified by an older generation subject to the bias of the reminiscence bump, a period in our lives around the mid-teens where music holds a lasting emotional impression (see Lecture 5). In the popular music sphere, the enormous market for re-releases, covers, comeback tours, tribute bands and a predilection for an artist's 'classic albums' is a testament to such a rose-tinted rear-view mirror perspective. Any published objective study which 'proves' the dynamic, harmonic or lyrical homogeneity of modern music compared to the creative past is shared with a gleeful indignation and over-hyped headlines. Any modern cover of a classic track is further evidence of the lack of new ideas, forgetting ironically that many classic tracks are themselves covers (*Blame it on the Boogie* was originally recorded and co-written by English singer-songwriter Mick not Michael Jackson (no relation), *I WIll Always Love You* is Dolly Parton's not Whitney's, Aretha's Franklin's iconic *Respect* was written and recorded first by Otis Redding, and *It Must be Love* was written by Labi Siffre in 1971 not Madness). A lack of familiarity with a style can group large swathes of music together[1]: through a jaded ear, all 'modern pop' (or contemporary jazz, electronic music, modern classical etc.) is 'the same' while we only see nuance in our favoured genres. This pessimism is also encouraged by a distortion in our perspective of historical time. We make judgments from an unfair comparison in the quality and amount of music produced and curated over the past decades and centuries, with what we happen to have heard in the past handful of years. Even in the vaguely defined field of 'classical' music with centuries of pieces to choose from, popular outlets like Classic FM cluster the majority of broadcasts around a relatively tiny selection.

That said, we should not just blame pessimism on listener bias, and take seriously the idea of musical exhaustion; musical progression after all involves a dissatisfaction with the prevailing timbral, melodic, harmonic parameters and hunt for original 'fresh' ideas. Perhaps there is an inbuilt limit to musical opportunities. Romantic harmony expanded to a deep chromaticism and erosion of tonal stability. Electric guitars in Metal have become increasingly saturated and dropped to the pitch of their big sister the conventional bass guitar which in turn have added low strings to encroach on the ever-depleting low pitch estate. With the enormous amount of music produced these days (it would take two centuries to listen to all of Spotify), perhaps it is not unthinkable that our possibilities are dwindling.

But the take home from an apparent homogeneity and repetition in music is not clear. Consider the so-called 'four-chord song' made famous by Australian comedy band Axis of Awesome who – by overlaying dozens of

[1] To quote Zappa again, before he was initiated into jazz: "Without certain musical glues, it all sounded like noodles [...] later, I was able to tell good noodles from bad noodles"

songs based on the I V vi IV harmonic loop – demonstrated a remarkably common device in post 1980 pop.[2] Academic investigations followed and it turned out that indeed out of a corpus of 2715 top 100 songs, a full 146 (that's over 5%) featured this 4-chord loop. In fact, the chord sequence was found to be *even more* prevalent than that; a further 186 songs also included this loop but starting on a different chord in the cycle (Axis of Awesome missed a nice trick here). One could take this as evidence for a dearth and recycling of ideas. However the optimistic view could be that a small idea, template, latent musical structure can be the seed to many musical outputs. Much of classical 'common practice' harmony can be similarly reduced to a template of conventional harmonic structures. Even tight musical constraints allow apparent endless music generation, like staring at a small area of space in the night sky, stars seem to emerge from the emptiness.

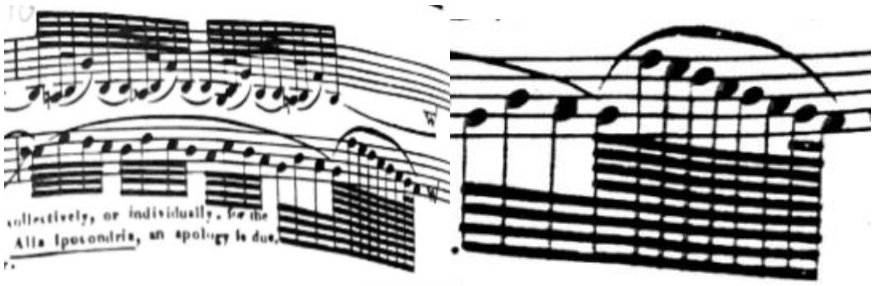
Little Infinities: Musical Slices, Cycles and Loops

Music and Time

Music – as discussed in Lecture Two – is made of time. It requires time in order to function, but also changes our experience of time itself. In music listening, there are points when we might feel fully in the moment, at others a sense of expansive time and space, or even a transcendent feeling outside of time. A survey for this lecture included reports to such deep but hard-to-articulate effect, much in accordance with research into the 'transcendent' in a range of global musical cultures: "To me it's like our souls thanking the universe " "I know nothing about musical mechanisms. I just know it stirred something in me beyond my body "It offers a continuous development, all the while taking the listener on an 'endless' journey through a landscape of the imagination", "a sense of floatiness/temporal detachment." and "It just feels as limitless as maths or physics, somehow". How can music — which is itself necessarily limited by its duration, its 'temporal wrapper' — create this sense of endlessness or detachment from time itself?

