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After the 12 Tones

tuning possibilities for the future-minded

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1 Introduction

1.1 Beyond the here and now

To move beyond *the here and now* there are two options: move beyond the here (move through space), or move beyond the now (move through time). Each of these two options lead to two more. To escape the now, we can move backwards in time or forwards in time. To escape the here, we can move along the surface of the earth or away from the surface of the earth. There is a strong correlation between outward spatial movement and forward temporal movement, made clearest in the negative direction: to find ancient instruments we must dig downward into the earth. This *downward* archaeology is the inverse of *upward* space exploration, the frontier of imagined futures. To imagine a different world is to begin to move beyond the here and now. Thomas More's Utopia illustrated an alternative to some of the oppressions of feudal Europe, and placed it *along the surface of the earth*, as a fictional land to be stumbled upon by the colonial expeditions of the age. In reality, those colonial expeditions tell us a very different story of the journey *along the surface of the earth*.

Escaping the here and now could, at various times, be called escapism. But today is not such a time. *The now* has become an active and malicious force in the popular imagination as it is repositioned in the wake of Fukuyama's post-soviet declaration of *the end of history*.[1] In order to maintain class domination, we have seen a system emerge with a simple core tenet, perpetual growth. All investment (and its flipside, debt) is founded on the assumption that productivity will grow exponentially forever. Today we are beginning to see the consequences of this delusion on the earth. To maintain a system of mythological perpetual growth, it has become necessary to manufacture a new common sense, this common sense we might call *the perpetual now*. The speculations of science fiction continue but with exclusive focus on dystopia, fictions of warning rather than possibility – of today's conditions and trends taken to their illogical conclusions: more privately run, automated and inescapable surveillance networks and police; more weaponised social media; more alienation; more paranoia; more celebrities; more now. This *perpetual now* consists in large part of Mark Fisher's diagnosis of Capitalist Realism, frequently summarised as the Fukuyamaist socio-politcial mood by which it is in Frederic Jameson's words 'easier to imagine the end of the world, than an end to capitalism', and in Margaret Thatcher's refrain, 'there is no alternative'.[2] Capitalist Realism then is the contemporary phenomenon that glues current economic system to the perpetual now, but apparently beyond society there is also nature – itself also a form of common sense (a stage on which to pretend to have no ideology), the laws of which – with the gradual retreat of religion – have taken scripture's place in forming an unchanging basis on top of which society is continually reproduced. This critique of the natural is expanded upon in chapter 3. The Gramscian understanding of hegemony constitutes the cultural side of the *perpetual now* just as much as the relatively recent cultural effects of capitalist realism (that is the tendency since the turn of the millennium towards constant revivalism of retro aesthetics, and an overall drought of grand new ideas, aesthetics, and sounds), though really the two are complimentary concepts. Hegemonies can be seen as a form of soft-power orthodoxy: now that the Vatican has ceased to tell composers what they may or may not compose, it is simply left to industrial capital's tendency towards standardisation to narrow the field of possibilities.

[1] Francis Fukuyama, *The End of History and The Last Man,* (New York: Macmillan, 1992)
[2] Mark Fisher, *Capitalist Realism: is there no alternative?*, (Winchester: Zero Book, 2009)

The perpetual now is then at once both the ideological common senses and unquestionables of capitalist realism, mythologised nature, and cultural hegemony, and including their perpetuation in education and the media, *and* it is the enactment of this ideology, as an exploitation of the future by the present, whether to invest or indebt, to gamble or insure, to pay employees with exposure, or to over-extract the earth's resources. Meanwhile, just as the expansionary nature of capital demands that the now invades the future, so does it demand that the here invades the there.

1.2 Domination

The music of the here and now is dominated by a singular tuning system in which the octave is divided into twelve equally spaced intervals, known by a variety of names, most commonly 12-tone equal temperament (12TET), 12 equal divisions of the octave (12EDO) or simply 12-equal. Simply to know these names is surprisingly rare. To name it is to acknowledge its existence, and like David Foster Wallace's fish who is asked *"how's the water?"* and responds *"what the hell is water?"*,[3] we find that it is hidden in plain sight by the forces of the perpetual now. It is largely in applying this Deleuzian frame of silent/invisible soft-power that rules contemporary *societies of control*,[4] that we will seek to understand how a single pitch system has come to dominate, in order to begin to combat its dominance, but also as an especially plain to observe, even somewhat measurable, case study of how domination and realism function together to standardise cultural codes.

12-EDO can be understood as having formed a monopoly within the so-called *free market of ideas*[5]. In part because ideas are nebulous and immaterial, and therefore not as measurable as commodities, the notion of a monopoly of the marketplace of ideas is not widely considered within the liberal framework, and so where monopoly over commodity supply can supposedly be regulated away, regulation of a monopoly of ideas would require active regulation with education and the media seen as illiberal. Therefore, anything other than a *free market of ideas* is seen as censorship. Institutional interference in artistic intention is certainly an undesirable restriction of freedom. Yet we frequently neglect to account for the present power of many such institutions: corporate media, arts funding councils, intellectual property enclosure, and policing all use soft and hard power to control what we are permitted to make. We should however regard the contest between censorship and the free market of ideas as a false dichotomy, one based in the assumptions of the pseudo-science of Social Darwinism. Social Darwinism is the application of the principle of the survival of the "fittest" to the justification of the exploitation of everyone else. The "fittest" essentially meaning the most violent and lucky. History has endowed the rich and powerful with riches and power, and the Social Darwinists would consider this its own circular justification, it is natural selection, and nature, they believe, must be just or at least

[3] David Foster Wallace, "This is Water" speech given to Kenyon College (2005) : https://fs.blog/2012/04/david-foster-wallace-this-is-water/

[4] Gilles Deleuze, "Postscript on the Societies of Control", in *October* (vol. 59) (MIT Press, 1992)

[5] 'The marketplace of ideas' was coined in the 1919 case of Abrams v. United States when activists were convicted for the distribution of leaflets condemning the invasion of the USSR, supreme court justice Wendell Holmes jr. stated: "The best test of truth is the power of the thought to get itself accepted in the competition of the market, and that truth is the only ground upon which their wishes safely can be carried out."
: Zechariah Chafee, Jr., "A Contemporary State Trial: The United States versus Jacob Abrams et al", *Harvard Law Review*, Vol. 33, No. 6 (April, 1920), pp. 747-774.

unquestionable. In music, therefore, the dominance of the Western European tonal language, is seen as natural and just. Western Europe has colonised the world; it has already happened, therefore it is history, it is tradition, it is natural. This is the narrative that has shaped the world. Whether with this secular Darwinist spin or not, the powerful have long used their exploitation of the rest as its own justification. Progress, which is to the Social Darwinist inseparable from evolution, is a series of mythologised tales in which the "strong" defeat the "weak". For Kropotkin, however, evolution is not a history of violent domination, but of interpersonal, intertribal, and interspecies mutual aid. In mutual aid we find an alternative to the so-called free market of ideas.[6] Rather than compete for the dominance of one idea, we can embrace a diversity of artistic approaches. Rather than enclosing intellectual property and treating our fellow musicians as competition, we can start from the basis that we would be nowhere without our ancestors and contemporaries, that all art is collaborative in one way or another.

For Fisher, realism is established in the neoliberal age with a unique level of *that's just the way things work*, the refrain of the defeatist jobsworth who upholds the position that they aren't responsible, they didn't make the rules, the rules just are.[7] This is a spirit echoed by many musicians, teachers, and technologists today as soon as the question of tuning is brought up. We could then perhaps call this musical epoch 12-EDO realism. Fisher writes:

> An ideological position can never be really successful until it is naturalized, and it cannot be naturalized while it is still thought of as a value rather than a fact. Accordingly, neoliberalism has sought to eliminate the very category of value in the ethical sense. Over the past thirty years, capitalist realism has successfully installed a 'business ontology' in which it is simply obvious that everything in society, including healthcare and education, should be run as a business.[8]

Those technologists especially are made to prioritise profit above all, which comes to be its own circular Social Darwinist logic, where what is *just* is what is *just good business*. Where software is held under closed licence, developers prioritise features that are marketable. Hence it has been only through exploiting the marketing possibilities of publically consulting relatively popular artists Terry Riley (Sequential Circuits), Wendy Carlos (Kurzweil), and Aphex Twin (Korg and Novation), that relatively large commercial synthesizer manufacturers have ended up integrating any microtonal possibilities into their products. For the rest of us, requests are constantly deprioritised as there is "no demand for it", itself a result of the lack of options elsewhere. Capital directs technologists to take up the marketable ideas, and neglect those that are non-scalable. As tunings historically have developed within local cultural contexts, many such ideas are inherently non-scalable. Where in Bali and Java each local community may have its own Gamelan with its own tuning, these tunings cannot be properly removed from their local and musical context, and so accommodating them is not a scalable or really *marketable* decision. When Native Instruments released a Gamelan sample instrument they did so with the possibility of one Javanese mode and with a switch to retune to 12-EDO.[9] There also *is* demand that gets neglected – Khyam Allami gives the example of the term "org", which has come to be a catch all term across the Arabic

[6] Pyotr Kropotkin, *Mutual Aid: A Factor of Evolution,* (London: Heinemann, 1908).
[7] Mark Fisher, "From Upper Crust to FOMO", talk given at CCI Collective's *All of this is Temporary,* (2016) : https://youtu.be/deZgzw0YHQI
[8] Fisher, *Capitalist Realism*, pp. 16-17.
[9] Native Instruments website : https://www.native-instruments.com/en/products/komplete/cinematic/balinese-gamelan/

subcontinent for synthesizer, and is derived from the prolific use of Farfisa's "organ" synthesizers which were a rare case of a widely produced synthesizer in the eighties which happened to add include the ability to retune keys.[10] There are also the reductively tuned and marketed so-called "oriental" keyboards from Casio, Korg, Kurzweil, and Yamaha, which have been the only widely available keyboards to offer anything other than 12-EDO, and so their preset sounds have become ubiquitous in Middle-Eastern pop music.[11]

The ideas that "win" then are not a neutral selection, nor a natural selection, but a selection biased towards the influence of the colonising powers. Through standardised music education, taught from the stave, we cement certain musical ideas as natural and unquestionable. *Pitch* becomes synonymous with *note*, meaning C, C♯, D, D♯, E, F, F♯, G, G♯, A, A♯, B, and then C again. As Philip Glass recalls his first flute lesson:

> '"Blow across the hole."
> I managed, after a few tries to get a sound out.
> Mr. Johnson then said, "That is a B."
> At the same time he pointed to a note on the middle line on a page of music paper with a G clef written at the left side. In far less time than it takes to tell, he had locked together a sound, my finger position, and a written note on the page.'[12]

This is the moment at which the unknowing fish is submerged in the water. With this relationship established at such early ages, the question of why the twelve notes are what they are gets swept under the rug, along with questions as to the nature of pitch and sound itself. This tale is an aside in Glass's recollection of his collaboration with kora player Foday Musa, which is throughout a very revealing document of what I would consider the default attitude to musical language. 'We didn't know where to start, so I suggested that we should first tune the kora to the piano.'[13] Immediately, the presumptive power dynamic is clear, of course the piano is not so quick to retune, but there are always other options. Glass continues:

> 'He told me that a lot of the players who come from Africa will not retune their instruments.
> "What happens then?" I asked.
> "They can't play with anyone because they're never in tune. If you want to come to Spain or England or Germany and you want to play, you have to retune your instruments and most of them won't do it."
> "Do you have any problem with it?" I asked.
> "I have no problem at all."
> What happened to Foday Musa was similar to what happened to Ravi Shankar. When Raviji first came to America and then went back to India, he was criticized for the success he had. He would have to calm the critics who thought he couldn't play anymore. He would put on a big concert in New Delhi or Bombay and play the traditional music fantastically well. He had to prove to them that he could still do it. That stopped after a while—they knew that he was able to do both. When

[10] Khyam Allami on *Interdependence* podcast with Holly Herndon and Matt Dryhurst (2021) : https://www.patreon.com/posts/microtonality-to-47044726
[11] Ibid.
[12] Philip Glass, *Words Without Music,* (London: Faber & Faber, 2015), p. 340.
[13] Glass, p. 339.

> Foday Musa would go back to the Gambia, because he had changed the tuning on his Western recordings, they thought he had lost the music. But when he returned to the original tuning of the kora, they were satisfied that he could still play the traditional music. Foday Musa and Raviji were able to move between musical cultures, and the real entry for them began with retuning their instruments.'[14]

It would be easy to extrapolate from this the benefits of a universal tuning standard, but at what cultural cost? Who gets to decide on that standard? How many of those musicians who 'will not retune' are excluded? For all of Glass's praise for their willingness to retune, would Glass be expected to adapt on a visit to the Gambia? I would suggest not, that this cross-cultural retuning is unidirectional, and even invasionary as what was established as European musical language comes to dominate not only in the settler colonial states, but *everywhere* through missionaries and occupying militaries at first, and eventually through neo-colonial forces of standardisation, both in instrument provision and music education. Music theories are not modular, but built around traditions that create certain relationships between the domains of structure, rhythm, pitch or timbre. To many it is sacrilege to strip the pitch content from the overall system and replace it with the system of the colonisers, besides which, as we will see in future chapters, tunings and instruments have deep symbiotic relationships. That is no mark against Musa or Shankar, it is not invalid to wish to retune to adapt to certain situations, but it is simply to say that the assumption that it is a positive, from Glass's point of view, is based largely in its convenience to him, and at the exclusion of some apparently bitter *other*. His argument here is not for the domination of 12-EDO over all else, but for both, that traditional musicians should learn their own systems alongside those of the hegemony. Whilst this has indeed worked well for Musa, it is not a viable or fair long term solution for the preservation of those musics in their entirety. In Kofi Agawu's words, 'Nowadays, the opportunistic embrace of something called hybridity, or the transnational or the cosmopolitan, together with an irrational fear of something called essentialism, have effectively muted, or at least discouraged, discussion of the transformations in consciousness brought by the tonal forms exported to Africa.'[15] This is to defend against statements of the "music is a universal language" kind, by which we bend cultures into the shape of our own and claim a universality that really centres the coloniser. Gargi Bhattacharyya writes that accepting difference in these respects 'forces us to reassess techniques of antiracism and, in particular, the continuation of genocidal erasure that might take place through the assertion of common "identities" in the interest of antiracism.'[16]

Historically this is part of a longer process of cultural erasure and assimilation, a process frequently defended through a Social Darwinist frame. As Agawu puts it, 'Some would argue that indigenous harmonic systems are not as strong as the invading European ones, but it is hard to sustain that argument if the imposition of tonal rule is accompanied by various forms of material and political control.'[17] That is, whilst the soft-power of technological inflexibility, context stripping appropriations, and the spread of US-American popular culture through neo-colonial influence have been erasing cultures for some time, it

[14] Glass, pp. 340-341.

[15] Kofi Agawu, "Tonality as a colonizing force in African music", CIRMMT Distinguished Lectures in the Science and Technology of Music, (2004) : https://youtu.be/z_sFVFsENMg

[16] Gargi Bhattacharyya, *Rethinking Racial Capitalism,* (London: Rowman & Littlefield International, 2018), pp. 76-77.

[17] Agawu.

was originally at the end of the gun that this language entered most of the African continent, not through pop songs but through hymns. 'To The Bible and the gun,' Agawu asserts, 'we can now add diatonic tonality as an instrument of colonial domination.'[18] The long supposed and imposed superiority of so-called "western culture", itself a false cultural conglomerate that imagines Pythagoras as the start of formal harmonic language when really he was preceded even in the mathematical justification of his own eponymous tuning built from stacking and octave reducing ratios of 3:2 (a perfect fifth) by Guan Zhong in China two centuries earlier.[19] This conglomerate was formed in justification of its own continuation and imposition on the world. Allami describes the power this delusion has exerted over music, thus:

> The influence of the French and the English all across the Arab world brought this idea that the opera is the ultimate form of musical expression, and therefore the orchestra is the ultimate instrument, therefore equal temperament is the ultimate system that needs to be used, et cetra, et cetra. I mean, we know this, this is a direct result of colonialist imperialist imposition. And the unfortunate by-product of that is that audiences across the world for the last hundred years have been listening to the detail of their own musical culture slowly being eroded away.[20]

Nevertheless, of course we must guard against the assumption that a change to the powers restricting musical material will effortlessly trickle through into a change in global power relations more generally, that creating space for traditional music to thrive is a substitute for the larger political project of decolonisation. Nor to assume that what we are addressing remains an intentional system. Musical pitch standardisation is, to me, an interesting case study *precisely because* it has no obvious economic or political reason, except perhaps from that which follows from my analogy with the English language – that its dominance places Europe and the USA at the epicentre of musical culture, but this is only a small component in that dominating relationship. Clearly, microtonality is not a threat to the power of capital, and it would be absurd to imagine that someone with nefarious intentions is deliberately perpetuating 12EDO realism, to intentionally hide the existence of other pitch systems. And yet structures and ideologies with wholly other intentions have led to this state of global pitch standardisation and a cultural attitude by which it is "easier to imagine an end to the world" than to imagine an end to the dominance of the Halberstadt keyboard, and by which trained musicians can go lifetimes without ever considering what's between the keys. It doesn't require an evil mastermind to run a hegemonic system, a structure of cut-throat competition with misguided goals will lead to certain systems being perpetuated unknowingly by their beneficiaries. But who are the beneficiaries of the dominance of 12-EDO? Big Halberstadt? Clearly there is no such cartel; those who profit from selling keyboards could just as easily profit from selling other designs if they were popular. Instead, this offers a revealing tale of how cultural artefacts are standardised and then naturalised through the processes I have discussed, that is through the marketisation of technology, education and music, and through the old unspoken biases of the delusion of the supremacy of something nebulously called western culture. All are bound together under the Social Darwinist ethic. This I find revealing of a tension at the core of Neoliberalism, that it espouses competition in all areas of life, but in its implementation seemingly unprepared

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[18] Ibid.

[19] Juni L. Yeung, *The Concise History of Chinese Musical Temperament*, Episode 1, (2019) : https://youtu.be/M_eMUQ3hleM

[20] Allami on *Interdependence*.

for the obvious outcome of such competition, what happens when that competition has a single winner, an absolute monopoly, which itself is supposedly incompatible with the original aim. This ideology apparently puts abundance of choice above all, but the case of 12-EDO shows us that, really, *choice* is only a concern where monopoly cannot be naturalised. The musician does not choose 12-EDO, nor is it thrust upon them by a dictatorial orthodoxy, it is simply all there is.

1.3 Future-mindedness

This project is described as future-minded because it attempts to enact practical approaches to untethering music practices from the limitations of the musical aspects of the perpetual now, and towards unearthing and collating underexplored musical possibilities as they relate broadly to ideas from across various tuning theories. This direction is a reaction to two arguably related conservative tendencies. In part, it is a reaction to the perceived xenharmonic tendency to escape the here and now through practices that move backwards (reviving Ancient Greek and Renaissance scales) or sideways (ripping pelogs and ragas from their greater contexts). In its other aspect, it is a reaction against Fukuyamaism and its most nihilistic responses.

When Francis Fukuyama wrote that in the aftermath of the Cold War, 'we cannot picture to ourselves a world that is *essentially* different from the present one, and at the same time better',[21] he saw no problem with this lack of imagination, and rather took from it the assumption that there was nothing else to imagine, that we had reached the end of history. The system could be tweaked but ultimately it was liberal capitalism that had been the end point of all of historical progress. What does the end of history mean for music? We can turn to its establishing text in which he writes:

> if we look around at the entire range of human social endeavor, the only one that is by common consensus unequivocally cumulative and directional is modern natural science. The same cannot be said for activities like painting, poetry, music, or architecture: it is not clear that Rauschenberg is a better painter than Michelangelo or Schoenberg superior to Bach, simply because they lived in the twentieth century; Shakespeare and the Parthenon represent a certain kind of perfection and it makes no sense to speak of "advancing" beyond them. Natural science, on the other hand, builds upon itself: there are certain "facts" about nature that were hidden from the great Sir Isaac Newton, that are accessible to any undergraduate physics student today simply because he or she was born later.[22]

This is a grotesque conclusion which mischaracterises science almost as much as it mischaracterises art. Art too 'builds upon itself', only such a Disneyified copyright regime and age of such extreme individualism would obscure this to anyone. That it's less impressive to see an undergraduate physicist write equations describing gravity than it would have been in Newton's day, is equally true of an undergraduate musician and writing a Bach-style fugue. It is true that no aesthetic is ever officially pronounced dead by a consensus but to extrapolate from this that there can be no progress without "facts" is absurd, and very

[21] Fukuyama, p. 46.
[22] Fukuyama, p. 72.

convenient for a project which positions the cultural dominance of Shakespeare and the Parthenon as a universal truth to justify the universal application of the dominant political system to emerge from the same continent. Contrary to romanticised notions, art is not eternal, music before we attempt to record it makes this the most obvious, it occurs fleetingly in the air. Music is more permanent than that though of course, it is also the language of sonic ideas it is made from though, but these are not eternal either, they are born and they die constantly, and are passed from generation to generation with aspects lost and gained at every step. This understanding of culture as dynamic and generative is essential to the idea of a future-minded project – we should understand that everything is collaboration and inheritance and therefore changing anything fundamental will require a change in the conditions the next generation arrive into, we therefore must emphasise education and technological development, which should both be approached with curiosity. A future-minded practice should be built in such a way that centres its pedagogy and seeks to break down epistemic barriers to entry. For the most part, tuning system design today holds central three fields, common practice music theory, acoustics and mathematics. Entering the realm of post-12-EDO practices then often involves what is for many an alienating amount of mathematics and advanced music theory. In Allami's words, 'I have met so many people who have at some point been fascinated by the idea of microtonality, they do a quick Google search, all they see is equations and this veiled jargon, very complex language and they immediately get put off and disappear.'[23] Whilst this thesis itself may not overcome this as it does include a little mathematics and a certain assumed familiarity with the tools of electronic music, this research does aim at the building of systems that would make possible a post-12-EDO practice that is friendly to musical beginners, and those with no interest or expertise in mathematics or the inner workings of technologies. Without the possibility of a non-expert practice, there can be no larger scale future for Xenharmony.