Slices and Ties

The common mechanics of music notation and terminology are time-based and particulate. We have symbols and terms to define durations to any extent or accuracy. Beats (crotchets or quarter notes) can be doubled in duration (minims or half notes) and doubled again (semibreves or whole notes), again (breves or double whole notes), again (*Longs* or quadruple whole notes), and again (*Maximas* or octuple whole notes). Even if we run out of familiar names we can tie previous durations together (or 'dot' them increasing the duration by 50%) and continue doubling durations indefinitely. At the other end of the time spectrum beats can be endlessly sliced (at least conceptually and notationally) to create smaller and smaller slivers of time. This practice is attractive to analysts wishing to capture the nuance of micro-timing (see 'Nina's Slice' from Lecture Two) and to composers in the hunt for exotic rhythms. This can happen to the point of ludicrous impracticality as in Anthony Phillip Heinrich's 1825 Toccata Grande where a passage features two notated *2048th notes*, that's demisemihemidemisemihemidemisemiquavers for those keeping score. Even at a gravely slow tempo they would if played correctly be so fast they would enter the pitch domain - around an F above middle C, strangely higher than the actual notated pitch. While there are human (and much higher technological) limits to the performance and perception of such temporal boundaries, such fundamental musical conceptions allow us to tear at the fabric of time to imagine the vastly small and large of time.



[2] Journey's 1980 *Any Way You Want It* appears to be the first pop recording of this loop.

Figure 1: A passage from Anthony Phillip Heinrich's 1825 Toccata Grande Cromatica (left, with the last moment zoomed in on the right). It features two notated 2048th notes also known as demisemihemidemisemihemidemisemiquavers. If played correctly at 40 bpm they would last under 3ms, themselves entering the pitch domain to produce an F above middle C.

Say it Again: Repeats, Fades, Cycles and Loops

Music allows – and usually relies heavily on – *repetition* in its structure and curating of predictive faculties. From the cycle time of West African drumming patterns, canonic to sonata form, minimalism, folk and jazz, repetition and re-use of material — whether partial or conceptually 'endless' — forms an essential component in music structure. Music notation understandably has bent to accommodate such circular reasoning. Not a modernist invention, *circle notation* has roots in ancient *maqam* and Renaissance music, and elegantly captures this cyclicity by wrapping around a linear stave onto itself. See Figure 2 for a beautiful example from 14th and 15th Century French composer Baude Cordier.

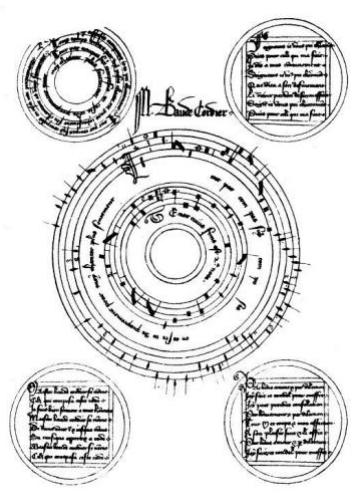
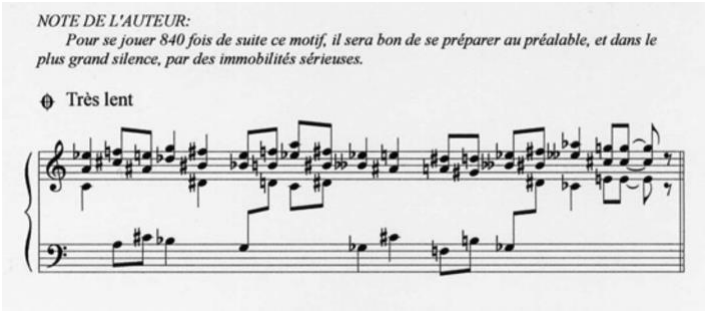


Figure 2: Baude Cordier's 600-year old score for 'Tout par compas suy composés'.

Perhaps less aesthetically pleasing than circle notation, but certainly more prevalent is the 'linear repeat', notated with *De Capo, De Segno* or simply repeat barlines. These save ink and time on the page, by instructing the performer (which now includes the machine) to jump back to previously written material.[3] These loops 'explain' formal structures, but also (as in circle notation) provide opportunity for indefinite (and even endless) durational ideas. Some of these are used sensibly but they also allow for the mischievous, or at least impractical, instructions such as Erik Satie's *Vexations* where the composer requires – for some reason – the performer to repeat the motif 840 times. He offers some characteristically eccentric tips: " "In order to play the motif 840 times in succession, it would be advisable to prepare oneself beforehand, and in the deepest silence, by serious immobilities."