Fisher diagnosed the end of history for what it is, a very successful systemic attack on the popular imagination, a form of 'consciousness deflation'[24] enabled through alienating bureaucracy and individualism, and a postmodern embrace of revivalism by which the incessant lurching from one mid-late twentieth century aesthetic to another takes the place of any sense of cultural progress.[25] This revivalism was to be understood in relation to hauntology, updated by Fisher to embody the death of the future and the ghostly cyclical haunting as revivals echoed times when grand futures had been promised ahead of us, leaving us with a glut of retro-futuristic dystopias in twenty-first century film and music. And then came the flip, as it so often does, from description to prescription. Amongst those concerned with Fisher's work, hauntology became self-aware as musicians began to intentionally conjure a hauntological aesthetic with the 2010s littered with electronic music in particular in myriad variations on hauntological music: vaporwave, chillwave, synthwave, hypnogogic pop, mallsoft, and plenty more, all sampling or anachronistically recreating the sounds of the seventies and eighties. Fisher's impact on music has been enormous, but the most common artistic takeaway has been that given we are stuck in a perpetual now, we must make music that vividly depicts that now. What I have called a future-minded approach would be to attempt to unstick ourselves, to break the cycle, to actively seek out new directions, and new visions of the future, and lay the foundations for a culture that no longer self-consciously regards itself first and foremost as trapped in the shadow of the apparently

[23] Allami on *Interdependence.*
[24] Mark Fisher, "From Upper Crust to FOMO".
[25] Mark Fisher, *Capitalist Realism* ; Mark Fisher, *Ghosts of My Life: writings on depression, hauntology and lost futures*, (Winchester: Zero Books, 2014)

unsurpassable canon of the twentieth century. Happily, I am not alone in this. The aesthetic trend to self-consciously embrace the gloom of a futureless or dystopian age, is not only present in music and art more generally, but also takes the form of political theory and continental philosophy in its most nihilistic guise perhaps in Fisher's contemporaries Ray Brassier and Nick Land. Yet there is emerging the will to reject this, which begins with diagnosing it, as Patricia Reed of Xenofeminist collective Laboria Cuboniks put it:

> Where's the will for a different image of the future? Honestly? And I'm not saying that we're coming here and we're going to tell you what the future is, I think we're equally guilty as not offering these kinds of images either, but at the same time what I see so often occurring, specifically in political theories especially from the left, is actually being told over and over that the imaginary is dead dead dead dead dead, and I feel that that just concretises that deadness even more, and I just want to say "OK thank you, I've heard and the diagnosis is probably true, but enough, and we need to start finding ways to activate the imagination for the future."[26]

Dystopias give warnings about existing maladies while utopias offer solutions, both ought to be necessary but in the total cultural dominance of dystopia we are not simply warned but worn down. What Reed gets at effectively here is the way that, ironically, Fisher warns us about the all encompassing gloom of dystopia, but this warning itself has come to be read as a dystopia situated in the now, and so the warning is despaired at in nihilistic surrender rather than addressed. One movement that has taken up the mantel of depicting positive futures is known as Solarpunk, defined in direct opposition to Cyberpunk's *high-tech, low-life*[27] embrace of dystopia as an aesthetic, 'Solarpunk can be utopian, just optimistic, or concerned with the struggles en route to a better world, but never dystopian. As our world roils with calamity, we need solutions, not only warnings.'[28] Climate grief, like capitalist realism, is an all encompassing cultural mood that petrifies us in both senses, debilitating us to act.

> A well-organized and conscious society could quite easily address the issue of climate change in the next few decades—by transitioning to all renewable energy, dramatically cutting down on consumption, and shifting away from an economic system that glorifies limitless growth. However, a society which believes that climate change is inevitable—that "things cannot be otherwise"—is a doomed society.[29]

It is against this climate grief that Solarpunk acts to generate the optimism needed to get anything done, by depicting possible futures in which solutions were found, not as escapism but to show possible routes, and 'because the only other options are denial or despair.'[30]

The term future-mindedness is itself chosen as opposed two potentially problematic terms: futurism and accelerationism. Futurism can often be its own fallacy, suggesting that if something seems futuristic it follows that it must be good – this can lead to prioritizing the

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[26] Laboria Cuboniks panel discussion at *Question of Will* (2017) : https://youtu.be/_jkE4BAkFek
[27] Isaijah Johnson, *"Solarpunk" & the Pedagogical Value of Utopia*, from The Journal of Sustainability Education vol. 23, April 2020, p. 3.
[28] The Solarpunk Community, *A Solarpunk Manifesto,* (2019) : https://www.re-des.org/a-solarpunk-manifesto/
[29] Johnson, p. 9.
[30] *A Solarpunk Manifesto,* (2019).

ideal over considerations of power, oppression and suffering, as indeed it did when it led the Italian futurists zealously into fascism. Accelerationism, meanwhile is a confusing tale. There are, in common discourse, two very different accounts of its meaning. The first is the one I can get behind: that, being in a time of unprecedented ecological danger, as climate catastrophe is well underway, it is both unrealistic and undesirable to think we can combat this with technological regression, that we can switch off the internet and never leave our neighbourhoods – instead the best path to take is that towards technological advancement, with a restructuring of society necessary to truly prioritise green technological research to be aimed at genuinely addressing the issues at hand rather than simply creating market buzz for profit as the Musk cult does today. That taking research out of the paws of profit might lead to an advanced society capable of automation on a scale that could enable a post work society, is a possible by-product of that first priority. This meaning is associated with Nick Srnicek and Alex Williams and with the Xenofeminism of Laboria Cuboniks. The second meaning seems quite absurd, but it is present across the political spectrum, that is, starting from Marx's claim of the inevitability of the collapse of Capitalism, we should then intentionally push society towards its worst contradictions to accelerate the collapse by accelerating the system. Not only is this almost entirely antithetical to the first point, but it relies on what seems an entirely unscientific thesis, that things can only get so bad before they collapse. How could we ever know this? How could we be sure that some force – like the extreme, alienated individualism now compounded in the COVID-19 pandemic, solidified in social media and so many other institutions – might come along and make solidarity on the scale necessary for revolution impossible? A brief look at the meat industry should show us that if mechanisms for solidarity and empathy can be bypassed with manufactured common sense, there are few limits to how beings can be treated without ever having a possibility of fighting back. This is the danger of a natural view of historical progression, that we treat the cycle of contradiction and revolution as if it as inevitable as the sun rising, when really the sun rising has easily modelled gravitational necessity, whilst the people rising is dependent on the interactions of billions of irrational consciousnesses. And this says nothing of the father of these, Nick Land's supposedly amoral accelerationism which frames capitalism as an artificially intelligent singularity in waiting, and human society as simply a precursor to something which for no other reason than Land's twisted aesthetic desire should be allowed to swallow the earth whole.[31] Furthermore, as Emile Frankel writes:

> Accelerationism rests upon the assumption that movement = progress; that speed = progress. These assumptions, imprudent and dominant imaginings of progress, can be traced back to the prominence of the industrial revolution in modern thinking (its own machinic spectre). The common assumption is that the industrial revolution marked the 'great advancement' of humanity. Problematically, what is mistaken here is a concept of radical change for an idea of scalability. Most of the 'progress' of the industrial revolution was in fact a movement of expansion and scalability. Most of the products of this period were not radically new, just produced in previously unfathomable quantities. In this 'progress' becomes equated with corporate expansion.[32]

The logic of this 'progress' was that of standardisation – of identical repeatability as a measure of quality control. Out of this new logic, it followed that music had to standardise its language, not least because of the physical requirements for standardisation in the mass

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[31] Nick Land, "A Quick-and-Dirty Introduction to Accelerationism", in *Jacobite*, (2017) : https://jacobitemag.com/2017/05/25/a-quick-and-dirty-introduction-to-accelerationism/

[32] Emile Frankel, *Hearing the Cloud*, (Winchester: Zero Books, 2019), p. 115.

production of musical instruments, but also because standardisation seeped into all areas of culture and especially became inherent to education, with national curricula, and in music education really a global consensus of a common practice music theory centred on Schenkerian analysis and the Germanic music it holds as ideal.

Frankel follows this diagnosis of a misplaced industrial logic with a positive solution:

> I am inspired by Anna Tsing, who urges us to turn our attention to the non-scalable. I would argue that a true conception of progress relates to new objects, structures and ideas which are resoundingly non-scalable. [...] Consider fragmentation: does the act of fragmenting *more* represent progress, or simply another form of scalability – the expansion of divisive thinking? Diversity is different from divison. Diverse ideas, both musical and not, mark radical difference and new forms of thought. Fragmentation is a splitting up of the same into smaller parts of the same.[33]

And so, capital's fragmented approach offers us a thousand competing models of Halberstadt keyboard, when the radical solution could be a thousand entirely different designs each offering wholly new approaches to music. This level of diversity is inherently non-scalable, since it suggests a thousand different musicians could in theory have a thousand different music theories. But the non-scalable should not be mistaken for individualism or the possessiveness of ideas. The future-minded must take a stand on the topic of originality. Today, in the realm of experimental music, there is an increasingly toxic cloud of naturalised intellectual property. By which I mean, musicians internalise the logic of I.P in very extreme and emotional ways that go beyond even the extents of the already restrictive law. Where there is an expected form (verse-chorus, 4-to-the-floor, 12-bar blues) there is rarely a question of intellectual property, they are regarded as within the public domain, or more accurately we might say they are simply viewed as outside of that legal realm. Experimental musicians however frequently gain a sense of identity precisely by their avoidance of these forms, and as such their internalisation of intellectual property is especially extreme as influences can become a taboo matter. For the musicians of previous centuries there was an understanding that culture is collectively inherited and collectively built upon. Plainsong, quotation, an entire century of music effectively based on the Sonata form, these things could not happen today. Partially this is a positive, there is no longer an official orthodoxy, as there was in the Vatican, that can tell you which intervals are or are not allowed. But we have gone so far the other way, that we risk telling *each other* which intervals are or are not allowed, on an individual basis. I am arguing for tuning diversity, and particularly in encouraging musicians to come up with their own musical languages, and in so doing, inviting tuning back into the pool of parameters to be considered *whilst* rather than *before* composing. There is then a risk that as it becomes a choice, musicians will seek to "protect" "their choice" with legal exclusivity or critical taboos, just as legal battles have been fought over melodies and chord sequences in recent years. We laugh today at those who said a hundred years ago that everything that is to be invented has been, but like any other resource we might have assumed infinite until recent decades, the fact we are now living in an unprecedented legal trap with accelerated production is making that increasingly a reality, especially in the cultural domains where Disney have shifted the goalposts again to a copyright standard of life plus 70 years. Stephen Fry's character in an *A Bit of Fry & Laurie* sketch in which a nauseating intellectual theorises about language, says: 'Imagine a piano

[33] Ibid.

keyboard, 88 keys, only 88, and yet, and yet, hundreds of new melodies, new tunes, new harmonies, are being composed upon hundreds of different keyboards every day in Dorest alone.' This is the perception of music and certainly it is true that there are as good as infinite ways to make music. But in 2020, Damien Riehl and Noah Rubin coded a simple combinatoric program to generate 'every melody' possible in an octave of major, minor and chromatic scales up to twelve or chromatic ten steps long.[34] They then put them in the public domain. Perhaps if they had copyrighted them, post-12-EDO music would now be a legal necessity. This would only be an acceleration of what is already happening as Riehl and Rubin intended to highlight the absurdity of many contemporary court cases fought over chord sequences and simple motifs. The age of 12-EDO realism has demonstrated the expansiveness of possibilities to be found from a single system, it has been used to create so much music including continuing innovations, but it might also be said that nothing particularly new has come in the harmonic domain itself since be-bop. This lack of unexplored harmonic area as it coincided with the wider availability of electronic instruments, has created the conditions for a dethroning of harmony that has been a welcome turn pushing many of us to new timbral, technological and narrative worlds. But pitch isn't going anywhere, and with 12-EDO the continued default, it's become more of a library than a workshop. Many electronic musicians who no longer want the over-familiar sound of this system turn to randomisation and drone, both powerful alternatives, but there are many other ways to reengage with pitch and harmony with intent that are not wrapped up in the familiar. This is not simply to shoehorn in my own concerns around intellectual property, but rather if the future-minded is to be concerned with the new in a musical context it should be clear about the simultaneous inevitability and impossibility of the new. That is, inevitable because nothing is ever the same, and impossible because nothing is ever independent of its environment. In fragmentation everything is the same, in diversity nothing is the same. Therefore, the new is dependent on its diverse environment.

The Left-Accelerationism of Srnicek and Williams positions itself in opposition to the non-scalable:

> We believe the most important division in today's left is between those that hold to a folk politics of localism, direct action, and relentless horizontalism, and those that outline what must become called an accelerationist politics at ease with a modernity of abstraction, complexity, globality, and technology. The former remains content with establishing small and temporary spaces of non-capitalist social relations, eschewing the real problems entailed in facing foes which are intrinsically non-local, abstract, and rooted deep in our everyday infrastructure.[35]

Srnicek and Williams here mischaracterise the local as inherently technophobic. This is understandable given works like Peter Gelderloos's *An Anarchist Solution to Global Warming,*[36] which build unnecessary technological turnings back of the clock into possibilities

[34] http://allthemusic.info/faqs/

[35] Alex Williams and Nick Srnicek, *#ACCELERATE MANIFESTO for an Accelerationist Politics*, (2013) : https://criticallegalthinking.com/2013/05/14/accelerate-manifesto-for-an-accelerationist-politics/

[36] 'Longer distance communication happens primarily through the radio. Most urban or semi-urban communities have telephone and internet. Highly toxic computer production has mostly ended, but a few cities use new, slower but cleaner methods to continue manufacturing computers at a minimal scale. However enough old parts are in circulation that most neighborhoods that want to can keep a few computers running. Many rural people live close enough to a city to access these forms of communication from time to time.' : Peter Gelderloos, *An Anarchist Solution to Global Warming*, (2010) : https://theanarchistlibrary.org/library/peter-gelderloos-an-anarchist-solution-to-global-warming

for self-governed communal living. Nevertheless, I hope to show with the notion of future-mindedness that scale variability is essential, and that the non-scalable and the technologically advance are not remotely incompatible. It is only through standardisation and intellectual property enclosure that non-scalable ideas are excluded from the cutting edge of technology, and only through Gelderloos's non-materialist, "primitivist" aesthetic biases that the forming of small horizontal communities is conflated with a distain for computers and a prioritisation of "alternative" medicines. The non-scalable should be understood not simply as the local community but also as the niche interest group that could never form locally and is entirely dependent on internet access for collaboration across the planet. Further, the open sharing of files and ideas is central to the phenomenon of the home workshop or local makerspace, kitted out with 3D printers and the like, and so the production of items, whether clothing, gadgets, or musical instruments can become increasingly local and simultaneously increasingly globally interdependent. In future it may be this technologically enabled new ease of DIY that may encourage musicians to engage with the design of their instruments and therefore their musical systems.

1.4 Musical systems

I have so far described musical language nebulously, conflating 12-EDO with 'western musical language', "standard practice" music theory, the stave and the Halberstadt keyboard, and so by the discussion of how these categories and others intersect, we may clarify a few terms which will be used throughout. It is true that 12-EDO is only one component of the standardised musical language as it exists in common practice music theory. It is also true, however, that it has a particularly strong sense of permanence because it is often physically built into instruments, where rhythm and note are enacted by the body. Therefore, for example, when Schoenberg and his posse looked to shake up musical language from within the concert music world they could change everything but the instrument and its tuning. This permanence also comes from the stave. Since we are taught from the stave, we are able to observe through study of musical history, developments in structure, harmony, melody, and rhythm. But since the stave typically neglects tuning, it is not taught as an orthodoxy to which we have arrived but remains unspoken, hidden between the cracks of an overbearing framework. Yet given how our tuning has been so well hidden in plain sight, we should not assume there is nothing else hiding in the assumptions of musical language. Certainly there are assumptions about what music is, the role it may play in our ceremonies, assumptions about which kinds of musical ideas should be in the public domain and which should not, assumptions about the social function of music, the separation of performer and audience, when it's appropriate to dance or make sound, and so on. Music itself is but a bundle of associations. And so musical systems could be any structure of rules, guidelines, conditions, or relationships influencing the goings-on related to this bundle of associations, within a mass of air molecules as much as an audio file, a record, a streaming service's sorting algorithm, a PDF, a sheet of paper, an instrument design, a classroom, a radio studio, a boardroom, a place of worship, a club, a concert hall, a supermarket, and so on.

The kinds of musical systems that primarily concern this thesis are tuning systems, which we might define as a structure of rules, guidelines, conditions or relationships determining which pitches are available for a piece of music or musical situation. We might then define a tonal, modal or harmonic system as how those pitches are combined. However, there is great complexity and ambiguity to the relationships between these terms, and so in general when focusing on tuning systems it can be assumed that other related systems are not excluded. I also wish to use the terms *pitch system* and *frequency system*. These are larger sets, I would place tuning systems within the umbrella of *pitch systems*, where examples of pitch systems that are not tuning systems would be harmonic and melodic ideas, microtonal fluctuations such as vibrato, particular microtonal tone combination which would not usually be considered harmonies in their context such as the ombak (intentionally detuning from each other to create beating effects) between two adjacent players in a Gamelan, or the similar stacking of multiple slightly detuned oscillators on a synthesizer. I would then place pitch systems within the umbrella of *frequency systems*, pitches are frequencies within the human hearing range, and so frequency systems can include any periodic or patterned systems (including the rhythmic and structural) spectral matters (such as filtering and other processes which can alter the frequency content of sound), and matters relating to frequencies less perceivable to humans, whether at glacial or ultrasonic rates. We shall see that it is possible to have entire frequency systems functioning from a single core mechanism.

By *language* I wish to expand on the metaphor that compares the role of the universal standard increasingly taken up by English, pushed by many of the same forces – colonialism of course, but within that more recently, the influence of digital standardisation and the communications demands of online space, as well as certain institutionally enforced global uses, such as in political diplomacy and increasingly for science and academia. A language today generally consists of permitted sounds, an alphabet, rules or guidelines for how to combine letters into words, a set of words with their prescribed meanings, and rules or guidelines for how to combine those words, as well as sayings, stories, songs, poems, and articles. The standardisation of all of the formal elements into cleanly defined alphabets and dictionaries is a relatively modern phenomenon, one which may have begun by describing the usage of the time but has morphed from description to prescription, from guideline to law in the hands of a particular kind of education system. A musical language then is first and foremost what musicians use to communicate, a mutually agreed sound world or specific pitches, rhythms, instruments, behaviours, song topics, and so on. From this, a repertoire of mutually understood cultural reference points can emerge, and go on shaping the formal elements, back and forth – a musical language is always a dialogue between theory and practice. Languages are also not distinct. I have found since moving to the Netherlands that Dutch reads like English but sounds wildly different, and so it is obvious that they share a relatively recent ancestor (proto-Germanic), languages influence each other through osmosis, splitting, merging and exchanging aspects. Similarly, though it has been always taught with Europe at its centre, 12-EDO theory today is not a monolith but has within it multiple parallel streams of harmonic language, from the Germanic Bach-centred core of much music education, to multiple possible approaches to jazz harmony, modernist atonal harmonies, and instrument-specific harmonic defaults like the power-chords of guitar-based rock.

I will describe systems sometimes in dimensions – these I define from the perspective of performing with the pitch system as on an instrument. For example, a standard guitar has two dimensions, the strings are a set of 6 in one dimension and around 22 in the other, the frets; without a coordinate from both the x and the y, the fret and the string, you would not be able to locate a specific pitch; pinch harmonics could add a third dimension. The Theremin, on the other hand, has only one pitch dimension, and, unlike the guitar's discrete axes, it is naturally continuous. A violin meanwhile would have one discrete dimension (the strings) and one continuous dimension (the neck). A trombone is an especially complex case. For some with fancy modern trombones, there are arguably up to six dimensions: the continuous slide dimension, the discrete harmonic series played by air flow, three valves which are their own binary dimensions, and then an additional binary dimension, the trigger to access a lower register – still, the position in every dimension is taken into account by the mechanisms of the instrument as it produces its tone. This categorisation can be expanded out into pitch systems in the abstract. For example, as will be expanded upon in chapter 2, Dolores Catherino's system of Polychromaticism is two-dimensional, with the first dimension a backbone of Halberstadt-format 12-EDO pitches, and the second a coloured division of the space in between into equally spaced microtones, improving "resolution" to say 108-EDO.[37]

1.5 Practicalities

This thesis will follow a narrative discussing various approaches to post-12 music based on broader musical questions, that is as oppose to offering purely an in depth manual to the specifics of my practical work. Therefore, I shall briefly outline the totality of that practical work in order to contextualise each of the smaller projects involved. With such grandiose and nebulous aims set, to contribute practically towards a post-12 world,[38] my practical work has branched out in a number of directions, amounting to a range of interrelated smaller projects in the fields of instrument design and musical composition.

The instrument designs might be subcategorised thus: *keyboards* (here referring only to controllers which send MIDI messages or control voltage, but which do not produce sound on their own), *polyphonic synthesizers* (here referring to only the sound producing part, most often controlled from a keyboard, and in this case always digital), and *algorithmic music tools* in the form of sequencers and other kinds of module for virtual modular synthesis environments and as alternative firmware for existing digital Eurorack modules (*Ornament and Crime* and *Bela Pepper*), as well as Pure Data and SuperCollider-based systems for real-time improvisatory control of algorithmic music.

The musical output can also be split into three subcategories: *demo pieces* (music composed or improvised to functionally demonstrate a particular musical system or instrument, as well as to find some of its potential musicality), *improvisations* (recordings of solo improvisations, bringing these instruments and systems into my existing set-up as I seek ways to better integrate new frequency systems into my live-electronics performance practice), and finally the largest project, *Infinitely Compact Scale*, a larger-scale cycle of pieces based on the first 12 iterations of the tuning system I call the infinitely compact scale (ICS), derived from what is known to mathematicians as the Farey series, at first taking the form of a series of concert performances but for musical reasons as much as the circumstances of the pandemic, now in the fixed form of an album.

It might well be asked why these overviews show such a practical focus on electronic music, with all of the instrument designs being digital. One the one hand, this is a practical choice. Besides the practicality of being already engaged in synthesizer design, there are many musical and practical possibilities unique to digital instruments. Perhaps the greatest

[37] https://polychromaticmusic.com/
[38] By 'a post-12 world' is meant not one without 12-EDO but one in which 12-EDO is no longer the assumed default.

of these in its influence so far is the pitch precision offered by digital instruments, which is unparalleled by acoustic or analog instruments. Besides this, digital approaches offer to blow wide open the concept of the tuning system by offering frequency relationships determined not just in the conventional sense (as a list of discrete pitches mapped one-to-one to a fixed finger position), but by creating algorithmic systems that set up complex, chaotic, or probabilistic relationships between the performer and the resultant sound, systems that rely on mathematical abstraction and the rapid performance of arithmetic, and systems that operate with frequencies on different time-scales and so constitute what are commonly considered separate parameters such as harmony, timbre, rhythm and modulation. These complex frequency relationships can then be produced with incredible accuracy and repeatability unparalleled by acoustic and analogue instruments. There is also a virtual plasticity to the process of digital instrument design that cannot be found in the analogue or acoustic domains, by which I mean the ability to save and recall, to do and undo, to copy and paste, to endlessly reproduce and share online, to iterate prototypes near-infinitely without material restrictions, and to be able to switch between multiple systems on a single physical device.

These are the practical considerations, but also, in part, the necessity of a digital approach stems from an appeal to future-mindedness, both personally in that my own practice has in recent years been moving away from acoustic score-based composition and towards an improvisatory electronic practice, and more generally, that I would consider electronic music still relatively young, and consistently very fertile ground for musical and technological innovation. In the academy, the western classical tradition dominates much of the discourse around alternative tuning systems, despite this being not necessarily the case in the xenharmonic community at large, and despite the reality that its reliance on long-established instrument designs and virtuosic human-computer-performers (that is, orchestral musicians who apply rigid training to translating fixed scores into sound) means it has the largest practical hurdles to overcome before we can see wide acceptance with more than the current handful of ensembles keen on microtonality. Despite this, score-based composition remains the basis of much of xenharmonic theory in its common form, with many microtonal theorists and composers restricting their ideas to that which can be communicated on the stave. Instead, I hope to show that the possibilities inherent to embracing contemporary technologies at the heart of new music theories can be instrumental in enabling a wider diversity of musical approaches.

2 Technologically-driven approaches to tuning

2.1 Limitations

Historically, tuning has frequently followed from the limitations of its contemporary technologies. Each instrument possesses some mechanism suggestive of certain pitch systems. Acoustic keyboard instruments such as organs, harpsichords, as well as tuned idiophones of all materials, and mechanical instruments based on these, all make sound from a gamut of objects (pipes, tone plates, etc.) which are similar except in size, and therefore all of these instruments are confined to a fixed gamut of discrete pitches. Fretted string instruments with multiple strings are especially suggestive of equal temperaments because where strings of different pitches are used, the intervals found along one string can be transposed up onto the next string, and therefore only equal temperament can deliver a fretboard in which the pitches found on one string can overlap perfectly with those found on the next. Typically, ensembles have had to tune to their least flexible member, and so in the European tradition, the likes of singers, trombonists, and violinists have long built what might have been their naturally continuum-based practises around the need to match up with the organ and piano.

In recent centuries, I would argue specifically since the Industrial Revolution, we have seen a trend towards the standardisation of tuning, in part a reflection of the industrial standardising spirit of the age as it seeped into culture – this is also the period in which the letters of the alphabet, the roles of punctuation, and the spellings of words all became fixed standards. But whilst this formalisation of language was enforced through education, it was necessitated by the technology, the printing press, and likewise we see in music that tuning standardisation is a by-product of the standardisation of instruments. However, whilst it was certainly true that at the birth of the Industrial Revolution in the urban North of England there were for the first time industrial processes used in large factories to produce certain instruments or parts for instruments, for the most part, luthiers and the like continued to handcraft. Jeremy Montagu suggests instead that the absolute dominance of standardisation really only got going much later when these tasks were automated:

> Even the bigger factories were far more relaxed up the end of the 1930s than they are today. Rudall Carte would make you any variant of flute system that you asked for and were willing to pay for; we have plenty of examples here of one-off systems or of special orders for a special, but not often asked-for, system. Even Boosey or Hawkes would produce a special model to order, like the valve F bass trombone here, and so would any of the Continental shops. That is one of the differences from today, for I rather doubt whether Yamaha, for example, would add special keys for you. Once you computerise and fully mechanise, it’s much more difficult to produce variants in ones or twos. This is something that people are better at than machines. But machines are cheaper, and they don’t go sick or want holidays, nor for that matter do they sleep.[39]

Since instrument production was relatively slow to be mechanised, then, the instrument maker’s workshop or factory was not, at first, the primary accelerator of standardisation. Rather, it was the larger factories and mines at the heart of the economic shift that had a more immediate effect on the standardisation of ensemble line ups. Montagu adds:

[39] Jeremy Montagu, *The Industrial Revolution and Music,* (Hataf Segol Publications, 2018) p. 168.

> Musical instrument factories, even at their biggest, never compared with places like cotton mills, steel mills, coal mines and so forth, which, in the early days of the Industrial Revolution had an insatiable demand for workers. Because the factories and mines tended to be clumped geographically, they were also inevitably competing with each other for workers. One way of attracting them was by encouraging outside activities, and there are many examples known of a factory advertising for a craftsman with a certain skill who also played a certain band instrument. The mill band, Black Dykes Mill, for example, or Foden Motors, or the mine band, became well established in the nineteenth century, and many still survive today.
>
> Bands in England became quite rigidly formalised. They started, of course, with whatever was to hand, but there grew up a strong competition movement, not altogether surprisingly; the idea of 'my lot's better than your lot', whatever the lot may be, is pretty well engrained in human nature. Competitions between widely differing ensembles are difficult, and almost impossible, to adjudicate fairly. And so they became formalised. There were basically two varieties: the military band and, once the valved brass were invented and established and available reasonably cheaply, that is to say factory-made, the brass band.[40]

As the new liberal spirit of competitive brand recognition replaced the local musical ritual with workers forming bands in the name of their employers, the rules of the competitions kick-started the culture of fixed formation ensembles that continued thereafter. Given, as I have argued, that the line up of an ensemble has the power to push its constituents to conform to the least flexible member, this standardisation of the ensemble inevitably led to greater uniformity amongst instruments. This endures to today as composers continue to write more orchestral works and string quartets than almost any other form, offered as templates when notation software is opened, safe in the knowledge that, should one particular group lose its funding, there will be plenty more matching the same line up who can perform the work. The same is true of individual instruments; from the perspective of replay value, economically it is a safer bet to write for piano, cello, or clarinet than some non-scalable esoteric instrument.

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That social limitations shape ensemble limitations which shape instrumental limitations which shape tuning limitations might paint a very negative image of the relationship between technology and tuning, but really the relationship between tuning and technology is bidirectional and inherent, and therefore can be restrictive or fruitful in different contexts. It is 'a chicken and egg question'.[41] Instruments are built around the structure of the tuning, but the tuning is shaped by the possibilities and limitations of the instrument. Where instruments are shaped around the confines of what is possible with acoustic interaction of physical elements, the physicality imposed restrictions. An organ once its pipes are built, a guitar once its neck is fretted, and a recorder once its holes are drilled, all are fixed to their physical form. But with the birth of electronic instruments those physical limitations seemed to be ripped up. Very quickly musicians associated with the Italian Futurists began to envision

[40] Montagu, pp. 168-169.
[41] Fabrice Marandola's response when I asked him how instruments have shaped tonality.
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a future of music outside of 12-EDO, with instruments to match. In *The Art of Noises* (1913) Luigi Russolo argued that music in its association with divine harmonies had been too high-handed, ignoring everyday life and restricting expression to sacred harmonies. He wrote:

> The result of this was music, a fantastic world superimposed upon reality, an inviolable and sacred world. This hieratic atmosphere was bound to slow down the progress of music, so the other arts forged ahead and bypassed it. The Greeks, with their musical theory mathematically determined by Pythagoras, according to which only some consonant intervals were admitted, have limited the domain of music until now and made almost impossible the harmony they were unaware of.

Russolo's solution was an embrace of noise through his mechanical instruments, the Intonarumori, reflective of the daily sounds of industry, 'This revolution of music is paralleled by the increasing proliferation of machinery sharing in human labor.' Ferruccio Busoni, writing six years earlier in the *Sketch of A New Esthetic of Music* (1907)[42] also identified musical pitch as naturally continuous and artificially restricted by an orthodoxy, calling for musicians to 'once again call to mind, that in this latter the gradation of the octave is infinite, and let us strive to draw a little nearer to infinitude.' His solution was to advocate microtonality made viable by new electronic instruments.

> I received from America direct and authentic intelligence which solves the problem in a simple manner. I refer to an invention by Dr. Thaddeus Cahill. He has constructed a comprehensive apparatus which makes it possible to transform an electric current into a fixed and mathematically exact number of vibrations. As pitch depends on the number of vibrations, and the apparatus may be "set" on any number desired, the infinite gradation of the octave may be accomplished by merely moving a lever corresponding to the pointer of a quadrant.
>
> Only a long and careful series of experiments, and a continued training of the ear, can render this unfamiliar material approachable and plastic for the coming generation, and for Art.[43]

Busoni is referring to the Telharmonium, a keyboard instrument and early proposed set up for music to be beamed into the home by telephone wire. It used spinning cogs known as tonewheels read electrically in one spot so that for each tooth there would be a cycle in the output waveform, and so by spinning a cog of 100 teeth one revolution in a second, a tone of 100Hz would be heard. In the Telharmonium this was used to produce co-phased tones in integer multiples of a fundamental, so that each key would control the rate whilst the readings from different cogs could be mixed, amounting to the first additive synthesizer. Other early electronic instruments such as the Theremin (1920), Ondes Martenot (1928), Trautonium (c. 1929), all dealt in the uninterrupted pitch continuum, whilst the ANS synthesizer (conceived of c. 1937) used 720 tone generators tuned in sixth-tones (72-EDO) so as to approximate the full continuum, it was composed for by etching shapes onto glass and so encouraged continuous motion rather than thinking in terms of discrete pitches.

[42] Ferruccio Busoni, *A New Esthetic of Music*, trans. Theodore Baker, (New York: G. Schirmer, 1911), pp. 30-31.

[43] Busoni, p. 33.

From the start then the technologies within electronic instruments promised an escape from the dominant twelve-note music theories. But at the same time the makers of these novel and alien devices wanted to see them accepted into the existing music world. The ribbon of the Ondes Martenot was combined with a Halberstadt keyboard, whilst the Theremin was learned as a virtuosic classical instrument by Clara Rockmore. In the sixties, when modular synthesizers were made viable for the first time, they took two different directions, the East-Coast and the West-Coast methods. The dominant of these in scale, reach and influence over the rest of the century's synthesizer designs was the East-Coast model where Robert Moog paired subtractive synthesis with a Halberstadt keyboard. The synthesizer came to be known as a keyboard instrument. As Suzanne Ciani explains:

> What happened was, to market the instrument, [...] a keyboard was put on it. And so everybody said "Ah! It's a musical instrument, it has a keyboard." The whole thing was hijacked, or short-circuited, or however you want to say it, but the potential of electronic music, it didn't get realised, it went down a left turn, and it's just coming back now.[44]

The keyboard, which had been developed as a response to the limitations of a finite number of discrete physical objects, organ pipes or piano strings, was transplanted onto an instrument which would have otherwise been capable of playing the infinite gradation of pitch space. What happened with Martenot's and Moog's inclusions of the Halberstadt keyboard, which later came to define the limits of the MIDI protocol into a 12-EDO-based model of music, is that the evolutionary symbiotic relationship between pitch systems and instruments was broken. *What was possible* continued to evolve and expand faster than ever before, but *what was actually done* had never been more static. When computers showed up, these possibilities multiplied even faster, and many microtonalists took note, with John Chalmers using his access as a biologist to university computers in the 1960s, to work with Erv Wilson to calculate the cent values to a high accuracy for hundreds of previously unexplored or underexplored just intonation and equal tempered tuning systems. In some ways though it was too late; tuning was already a niche concern kept out of view of most musicians. Interviewed in the podcast *Now & Xen*, Chalmers remarked: 'It's really unfortunate that electronics didn't become really widespread until recently, because you had all these theorists in the twenties, when people really were serious about quartertone music, and maybe even earlier – 19 [EDO] could have replaced 12 perhaps.' Viewed from the perspective of the microtonalist, then, the history of tuning is deeply hauntological, it is a history as much defined by what occurred as by those potentials left unfulfilled, both, as Chalmers evokes, the tuning possibilities promoted by curious musicians that were left unfulfilled by the technological limitations of the time, and as Ciani evokes, the opposite, the technological possibilities left unfulfilled by the uncurious musicians of the time. Commercial music technology continued to push the envelope on matters of timbre and to some extent rhythm but surrendered pitch to the standardisation codified in the MIDI grid.

To reform the relationship between technological development and pitch system development, we can begin by meeting technologies where they're at, but with an ear to the tunings that result. Rather than seek to bend the will of a technology to a musical system, we could do the opposite, by allowing the features of the technologies to offer their own simplest solutions. This is what I call an Occam's Razor tuning solution, and part of a

[44] Waveshaper Media, *SUBTONICK: Suzanne Ciani on Morton Subtonick,* (2017) : https://youtu.be/-Rj6IJBR77g

limitation-based technology-driven approach to tuning. An Occam's Razor tuning solution is when you take a certain context from which you wish to derive a tuning system and from it attempt to make the least number of assumptions and extrapolations possible to arrive at a solution. An example of this would be that many tuning systems are derived from the harmonic series, but usually assume that they must be finite octave repeating scales, and that intervals run through chromatically should be roughly the same size; these assumptions are not natural inevitabilities of the harmonic series, and therefore the Occam's Razor tuning to be derived from the harmonic series is to use the harmonic series itself as a scale. In combination with the notion of a limitation-based technology-driven approach to tuning, this means seeking tuning systems that are the simplest solution given the possibilities and limitations of a technology. To give an example with the same solution – when programming a MIDI synthesizer in an environment like Pure Data or SuperCollider, MIDI note numbers are received and then generally converted through a "MIDI to Frequency" converter which by default converts the input note number to the frequencies of that numbered note in the scale of 12-EDO. The Occam's Razor solution could be to bypass this conversion, and so as the MIDI gives note numbers 0-127, the keyboard would play frequencies of integers up to 127Hz, otherwise known as the harmonic series with fundamental 1Hz.

Peter Blasser has twice built instruments that embody this idea of a limitation-based technologically-driven tuning. The first of these to consider is *JustInts*, a software instrument controlled from a custom keyboard (a USB variation on his Sidrazzi Organ) which uses 'integral math' (which in a computing context means maths done with integers) to determine frequencies of oscillators. The integers are paired into ratios resulting in a justly tuned system. *Ints* are the simpler of the two main ways numbers are stored digitally, the other being *floats* (floating points) which are needed to store what we think of as the decimal numbers in between the integers. The limitation of using only ints is intentionally applied as a kind of technology-driven pitch system, as he explains:

> A symbol of it being digital was that I was trying to honour that by using just ints, and also ints are lower power, so for "green business", you know, I mean seriously floats use about 60 times as much power [...] so I want to push it as far as you can with ints, just seeing what ints can do, and it turns out it makes some pretty sweet intervals come out.[45]

Tristan Perich's early 1-Bit music also allows the tuning to follow from the technology, similarly, playing in just intonation, but here because it is the simplest to achieve in 1-bit audio that is, where the speaker cone jumps between only two states based on a binary script. Interviewed in Vice he says:

> With my first album, *1-Bit Music*, I kept the code as direct and simple as possible, so pitches were represented in terms of multiples of the base sample rate. The pitch system was in pure intonation, with no easy translation to my familiar way of writing music. Composing for that album was more a form of continual experimentation and refinement.
>
> When I began composing for classical instruments accompanied by the 1-bit electronics, I adapted the electronic pitch system to match the musicians (this felt more natural than the other way around), and so I was able to write in

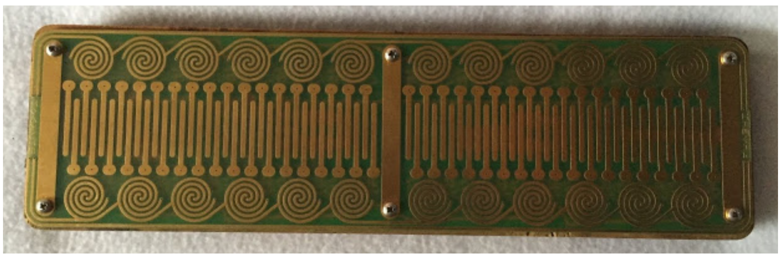
[45] Momasu, *Peter Blasser demonstrates some amazing instruments*, (2012) : https://youtu.be/abkeqcQCpnQ

standard equal temperament. With *1-Bit Symphony*, I took this approach so I could put more focus on the compositional aspects of writing music and less on the artefacts of the system itself.

Raw data sonification, as can be done in Audacity, also follows the structural logic of the various nested levels of patterns of bits in any machine code. The sounding result is a rhythmic, harmonic and timbral nesting of integers. The result is often chaotic and noisy but also sometimes becomes a drone or takes up clear just intonation patterns. This is because a lot of algorithms follow repetitive patterns of various integer lengths. I have included some of the more harmonious examples from files I happened to have on my computer. In audio example 1, you'll find a conversion of the Blender 3D file for my design for a string-fretted multi-ribbon keyboard (discussed in 2.3) into a mono audio file of sample rate and depth of 96kHz and 16-bit respectively. In it you can hear a section that repeats exactly 19 times, with a harmonic series melody of {6,8,5,8} with a fundamental of roughly G, so {D, G, B, G}. Audio example 2 is I think an especially musical example from a conversion made before I thought to keep a record of the source files, with a sample rate of 5kHz. What we hear in it is a pulsing drone of an 8:15 (just major seventh) harmony with an intermittent refrain of an 8:12 (or 2:3 perfect fifth), from which we can guess at some of the code's structure contributing to this Pythagorean stacking of fifths as some sort of recursive structure based on multiples of 3. Where audio example 2 is only an extract of a conversion at a sample rate of 5kHz lasting four and a half minutes, audio example 3 is the entirety of the same file condensed into 3 seconds, at a sample rate of 7372.8kHz (1474.56 times faster). What is heard at this time-scale is simply one tone followed by another a fifth below. The same recursiveness that led to stacked fifths producing a Pythagorean pitch set in example 2, exists at the macro-structural level which when sped up is heard as related harmonies. Audio examples 4-11 are also raw data conversions with prominent just harmonies for the reader's perusal.

The second example of a technologically driven tuning system in Peter Blasser's work is the Ciat-Lonbarde *Tocante*, (fig. 1) a small solar powered polyphonic analog touch-plate keyboard where the pitches of the oscillators are determined by using in the oscillator circuits the industry standard for the most widely available Ohm (Ω) values of resistors. These are the values 10Ω , 15Ω , 22Ω , 33Ω , 47Ω , and 68Ω , and they repeat also with multipliers of 10^n, so also 100Ω , 150Ω , ..., 1k Ω , 1.5kΩ , ..., 10kΩ , 15kΩ , and so on. As Blasser writes, 'The *Tocante* instruments rely solely on the materials of electronic components to tune the oscillators, thus eliminating the need to intentionally control tuning by both instrument builder and performer.'[46] If this were a 12-EDO instrument, these resistors would be found in oscillator circuits combined with others and potentiometers there to adapt the oscillators to a human system. Instead, by removing the extra steps that make a raw oscillator circuit design safe for 12-EDO use, the tuning system is made technology-driven as the components themselves take charge of tuning. However, the human perspective is not forgotten, but is in in the touch sensitive interface which allow

Figure 1 *Ciat-Lonbarde Tocante*



[46] Peter Blasser, *Stores at the Mall*, (Connecticut: Wesleyan University, 2015), p. 110.

the performer to join the circuit. 'The Tocante line of musical instruments is "about" and "touching" the materials of electronics'[47] as Blasser puts it. We might also add that it is about standardisation in the sense that it replaces the industrial standardisation of pitch with pitches derived from the industrial standardisation of electronic components.

It's hard to imagine another tuning system that could get at the material of analog electronics so directly, but many tuning ideas result from the logic of particular analog processes and devices, and existing frameworks like the equal division of pitch space can be achieved with commonly available analog tools. Typically, the source of pitched sound in an analog synthesizer is a voltage controlled oscillator (VCO) which in the most common format, Eurorack, uses the standard 1 volt per octave, meaning that, compared to the pitch heard when no control voltage is sent to the VCO, if you send 1 volt you will hear the oscillator an octave higher, with a logarithmic distribution so that $\frac{1}{12}$ volt would mean moving up a semi-tone. Any voltage source can therefore provide a pitch system of some sort. Commercially available keyboards, sequencers and voltage quantizers for modular synthesizers with digital innards are frequently pre-programmed to work only in 12-EDO. However, with the logarithmic convenience of the 1 volt per octave standard these voltages can be processed through common devices such as an amplifier or attenuator to change the size of the repeated interval, so that attenuating the received direct current to 50% of its original amplitude would condense the output into half the range whilst sounding as 24-EDO, alternatively amplifying that original signal to 240% of its amplitude would sound as the macrotonal 5-EDO. Freely tunable voltage keyboards and sequencers are a common part of modular systems which can be tuned by hand, whilst there are also plenty of random or chaotic voltage generators which could be used to produce a pitch system that is far less repeatable. Steady voltages can also be taken from batteries or the pins of a microprocessor. An Arduino has 3.3v and a 5v pin as well as the 0v ground; assuming the VCO is tuned to C1 by default, using these voltages only would give the small and very wide-ranged pitch set {C1, E4 –40cents, C6}. That is, if the oscillators track perfectly, which none do, meaning that although the intention is to a have 1 volt per octave correspondence for the full range there are imperfections which lead to differing tracking in certain pitch ranges. Therefore, using multiple oscillators with the same voltage source can provide slight variation in pitch between them, this is often corrected for with digital pitch correction as in the Tubbutec *μTune*, but the Occam's Razor solution could be to embrace and intentionally explore these microtonal non-unisons. Two sine wave oscillators ring modulated together produce sine waves at the sum and difference of the input's frequencies. Harmonic systems can be derived from this operation, and often have been by composers translating these operations into the acoustic realm. Claude Viver's *Lonely Child*, uses a technique he calls *les couleurs*, where parallel bass and melody lines are composed, and then the ring-modulation-derived combination tones of these two frequencies produce two more pitches, now outside of 12-EDO, the same process can be repeated for the tones just generated, and in this way a microtonal chord is derived from the initial bass and melody in combination with the mathematical function of ring modulation.