[3] As it happens one can make music that sounds repetitive but is provably not. My *Irrational Music* —as a cheeky response to a criticism of my 'overly repetitive' music — converts the digits of the irrational numbers ε, π and φ into a conceptually infinite 3 part counterpoint.

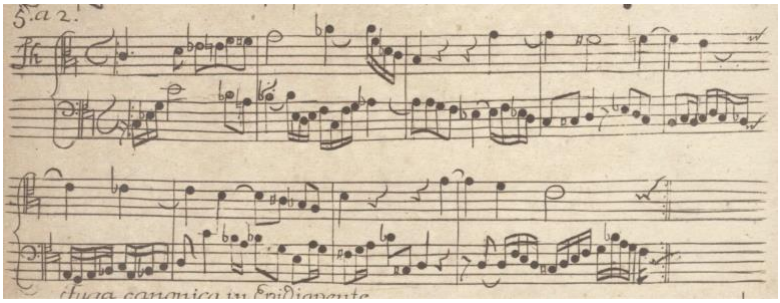


Figure 3: Erik Satie's Vexations *with an instruction to repeat 840 times (top). Below is J.S. Bach's* Canon a 2, *from* The Musical Offering — an endlessly rising canon that modulates up a tone hinting at an infinite progression.

A repetition can also hint at the indefinitely long. The cyclic harmonic structures and particularly the 'open vamps' of soul, jazz and funk hint at such durational openness. Musicians can amplify this sense of endlessness by de-amplifying material: such as the appropriate fading away of Haydn's *Farewell Symphony.* The studio also employs technology (now routinely) to hint at this endlessness with a 'fade out' – whether applied through laziness or aesthetics – it's as if the music occurs forever and drifts over the horizon. Early 20th Century broadcasts would use this device practically as segues, but early recorded instances occurred in 50s Rock 'n Roll such as Bill Hailey's (1951) *Rocket 88*. The reverse was later invented — a *fade-in* implying no beginning to the music — first with The Supremes' 1964 *Come See About Me,* and The Beatles' *Eight Days a Week* shortly after. Now studio technology can not only fade in and out, but – by splintering sound into tiny 'grains' — 'freeze' a moment in time so the listener can admire its once fleeting structure as a sonic statue.

Some repetitions are not so 'flat' but suggest a larger musical cycle at work. J.S.Bach's 'Endlessly Rising Canon '(*Canon a 2, per tonos*; from Bach's *Musical Offering*) does just so with the most economical of markings (Figure 3 lower image presents it in its entirety). It begins in C minor but concludes in D minor, a tone higher. In fact it is no conclusion, but an invention to repeat, modulating up an octave "in glory to the King". After six repetitions of the canon we return to C minor, one octave higher, but musically 'the same'. Such a smooth cycle hinting at the infinite is echoed in the Shepard Tone, an auditory illusion which, like Bach's perpetual canon, exploits our tendency to hear octave equivalence and make sense of horizontal line. A loop of a few seconds is experienced as an endlessly rising line with no end or beginning.

Cyclical structures abound in music from rhythmic cycles, the cycle of 5ths (and other intervals), the chromatic and microtonal circle, modal spectra and the tonnetz — an interlinked and wrapped lattice of the 24 major and minor triads — to name but a few. The equal tempered tonnetz wraps around and different rates in 3 trajectories. It is shaped like a *torus* — a doughnut — of interconnected major and minor triads. Musicians are hungry to create patterns within such cyclical spaces; endless cycles, fractal self-similarities and other strange loops providing — within limited durations — glimpses of the infinite. One beautiful example is Schubert's exploitation of the cyclicality of the tonnetz[4] in his Sonata in B-flat major, where he — through close voice-leading, just changing one note at a time — 'wraps around' the pitch surface to his starting chord without backtracking (Dm-F-Am-C-Cm-Eb-Gm-Bb-Dm). A graceful loop around the harmonic doughnut (see Figure 4)

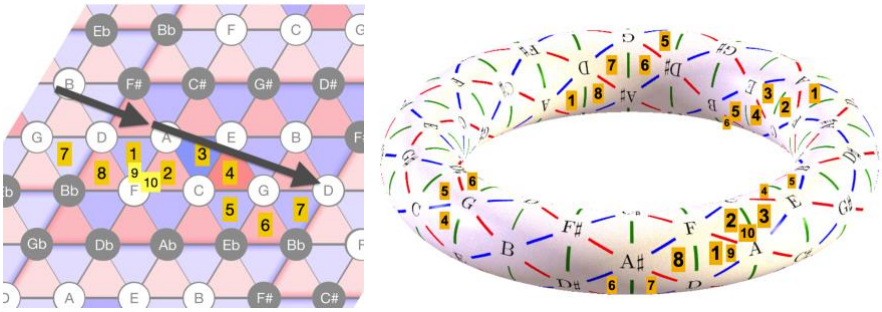


Figure 4: 'Schubert's loop' – a representation on the tonnetz of a harmonic sequence in Schubert's Sonata in B-flat Major IV mm.119–130 'wrapping around' the torus structure (illustrated below) to its starting chord

[4] The equal tempered tonnetz is in fact a *torus* — a doughnut of interconnected major and minor triads.

through elegant voice-leading.