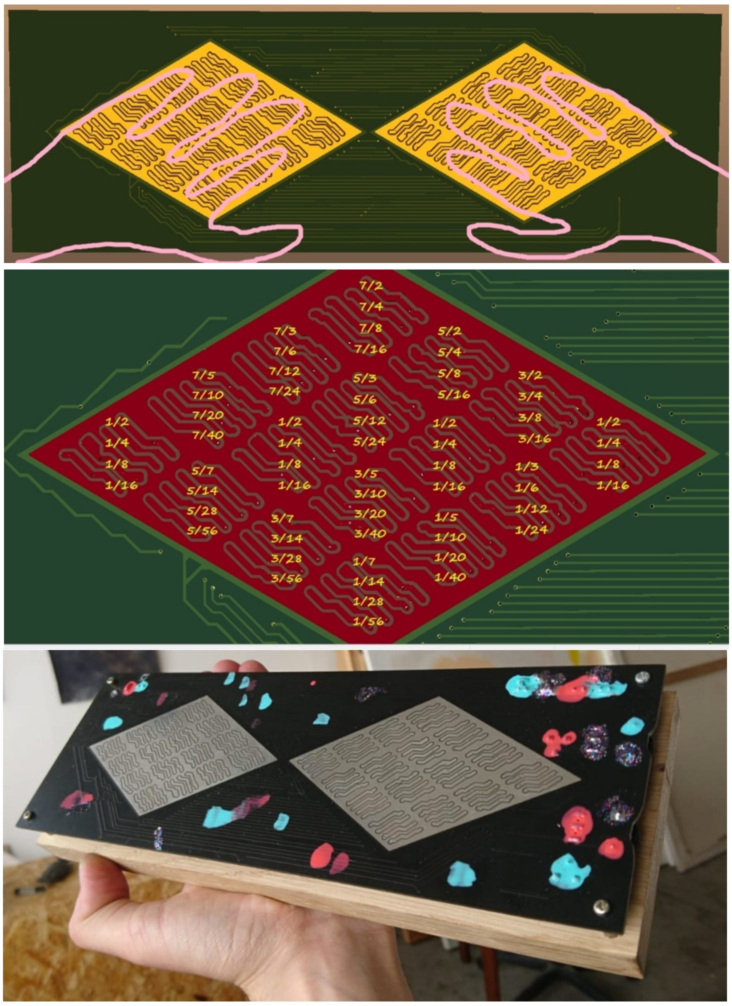
There are also many analog processes which result in just intonation harmonies, which is to say where the frequency of an oscillator input can be multiplied into harmonics or divided into subharmonics. For analog envelope generators, a voltage spike will trigger the onset of the envelope, but for many a second trigger is received during the rising attack phase, it will complete its initial envelope rather than restarting. The result of this is that

[47] Peter Blasser, *Synth Mall* : http://www.synthmall.com/tocante/index.html

given a pulse wave input, with an attack stage set long enough, the output will skip cycles in the input waveform; if the attack stage is long enough to skip one cycle the resulting signal will be half the frequency, an octave below the input, if it is long enough to skip two cycles, the resulting signal will be a third of the frequency and so on. Many envelopes have voltage control over the attack stage length and therefore can be used as an oscillator that is by its nature quantized to the subharmonic series, in which an input sequencer or keyboard could be used to determine the subharmonic. Clock dividers and resettable analog sequencers can also be driven at audio rates to produce subharmonics. An oscillator can be synced to another so that its waveform resets each time the other begins its cycle, this way, when the first oscillator is shifted up in pitch it does so in multiples of the steady oscillator, creating a harmonic series. And likewise, if a steady sawtooth oscillator is fed through a very resonant filter, the resonances will pick out the overtones of the sawtooth wave, also producing a harmonic series. Many of these tricks are well known, but what is the perhaps underexplored notion of analog just intonation as a technique of combining undertone-producing processes with overtone-producing processes to create in totality a numerator over denominator system. For example, a steady oscillator could be run processed with the envelope trick to divide the frequency down to for instance missing two cycles and therefore sounds at a third of the frequency of the input oscillator, and then the envelope's output could be processed through a resonant voltage controlled filter to multiply the frequency up, for instance by picking out this new tone's fifth harmonic, with the overall result of a tone in a 5:3 harmony with the initial oscillator. This same oscillator can be routed to multiple such processes so that many just intonation pitches can share that common fundamental. To play these pitches from a keyboard could be achieved with a dual channel voltage offset keyboard where one channel sequences the numerator (the pitch of the synced oscillator) and the other sequences the denominator (the length of the attack stage of an envelope).

Mike Page is currently developing similar ideas into a tactile instrument. As with the Tocante, it would involve touch control of the amplitude of oscillators, except that, rather than have a separate oscillator for each touchplate, a single oscillator can be divided and multiplied by a network of simple binary counter chips and diode logic into an array of frequencies. Figure 2 shows the 7-prime-limit ratios to the fundamental oscillator heard at each position on the touchplate, with both hands using the same pitch set but mirrored to match the

Figure 2 *Mike Page's Just Touch synth*



geometry of the hand. Because analog just intonation processing of waveforms is a matter of multiplying and dividing an input, that input does not have to be a static oscillator but is instead a voltage controlled one. We might say that this instrument is in part built around the harmonic logic of a selection of simple binary counting integrated circuits.

2.2 Possibilities

Since I have been drawing a distinction between limitations and possibilities, it is worth noting that these are comparative terms, a characteristic of a technology is seen as a possibility if it offers something that other technologies do not, whilst it is seen as a limitation if it lacks some characteristic that other related technologies possess. As such, what is considered a limitation or a possibility is very much time-dependent. It is in this sense that we should understand the general assertion that computers are associated with possibilities where analog technologies are more often valued for their limitations. This is evident in the way we frequently emulate analog limitations in the digital realm – whether for hauntological aesthetics (tape hiss and warble, vinyl skips and crackle, and the pitch drifting of analog oscillators) or for the convenience of those who were used to an old system (the mixing desk recreated in digital audio workstations). Really, subharmonics are a relatively rare natural occurrence in acoustic instruments, and so the many analog processes capable of producing subharmonics can very much be seen as possibility-based technology-driven systems. *JustInts* uses a rare case in the digital realm of an obvious "limitation" tied to the actual hardware, and even there it is a self-imposed limitation, to avoid floating points, although it may indeed save energy.

Today, for the most part, tuning systems implemented in computers are not limited by processing power but by software design decisions. Therefore, since the majority of commercial software neglects to involve sensible solutions for retuning to something other than 12-EDO, microtonalists have been left with little choice but to program their own – greatly slowing down the music making process, excluding those who do not have the time or desire to learn to program, and excluding the use of many very powerful tools that already exist. Originally, MIDI was related very directly to hardware limitations, as any digital protocol confined to 1981 computer technology would be, but as computer music making has advanced towards the wide availability of powerful and complex digital signal processing (DSP) bringing with it an explosion of timbral possibilities, the systems for controlling pitch have remained limited to the same MIDI protocol with only durations and a maximum of 128 static notes tuned by default to 12-EDO. There have long been a number of work-arounds involving pitch bend, but MIDI pitch bend is applied to all notes at once. By breaking out into individual MIDI channels, each of which can have its own pitch bend value, we have recently seen the formalisation of MIDI polyphonic expression (MPE). The first channel is kept for general control data leaving the 15 other channels, giving a maximum of 15 voices of polyphony. This may be more than we have fingers but there are many situations when exploring experimental approaches to harmony in which it would not be enough. Pitch bend has also been used to make microtonal melodies monophonically which could then be multi-tracked into polyphony, however this means you must know what it will sound like before you play it. In lieu of some of these limitations we have seen in recent years the construction of a second generation of the protocol, MIDI 2.0, yet to be widely implemented, which sees mainly a prioritisation of ways of communicating default mapping configuration whilst maintaining backward compatibility with older MIDI devices. The points concerning microtonalists seem to be a sort of a marriage of MIDI and MPE where each note number will have its own pitch bend. Consequently, we will soon be able to have up to 128 voices of MPE, a definite win for the future of microtonal compatibility.

> For microtonal composers. you can carry detailed pitch information in every individual note and event. When you did microtonal work before, you'd have to set up individual scales within a synth - often using Scala tuning files. Now you can have a Note On event each time you hit middle C that actually sends out a different microtonal pitch - and that's carried directly in the datastream, it's not a configuration thing.[48]

The issue with this as a solution to previously under-accommodated microtonality is that this model of microtonality defined by a list of 128 frequencies in a Scala or text file only developed as a result of the limitations of MIDI in the first place. As Sevish writes in a 2016 blog on what microtonalists require from the then forthcoming MIDI 2.0 conferences, 'Oh don't get me wrong, 128 notes is more than enough for standard tuning, but this isn't 1890 anymore. People are starting to want something more than standard tuning.'[49] The Tonal Plexus keyboard for example uses 205-EDO. And in the age of synthesizers, we want access to a wider range than a piano can handle, indeed we should be able to play over the whole audible spectrum which is a little under ten octaves, to cover ten octaves with 205-EDO would require 2050 different notes. In MIDI 2.0, two adjacent pitches could be played on such a keyboard by assigning them to two adjacent note numbers and then pitch bending each into that 6 cent microharmony, but then what if I want to play another in the same region, another key from even further away must be taken up, and so on. This is a work-around that the programmer of the keyboard will have to pre-program rather than simply giving a note number to each key as a Halberstadt MIDI keyboard would have. There are many possible work-arounds, but they mostly involve the impossibility of playing all of those notes at once. This may not seem much of a limit, but I would argue that if we are today fixing the inadequacies we failed to account for in the MIDI protocol of 1981, we should at least be able to accommodate everything we can think that we might want to do today – that is if MIDI is going to continue to be the musical nervous system of software. Given that this protocol might be expected to dominate for as long as the previous iteration, 40 years, it should be concerning that we can already see unnecessary limitations. As we will see in the following chapter, if there is more and more interest in holistic approaches that deal with harmony and timbre as one, such that partials and notes are no longer considered separately, the requirement for more and more voices will continue to grow.

Our analysis of MIDI should not take work-arounds too seriously because as we zoom out of individual cases, inconvenience remains an insufficiently accounted for player in the larger shaping of music today. As Robert Barry puts it in *The Music of the Future:*

> There are all sorts of things that you can do with the MIDI grid, but most people don't because, frankly, it's a pain. The System suggests a certain way of working – the use of quantised rhythms and discrete, tempered pitch classes – by making them the "default" settings. Most people just tend to go with that. Today it forms in [Jaron] Lanier's words, "the lattice on which almost all the popular music you hear is built."[50]

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[48] https://www.musicradar.com/news/what-is-midi-20-and-what-does-it-mean-for-musicians-and-producers
[49] https://sevish.com/2016/2-features-we-need-in-midi-2-0/
[50] Robert Barry, *The Music of the Future*, (London: Repeater, 2017), p. 159.

The way that MIDI quantizes and standardises culture is an example of what Lanier describes as something particular to software, 'The brittle character of maturing computer programs can cause digital designs to get frozen into place by a process known as lock-in. This happens when many software programs are designed to work with an existing one.'[51] When a digital design 'frozen into place' has such a colossal cultural impact it should be considered a constituent of the wider phenomenon of the perpetual now. And so at this rare junction, after four frozen decades, at which we lay out the future of MIDI 2.0, we should be fully engaged with shaping its formative years, whilst assessing whether we want this updated MIDI (improved but ultimately limited by its emphasis on backwards compatibility and the continued centring of the Halberstadt keyboard) to be our nervous system in the future.

As Barry suggests, the centrality of the MIDI grid to the digital audio workstation (DAW) has, in quantising our pitches and rhythms, set the stage for one of the major tendencies of music in recent decades – what I call hypertuning. By hypertuning I mean the trend since the development of digital synthesizers and DAWs, towards more precise tuning than the natural voice, and more precise rhythm than the natural hand. It is an extension of the abilities we now have to edit our performances onto the beat and into tune, or however else to make subtle adjustments to design the perfect performance in the edit from a number of recorded takes. This quantisation, especially in the pitch domain with autotune has been often maligned by the critical establishment and by fans of older methods, for permitting those who are called "non-musical" to make music without what is called "natural talent" or indeed without years of training or expensive lessons. Autotune, whilst serving as an effect with its own aesthetic, does lock the voice ever closer to a platonic form of the tuning it is used with, but I would also point to the example of a classical singer who recently on a forum asked 'How close are good singers getting to their target pitch in terms of cents?' Digital sound analysis has brought a fundamental change in the way musicians can measure the accuracy of intonation, and that measure then comes to shape a spirit that considers hyper-precision desirable. Ironically, whilst this hypertuning may be the strictest and most robotic enforcer of 12-EDO today, these same technologies and aesthetic trends have created the perfect conditions for a new rise in interest in xenharmonic ideas and less conventional rhythms. Hypertuning to some extent conceptually condenses pitches from zones (pitch classes) to nodes (frequencies), with the result that musicians and listeners may gain a finer ear for pitch and lose their tolerance for the out-of-tune – and with this we may find that those pitches in between can take on a far more intentional role. Hypertuning has created gaps in pitch space, just the right size to be filled by an embrace of the microtonal. This relatively new digital frequency precision makes more possible than ever the filling of those gaps. This includes the possibility of highly microtonal keyboards made more feasible than they were with analog technologies. As Terumi Narushima notes of Erv Wilson's generalised keyboard design:

> Wilson designed a 22-note keyboard based on his 1967 design for musician Gary David and a prototype was built by Robert Moog, the inventor of the Moog synthesizer, with the help of Paul Beaver. Unfortunately, the instrument could not be completed due to problems with pitch stability in the analogue technology available at the time, so Moog refunded David's money with interest. In 1970, Wilson wrote a letter to Moog encouraging him to persist with the design and construction of a generalized keyboard, but in fact Wilson had to wait for

[51] Jaron Lanier, *You Are Not a Gadget: A Manifesto* [e-book version], (New York: Alfred A. Knopf, 2010), p. 17.

developments in digital audio synthesis before his keyboard design could be realized in practical terms. This came in the form of the MicroZone keyboard built by Starr Labs [in 2000].[52]

And so such instruments are uniquely digital possibilities. The possibilities for highly microtonal music then are more numerous than ever, but for now at least MIDI continues to box us in with convenience.

The role that MIDI serves, which I have described as a nervous system, is one that I would like to attempt to find a term to generalise for digital instruments. There is the digital signal processing (DSP), where functions are usually performed on a block of samples at a time, dealing in audio signals and time-dependent synthesis functions (oscillators, filters, and so on), on the other hand, there is numerical data, the domain of MIDI, which pipes numbers controlling all kinds of parameters, but most relevantly to our concerns, pitch. Though these kinds of data can be converted between, I will for now use the model of considering DSP functions as organs and numerical functions as vessels. I would argue that today the piping of numbers, the vessel element of music software has been deprioritised to the extreme so that all pitch information can be communicated with one dimension of 7-bit information (integers 0-127). Early on it was clear that this "piping of numbers" was the strength of digital synthesis, as so many of the earliest digital synthesizers, Bell Labs' Alles Machine, the Synclavier, Fairlight CMI and Yamaha DX7 all worked on the bases of additive synthesis or frequency modulation, which involve the stacking of multiple oscillators (or "operators") with integer-based harmonic relationships, and modulating their amplitudes. In many ways these can be considered harmonic systems, indeed, I would describe John Chowning's frequency modulation (FM) synthesis algorithm, as used in the DX7, as one of the most important harmonic developments of the last century. We usually think of pitch movement as melodic, a contour of discrete or sometimes slid-between pitches in a sequence, but FM synthesis is pitch movement at audio-rates, which fundamentally changes the perceived outcome of a pitch movement, from a melodic experience to a timbral one. Analog FM synthesis preceded Chowning's algorithm and produces strange inharmonic tones with their own character, but only with the precision of digital technology was it possible to implement Chowning's idea of FM where the modulator is in an exact harmonic ratio with the carrier, this produces a timbre that is purely harmonic (its overtones are integer multiples of its fundamental). And so this is a timbrally versatile synthesis technique produced by a uniquely digital complex pitch system which combines just intonation relationships between operators with frequency modulation, which we can think of as vibrato at rates impossible on acoustic instruments. In these early synthesis algorithms, we might say that the organs were very simple, usually just sine waves, whereas the vessels are far more complex than they ever could have been in an acoustic or analog system. My own approach to synthesizer design is also a reprioritisation of the "vessels" that seeks to exploit the possibilities unique to the computer – to perform a large amount of arithmetic very quickly, and to analyse, measure and produce sounds very precisely. The other side to this is that for now at least the "organs" remain mainly simple sine waves, or are replaced with wavetable oscillators.

Some ideas for these "vessels" are isolated from the particularities of the synthesis, they are algorithms for generating pitches, what we might call sequencers or quantizers in the language of modular synthesis. I have therefore imagined them as modules, taking

[52] Terumi Narushima, *Microtonality and the Tuning Systems of Erv Wilson*, (New York, Routledge: 2018), p. 20.

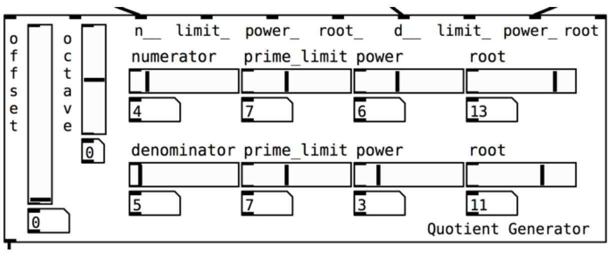
multiple control signals as inputs and outputting something like a 1 volt per octave control signal. The long term plan is to program these ideas and others into an alternative firmware for open source Teensy-based Eurorack module Ornament & Crime,[53] for which I began by making a simple harmonic series quantizer as an add-on to the original firmware, built as an expansion of the simple sample and hold detailed by Beige Maze.[54] The goal is not only simple add-ons to the existing firmware but to build a suite of selectable programs all providing unusual microtonal sequencing possibilities. I have also been developing them for virtual modular environments – for now, Pure Data-based virtual modular synthesizer Automatonism (2017) made by Johan Eriksson – which are not only an easier way to build and test them but are free for anyone with a computer to use, and have the benefit that using more than one of a module involves simply copying and pasting rather than a multiplication of physical resources.

One possible method of generating pitches that goes beyond the one-dimensional MIDI note model, is my design for the Quotient Generator. In mathematics, $\mathbb{Q}$ is the set of all rational numbers, otherwise known as quotients or fractions, that is, any number that can be made by diving one integer by another. Applying this to frequency gives the set of all just intonation intervals. The first designs for the Quotient Generator split pitch sequencing into two dimensions, the numerator and denominator. As a module, we can imagine this as taking two signals in, one controlling the numerator and the other the denominator, and outputting the control signal that would produce the pitch that results from that quotient. Additionally, each side of the quotient has a second control for the prime limit. Every positive integer consists of a unique combination of prime factors, 2021 for example is 43 x 47, and so just intonation theorists use prime limits to limit the set of possible fractions to those only consisting of prime factors up to a certain limit. Pythagorean tuning is based on stacked and inverted fifths and octaves only and so is "3-limit", whereas 12-EDO tonal language today relies heavily on the major third and major seventh and major second, (approximations of harmonics 5, 9 and 15 respectively), all of which obey a 5-limit. The ability with the Quotient Generator to set separate prime limits has some plain practical uses, for instance by setting either side to a prime limit of 2 it can be used as an octave shifter while the other side gives a harmonic or subharmonic series. More unusually, it could define the rules of a pitch set that might be called *Pythagorean* in the otonal direction and *extended* in the utonal direction, meaning that the numerator has a prime limit of three and the denominator has a high prime limit higher than five or no limit at all. The prime limits can also be modulated in real time. Audio example 12 was made in Automatonism with five instances of the quotient generator, four voices of harmony and a fifth controlling the frequency at which the chords are pulsing. All of the Quotient Generators have different prime limits and are being controlled with two step sequencers each, for the numerator and denominator respectively. This was the first iteration, but a later addition came about by asking: *what would be needed to accommodate EDOs in this system?* Frequency multipliers in EDOs are outside of $\mathbb{Q}$, meaning they include irrational numbers, numbers like $\sqrt{2}$ for which there is no fractional form. The frequency ratio from a given pitch to a 12-EDO semitone above is 1: $\sqrt[12]{2}$, and another two semitones above *that* would be multiplying that by $\sqrt[12]{2}$ twice more, so $\sqrt[12]{2} \times \sqrt[12]{2} \times \sqrt[12]{2} = (\sqrt[12]{2})^{3} = 2^{\frac{3}{12}}$. This shows the general form $n^{\frac{x}{y}}$ where n (numerator) is the pitch distance being divided (2 being an octave as the second harmonic is an octave above the fundamental), p_n (power for the numerator) is the number of steps through the

[53] A digital device that outputs four channels of control voltage following a variety of algorithms.
[54] http://butmostlycrime.blogspot.com/2018/06/tutorial-sample-and-hold.html

scale, and r_n (root for the numerator) is the number of divisions of the pitch space. For another example, Bohlen-Pierce tuning divides the tritave (1:3 so an octave and a fifth stacked) into 13, and so the fairly sharp Bohlen-Pierce major sixth (which is very close to a just major sixth, 5:3) is six steps above the tonic, and so we would calculate that distance as $3^{\frac{6}{13}}$. To accommodate this within the Quotient Generator, the numerator can also be taken to its power and root; the extension of this to the numerator side maintains symmetry and opens up more possibilities that go beyond the usual microtonal domains of just intonation and equally divided pitch spaces. There are then eight main controls, each of which can be set from a knob or modulated with external signals, these are the numerator (n), the numerator's prime limit, the power the numerator is taken to (p_n), the root the numerator is taken to (r_n), the denominator (d), the denominator's prime limit, the power the denominator is taken to (p_d), and the root the denominator is taken to (r_d), all of which must be positive integers. Combined these give the frequency multiplier $\frac{n^{\frac{p_n}{r_n}}}{d^{\frac{p_d}{r_d}}}$. Even with just moving the numerator side of this we are opening up forms of harmonic modulation not possible on physical instruments, for instance, by only ever moving one knob by one position at a time, we can have a melody that moves from the 8th step of 14-EDO ($2^{\frac{8}{14}}$) to the 7th step of 14-EDO ($2^{\frac{7}{14}}$), to the 7th step of 13-EDO ($2^{\frac{7}{13}}$), to the 7th step of equal Bohlen-Pierce ($3^{\frac{7}{13}}$), to the 7th step of 13 equal divisions of two octaves stacked ($4^{\frac{7}{13}}$), to the 6th step of 13 divisions of two octaves stacked ($4^{\frac{6}{13}}$). When modulating these indices for the denominator too, with multipliers along the lines of $\frac{4^{\frac{6}{13}}}{5^{\frac{3}{11}}}$ (the number shown in figure 3), this very quickly becomes something which doesn't fit neatly into the usual microtonal theorists' categories of just intonation and equally divided pitch spaces, but rather as a macro-set from which both and more can be derived, amounting to something like an open world game environment in which one can wander down these familiar paths (the harmonics, 12-EDO, and so on) or veer off into the woods only to find another relatively familiar path out of them. To modulate the numerator, the denominator, and their powers and roots all at the same time would require six modulation sources all to control a monophonic voice, to build harmonies from this system could require several times more. This is an impractical number for a hardware modular system but can be easily achieved with a virtual modular system. These modulation sources could be typical step sequencers, random sources, hands-on controllers such as keyboards or joysticks, or many other possibilities, theoretically including audio rate modulation. Additionally, as the Chowning FM algorithm has control over the harmonic ratio for each operator which is equivalent to the numerator control on the Quotient Generator, we can extend this system so that this ratio control is expanded from the one dimensional harmonics to the multi-dimensional "open world" of all possible values of $\frac{n^{\frac{p_n}{r_n}}}{d^{\frac{p_d}{r_d}}}$. Whilst tuning approaches have often been excessively focused on mathematics, this is a different matter in that the mathematics is baked into the instrument itself. Where explaining tuning through abstract maths may have the effect of alienating us somewhat from musical expression, the

***Figure 3** Quotient Generator as a virtual module in Pure Data*

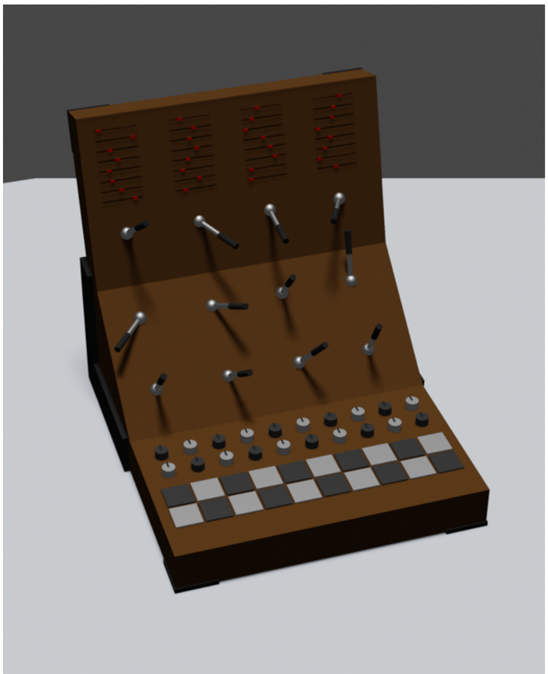


Quotient Generator makes those mathematical relationships far less abstract as they are made audible. It would therefore also be a useful tool for learning about the mathematics of pitch, and for beginning to tackle denser mathematically-driven music theories with real-time audio feedback.

Another kind of sequencer acting in ways made possible by digital technology is my design for the Dissonance Generator. The premise is that first, for a given set of just intonation pitches, each possible interval has its dissonance measured as its Benedetti height. The Benedetti height, a simpler form of the Tenney height, is a measure of dissonance that multiplies each side of a ratio together, based on the assumption that low integer ratios are the most consonant – so the just major third 5:4 has the Benedetti height 20. Given a starting pitch of 1 then, the Dissonance Generator would rank every possible next pitch and then the performer could control where in that ranking they want the next pitch to come from – whether they want the next pitch to be the most consonant, most dissonant or somewhere in between, in relation to the pitch just played. Building on this idea, the Markov Chain Dissonance Generator, used in *ICS-5: Birth of Atom*, instead interprets this ranking as a set of probabilities, with the performer's control now over whether they want to weight the probabilities towards the likelihood of the most consonant or most dissonant next pitch.

The Polyharm (or polyphonic harmonic synthesizer) is my design for an additive polysynth (fig. 4). This began with the desire to play with *the harmonics of the harmonics*, that is, a system wherein you tune your keyboard to the harmonics and then play with timbres that are constructed additively from the harmonics of those pitches. Originally the intention was to control the partials by the conventional interface for additive synthesis, a mixer in which the loudness of each harmonic is adjusted individually like with the slideable stops of a Hammond Organ, or the modulatable levels of the partials in Verbos's *Harmonic Oscillator* (2014). This was combined with built-in LFOs to modulate each of these levels, and a control for the quadraphonic panning of each partial so that the timbre of a single pitch can be made to surround the audience. It became apparent with tests that this mixer-based method would make fast timbral changes in live performance impossible, limiting its use to timbrally consistent or slowly evolving music, where I would also like to have also used it in to play in faster-moving reactive improvisation contexts. Mark Verbos's solution was to have an additional macro control, a harmonic tilt which could move from a dull to a bright timbre. I have instead followed the idea of preset spaces. Where a preset saves multiple settings in a single state, a preset space can have multiple presets assigned positions in a plane, here in four corners of a square, so that moving through that two-dimensional space morphs continuously between settings, to be controlled from a joystick (a two dimensional potentiometer). Whilst this could be done for all parameters at once, the Polyharm splits its parameters into eight preset morphing planes stylistically referred to as levels, tunings, partials, waves, wobbles, algorithms, places and paths. This is given a limited number of partials, intended to be sixteen, although tests

Figure 4 *Polyharm*



have continued to show, at least with it programmed as I have in Pure Data, that this may be too many voices for the level of complexity required to run on an ordinary laptop CPU.

"Levels" refers to the mixing aspect, how loud each partial is. Each of the four presets could be controlled through the mixer-structure defined before, and then the morphing works such that half way between two presets would mean taking the mean average of the amplitudes for each partial. Relevant to this parameter is also the brightness control. Comparing theoretically perfect square waves to triangle waves, we would observe that both feature only odd partials, but whilst squares do so with the amplitude formula $\frac{1}{H}$ (H being the harmonic in question) meaning that for example the third harmonic is $\frac{1}{3}$ of the amplitude of the first, and the fifth is $\frac{1}{5}$ of the amplitude of the first, a triangle wave does so with the amplitude formula $\frac{1}{H^2}$, so that the amplitude of the third harmonic is $\frac{1}{9}$ of the first harmonic and that of the fifth harmonic is $\frac{1}{25}$. The brightness control applies these kinds of scalings to whatever levels are set, effectively changing the range and distribution of the level sliders.

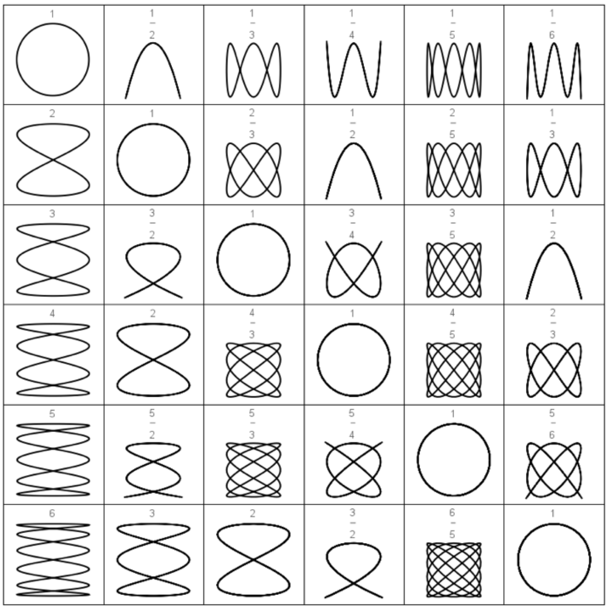
"Partials" refers to which harmonics are heard. Typically with additive synthesis, if you have 16 harmonics these will be stuck controlling only harmonics 1-16, but on the Polyharm, the same maximum of 16 harmonics can be used as much higher harmonics, a choice inspired by work on *Music To Walk Through #1: Euclid's Algorithm*, an installation which used wide ranging sets of harmonics, including for the Fibonacci numbers up to 144, which were spatialized from individual speakers along a bridge at the ZKM centre in Karlsruhe in 2018.[55] These kinds of distributions of partials, using integers which are more and more spaced apart without repeating around intervals creates timbres which can still sound together as a cohesive tone, but which at the same time contain very particular harmonic flavours. With the preset morphing space, multiple distributions of partials can be set up and morphed between continuously, except that the frequencies of harmonics are not continuous, they are stepped in integers. I have therefore included a switch to decide for each context whether or not this morphing should be a continuous morphing between frequencies which moves through inharmonic timbres, or a stepped morph which moves through harmonic timbres only. With continuous morphing of frequencies and amplitudes, if the two joysticks are moved along the same path what is heard is live human control of the electroacoustic technique of spectral morphing. These have been considering the partials set to be integer harmonics, but they can also be any frequency ratio in between. Uses for this could include constructing timbres based on tonal systems as will be explored further in chapter 3, as well as morphing between a cleanly tuned unison and very fine microtonal variations to create especially controllable detune effect, to intentionally produce beating effects which thicken the sound as used in the supersaw, a large number of sawtooth waves stacked with slight tuning variation. Another control of relevance to the "partials" setting is the "inharmonicity", which simulates the way in which a bell's timbre is not perfectly harmonic but bends each harmonic progressively sharper. The inharmonicity here can be a deformation upwards or downwards, as a function applied to the frequency multiplier of each partial.

"Waves" is a morphing between different waveforms as the atomic sonic material of this system. Sine waves are by default the atomic material of additive synthesis as they contain no other harmonics within them, but having other waveforms in the form of

[55] Wilf Amis, *Music To Walk Through #1: Euclid's Algorithm*, (2018) : https://youtu.be/fp5GZV8n1bU

wavetables, whether constructed additively, as graphic functions, drawn by hand, or recorded in, can add an additional layer of timbral variation, and indeed an additional layer of recursion in that with a harmonic series keyboard, one could be playing *the harmonics of the harmonics of the harmonics*.

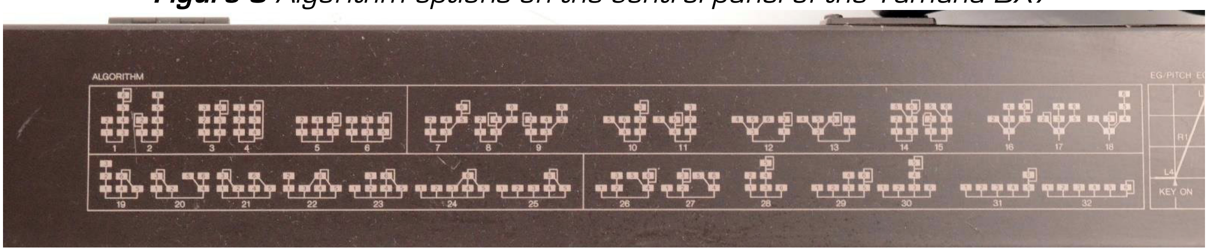
Figure 5 *Lissajous curves*



"Places" morphs between presets for the static placement of partials within a quadraphonic sound stage, whereas "paths" morphs between presets for the dynamic movement of those partials around the origin set by "places". Initially these paths were set to circles, with control over the speed, direction and radius, but with my interest in expanding harmonic ideas into other parameters these have taken up another form, Lissajous curves. Lissajous curves are the geometric form made by tracing a point as it is oscillated in the X direction at one frequency and the Y direction in another; perfectly harmonic ratios form the neatest of Lissajous curves. With the Polyharm, it is possible then for each partial within the timbre to seem to travel around the room following a Lissajous curve of a particularly relevant harmonic relationship.

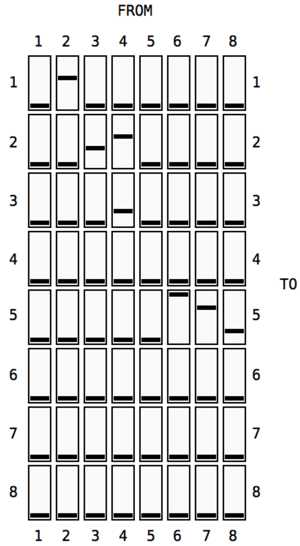
"Wobbles" refers to amplitude modulation, LFOs can be used to modulate the amplitudes of the partials and so create an ever-moving timbre, but these could also be at audio rates, morphing between these presets makes changes with respect to both the frequency and amplitude of these modulators.

Figure 6 *Algorithm options on the control panel of the Yamaha DX7*



"Algorithms" adds in an element of Chowning-style FM synthesis. FM synthesizers typically have multiple algorithms which determine the modulation path so that one operator 1 might frequency modulate operator 2 and operator 3 might frequency modulate operator 4, and then both operators 2 and 4 may be mixed together and heard at the output. Within this system is the possibility of an algorithm in which no operator modulates another but all go straight to the output, which describes the architecture of an additive synthesizer. And so, whilst additive synthesis has been the main intention, it can also be seen as a subset of FM synthesis. For the Yamaha DX7 these algorithms are discrete settings represented as flowcharts (fig. 6), but in order to morph between algorithms they can be understood as a continuous modulation matrix (fig. 7). The other aspect of additive and FM synthesis is the envelopes applied to the amplitude of each operator, typically they are of different lengths and shapes so that the sound evolves over the course of a note's duration. Since I am focusing on control by polyphonic aftertouch, I have taken an alternative approach. This aftertouch uses the range 0-127, and so what we can do to use this one dimension to control different operators differently is to map segments of that range to the amplitudes, and with different distributions. For instance, it might be that the segment 100-127 (which is only reached when the player presses especially hard) will introduce an extra overtone or modulating operator, not unlike the way that extra bow pressure on a stringed instrument will produce a harsher timbre. With this method, what is being mapped is a single 0-127 dimension and so pressure can be easily substituted out for ADSR envelopes, or any other kind of one-dimensional signal.

Figure 7
Algorithms modulation matrix for Polyharm



Having decided that the initial plan for the Polyharm to be simply a keyboard for the harmonic series was too prescriptive, I decided to take a technologically-driven approach to tuning. Polyharm's "tunings" mechanism follows from the logic of the two-dimensional preset morphing space that is the basis for the control of every other parameter. Four parallel tunings, one for each corner of the square, are set, such that different microtonal variations on a harmony can be morphed continuously between. The movement through the preset space is movement through logarithmic pitch space, so that if at the bottom left (0,0) the interval between MIDI note 60 and MIDI note 64 is 400 cents, and at the bottom right (1,0) the same interval is 360 cents, then half way in between (0.5,0) will give 380 cents. The four tunings are always compared by their corresponding MIDI note numbers, therefore, it is generally a more coherent set up if the corresponding pitches are nearby each other, and so if using octave-repeating scales the four tunings should have the same number of notes per octave, otherwise the overall feeling will not be a subtle morphing but a general pitch shifting that will make it difficult to tell the microtonal subtleties. Also, where scales repeat around octave-equivalences, morphing takes on a clear function of morphing between different flavours of a, perhaps functionally similar, interval. There are two main ways one could approach configuring these four tunings – the first is to use existing tuning systems, for example, in the demo given in my April 2020 colloquium, I used four existing 12-note scales: 12-EDO in the bottom left corner, ICS-6[56] in the top left corner, La Monte Young's Well Tuning in the top right corner, and Pythagorean tuning in the bottom right corner. Another more general example would be the mapping of multiple modes from a single scale, or a single vague idea of a scale like "major" that can be constructed from multiple different tunings. The idea of morphing *between* tunings in this way is a bizarre one that strips tunings of their contexts, in this, indeed in its core mechanism, it relies on the format of the 128 frequency text file which itself strips tunings of their contexts. It is therefore worth being sensitive to how this is used, as like with the placement of artefacts in a museum, the stripping of context from cultural artefacts has a very different power dynamic for the histories of colonisers from what it does for histories of the colonised. Nonetheless, what I hope to encourage with this intentional misuse of some tunings is a level of alienation from the initial material, with the purpose of dethroning tuning practice even as we seek to elevate it in the wider collective imagination. Here, dethroning doesn't mean to remove, but instead to counter the temptation to hold tuning systems as

[56] The sixth iteration of the system I call the Infinitely Compact Scale, described in chapter 3.4

perfect platonic forms in a realm somewhere intellectually *above* music; we should not worry about using Pythagorean tuning in the "wrong" way. The second way to approach this system is to specifically design a set of four tunings to work together in such a way that takes into account the continuous morphing and the relationships between the four tunings. For an example I have developed a four-cornered pentatonic system (fig. 8) which by the Polyharm's tuning mechanism would place 5-EDO at its centre point. In other words, for each of the five steps of the scale, the average calculated from all four scales combined must be the same as it is for that step in 5-EDO. The design of the Polyharm has been one of the larger projects throughout this research, taking up more time than perhaps anything else. Despite this, because of limitations of available CPU and the inefficiency of coding such a complex system in Pure Data, all of these interrelated functions have been tested and function separately but have not all been brought together as one into the final functioning synthesizer. In future, this will be reinterpreted in more efficient programming languages and realised as one hardware synthesizer with eight joysticks for all of the morphing functions, a number of controls through which to build presets through the conventional mixer-like approach to additive synthesis, and a built-in keyboard in one of the forms described in the following subchapter.

Figure 8 *5-EDO-centred four-channel scale for Polyharm (values in cents)*

Front-Left	Front-Right	Back-Left	Back-Right	Mean
0	0	0	0	0
210	321	196	233	240
381	523	408	608	480
741	647	790	702	720
1061	921	963	895	960
1200	1200	1200	1200	1200

As well as through such instrument designs, programming environments give a unique set of tuning possibilities to algorithmic music, including the ability to do arithmetic at speed, the ability to produce tones of very precise frequencies and waveforms, and with those, the ability to build systems which unfold over time. *99 To 5* (video example 1) is a simple case in point as it shows a tuning system unfolding over time, or at least the simple ability to modulate between tunings in ways not feasible outside of computer music. Euclid's algorithm, which is used to find the greatest common factor of two integers, can also be used to find the maximally equal division of a discrete equally divided space. Godfried Toussaint showed that when this system is used to define rhythms, it tends to describe many rhythms commonly in use in various traditional musics, and really any music since these are ways of dividing a fixed meter that feel relatively natural, for example one of the most even ways to fit 3 hits into a bar of 8 is [x - - x - - x -], one of the most common rhythms across all music today.[57] Applying this same idea to the equal division of pitch space, the same algorithm can be used to find, for example, the 5 most equal divisions of 12-EDO. 5 into 12 gives [x - - x - x - - x - x -] and so {C, E♭, F, A♭, B♭}. *99 To 5*, goes through every EDO from 99 down to 5, Euclideanly dividing each into 5 as equally as possible. Each EDO is in use for only a single chord to be played, that chord that is as close as possible to every 5-EDO pitch at once. The fundamental is 100 Hz, but if we imagine it is C the chord would be voiced C2, G2(+20 cents), F3(-20 cents), D4(+40 cents), Bb(-40 cents), this is the chord that it ends on as this is 5-EDO which divides perfectly equally into 5, but it also occurs every five chords because multiples of 5 such as 10-EDO and 15-EDO also equally divide into 5-EDO. In between, the chords are as if they are being forced into certain shapes by their macro-set

[57] Godfried Toussaint, *The Euclidean Algorithm Generates Traditional Musical Rhythms*, (McGill University: Montreal, 2005).

whilst attempting to stay as close as possible to 5-EDO. The general harmonic motion, and I think the overall feeling, is the sense that you are attempting to correct your feet constantly to stand as still as possible on a boat that keeps rocking. Since higher order EDOs are finer approximations of the continuum, when 99-EDO is divided into 5 the result is very close to 5-EDO, and 98-EDO likewise, and so initially the changes from chord to chord are very subtle, and over time they get less subtle until the final progression from 10-EDO to 5-EDO strays much further from the 5-EDO centre, as attempting to approximate 5-EDO within 6-EDO is really just playing 6-EDO without one note and so has a very different harmonic flavour. Euclid's algorithm is itself relatively simple but in SuperCollider this Euclidean division is largely pre-programmed into the object "Bjorklund2", and so as this piece follows a simple process of calculating each of these divisions of EDOs in series, the whole thing can be written in a single routine which, with the synthesizer's code included, can be expressed in a single page.

Whether modulating between each EDO in *99 To 5*, morphing continuously between four preset tunings on the Polyharm, or travelling between different mathematical tuning domains on the Quotient Generator, digital technologies make possible novel forms of harmonic modulation which not only reintroduce tuning as a question at the beginning of the composition process, as often is the case with setting a tempo or tonal centre, but also regard tuning as a parameter that can be altered over the moment-to-moment progression of a piece of music. This is possible because, unlike with acoustic and analog instruments, software, before it is entombed in license-protected applications, is almost infinitely plastic.

Finally, we should note the most complex digitally-enabled technologically-driven tuning system of them all, the xenharmonic community, who are more connected than ever in the age of forums and internet based distribution of music, video, and text. From the *Xenharmonic Alliance* forum on Facebook as well as many smaller forums with more specialist focuses, to the *Xenharmonic Wiki*[58] which has community contributed information for thousands of tuning systems and ideas relating to tuning, pitch and harmony, relevant theory is easier than ever to access, and the development of theory and tools is moving faster than ever because active communities of musicians working across many musical styles are able to compare notes in positive ways. The internet can also host useful tools, such as Sevish's *Scale Workshop*[59] and Khyam Allami and Counterpoint's *Leimma* and *Apotome*,[60] which are powerful browser-based tuning system development tools which also help to bring such ideas into softwares that hide tuning possibilities behind complex scripting such as in Native Instruments' *Kontakt*. Open-source applications and freeware such as the tuning system development tool *Scala*[61] and a number of synthesizers are also available and are made expansive by communal development.

2.3 Versatile Keyboards

One of the great challenges of embracing a diversity of tuning systems is that different systems demand different interfaces. The physicality of an instrument usually determines that it must use one system only, historically it has been precisely this that has led to the homogeneity we are now addressing. The microtonal guitarist must choose a fretting and

[58] https://en.xen.wiki/
[59] https://sevish.com/scaleworkshop/
[60] https://isartum.net/
[61] http://www.huygens-fokker.org/scala/

commit to it since fretting is a long process which has a permanent effect on a guitar neck. Yet there are so many possible tuning systems to explore, and so much will to explore them, that microtonal guitarists have, out of necessity, developed a number of ingenious adaptations for their instruments. Fernando Perez and Jose de Prados have developed a guitar with interchangeable fretboards,[62] Tolgahan Çoğulu has developed two guitars with movable frets, one with metal fretlets (frets that cover only one string) which can be moved around and one with a Lego fretboard onto which the user can attach plastic fretlets,[63] and Joakim Larsen and others on the Multichannel Guitar Forum[64] have developed a method for playing microtonally using a fretless guitar with a multichannel pickup (that is one with a separate output for each string), running each string through autotune software. Each of these solutions bring unprecedented versatility to the fretted guitar, making it viable to play in multiple tuning systems whilst avoiding the numerous downsides of requiring multiple instruments: affordability, sustainability, and the space required for travel or storage.

All of these same factors apply to keyboards, but keyboards differ in that they are in a sense a remote activation device. The keyboard as a remote activation device originates in the organ, turning on and off airflow in each of a set of pipes of various sizes, itself a variation on the general idea of tuned percussion, that one could collect or build a set of objects alike but different in size and therefore resonant frequency, and then excite these objects. The act of placing these objects into a particular arrangement, taking a certain shape and order, is the precursor to the art of keyboard design, and at the same time a form of pitch system design. Since these resonating objects are separate, the arrangement of them will do nothing to affect the sound, and so keyboard design, like that of idiophones, lamellophones, and lyres, builds direct relationships between position and pitch without subservience to the physics of pitch – by contrast, a necked string instrument must get higher in pitch, the higher up the neck it is played. As if by extension of the idea of remote activation from pipes to people, the keyboard is often seen as the hub of composition and therefore music theory. As much as it is a chicken-and-egg issue, the dominance of the Halberstadt format has been a key factor in reifying the system of twelve pitches per octave, literally made solid in the form of the piano. The keyboard goes beyond the idiophone in that pitches can be played per finger rather than per hand, and so the keyboard really is the hub of harmony in particular, which is why, for those looking to explore new harmonic languages, a keyboard is a useful tool for getting acquainted with the sound and theory of an unfamiliar system. As Terumi Narushima writes:

> Keyboards are particularly useful instruments because they provide direct access to a large range of pitches at the fingertips of the performer. They allow a single player to control as many notes at a time as the number of fingers on two hands, a convenience not afforded to wind instrument players, for example. This versatility makes the keyboard an ideal musical interface for the performance of harmony and polyphony, and is one of the reasons why many individuals have tried to build the ideal microtonal keyboard. For [Erv] Wilson, this was his Holy Grail.[65]

In the age of electronics, the dethroning of harmony has paved the way for a world of noise and timbral imagination, and eroded the centrality of the western classical tradition to what

[62] https://josedepradosguitars.weebly.com/fernando-perez-model.html
[63] https://hackaday.com/2020/02/20/lego-microtonal-guitar-building-blocks-of-music-theory/
[64] A forum on Facebook (https://www.facebook.com/groups/660323021120062)
[65] Narushima, p. 14

we must learn to become musicians – these points we can acknowledge as positives, but harmony continues to be a sonic phenomenon and its dethroning really only freezes it to 12-EDO, so at some point it must re-enter the mainstream of musical innovation with new approaches. Hence with the keyboard as the ultimate tool for exploring harmonies, we will need new keyboards.