Musical Collections

Musical Dictionaries:

Humanity's desire to hunt, collect, collate and categorise is evident in music. The *Andalusian Muwashahat* – believed to have been developed in the 9th Century - is a large collection of Arabic rhythms (*wazn*) deeply linked to poetry, a dictionary of temporal structures – both metric and prosodic — ranging from 2/4 to 48/4. The teaching of the *Q'in* — the ancient Chinese Lute — is accompanied by a catalogue of evocatively described ornaments and techniques. The 72 *Melakarta* of Carnatic music (See Lecture Four) are a systematic collection of *raga* scales representable (based on their various scale degrees) in cyclical form. Barlow and Morgenstern's 1949 *A Dictionary of Musical Themes,* a large volume of 'classical' melodic motifs — which can be searched in the index via a pitch-contour normalised to the key of C — is aptly named. A dictionary captures the commonly used words in a language, and is updated when needed. And *A Dictionary of Musical Themes* does just that — it looks outward collecting music in its 'natural' state. Music recognition software like Shazam (working on audio) and Google's song search (working on abstract melodic structures) are more contemporary, faster and comprehensive versions of the same idea.

A dictionary, however is not a catalogue of all possible words, just the ones that happen to be noticed and accepted and so far invented. Is there a way to capture a more exhaustive set of musical objects?

Musical Spaces

An alternative approach to musical dictionaries is not to just collect pre-existing musical objects but to *generate* (usually within very strict constraints) a complete set of musical objects. The *Melakarta,* not only a collection of practical scales, might also be seen to meet this criteria of a 'generative musical space'. Within certain constraints of scale construction, every possible combination is given. Pat Martino''s use of the *I Ching* hexagrams in order to represent every combination of guitar string use also fits this definition. These are more like periodic tables than dictionaries, they work from the musical ground up, not just capturing 'naturally occurring' musical elements, but hypothesising all that theoretically might exist.

More ambitiously, music theorist Allan Forte, by simplifying the musical universe to 12 pitch-classes and 6 interval-classes, catalogued, analysed and named (with a *Forte number*) every possible 'pitch-class set' (introduced in Lecture 5). His collection includes every familiar[5] and unfamiliar 12-TET chordal and scale structures from silence to the chromatic scale.

The astonishing Ukrainian-born polymath Joseph Schillinger's (1895–1943) *Encyclopedia of Rhythms* and Nicholas Slonimsky's 1947 *Thesaurus of Scales and Melodic Patterns* are similar systematic constructions in the rhythmic, and ordered pitch domains respectively. Slonimsky's thesaurus builds scale and melodic collections with a small set of tools. It employs systems such as the slicing of varying expanses of pitch space into equal parts, and using a set of devices, ornamenting with exotically named decorations.[6] As with Forte, 'naturally-occurring' musical objects would occasionally appear along the pathway of comprehensive generative construction. Three of the many remarkable musical objects in the *Thesaurus of Scales and Melodic Patterns* are shown below.

[5] The Hendrix chord for example, is given the rather astronomical name *4-z15*

[6] Some examples: Diapente progressions with Infra-Ultrapolation, the Grandmother Chord and Invertible Dodecaphonic Progressions.

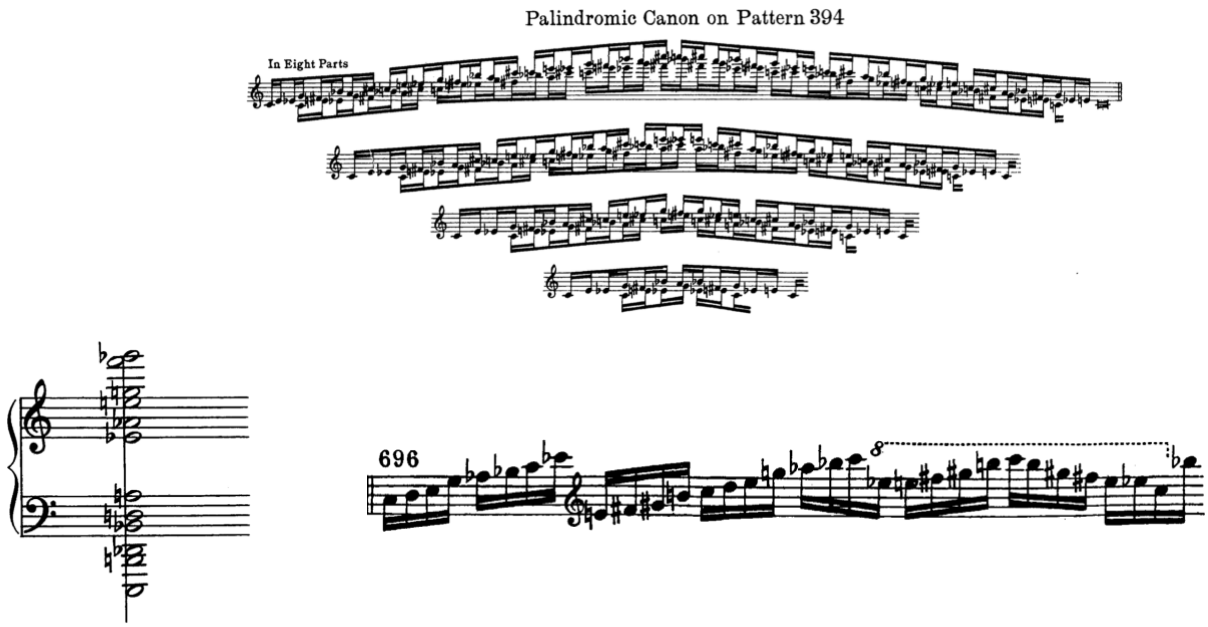


Figure 5: A selection of objects from Nicholas Slonimsky's 1947 *Thesaurus of Scales and Melodic Patterns. A Palindromic canon (top), the 'Grandmother Chord' (lower left) and the lower right pattern (696 in the thesaurus) is reminiscent of John Coltrane's soloing approach on 'Giant Steps'*

Slonimsky's thesaurus has become a coveted book in the serious jazz musician's library ever since the Jazz saxophone pioneer John Coltrane (1926–1967) practised with it extensively in his seminal late and post-bop era. A transition from 'running harmonic changes' to a more open 'spiritual' approach. One can hear clear evidence of Slonimsky's patterns 694, 696 and 697 and symmetrical harmonic approach in the jazz classic *Giant Steps,* itself having attributes of a self-similar 'fractal' form.[7]

In John Coltrane's solo *Acknowledgement* from *A Love Supreme (1965)*, a simple 3 note motif (incidentally with Forte number 3-7b) is transformed in terms of three parameters: metric placement, chromatic transposition and duration. I found that placing the motifs in three-dimensional space (rather than a linear score) gave a far better picture of the musical space Coltrane was exploring (see Figure 6, right). I was struck by its similarity to ***Raup's cube*** (Figure 6, left), an illustration of shells existing in genetic space. Three genes (spire, flare and verm) contribute to the shape of the shell. The shaded area of the cube represents the shells existing as a product of natural selection. ***Coltrane's cube*** similarly shows all possible motivic variations given these dimensions, along with his 'naturally-occuring' selection. His improvisation is an elegant slight through this space of musical possibilities.

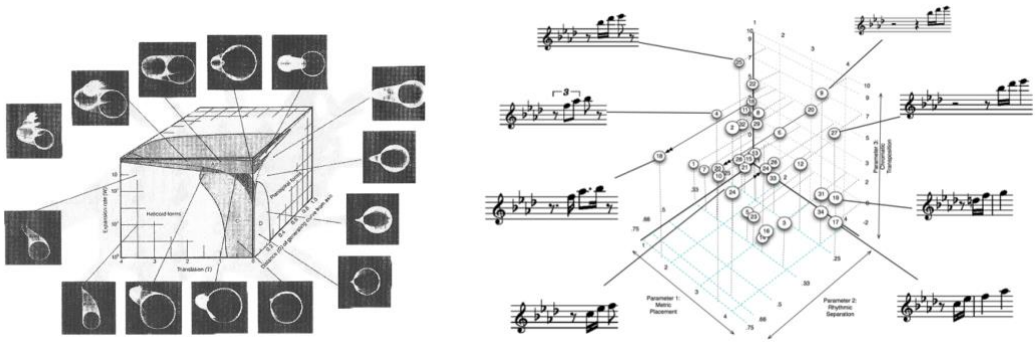


Figure 6: 'Raup's cube' (left): Illustration (from Raup, cited in Dawkins 1996:192) next to 'Coltrane's Cube' (Mermikides, 2010)

[7] Giant Steps modulates in a looping descending major 3rd pattern, both on the bar and 4 bar level. Other examples of musical fractals are reported in Bartok's structures, Gamelan motivic layering and overtly, *Phibonacci Nova* a Bossa Nova about and of the Fibonacci series.