The dominance of the keyboard has already shaped electronic music a great deal more than it perhaps should have, through the popular consensus over the previous century that the synthesizer was to be a keyboard instrument. Referring back to Suzanne Ciani's comments on the 'hijacked' unrealised potential of the synthesizer, as an assessment of the history of the synthesizer as it followed from Robert Moog's tradition of East-Coast synthesis controlled by a standard Halberstadt keyboard, as well as an explanation of the boom in interest in modular synthesis over the last decade, this is, I believe, very accurate. However, Ciani, as a proponent of Don Buchla's "West-Coast" tradition, does use what we might call a keyboard, in the form of the Thunder. Buchla and Serge Tcherepnin both developed keyboards, or *controllers,* that could control pitch, but equally could control a timbral parameter, or a variable in some chaotic algorithm. The controller in a modular context is a generator of control voltage just like a sequencer or modulation source – rather than twist a knob or move a fader on the synthesizer, such a keyboard would send one of a set of voltages, switched between by hand. The lost and recently found future that Ciani is evoking, of the modular synthesizer as a keyboardless instrument, is about following the generative musical logic of something akin to analogue computing, where a form of live composition can occur temporally abstracted from the standard model of instrumental performance as a physical act that directly produces a sound, rather than using these new tools to emulate old ones. With systems like the Quotient Generator, I have sought to bring ideas from xenharmony into these more algorithmic and temporally abstracted methods of music making. What this age of live composition through short-term temporal abstraction (modular synthesis, live-coding, and so on) brings to our horizon is a *post-virtuoso* world – that is, a world in which giving voice to the intricacies of bodily gesture is a choice and not a necessity of live music making, and a world where the model of musicianship is not dictated by the enshrinement of craft and hard work for the sake of hard work, but by taste and play. And so by refocusing the conversation back to keyboards, the hope is not to re-'hijack' electronic music back to emulation of the old, but to ask the question: what role might the real-time tactile gesture of keyboard performance play in a post-virtuoso world?

One answer I would suggest is as an environment of *play*. This element of play is important in live music but is arguably lost in prewritten music. Play can involve getting good at it if you want to, but play should also be fun and capable of producing "good" music if you just pick up an instrument for the first time and get the feel of it. This offends some people's sense of craft, but I think it's the future-minded approach. Personally, I have always gravitated towards play, even if that means sitting down at the piano just to lock down the sustain pedal and whack away at its most convenient keys, C major or G♭ major pentatonic, the white or black keys, with the sustain pedal doing the work of blending together the pitches. This is an example of what I would call a *sustain cheat,* where a musician less able to produce an accurate, consistent and fast playing of notes, finds the benefits of a more minimalist approach which sustains or repeats musical events by technological means. Likewise, the various technological extensions of the body found in hypertuned practices, from autotune and rhythmic quantising to the (Glenn) Gouldian designing of the perfect take edited together from many, are widely stigmatised as forms of musical "cheating".

Glenn Gould himself embraced the future aim of a dethroning of virtuosity, as David VanderHamm writes:

> Ultimately, Gould imagined the virtuoso becoming obsolete: “In the best of all possible worlds, art would be unnecessary. Its offer of restorative, placative therapy would go begging a patient. The professional specialization involved in its making would be presumption. The generalities of its applicability would be an affront. The audience would be the artist and their life would be art.” Gould imagines both the dissolution of the market for art and the disbanding of the specialized guild of artists. The amateur returns to prominence in this media utopia. In the best of all possible worlds, each of us is a virtuoso.[66]

I happened to stumble first into the most socially acceptable form of this kind of musical “cheating”, the sustain cheat of slathering an electric guitar in effect pedals, and because that path has been walked a thousand times before into its more ambient and experimental outcomes, there was a place for me in higher music education. I use the term "cheat" in an entirely positive way in rejection of the cult of the hustle and the grind, that is, the evolution of the protestant work ethic for the age of the gig economy. For those of the Playstation 2 generation, cheats mean the ability to turn off gravity and fly – to reach beyond the usual confines of nature. At the same time, “cheat” is used ironically in acknowledgement that these are not cheats, they are tools, and so – like the transhumanist who demands a better excuse from those who would not accept hypothetical life extending technologies as they cross some imagined threshold of the natural, even whilst they pop a paracetamol, don a pair of glasses, or throw on a jumper in the winter cold – we might ask if there can really be a line drawn between user-friendly instrument design and making something too easy. Instead the difference is found in incorporation within the perpetual now. Whilst, from the Disklavier to the Seaboard, many of the ideas present in the piano continue to evolve, at the same time, the piano and violin have become frozen artefacts, continually reproduced in the image of their platonic forms, the Steinway and Stradivarius, never again to be modified with the body of the performer or the future of music in mind.

Almost all musicians are trained as specialists in 12EDO. Upon breaking open the wider possibilities of pitch, many are keen to experiment with a range of new pitch systems. Either to – by trial, error and comparison – find a new favourite, a new specialism to pursue, *or* to become a generalist. Certain technologies potentially permit us to become *a jack of all trades* without the catch, *master of none*, or rather this mastery is no longer a necessity in its limited technical sense. The image of the virtuoso was always exclusionary, it was the domain primarily of the wealthy and able-bodied. Even the mildest of motor disabilities like my own dyspraxia can be enough to make virtuosity above a certain level inaccessible, or at least a feat that could take a disproportionate amount of work. This is part of the issue with the *10,000 hours* myth, not all bodies and minds are optimised for every craft, not everyone processes things in the same way. There is no way to really get at the truth of this issue since survivorship bias logically dictates that those with the bodily ability (and financial support) needed to reach what is defined as virtuosity will be the majority of those who get a seat at the table to define what musicianship is for the next generation. But for the fringe cases like me who were never sure how much blame rested on their own heads

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[66] David VanderHamm, *The Social Construction of Virtuosity*, (Chapel Hill: University of North Carolina, 2017) pp. 279-280.

for that physical struggle, for those who by other factors (for me a split with the maths department) were able to sneak into higher music education without a grade 8 certificate, there is perhaps an onus to question the premise of virtuosity, and how it shapes our instruments and education. Unique to our age, there are plenty of very playful esoteric instruments that are abstract enough to invite immediate play, sometimes breaking out of conventional music theory. A versatile keyboard accommodating of such approaches could enable a break from 12-EDO specialism by breaking from specialism entirely, since a major barrier to exploring a diversity of tuning systems has been the increased difficulty of gaining virtuosic relationships when working with multiple systems. Indeed, with the current model of musicianship assumed, the harmonic generalism I am proposing is a tough sell.

Extract from Erv Wilson's letter to Gary David c. 1968 (quoted by Narushima, p.15-16):

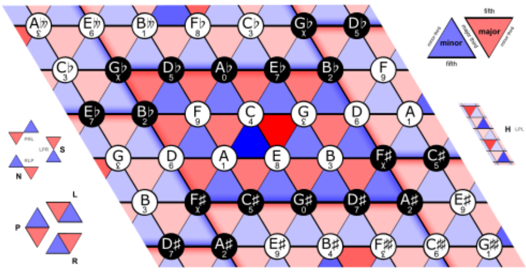
> The keyboard may be visualized as a Navajo loom upon which intricately lovely and endlessly variable scale patterns may be woven. A canvas. Arbitrary limitations to this variability must not be designed into the instrument. The keyboard is an art, an interface, a crossroads and a bridge. The keyboard is a ship. In the tunable generalized keyboard we have the birth of a new art and the rebirth of an old art, as ancient as man. The keyboard must Breathe, poetically speaking, for it is the extension of a living process. The scale is a volatile genie that knows how utterly to transform its shape. Every effort must be made to accommodate this mercurial creature-of-the-psyche through the keyboard. The keyboard/console must animate the scale. While undoubtedly it is valid and admirable to study the scales of other peoples and other times, we are concerned primarily with the creative processes and the development and expression of our own arts. We see the keyboard in an attitude of creative anticipation, and to jealously guard against closed, limiting, non-living attitudes, and the great body of "tacit assumptions" and "forgone conclusions" (which, incidentally, we do not assume ourselves to be free from) which might hobble or render ineffectual those subtle intuitions of beauty.
>
> Design philosophy, in a word, should be OPEN. Keep it general(ized), viable, versatile, changeable. Guard against the proverbial cul-de-sac, the one track, the squirrel cages! My heavens!
>
> The keyboard is a transient lens through which a cosmos of musical relations may be observed. Keep it volatile. Forgive the metaphor! Our interests are primarily "just" and in that regard the universe is seemingly endless.

Wilson pre-empts me here a thousand times over. If we desire to see a proliferation of musical languages, then we will need a proliferation of keyboards, or for the practical reasons already stated, a single instrument versatile enough to allow the user to explore a wide range of systems. This is not versatility in the sense of suggesting that we can design a single instrument to accommodate everyone's needs, but only that we can accommodate some of those who desire versatility. Wilson's favoured solution is the *Generalized keyboard* for which his designs built upon the 53-EDO keyboard design implemented in Robert Bosanquet's 1873 enharmonic harmonium.[67] The generalised keyboard has since become perhaps the most ubiquitous of microtonal keyboards, adapted for the 31-EDO Fokker organ (1950), the incomplete attempt by Robert Moog to build Wilson's designs (1970), the Motorola Scalatron (1974) for which two models were made with George Secor's

[67] Narushima, p. 18.

adaptation of the Bosanquet design, Harold Fortuin's Clavette (1995) developed at STEIM and here at the Institute of Sonology, which with its interchangeable paper overlays and early polyphonic expression is a precursor to my own microtonal use of the Sensel Morph,[68] Starr Labs's implementation of the updated Wilson designs in 2000, the Terpstra keyboard, prototypes for which emerged in 2006,[69] the Axis-49 and 64 (2007), the Snyderphonics Manta (2009), Twisted Electrons' small Eurorack keyboard Cells (2016), and finally the Lumatone (2020) which allows the user to change the colour of each key to fit their design. Generalised keyboards follow an isometric pattern that tessellates around the general form of a hexagon, although they need not be presented as a hexagon – Bosanquet's harmonium and the Fokker organ both use rectangular keys in a staggered arrangement. This geometry lends itself to isomorphic pitch structures. The easiest of these to understand for the non-microtonally-initiated would be the 12-tone Tonnetz, the basis of Neo-Riemannian music theory. In the Tonnetz as pictured in fig. 9, a step to the right is a move upward by a fifth, a step up-right is a move upward by a minor third, a step down-right is a move upward by a major third, and a step directly down is a step upward by a semitone. Moving a step up-right and then down-right lands in the same position as a step right, as stacking a minor third and major third lands at a fifth in 12-EDO. A step in these directions gives the same pitch shift wherever you are on the grid, and so in the context of a keyboard, a melody or chord in one position will form the same shape when transposed – akin to shifting a bar chord up or down the fretboard of a guitar, as opposed to on the piano where the same chord transposed into each key might have twelve different shapes. This carries consequences for the way the instrument can be learned. As Narushima writes:

Figure 9 *Neo-Riemannian Tonnetz*



> In theory, a generalized keyboard is quicker and easier to learn than a traditional Halberstadt keyboard because the same fingering applies to all transpositions of a scale or chord, and this becomes an important issue as more notes are introduced per octave. George Secor [...] estimates that it took him 50 hours to reach the point where he was as fluent on the generalised keyboard as on a traditional one.[70]

Yet the relationship that we might develop with this keyboard is of a different kind, since a range of systems can all be mapped to the same geometry, it separates muscle memory from the pitches that sound. With the generalised keyboard, a certain dynamic is tacitly implied wherein the building of a tuning system can be part of the composition process, so that a composer might create a score and include with it a mapping for the keyboard. A performer who has developed virtuosity on the generalised keyboard could then realise the work by reading and translating it into finger movements potentially without understanding anything of the pitch system or even listening to the output. The ease of transposition is the positive side to something that is arguably very much lacking in the generalised keyboard – the ability to sense by touch alone where on the keyboard you are. And so the generalised keyboard sacrifices muscle memory as it relates to absolute position in favour of ease in commanding relative position, which is to say that muscle memory will serve shape and

[68] http://www.fortuitous-artists.biz/clavett.html
[69] https://www.matrixsynth.com/2006/10/cortex-design-terpstra-keyboard.html
[70] Narushima, p. 18.

proportion but, less so, precisely where you are on the keyboard. What is therefore prioritised above all else is the old form of modulation, moving from one key to another by various pivoting harmonic devices, which is one of the driving forces of western classical music and jazz, but which barely features elsewhere, however much the classical framing of music education might push educators to seek out counter-examples in pop songs. A future-minded approach might seek to explore novel forms of modulation such as shown in Stephen James Taylor's film about the work of Wilson, *Surfing The Sonic Sky*, in which he demonstrates a repeated riff played over and over in the same position on the generalised keyboard, while software modulates through iterations of the system known as Moments of Symmetry,[71] here the software has done what the keyboard cannot, to go far beyond the reaches of straight-forward tonal modulation. Similarly, I have proposed novel forms of modulation like moving through the EDOs in the piece *69 to 5 (EDO Euclidean Division)* and wandering through the 6-dimensional corridors of the Quotient Generator, or otherwise simply accepting that the majority of music does not centre on tonal modulation and so it would make sense for it to take a less central role in the keyboard. Wilson developed methods for mapping many kinds of scale to the generalised keyboard,[72] and so it is certainly a very versatile design. But given the preferential treatment of modulation and isomorphic pitch systems, I would argue that this is far from a neutral form of keyboard, and that really there is no neutral keyboard – rather that each keyboard is a pitch system in itself, even if it is retunable, as Wilson's generalised keyboard is, since the geometry of a keyboard plays such a central role in the forming of a harmonic language.

But what if we could have one instrument with multiple geometries? The wide availability of touchscreen devices represents just such a possibility: easily customisable and non-permanent interfaces for sending MIDI and other such control data. Interface designs can be swapped easily whilst playing, and keys could change colour or even move around the screen. With my earliest prototype of the Polyharm, I used the custom MIDI controller app TouchOSC to play a keyboard in the shape of Erv Wilson's Harmonic Spiral. However, I soon found that a touchscreen device can not be truly tactile, and therefore it cannot be played without sight, which as well as excluding those with visual impairments, also makes difficult forms of performance, common to electronic music, in which performers wish to apply their sight to view other controls related to timbral modulations, this is the classic model of interaction with a keyboard synthesizer. Even as we might reject the necessity of virtuosic muscle memory, some basic level of tactile relationship is desirable. The geometries that shape our pitch systems contains not only the X and Y dimensions, but the Z, which is to say not only the shape of the keys but the way they respond to the hand; the keyboard of the future is not one of binary buttons or those with initial velocity control but those with continuous aftertouch, making sounds far more reflective of the bodily gestures it receives than the old stave-friendly idea of a note as made up of a static pitch and its duration – of the on-off airflow of the organ pipe, the hammer-damper mechanism of the piano, and the attack-decay-sustain-release envelope of East-Coast synthesis.

The Sensel Morph, first brought to market in 2015, is a tablet-sized touch sensitive surface onto which one may place overlays. The great advantage that the Morph has over a tablet is that its surface is sensitive to pressure rather than to the capacitive touch of human skin, therefore non-capacitive materials can be placed between the player and the surface without significantly reducing sensitivity. The emphasis of their marketing is

[71] Stephen James Taylor, *Surfing The Sonic Sky*, (2012) : https://youtu.be/L3gg5yrmwvs?t=909
[72] Narushima, pp. 29-58 and pp. 109-139.

on the use of their own overlays, which can be quickly swapped whilst playing to use: a piano keyboard, an MPC-style device, a version of the Buchla Thunder, drum pads and others, all of which send MIDI or MPE. Indeed, it is mostly as a cheaper and more versatile alternative to commercially successful MPE devices such as the ROLI Seaboard, that Sensel advertise. They also have other such available overlays for non-midi purposes such as keyboards for typing and a surface intended for fast video editing. However, it's strength for our purposes is the possibility of creating custom overlays. The Morph comes with an interface editing software that works much like that for TouchOSC, a small range of shapes of button can be placed onto the blank canvas as desired, and then each shape can be mapped to some MIDI, MPE or other functionality, for example as a "MIDI XYZ pad", in which case your fingers position on the button may determine the X,Y dimensions sending two channels of MIDI CC as well as a third for pressure, the Z dimension. Where this system differs from TouchOSC, is that rather than upload this custom design to the screen, it can be printed onto paper and placed on top of the device. This paper option is by far the easiest method, ideal for quick experiments, but it does nothing to combat the issue of tactility. To preserve pressure sensitivity, an overlay should be created from relatively soft materials, such that a force exerted on top is felt underneath. After paper experiments then, the next step can be to create a tactile overlay, whether from silicon, rubber-like plastics, or textiles more common to clothing such as cottons, felts and leathers. To me, this possibility was an exciting realisation – almost all instrumental interactions involve wood, metal or hard plastic, a soft fabric interface offers a very different form of tactility.

Figure 10 *Chair at my parents' home*

Figure 11 *Generalised keyboard on the Sensel Morph*

Over the period of December 2020, I collaborated with my mum, who is a prolific sewer of curtains, clothes and cushions, and keeps piles of offcuts of fabrics from old projects around, to realise a number of keyboard designs as fabric overlays for the Morph. Working entirely from these offcuts – partly out of necessity given the closure of non-essential shops at the time, and partly in service of the two criteria, affordability and sustainability – was a particularly clear case of a technology-driven approach, since the designs would partially follow from the patterns and feels of the available materials – the technology here being the fabric itself. This had a particularly satisfying result with one scrap of fabric which happened to be only just the right size to wrap around the Morph. Its original use is seen in figure 10, and what we see in this fabric is in essence an isometric pattern of just the right size to make for a generalised keyboard, when sewn into a band, with each coloured spot marking a key, with 54 in total. Besides this coincidence yielding an easy generalised keyboard, more active design processes have led to three more fabric keyboards, and two as yet unrealised 3D models. The first of these unrealised 3D models is based on Erv Wilson's diagram of the harmonic series as a spiral (fig. 12), used to play with the harmonic series as a scale in itself. We tried a number of methods for creating this spiral in fabric form but it was just too intricate and complex to sew. We might have succeeded in simply embroidering the pattern onto a plain piece of fabric but the purpose of the fabric keyboards is that everything should be easily tangible to the touch, and when I conducted some experiments with embroidery, I found that they were too subtle to feel. Instead, I have designed a version where each key stands out as a bulbous node whilst the spiral and the octave-equivalence lines that connect them are also easily tangible (fig. 13). This could be 3D printed out of a soft or rubbery material or formed with silicon from a mould.

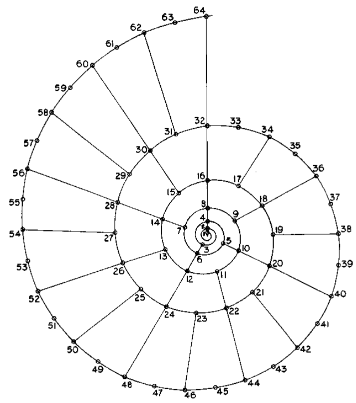


Figure 12 *Erv Wilson's harmonic spiral diagram*

The microtonalist may see something perfectly possible within the hardware capabilities of a commercially available instrument, but for the restrictions of the licence and opaqueness of the software guts, these possibilities may be kept out of bounds. Therefore, for a diverse range of artistic approaches to thrive, technologies should be made open source. Open source licensing shifts the focus of technological development from profit motivation to the motivation of pursuing personal and communal interests, and so ideas such as microtonality which cannot take off in popularity without considerable technological groundwork, may benefit from the voluntary collaboration of those with special interests. Sensel do not have an open source licence, and so there is to be found just such a limitation, one which should be avoidable given the hardware. Sensel's interface designer and mapper allows only up to 96 buttons in total, despite having space for far more. For many of the designs I had hoped to experiment with, this would not be enough, for example a spiral keyboard for the first 128 harmonics, or a keyboard with two octaves of a highly microtonal scale such as 72EDO. I submitted a request through their forum, but under the restrictions of enclosed intellectual property, Sensel alone have the power to decide whether the possibility of more buttons is a feature worth adding. Though they do not have an open source licence, Sensel do have the next best thing, APIs for a range of programming languages including C, C#, Python, Arduino, Max/MSP and Pure Data, which allow for the extraction of the touch data for functions that sidestep the limitations of their own digital infrastructure. Therefore, I have experimented within Pure Data, dividing the interface into a grid of far more segments through simple functions of the overall X,Y position. The initial reason for wanting as many as 410 divisions of this space would be to make a keyboard for two octaves of 205-EDO, the system used in Aaron Andrew Hunt's instrument the Tonal Plexus, as played by Dolores Catherino.

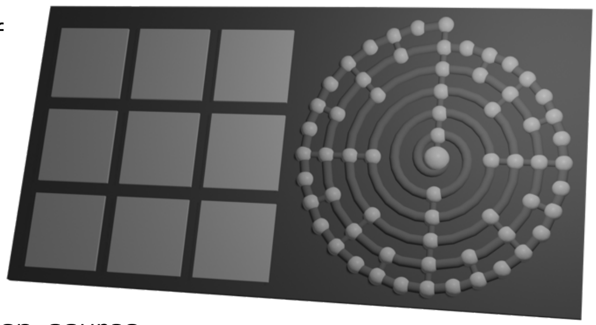


Figure 13 *Harmonic spiral keyboard*

Another of the fabric keyboards is based on Catherino's idea of Polychromaticism, the use of 12-EDO as a basis for exploring "high resolution" EDOs. For musicians who are already familiar with 12-EDO, the exploration of new microtonal possibilities is simplified as "colours" of familiar notes. Rather than giving cent values or attempting to define and learn 8 new accidentals, the notes of a 96-EDO keyboard can be called *red C, orange C, yellow C, green C, turquoise C, blue C, purple C, pink C, red C♯,* and so on. This system seems a very accessible way to greatly expand one's harmonic palette into what may seem otherwise highly complex territories - that is, accessible except in one very important sense: all of the keyboards on which polychromaticism can be practised cost thousands of euros, and so I hoped to develop an alternative. Despite frustration with the Morph's 96 button limit, I found good reason to embrace it as justification of a 96-EDO keyboard, as a technology-driven approach, since the Blasser-esque embrace of technological limitations also occurs in Catherino's explanation of polychromaticism:

> I utilize a bottom-up approach in the sense that I begin with the pitch continuum and seek the highest pitch-resolution possible (via equal divisions of the octave) within technical constraints of an instrument design. Then I empirically explore pitch/interval relationships which are bounded in aural perception and contextually determined (dynamic, non-fixed).[73]

In order to achieve a maximally tactile interface with the juxtaposition of fabrics, I determined that no two adjacent keys should be made of the same or same-feeling fabric, making for a patchwork keyboard. For the keyboard to communicate what is present in a polychromatic system, it needs to simultaneously show the black and white key pattern of the Halberstadt keyboard, and the colour scale of the polychromatic system. To show both at once, whilst obeying the criterion of maximally different fabrics adjacent to one another, we can imagine a checkerboard pattern over the whole keyboard, except that where the white squares would be we have a window onto the Halberstadt keyboard, and where the black squares would be,

Figure 14 *Each of the keys glued on, ready to be sewn*

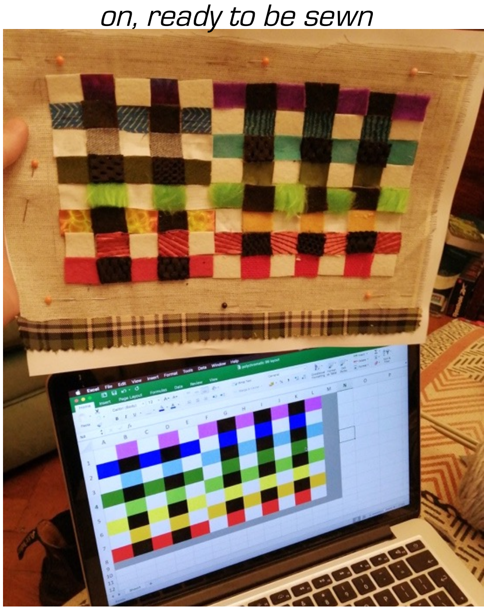


Figure 15 *Polychromatic keyboard*

[73] Dolores Catherino, *Pitch Continuum*, https://dolorescatherino.com/musings/411/

we have a window onto the polychromatic colours. To the touch, the keys are small rectangles of bright green plastic fur, purple plastic velour ribbon, black netting, green felt, light blue denim, dark blue silk, red tartan, yellow pleather, old white napkins, and more.

> They make complete fools of themselves with their “close” intervals, applying their ears to the instrument as if they were eavesdropping on their neighbours. One group claims it can still distinguish an intermediate sound, and says this is the smallest interval which should be used as a unit of measurement. Others disagree. They say the two sounds are the same. Both groups trust their ears in preference to their reason.[74]

The experiment here described by Glaucon in Plato’s *Republic* is an attempt to find the Just Noticeable Difference (JND) of pitch perception. Instruments with very high order EDOs or otherwise very microtonal systems, can be seen as the brute force method of providing versatility. The ANS, a 72-EDO optical synthesizer developed in the USSR over a long period from the 1930s-50s, used a system wherein the user would etch onto glass the shape of a pitch gesture, the intention being that we would hear a continuous pitch gesture, rather than a succession of microtonal pitches.[75] This is very similar to Catherino’s approach, and so explains her use of the phrase ‘pitch resolution’, which draws a parallel with other forms of resolution such as audio bit depth, which measures into how many steps we divide the continuum of possible amplitudes when we encode audio. By this conception of pitch, 12-EDO is very low resolution and so a continuous pitch motion quantized to 12-EDO is barely recognisable. In search of the figure which seemed to Glaucon so incalculable due to the impossibility of consensus between different ears (and indeed the same ear in different registers), Aaron Andrew Hunt combined a number of pitch perception studies to show the average JND to be around 6 cents.[76] To satisfy the feeling of a stepless pitch continuum with an octave-repeating scale, then, requires a minimum of 200-EDO. This is a key detail informing the design of his Tonal Plexus. This was combined with both: a quest to optimise the consonance of certain just intervals for which the approximations given by 41EDO are unmatched, and a desire to keep 12-EDO as a more or less in tune option. The solution he gives is 205EDO. $41 \times 5 = 205$, meaning 41-EDO is preserved exactly within 205-EDO, and $12 \times 17 = 204 \approx 205$ meaning 205-EDO divides *almost* exactly into 12-EDO, plus it satisfies the JND by being an EDO of order higher than 200. The Tonal Plexus, can be seen as a pitch system on a macro-level, a guiding framework onto which one can project the micro-level, be that fixed pitch subsets, or other more fluid approaches. Viewing it as a framework, we can for example approximate lower order EDOs, approximate just intervals, construct our own subsets by listening and intuitive taste, play freely without regard to any subset, apply a dynamic system of tonal modulations or approximated glissandi, or combine any number of these in a fluid manor without ever having to flick a switch or load a Scala file. This matter of being a fluid, *no-loading* system is perhaps the greatest strength of all instruments which provide or approximate the entire continuum.

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[74] Plato, *The Republic* (trans. Tom Griffith, ed. G.R.F. Ferrari), (Cambridge, Cambridge University Press: 2003), p. 239.

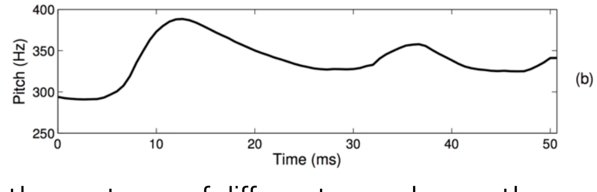
[75] Andrey Smirnov, “UPIC’s Precursors” in *From Xenakis’s UPIC to Graphic Notation Today*, eds. Peter Weibel, Ludger Brümmer, Sharon Kanach, (Hatje Cantz, Berlin: 2020), p. 107.

[76] Aaron Andrew Hunt, *Tonal Plexus Microtonal Keyboard: Regent for the Future of Music*, (self-published for Huygens-Fokker Institute, 2015) :
http://hpi.zentral.zone/pdf/articles/TonalPlexusMicrotonalKeyboard2015.pdf

We might ask, if we desire access to the entire continuum, why use any discrete scale at all, however high-order the EDO, it is excluding pitches in between, would it not be simpler and more complete to simply present us with the raw continuum, as it is found on the theremin or the neck of a fretless string instrument? This is a question of what results are wanted. If we desire to use vibrato or glissandi, or to embrace the sonic effects of human instability and inaccuracy, then yes; if we want accuracy of intonation, and reproducibility of pitches, then this is better achieved with a quantized system. A quantized system also is something of a leveller in reducing the necessity of virtuosic muscle memory. Would we have punk music if guitars were fretless? Access to a full continuous pitch system can have a restrictive influence too in its avoidance of steady pitch, suggestive of certain cliché gestures just as there has historically been arguably a glut of glissandi in the repertoires of the trombone and theremin, and of vibrato in the repertoires of classical voice and violin. It should also to be noted, returning to the concept of pitch resolution, that no digital instrument can provide a continuum without approximation to some finite resolution. MIDI pitch bend has a bit depth of 14, which means it can be divided into 16,384 divisions, over a pitch range set by the user or instrument designer. Let us say we wish to maximize the resolution from this restriction, then we would give this pitch bend a range of a semitone, we could therefore describe such a system as 196,608-EDO. Clearly this appears an arbitrary distinction, no human ear could possibly distinguish between two adjacent pitches in 196,608-EDO, but this leads us to precisely the purpose of the JND applied by Hunt to the Tonal Plexus. A resolution that goes a thousand times finer than the JND is simply an inefficiency, although there's certainly an argument for going a little further since the JND is applicable to pitches played one after the other, whereas small differences between those played in harmony will be easier to detect.

When this research began, tuning and harmony were to me as they are in the tuning of a fretted instrument and the harmony of the stave, matters concerning sets of discrete pitches, singular points in the continuum. Yet many pitch systems do not really have fixed points. Even the common practice systems that we default to and which give us this assumption, often seem to operate in pitch zones rather than points. In acoustic performance we necessarily do not expect exact intonation but something within the zone, A is 440Hz but it is also seemingly the pitch class that surrounds 440Hz and in some sense even as far as an accidental can take it. Just intonation theorists would describe 6:5, 7:6, 20:17, 13:11, 19:16, 32:27, 25:21, and more as minor thirds. Glides, bends and vibrato are arguably underdeveloped notions in the language of the stave, usually notating destinations but not journeys, whereas gamakas in Carnatic and Hindustani classical music far more formally describe the contours of fluid motions between steps in a raga. Harsh Vyas, Suma S. M., Shashidhar Koolagudi, and Guruprasad K. R. have formalised this further through technologically facilitated analysis of Carnatic gamakas, mapping the contours of different gamakas as they apply to the same notes in different ragas, as an alternative to reductive analyses that imagine a raga flattened into a discrete pitch set (fig. 16).[77] In *New Musical Resources* (1930) Henry Cowell points out that so far, in the western classical tradition, 'a very frequent

Figure 16 *Note 'Dha' with inflections in raga*

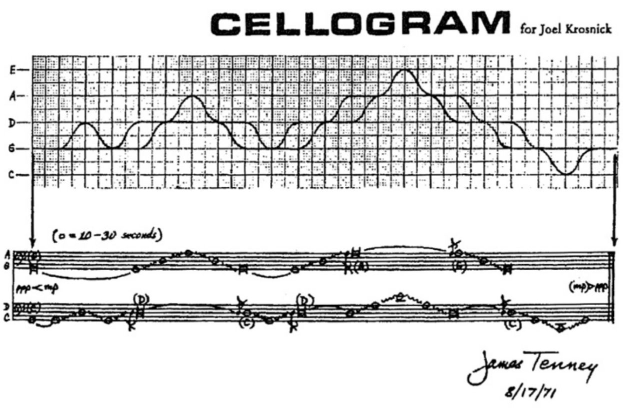


[77] Harsh Vyas, Suma S. M., Shashidhar Koolagudi, and Guruprasad K. R., *Identifying gamakas in Carnatic music*, (2015)

use [of sliding tones] has been considered in bad taste',[78] indeed this continued over the rest of the twentieth century, with sliding motions on the trombone and swanee whistle gaining an inescapable association with slapstick comedy, and on the theremin with old horror and science fiction film tropes. Yet Cowell also points out that in other contexts these are very common sounds to our ears:

> Natural sounds, such as the wind playing through trees or grasses, or whistling in the chimney, or the sound of the sea, or thunder, all make use of sliding tones. It is not impossible that such tones may be made the foundation of an art of composition by some composer who would reverse the programmatic concept, such as expounded by Richard Strauss. Instead of trying to imitate the sounds of nature by using musical scales, which are based on steady pitches hardly to be found in nature, such a composer would build perhaps abstract music out of sounds of the same category as natural sound – that is, sliding pitches – not with the idea of trying to imitate nature, but as a new tonal foundation.[79]

Figure 17 *score for James Tenney – "Cellogram"*



To Cowell then, Strauss's mimesis of the sea and birds through fluid pitch is a cheesy dead-end. Instead fluid pitch could be the foundation of a radical new musical language. Since Cowell suggests that almost all musical systems can be seen as extrapolations of the harmonic series,[80] it is notable that he writes: 'Sliding tones do not seem to have specific connexion with overtones, and are mentioned here to indicate the possibility of musical systems derived otherwise than from overtones.'[81] Cowell does not explore this point much further but leaves open the possibility of future languages based around fluid motion. For such a system to go beyond the novel comedic effects of the swanee whistle and theremin could require a move from monophony to polyphony, to embrace its potential for continuously changing harmonies, with the effects that would have for beating patterns which would slow and speed up as just harmonic relationships are moved past. This is a mantel very much taken up by James Tenney in *Cellogram* (1971) (fig 17) which details pitch contours to follow for two cellos, but does so in perhaps an intentionally basic form with discrete pitches continuing to play a central role as resting points, and whilst avoiding the possibility of the two lines both moving at once, for example in contrary motion. Such approaches are often categorised by how they relate to discrete resting points, akin to viewing a journey through its destinations, whereas different approaches could also be categorised by *how* they travel: following a musically defined contour as in gamakas, following a mathematically defined curve as in the sinusoidal-esque motion of *Cellogram*, linearly or nondescriptly as in line with western notation, or stochastically perhaps following algorithms such as Brownian motion or tendency masks. In the context of analogue synthesis, the motion between pitches can also be determined by the particularities of a slewing filter circuit, the falling voltage of an analogue sample and hold

[78] [78] Henry Cowell, *New Musical Resources*, (Cambridge: Cambridge University Press, 1996), pp. 19-20.
[79] Cowell, p. 20.
[80] Cowell, p. 3
[81] Cowell, p. 20.

circuit as its capacitors leak, or the usual temperature-dependent chaotic drifting of analog oscillators. I am not fully in agreement with Cowell over the cheesiness of mimetic fluid pitch, rather, my interest in taking up or at least facilitating the taking up of this often neglected realm of harmony was initially sparked by the possibility of modelling of real-world fluid scenarios. Spectral analysis of sounds from physical material has been used many times to determine static pitch sets, but for many physical events it shows continuously fluctuating frequencies. The sound that captures this most clearly to me is exciting and then swilling a pan half full of water, to listen to its moving tones as, from the air inside the pan's point of view, the pan of water effectively morphs continuously between physical shapes. All of these are potential trajectories for fluid harmony, but fluid harmony's integration into tactile instruments may begin a little simpler, with the emphasis on the fluid movements of bodily gesture. To some extent, with polyphonic aftertouch controlling amplitude or timbral qualities, something of the human imprecision of a bodily gesture is captured, but with pitch this is far clearer – in a post-virtuoso world, this imprecision may be something to celebrate rather than hide as keyboards have tended to do.

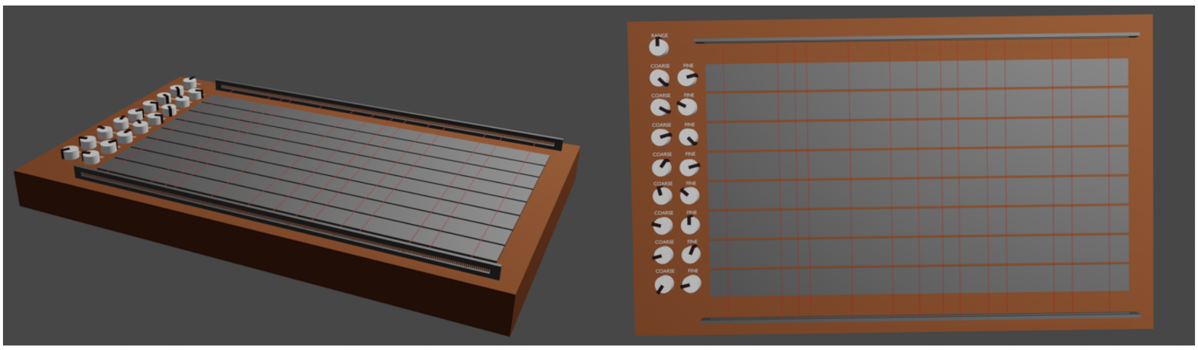
The Multi-Ribbon Keyboard (fig. 18) is my design for a fluid pitched fabric keyboard for the Sensel Morph. Multi-ribbon really is short for multiple-*touch*-ribbon, to differentiate it from instruments like David Vorhaus's Kaleidophon (c. 1975), Artiphon's Instrument 1 (2013), and Gustavo Silveira's XT synth (2018) which also have multiple continuous ribbons, but which obey the logic of the viola's strings in that, per ribbon, only one note can be played at a time. The Haken Continuum, which began development in the early 1980s but wasn't publicly available until 1998, was seemingly the first to make a fully polyphonic continuous pitch controller, but differs in that it positions that continuum along a single line, it is one dimensional. This limits how much of the spectrum can be covered at once by the hands. The great advantage of the Continuum is that it is perhaps freer for pitch since, if you aren't restricted by the visual guidance of the 12-EDO keyboard, it does not have the discrete second dimension imposing some pre-decided structure. A single dimension can also be simpler to navigate with the hands. The multi-ribbon keyboard, meanwhile, is very compact, fitting potentially six octaves onto the Morph where the commercially available Halberstadt keyboard overlay would fit only two. To achieve this, it has two dimensions, the continuous dimension running from left to right, and the discrete dimension with its six discrete ribbons, running from front to back, much like having a six-stringed fretless instrument. These continuous ribbons should each cover the same amount of logarithmic pitch space, generally just over an octave so that glides of an octave are possible. The discrete dimensions could be tuned in infinite different ways, but the most familiar set ups would be: in octaves (the advantage being that when observing octave equivalence, the same pitch classes would be easily found by moving a finger from one ribbon to another whilst keeping the same X dimension), in fifths (the advantage being both that it is familiar to string players, and that there are multiple places to find each pitch in the range which will make many harmonies easier), in a guitar tuning such as EADGBe (the advantage being as with in fifths, but for guitarists), or in the harmonic series (which would make for a

Figure 18 *Multi-ribbon keyboard*

system where the X dimension determines the fundamental, and the Y determines the harmonic).

As well as enabling fluid harmonic systems, continuous pitch spaces also offer ways of defining discrete scales. My mum's own taste for textiles meant that the resources we were reusing were primarily a flamboyant selection of patterned fabrics, and so when it came to deciding which to use in the creation of the Multi-Ribbon Keyboard, I followed the notion that the pitch system might be driven by the technology, again to the conclusion of following the fabrics' patterns, as I had with the generalised keyboard. A variety of spotted fabrics were used for the ribbons, to invite the player to follow those spots as a division of the pitch dimension, and therefore as a tuning system. Assuming octave tuning in the discrete Y-dimension, octave-equivalence is avoided by use of a different fabric for each ribbon. The pitch systems which emerge are suggestive rather than well defined, some spots draw the eye and therefore dominate the system more than others, and some are large enough that they constitute pitch zones rather than nodes. The bottom ribbon, the brown tie-like material with blue flowers on, divides the space into 25 equal divisions. The yellow row, doesn't use spots but a repeated pattern of lines that seem to invite the shape of a finger into each repetition, but which could be read as a "u" or in the space between as an "n", each giving different offsets to the equal division of the space into 13. The other fabrics all have spots that are not equally spaced but spaced according to the conditions desirable in creating a chaotically spotty-looking piece of fabric – which to accommodate industrial printing processes does involve repetitions, as can be seen in the white row, but the pattern that repeats is intended to look random without leaving drastically uneven amounts of space. The resulting system from all of these patterns stacked in octaves on top of one another, could not have emerged from mathematical justifications of tunings, nor from random distribution, instead we find patterns that emerge from the literal patterns of the fabrics. After the indeterminate dropping of overlaid elements in the various parts of John Cage's *Variations* series,[82] I have also experimented with dropping small objects such as coins onto this surface to allow where they fall to determine a pitch set.

Figure 19 *String-fretted multi-ribbon keyboard*



A variation on this multi-ribbon keyboard is the second of the as yet unrealised 3D designs (fig. 19). The *String-Fretted Multi-Ribbon Keyboard* offers another form of hybrid fluid-discrete interface, making use of the continuous pitch space as a medium for experimenting with physical derivations of pitch systems as with the fabric patterns and object dropping, but also enabling a more conventional approach with the deliberate placement of pitch nodes within the continuum according to any other system such as just

[82] John Cage, *Variations I,* (New York: C.F. Peters, 1958); John Cage, *Variations II,* (New York: C.F. Peters, 1961).

intonation or equal divisions of pitch space. A keyboard of multiple parallel ribbons (here eight rather than six) is positioned as before, however, not as an overlay for the Sensel Morph but as a standalone instrument using capacitive multi-touch strips such as the Bela Trill Bars, which can sense up to 5 touches at a time as well as the touch size so that polyphonic aftertouch can be kept, although the Trill Bars are just over 10cm, whereas the ideal length for this would be about as far as two hands can cover at once, somewhere between 20 to 40cm. These ribbons running from left to right, are here not programmed to have a particular tuning but can be tuned by a pair of potentiometers giving coarse and fine tune as if with the tuning pegs at each end of a violin string. Running from top to bottom, over the top of the ribbons, are strings marking the divisions of the pitch space. These are not strings in the usual musical sense that you pluck or bow, but looser strings that are there to guide the fingers to the desired pitches, more like the frets of a viola da gamba. Pressing down on the string then gives the possibility of vibrato and bends along the ribbon. Digitally at least, the string-fretted multi-ribbon keyboard is a no-loading system, which is to say that whilst changing tunings on it does take time and effort, that time and effort is outside of the computer, making it compatible with children and technophobes in a way that configuring the Sensel Morph or Lumatone could never be. The other advantage to this occurring outside of the computer is its visibility and tangibility, just as any fretted instrument presents its tuning physically, where a keyboard can hide it behind the curtain of remote activation. In comparison to this feature of fretted instruments, it also has the advantage of using a logarithmic pitch space, so that whereas a guitar on first glance may not seem obviously to use an equal division, the string-fretted multi-ribbon keyboard would be. This also makes the most of the otherwise restrictive division of the continuum into sections; to compare it again to the Haken Continuum, this system would not work for octave-repeating scales on the Continuum because you would need to string up the pattern multiple times over the length of the keyboard. Whilst this could risk naturalising octave-repeating scales, it could be periodic in different intervals by retuning the ribbons, or it could be aperiodic through a more playful approach of not only running the strings parallel to the ribbons, but running them diagonally and in criss-cross patterns. Diagrams showing possible frettings can be seen in appendix 1. In order to have something to tie these strings onto that isn't so tall that they obstruct the hands from reaching the keyboard, there would need to be a form of very small but relatively long ladder with rungs to tie the string to, and therefore there would be some predetermined system to which any system made would have to be a subset. My suggestion for this would be a very high order EDO, so that it was as close as possible to a free choice from the continuum. If this is not precise enough for a just intonation system, alternative ladders could be made even by hand with wood and pins.

Adding moveable frets to the multi-ribbon keyboard overlays onto the continuum the framework of a discrete set of pitches that are not inherent to the design but can be physically retuned by the performer. This is a framework made simpler in the last of the fabric Morph overlays, the tunable keyboard, which can be understood as a digital polyphonic expansion of the monophonic or paraphonic touch-controlled voltage banks pioneered by Don Buchla and Serge Tcherepnin. The Buchla 112 and 114 – controllers for the

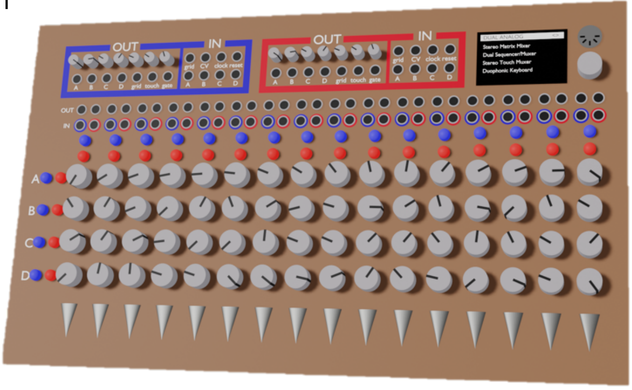


Figure 20 *SKMMM*

first ever Buchla modular synthesizer, made for the San Francisco Tape Music Centre in 1963 – allowed the keyboard to control two voltage outputs, tuned from two parallel rows of potentiometers, and selected with the keyboard by switching between different input voltage offsets.[83] One of these outputs could be used to control any parameter. From the perspective of exploring pitch systems, this was a brand new proposition, a duophonic keyboard that could be retuned freely from the continuum in real-time. I have an unrealised design for this kind of paraphonic keyboard in the form of the Sequencer-Keyboard-Multiplexer-Matrix-Mixer (SKMMM) (fig. 20). It would run a Markov chain sequencing mode that would read the inputs of the four channels A, B, C, D and assign them as A = main voltage out (so maybe for pitch), C = option 1 for what the next step will be, D = option 2 for what the next step will be 2, with B = probability of next step being option 2. And so with a row of 16 you could have 16 different pitches, and up to 16 of these could be nodes in a stochastic, repetitive but not looping phrase. With the Arduino connected to the VCAs at each input, it would run a range of sequencing modes including the Markov chain one, and would include the option of running two sequences at once in polyphony made possible by the use stereo potentiometers, plus, although the voltage offsets would be normalized to the inputs of each column, this normalised circuit could be broken and replaced with an external signal, and so would be a multiplexer, giving the possibility that each step (or key) could have randomisation, vibrato or audio-rate frequency modulation rather than a steady pitch. The limitation from the perspective of seeking a versatile keyboard for the exploration of harmonies is that the “harmonies”, or rather parallel voltage streams, are homorhythmic, and further it is mono-touch, so for example you could not press one note with one finger and then add another note with another finger, this is as true for the duophonic Buchla 112 as it is for an expanded Make Noise *Pressure Points* which could give you seven voices if you were to apply them all to pitch. Whilst my hope is that SKMMM’s use of stereo potentiometers would make the running of two rhythmically independent sequences from the same set of pitches possible, and possibly that it could be played in true duophony, which is to say that the hands could play two synthesizer voices separately with independent amplitudes, the desire to construct harmonies a pitch at a time that go beyond duophony, from a tunable keyboard cannot be fulfilled with the SKMMM or any voltage selecting keyboard. The analogue realm does have a form of polyphonic tunable keyboard in Soma’s LYRA-8. Rather than a keyboard which sends control signals to send to an oscillator, it is a keyboard of eight keys for which each gets its own oscillator, with the key providing direct touch control over the amplitudes of each. Each oscillator can be tuned independently and then there are a number of ways that the oscillators interact with one another in a network of cross-modulation that will be explored further in the following chapter. Without this cross-modulation, with the LYRA-8 in its simplest organ form, the performer manually tunes a set of eight pitches from which harmonies can be built from the combinations.