They each represent the number of possible seashells and motivic variations based on three parameters, with a 'naturally-occurring' selection from the cube of all possibilities.

The Musical Library of Babel

"*To see a World in a Grain of Sand*

And a Heaven in a Wild Flower

Hold Infinity in the palm of your hand

And Eternity in an hour"

From *Auguries of Innocence* — William Blake (1803)

The advent of digital technology has made possible a more completist musical space: Damien Riehl and colleagues in a purported act of copyright freedom, generated billions of melodies[8]. A completist — within criteria — list of 'every conceivable melody',[9] This project may be fascinating and even historic, but the claim is not too convincing: it is first of all wholly equal-tempered and divorced from harmonic, timbral and many other important musical contexts. Music is not just abstracted melody, but thrives in the cracks between convenient copyrightable lines. The top line melody of say *Kaval Sviri* sung be the Bulgarian State Television Choir may appear in the list of combinations but lacks the transcendent timbral and harmonic expressivity. Riehls' drive also ignores completely the subtle expressivity of *interpretation*. The 'same' melody has countless variations and opportunities for personal expressivity, the same skeletal melody, but different musical realisations. For a beautiful and novel demonstration of the variation of melodic interpretation, see *Every Recording of Gymnopédie No.1* which overlays multiple recordings of the Erik Satie piece on top of each other forming a hypnotic kaleidoscope of simultaneous interpretations, a piece in its own right. Such opportunities for music are llost to a reductionist view of melody. How then can we cover all of music's rich tapestry?

A short story by the celebrated Argentinian writer Jorge Luis Borges (1899–1986) is useful here. In *The Library of Babel,* Borges posits a vast library containing every possible book that can be generated from a limited set of characters (letters, and basic punctuation). The library consists of hexagonal rooms filled with shelves of books, each book containing a random arrangement of letters and punctuation. Most of the books are nonsensical or incomprehensible, but hidden within this infinite expanse lies *every conceivable book ever or yet to be written*. The story follows the librarians who inhabit this labyrinthine library, dedicated to searching for the elusive *Vindications:* a series of books that would explain the library's existence and offer meaning to their lives. Despite their efforts, the librarians struggle to find order or purpose in the systematic chaos. Consider for example that the library not only contains the *Vindications* but countless 'inaccurate' counterfeits and convincing refutations to the truth. Borges' strange and beautiful tale not only acts as a metaphor for the quest for knowledge and the human condition, but some readers start gathering the eerie insight that the story we are reading is itself just one of the books on the shelves of this vast – yet finite – library.

The musical dictionaries so far discussed (the *Melakarta,* cycle of 5ths, the *Tonnetz,* Forte numbers, Schillinger's patterns, Riehl's drive, Coltrane's Cube and so on) are all restricted attempts at this Musical Library of Babel. This simplification is both necessary and severe: Martino's hexagrams are only concerned with guitar string activity while Forte numbers take the alphabet of music as the 12 pitch-classes, ignoring octaves, intervallic direction, microtonality and of course every other vital component of musical expression in the rhythmic, timbral, and structural domains. They are but toy-like miniatures in the musical cosmos. Even with such stringent criteria, musical permutations are staggering and escape the scale and intuition of humans. Two normal-sized hands at the piano give the opportunity for billions of chord voicings. At two a second – think funk fusion – that's still a decade of playing chords without repetition. Introducing even the most modest of additional musical parameters to these chords, such as a handful of rhythmic values, increase the possibilities exponentially well beyond that of human lifespans. Permutations – even of a

[8] 68.7 billion to be precise.

[9] This is available for free as a 6GB download at: http://allthemusic.info/

limited set of objects – get very big, very quickly. It is overwhelmingly likely for example, that a fair but quick shuffling of a deck of cards (one of 52! = 52x51x50…x1 possibilities) will produce an ordering never seen before in the entire history of countless games at homes and casinos. As Gresham Professor of Astronomy Chris Lintott puts it "Permutations always win".

So how can we get some impression of the enormous picture of a complete Borgesian monstrosity, a Musical Library of Babel which captures all the core musical attributes alongside their interpretive and expressive nuances? We would need to take, not conveniently sliced musical objects, but sound itself: the very fabric of the sonic canvas. Digital audio – which represents sound as data, a series of 1s and 0s – provides us an inroad to this daunting journey. If – and it is an if – we accept sound can contain any music (at least a point of music's realisation), and we can capture that sound to the extent of human perception, then this represents a canvas upon which every or any piece of music can exist. There is a limit to our ability to recognise deviations of frequency and amplitude, and digital audio aims to meet these limites: CD quality sound (44.1kHz, 16-bit)[10] takes (for each 'ear') 44,100 samples a second and represents each slice as a series of 16 bits (16 ordered 1s and 0s). While some suggest that higher fidelity is necessary to capture all sonic detail, any benefits to higher fidelity diminish rapidly and so the principle remains: much (if not all) of a perceived sonic or musical object can be represented as a series of digits, however long. So digital audio only has an alphabet of two letters (a 0 and a 1), but the books are large. A CD (originally capped at a duration of 74mins which can – reportedly by the design of Sony President Norio Ogha - fit Beehoven's 9th Symphony) is an ordered sequence of around 5–6 billion 1s and 0s. [11]

So with these parameters in place, the number of possible pieces of music (up to 74 minutes) is $2^{5,200,000,000}$

[12] Even though this number can be written quite succinctly – particularly given it includes all the music that has and can possibly be made – it takes some creativity to communicate in any way that the mind can grasp. So here goes.

Let's imagine each of these musical books (CDs, length of digital storage or however you'd like to think of them), are the size of a grain of sand. There's your favourite recording of Beethoven's last finished symphony as one grain of sand in your palm, Afunakwa's *Rorogwela* recording in another, *Every Recording of Gymnopédie No.1* in another. A typical lifetime of listening in a handful of two. Spotify holds a bucket of sand, and we can generously suggest that our entirety of recorded music is a few sandcastles. The amount of possibilities – and extent of human musical imagination – does not stop there. It not only fills a beach, but the entirety of the Earth's surface would be covered with music. We are hardly started – permutations always win – our sandy layer of music would build and build over the planet's surface covering the peak of Mount Everest and then ascend to the moon. All the way we must remember that each grain of sand might represent your favourite or any musical song, piece, symphony, album, news report, unrecorded dinosaur roar, podcast, audiobook and piece of sonic art you can imagine. The sphere of musical sand would swallow the Earth's orbiting satellites, the moon, then the planets and Sun before heading out into intergalactic space. NASA's golden record on the Voyager space probe would be caught in the flood of sand that would continue for billions of light years to the edge of the observable Universe. You may think we were done, but at this point, even with a universe of music, we must get creative to capture the extent of the library. Let's now represent this universe of music again as a single grain of sand. A universe of music now in a single grain of sand. But the flood of music would continue to fill the Universe again. And again, until we had a handful, then bucket, then beach of sand. Every grain of which is a universe full of music. In fact we would fill the Universe again with these tiny meta-universes. But not just once, yet again we would have to go a level deeper into meta-meta-universes, each grain of sand now representing a universe of sand universes. This staggering process of inception would continue millions of times before we started to close in on the complete musical library. It is hard to decide which is more dumbfounding, the sheer size of the library or the fact that it is ultimately finite. There is, from this perspective, a limit to human imagination. Anything that's been made, will be and could ever be made is in

[10] There's some evidence (see Reiss 2016) that trained listeners can detect small but significant differences in higher fidelity audio. However despite vehement opposition, vinyl – under blinded and fair tests – does not seem to be preferred to high quality digital counterparts. Sure vinyl introduces sonic characteristics which some may prefer, but these seem to be able to be preserved in the digital domain. In short, the bulk of the evidence suggests that vinyl preference is in the ritualistic and other non-sonic experiences of listening. Don't shoot the messenger, all good musical experiences are good.

[11] Depending on the production process standard CDs can store from 74 mins (650MB = 5.2 billion) to 80mins (700MB = 5.6 billion) of uncompressed CD quality sound..

[12] A number I – when CDs were a thing – dubbed immodestly a *miltillion.*

one of these grains of musical sand. And to this library I humbly submit this and the other five lectures of the *Nature of Music* Gresham College series. Just six grains of sand in the nested multi-verse of sonic possibilities.

We might ruminate over which of these possibilities are mere variations, interpretations and permutations of the 'same' music, what is meaningless noise and the details of the criteria, but one can't help feel that even if the minutest fraction of a percentage of this vast library help musical meaning the number is practically infinite. Even if the number of possible musical configurations is finite, what music – embedded in the tiny grains in this overwhelming sandstorm – means to each of our lives, with their personal histories, associations and unique experiences, is – we might safely and thankfully say – without limit.

References and Further Reading

Aldridge, D. & Fachner, J. (2006) *Music and altered states: consciousness, transcendence, therapy and addictions*. London: J. Kingsley.

Borges, J. L. (1998) *Collected Fictions*. New York, NY: Penguin Books (Penguin Classics Deluxe Edition).

Capuzzo, G. (2006) 'Pat Martino's *The Nature of the Guitar:* An Intersection of Jazz Theory and Neo-Riemannian Theory', *Music Theory Online*, 12(1). Available at: https://doi.org/10.30535/mto.12.1.4.

Cohn, R. (1998) 'Introduction to Neo-Riemannian Theory: A Survey and a Historical Perspective', *Journal of Music Theory*, 42(2), p. 167. Available at: https://doi.org/10.2307/843871.

Dawkins, R. (2006) *Climbing Mount Improbable.* Revised edition. London: Penguin Books.

Gould, E. (2011) *Behind bars: the definitive guide to music notation*. London: Faber music.

Herbst, J.P. (2017) 'Historical development, sound aesthetics and production techniques of the distorted electric guitar in metal music', *Metal Music Studies*, 3(1), pp. 23–46. Available at: https://doi.org/10.1386/mms.3.1.23_1.

Forte, A. (1980) *The structure of atonal music*. Nachdr. New Haven: Yale University Press.

McGrath, J. (2017) *Samuel Beckett, Repetition and Modern Music*. London: Taylor and Francis.

Mermikides, M. (2010) *Changes Over Time: Theory & Practice*. PhD thesis. Guildford, UK: University of Surrey.

Mermikides, M. (2023) '*The Digital Fretboard'* in Perks, R. and McGrath, J. (eds) *21st Century Guitar: Evolutions and Augmentations*. 1st. New York: Bloomsbury Academic.

Mermikides, M. (2024) *Hidden Music: The Composer's Guide to Sonification.* Cambridge University Press.

Mermikides, M., & Feygelson, E. (2017) 'The shape of musical improvisation' in Leech-Wilkinson, D.l, & Prior, H.M., eds. *Music and Shape*. Vol. 1. Oxford University Press.

Richards, M. (2017) 'Tonal Ambiguity in Popular Music's Axis Progressions', *Music Theory Online*, 23(3).

Available at: https://doi.org/10.30535/mto.23.3.6.

Reiss, J. (2016) 'A Meta-Analysis of High Resolution Audio Perceptual Evaluation', *Journal of the Audio Engineering Society*, 64(6), pp. 364–379. Available at: https://doi.org/10.17743/jaes.2016.0015.

Schillinger, J. (2003) *Encyclopedia of rhythms: instrumental forms of harmony : a massive collection of rhythm patterns (evolved according to the Schillinger theory of interference) arranged in instrumental form*. Harwich Port, MA: Clock & Rose Press.

Serrà, J. *et al.* (2012) 'Measuring the Evolution of Contemporary Western Popular Music', *Scientific Reports*, 2(1), p. 521. Available at: https://doi.org/10.1038/srep00521.

Sterne, J. (2006) 'The death and life of digital audio', Interdisciplinary Science Reviews, 31(4), pp. 338–348. doi: 10.1179/030801806X143277.

Stone-Davis, F.J. (2016) *Music and transcendence*. London: Routledge.

Slonimsky, N. (1986) *Thesaurus of scales and melodic patterns*. New York Paris London: Amsco publ.

Van Gulik, R.H. (1940) 'The Lore of the Chinese Lute. An Essay in Ch'in Ideology [Continued]', *Monumenta Nipponica*, 3(1), p. 127. Available at: https://doi.org/10.2307/2382409.

Zappa, F. (1986) 'Revolt Against Mediocrity' by Batya Friedman and Steve Lyons in *The Progressive*, Volume 50, Number 11: 35–36. The Progressive Inc: Madison, Wisconsin.

Zappa, F. & Oliver, M. (1989) *The Real Frank Zappa Show.* BBC Radio 3. Broadcast 1 September 1989.

Web Resources

All The Music Project. http://allthemusic.info/

Hey Exit, *Every Recording of Gymnopédie No. 1*. Soundcloud content. Available at: https://soundcloud.com/hey-exit/every-recording-of-gymnopedie-1

Key, Jordan Alexander (2018) Baude Cordier Circle Canon Animation. Youtube video. https://www.youtube.com/watch?v=iaeOWdXM4Pg

Mermikides, M. (2015) *Irrational Music.* Unlisted Youtube content. https://youtu.be/8C6JVQ1lBr4

Mermikides, M. (2023) *Every Chord in the Universe.* Video Presentation. Available at: https://www.youtube.com/watch?v=qWFFk3FoDdA

Mermikides, M. (2023) *Fibonacci Nova.* Video Presentation. Available at: https://www.youtube.com/watch?v=4jDSRi3VTNI

Mermikides, M. (2021) *The 4 Chord Loop(s).* Video Presentation. Available at: https://youtu.be/gzwQehgwRho?si=Wdn9NYr3jKJIsTQQ

TedX Talks (2020) *Copyrighting all the melodies to avoid accidental infringement.* Available at: https://youtu.be/sJtm0MoOgiU?si=MeV_nIfv623pQ2g_