[83] https://www.synthmuseum.com/buchla/buc11201.html

The tunable keyboard in its digital polyphonic form, offers twenty keys, presented in two rows of ten to accommodate a relatively static positioning of the hand, with a column for each digit at resting position (fig. 21). Each key is a square with a matching rectangular tuning key of the same colour and material positioned in the same column. In order to meet the fabric keyboard criterion of maximally different-feeling adjacent keys, this design uses a checkerboard pattern of a dark red carpet sample with a linearly grained corduroy-like texture and the white reverse side of another carpet sample with a rubbery spotted texture. The tuning key could use the singular Y dimension if it were mapped to MIDI pitch bend's 14-bit division of the continuum into 16,384, but if controlled from other control change messages which are 7-bit, the continuum is divided into 127, and so in my implementations so far the tuning key has been split into two narrower sliders giving a coarse and a fine tune. This allows a wide frequency range with an identical range covered by every key, whereas a lyre, harp or zither's strings, whilst independently retunable, would follow an order of different lengths, thicknesses and tautnesses, there is a certain order baked into the instrument, a logic which is followed to some extent by the LYRA-8 as it gives the tunable range of the oscillators further to the right as higher pitched. The advantage of giving each key identical ranges is that it removes the restrictive assumption that pitches should be sorted by pitch and ordered from left to right. This system, that we might call the melody row, is partly based on the practice of playing scales in order, but also can be partly justified by its simplicity – on a first encounter with a piano, this relation (left to right = low to high) could be easily observed by a curious alien or child, whereas other layouts which might have ergonomic or harmonic reasons would be less easy to intuit. By extension of the simplicity of this mapping, this is also regarded as a neutral system, whilst keyboards organised by harmonic function would be very suggestive of certain harmonies, removing the sense of a blank canvas. There is however no neutral system, no tabula rasa keyboard geometry or order. The melody row's pseudo-neutral ordering is described by Bill Wesley as an easy design which he believes leaves an unnecessary proportion of the cognitive work to the performer.

Figure 21 *Tunable keyboard*

> The geometry of the melody row is easy to design but physically difficult to play well enough to effectively convey emotion. Most people become frustrated by the difficulty they encounter with the melody row, and incorrectly conclude that they are incapable of expressing emotion with a musical instrument. We have created new instruments based on the Harmony Array, a design that ranks notes from harmonious to inharmonious in a plane. These instruments are two-dimensional. The geometry of a harmony array is difficult to design, but physically easy to play.[84]

This notion that the work required to get good at playing an instrument is shared between the instrument maker and the performer is echoed as an extreme case in Evan Parker's

[84] Bill Wesley, *Geometry of Music*, talk at TEDxAmericasFinestCity (2011) : https://youtu.be/SU2JztST_TY

analysis of Hugh Davies's contributions to group improvisations, 'Hugh's virtuosity was expressed more in the building of an instrument than in the playing. Playing most of his instruments was often a matter of letting them speak, but at the right time and at the right dynamic level.'[85] Many folk instruments, including the autoharp, harmonica, and accordion build chords into the layouts of the instruments themselves. When we do this we prioritise certain harmonies within the basis of the instrument, in such a way that may seem to some too prescriptive. This is the other side of the coin to the assumptions implicit in the Fisher-Price glockenspiel in its typical form with the accidentals removed. Part of that logic is to fool the parents, or at least protect their ears from the more Schoenbergian harmonies a child might otherwise wish to explore on a full Halberstadt glockenspiel, and so certainly making a particular harmony easy to access is not always done for positive reasons. Yet we should also notice that historically, in Europe, the divide between instruments which make chords readily available, and instruments that make you work to find them, is exactly the divide between the folk musician and the musician of the royal court and its Romantic alternatives, what we think of today as the classical world. Hence, the design philosophy that posits the melody row as a blank canvas, simultaneously seems to avoid harmonically oriented geometries on the basis of snobbishly regarding them as anti-virtuoso cheating. I would therefore suggest that the dominance of the melody row – considered as a tabula rasa from which to learn harmony as an academic stave-based study to be mentally translated to melody row positions – has fed off of the cult of pseudo-meritocratic *work for the sake of work*. As Wesley suggests, the Halberstadt keyboard leaves work to the musician that could be easily simplified by the designer. The generalised keyboard (at least when tuned to the Tonnetz) and Wesley's own Harmony Array, order their pitches by harmonic function so that a move to a nearby key is always a consonant one. The tunable keyboard provides no such inherent order, but highness of pitch, melodic shape and harmonic functions can optionally be considered when tuning its keys, alongside other considerations such as the beating effects certain combinations of tones might produce. These considerations can be wedded to particular ways of dividing the keyboard. The tunable keyboard's design provides many ways to group its keys, to split: into the two colours which checker the keyboard, into the two rows, into the two sets of ten keys that are by default covered by each hand, or into smaller sets like into five square Battenberg cake slices of four pitches each. As well as using these distinctions to form distinct harmonic areas of exploration, there could be a general idea that those toward one end might be higher pitched or some combination of these kinds of splits and guidelines. The most common way I have enjoyed tuning it has been with the very lowest notes on the outside (keys 1A, 1B, 10A and 10B), getting higher as they move inward (with the highest pitches on keys 5A, 5B, 6A and 6B). Dealing like this in inside and outside rather than left and right, matches ergonomically with the mirror symmetry of the hands, with the thumb always taking up an inside position, as is commonly realised in the design of lamellophones such as mbiras. Extending this to include the whole hand means that the relatively natural way the hand can curl into a repetitive tapping of the fingers can make for an easy arpeggiation as demonstrated in video example 3. With the finger order mirrored on each hand then, the simultaneous result of tuning from low to high from the centre to the wing, is that the keyboard is split into four scales or chords each in highness-of-pitch order: (5A, 4A, 3A, 2A, 1A), (5B, 4B, 3B, 2B, 1B), (6A, 7A, 8A, 9A, 10A), (6B, 7B, 8B, 9B, 10B), these are the sets which are arpeggiated in video example 3, but say nothing

Figure 22 *Tunable keyboard's keys labelled*

1A	2A	3A	4A	5A	6A	7A	8A	9A	10A
1B	2B	3B	4B	5B	6B	7B	8B	9B	10B

[85] Derek Bailey, *Improvisation: it's nature and practice in music*, (Boston: Da Capo Press, 1993), p. 94.

of what those pitches should actually be – that question is decided entirely by ear. For the player who wishes for the ability to reorder the keys in this way, but with the predetermined structure of a discrete tuning system, this same Morph overlay can also be used with 7-bit tuning keys mapped to the MIDI notes 0-127, with microtonal tuning files, such as Scala or text files, used as lookup tables to assign each MIDI note a frequency.

In the five months since I made the four fabric keyboards – the generalised keyboard, the polychromatic keyboard, the multi-ribbon keyboard, and the tunable keyboard – it has been the tunable keyboard that I have reached for most often, to *play*, to experiment with harmonies, and especially to meet the challenges of free group improvisation. When you have no idea what sort of pitch material might come your way, the ability to retune in real time and define harmonies and modes freely with an absolute prioritisation of listening, and to do so without sacrificing the ease of repeatability that may be lost with the multi-ribbon keyboard, makes the tunable keyboard a *go-to*. With this freedom to retune on the fly comes also the fact that you must make these musical decisions within a performance context, and so tuning, which we wish to encourage the change from being considered "set-and-forget" to being a musical decision we all make when we compose, becomes a decision not only to make at the beginning of a work, but which we can continue to make on a moment-to-moment basis in the heat of improvisation. This immediacy also makes tuning a very obvious physical act. In education, if we are to escape the perpetual now, it is of the utmost importance that nothing is presented as a given, everything demands explanation. For this reason, Tolgahan Çoğulu's hope that his Lego guitar fretboard design 'will be used for teaching the music of different cultures and also used for standard guitar education'[86] is an important one. On such a guitar, the fretboard has no frets until you place them there, and therefore music theory can be taught from scratch so that every pitch must be placed with intention and therefore understood as a choice with a particular rationale behind it. Extending this idea, the tuneable keyboard and the string-fretted multi-ribbon keyboard also make tuning a physical act requiring active engagement with the decision making process, and so would likewise be ideal for this educational use. In comparison to the account of Philip Glass's formative experience of the instantaneous reifying marriage of a pitched sound to a particular finger position, note name and stave position, we can imagine that a child introduced to pitch through a system that must be built from scratch would have a lot more of an understanding of the artificiality of musical language. The generalizable keyboard also invites retuning, but does so through more complex means, usually navigation of software, and so I would argue is a more advanced concept for which beginning to understand the keyboard requires understanding the harmonic functions of the system, although at the same time, it would be a great advantage to learn these through playing as would intuitively be done on the generalizable keyboard far more easily than the Halberstadt. The polychromatic approach, meanwhile, is ideal for a different educational scenario: the expansion of the harmonic palette for musicians who are already acquainted with 12-EDO-based harmonic language. Finally, I would suggest that the process of keyboard design itself could be a starting point for creative music theory suitable to all ages. The act of crafting things from scraps of leftover fabrics is a mainstay of early education, and so, if coupled with a technological backbone even more affordable and easily programmed than the Morph, the process of designing and building fabric keyboards could be simplified into something scalable to the classroom or workshop. In the spirit of allowing the tuning to follow from the technology, a child who designs a pattern for a keyboard with the visual aspect in mind, could then learn to translate its geometry into a musical system, and so be introduced to the idea,

[86] Tolgahan Çoğulu, *Lego Microtonal Guitar*, (2020) : https://youtu.be/rPCElmSfCwc

by comparison to the Halberstadt, that the systems they inherit are not the only way things can be. And by extension, in inviting musicians to make and compose with their own homemade systems, the emphasis of creative play over the learning of rules could be welcomed far beyond the glockenspiel-assaulting stage of music education.

Rolky (1985) was a virtual modular music studio designed around optically achieved 'poly-touch', a cumbersome arrangement of CRT screens, TV cameras, lamps and mirrors around a glass surface amounting effectively to an early touch screen.[87] Its creator, Eric Johnstone, thought of it as an ecosystem that would continue to evolve according to the ideas of musicians involved in it. He explains that a musician could 'call up or create musical instruments with playing surfaces,' adding, 'Imagine, for instance, a keyboard for a microtonal scale. Something along the lines of a piano keyboard with white and black keys in new positions could be tried – or perhaps a third type of key would be needed. Having created such an instrument, it is available to other musicians to use or modify.'[88] This aspect of building on each other's designs is especially key. Johnstone writes:

> As new devices and controllers are created they are added to the storeroom. In a multi-use environment the Rolky studio can be likened to a living evolutionary system. An organism is the expression of its DNA. The device into which the Rolky is configured is an expression of its program code.
>
> In a living evolutionary system, a progression toward higher levels of organisation occurs through mutation of the DNA and through environmental selection pressures. In a multi-use Darwinian Rolky studio, every user (not only the programmers, as in a Creationist studio) can mutate devices, Deficient devices can be erased and become extinct; the users also supply a selection pressure. A new idea can completely redefine the Rolky studio and take it down a different evolutionary path.[89]

What Johnstone hints at is the dream of an endlessly versatile and malleable studio and its instruments as a product and driver of continual collaboration with a result that it never solidifies but is constantly evolving. It is in many ways a precursor to what I have attempted with the Morph, to show that what is needed is a single device that can metamorphose into multiple keyboards. Johnstone was describing Rolky as existing on an isolated computer, for a multi-user situation like a university studio, where different musicians would interact with the computer and as a community build on each other's programs and interface designs. If scaled up from a single studio to a global network, not that this was Johnstone's intention, and beyond the studio, to also the classroom, the concert hall, the club, and the radio, the selection-oriented dynamics described might be considered an excessively aggressive human manifestation of natural selection, in other words Social Darwinism. But the future minded dream would see this potential for social collaboration scaled with a change of emphasis from competition to collaboration, whilst swapping the embrace of extinction for the preservation of the non-scalable. Today, in an age of tablets, internet communities, and open source culture, this dream could be far more scalable, and has proven so as communities freely sharing patches have become a core part of virtual modular environments such as Pure Data, SuperCollider, and VCV Rack, as well as for commercially licensed alternatives like Max, Reaktor and Kyma – this occurs although to a lesser extent

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[87] Eric Johnstone, "The Rolky: a poly-touch controller for electronic music", in *ICMC '85* (Montreal: McGill University, 1985), pp. 291-295.
[88] Johnstone, p. 294.
[89] Johnstone, p. 295.

in interface design, with communities contributing layouts for TouchOSC and the Sensel Morph. A post-virtuoso world in which many musical systems coexist in peace could be facilitated by such collaborative open systems as these, with freely available platforms as versatile as tablets and the Morph, and with local community-run instrument libraries full of all manner of beautiful devices. The reinvigoration of creative music theory is dependent on the free sharing of ideas and technologies.

3 Narrative-driven approaches to tuning

3.1 Nature

> *Xenofeminism indexes the desire to construct an alien future with a triumphant X on a mobile map. This X does not mark a destination. It is the insertion of a topological-keyframe for the formation of a new logic. In affirming a future untethered to repetition of the present, we militate for ampliative capacities, for spaces of freedom with a richer geometry than the aisle, the assembly line, and the feed. We need new affordances of perception and action unblinkered by naturalised identities. In the name of feminism. 'Nature' shall no longer be a refuge of injustice, or a basis for any political justification whatsoever!*
>
> *If nature is unjust, change nature!* ***– Laboria Cuboniks,*** **XF Manifesto**

The narratives we construct have always shaped our world. So far, in the development of pitch systems, no narrative has held more power than that of nature. Wielded by the Social Darwinist, it is the the justification for 12-EDO's dominance; wielded by the conspiracy theorist, it is the justification for the A = 432 Hz pitch standard; wielded by the Pythagoreans, it was the justification for the divine perfection of 3-limit just intonation; wielded by a younger me, it was the justification for the utopian perfection of the harmonics. As a nebulous web of definitions, ideas, prejudices and anthropomorphised characters, nature is constantly changing its form to accommodate just about any agenda.

And yet if there is one thing we seem to be sure of about nature, it is that it never changes. Nature's laws seem to have been in place since the start of time, and to reach ever into the future, undisturbed by anything we might do in the present. Nature then is thought of as fixed, a constant, the ground on top of which society is produced and reproduced. But given that this ground itself, nature, is conceptually malleable, socially constructed prejudices inevitably get, slyly or inadvertently, bundled in with nature, buried within the same ground. These assumptions then become the deepest entrenched elements of the perpetual now. In becoming so, we say that they have been naturalised. Which assumptions get naturalised is dependent on the other constituents of the perpetual now: capitalist realism, cultural hegemonies, and sometimes scripture. 'An ideological position can never be really successful until it is naturalized, and it cannot be naturalized while it is still thought of as a value rather than a fact.'[90] It is, I would suggest, as cultural collateral damage that 12-EDO has been naturalised as a relatively benign constituent of the perpetual now. That is, it is in large part a side effect of having an education system which actively discourages the questioning of nature and its authority, by reducing maths and science to lists of formulae to learn, and exercises in which to prove you remember them, emptied of the fundamental questions over the relation of number to the world. Music education does likewise by reducing harmony to formulae, to be reproduced on the stave and its ancient cousin, figured bass. Pitch becomes a list of scale degrees to remember the sound of. Chords become lists of notes and their Schenkerian functions. Timbre becomes a list of instruments to recognise poking through the mix of an orchestra. Rhythm and structure become shortlists of keywords. This framework is extremely reductive even when applied to the classical works it was meant for, let alone as a basis for general music education. In cases such as these there is a clear distinction between what is naturalised and what is

[90] Fisher, p. 16.

natural in the human-exceptionalist sense. Somewhere in between the supposed natural purity of mathematics, and the supposed uniquely human invention of language, seems to exist musical language, partly an encoding of natural phenomena, and partly an expression of human genius and divine inspiration.

There is, however, a tendency, even within xenharmonic music theory, to imagine western tonal functions as a part of nature. Commas, as explained by Scott R. Wilkinson, are 'small *anomalies*, or errors, that are inherent in the nature of intervals.'[91] This is by no means an explanation unique to Wilkinson, it is almost standard to hear tuning theory described as a history of attempts to solve the errors of nature. This "anomaly" occurs when we travel the circle of perfect fifths to find that we did not end up on an octave equivalent of the starting pitch. In mathematical terms of proportional frequencies, when we take 3 to the power of, say, 12 it cannot not end up equal to 2 to the power of something. Of course, this is no anomaly – for a simple proof, we know that an odd number multiplied by an odd number is always an odd number and an even number multiplied by an even number is always an even number, and so it is the nature of the fifth that it will never stack to an octave equivalent. Therefore, this is no error, it is the way that these integers behave, and the error is to imagine that a perfect circle of fifths is possible. Of course, this might seem pedantic, since no doubt the theorists who express it in this way understand perfectly well the mathematics at hand, but the point I wish to get at is that theorists, having been trained to think in terms of temperaments, and with transpositions as such a core element of harmonic thinking, frequently act as if they are entitled to the transposition, or more relevantly, that the western musical language is so naturalized that pure mathematics itself must be unnatural if it does not permit a well tuned circle of fifths.

We also talk frequently of "discovering" tuning systems, as if they are natural laws waiting to be put on paper by a scientist or mathematician. Indeed, I would argue it is because so many tuning systems are sonifications of mathematical sequences that they are thought of in this way. It is also especially the case that we would likely call something discovered rather than invented if it is a complex internally logical system. The Neo-Riemannian Tonnetz is a clear example of this. It is an internally logical structure capable of matching up simple geometric transformations with common practice harmonic motions, but that internal logic is not a reflection of any acoustic law; rather the harmonic basis of the major triad is acoustically fudged, and if it wasn't, leads to the very "errors" mentioned previously. It is as if they have inherited two contradictory natures, the nature of the harmonic series, and the nature of western tonality, and so decided that a science must be invented, the science of temperament, in order to square the circle. Of course this is chronologically inaccurate - temperament and tonal language necessarily evolved together symbiotically as two sides of the same coin. And so the hidden truth of standard transposition-based music theories is that they draw a false equivalence between these different natures, when really the acoustic mathematics is the only a priori part.

So then it is rational systems, *just intonation*, that are natural, right? Well, no, not really. The *true* part, what we might call *nature*, is what Fourier tells us, that a periodic oscillation can be expressed as the sum of a series of sine waves with frequencies of integer multiples of its fundamental frequency, and so any pitch produced by acoustic or analog means can be understood as containing the harmonics mixed in with it, and that we can amplify or attenuate specific harmonics by acoustic or electronic filtering, by touching a

[91] Scott Wilkinson, *Tuning In: microtonality in electronic music,* (Milwaukee: Hal Leonard Books, 1988), p. 19.

string in the right way, by varying the air pressure we oscillate through a horn, and so on. Sustained oscillation, outside of the digital realm, whether in a bugle, a bowed or e-bowed string, or an op-amp-based analog oscillator, is the result of simple positive feedback systems, and so any oscillation that fits exactly into the fundamental will resonate along with it.

To treat the harmonics as a tuning system then is not natural, no abstraction is (in the human-exceptionalist sense). However, like the Occam's Razor tuning solutions of the previous chapter, the harmonics can be seen as the simplest tuning solution given the pre-existing system (or inherited model) we call acoustics, the physics of sound. Other systems, such as 12-EDO, then, often appear to have their basis in the harmonics, but are a few layers of abstraction further from the natural phenomena, which is to say that there are more human constructs and biases taken into account, and so they can be seen as relatively "unnatural". As Harry Partch explains:

> In this brief examination of contemporaries we are also very conscious of their repeated use of the word overtone, their evident desire to tie our everyday scale to something a little beyond us, to one of the phenomena of nature. For centuries, ever since Mersenne, a procession of exegates has been polishing the ritualistic platters with overtones, in dozens of theoretical disquisitions. (Křenek, too, objects to this, but in getting away he bolts through the first open door he sees, one labelled "Occult.")
>
> Let us look at the facts: the genesis of twelve-tone Equal Temperament had nothing to do with overtones. It evolved from three prime factors: (1) the ecclesiastical modes and the desire, largely unconscious, for small-number-ratios; (2) the growth of faux bourdon and other popular forms, and of keyboards (which grew together); (3) the tyranny of the five-fingered hand.
>
> Now let us look at the vehicle: it is a "cycle" of twelve 3/2's compressed into seven 2/1s, with the result of twelve equal "semitones," in the framework of which, fortuitously, the all-important 5/4's and 6/5's are only so out-of-tune as to be not quite insufferable.[92]

For two and a bit years, beginning in late 2017, I worked almost exclusively with the harmonic series.[93] In that time, there were fixed compositions such as *Forwards*, a web app *Internet Composition #1* and performance with it titled *Improvisation in 48Hz and its Harmonics*, *Evolution Simulation,* a pair of pieces based on a genetic algorithm, one performed by the New European Ensemble and the other by myself on synthesizers, an installation that sonified the steps along Euclid's algorithm as the harmonics of 48Hz with each step as a sine wave given its own speaker along an indoor bridge, a Max-for-Live-based early version of the Polyharm which only played in the harmonic series, and a very basic harmonic series voltage quantizer to add onto the firmware of *Ornament and Crime*, an open source voltage multi-tool for modular synthesizers. I had been first made aware of the existence and non-necessity of 12-EDO by Rob Sturman, a maths professor armed with a copy of Ross W. Duffin's *How Equal Temperament Ruined Harmony: And Why You Should Care*.[94] Seeing 12-EDO now as sonically and mathematically arbitrary, and a key element in the force of an ongoing neocolonial musical standardisation, I looked to the harmonic series

[92] Harry Partch, *Genesis of a Music*, (New York: Da Capo Press, 1974), p. 423.
[93] Besides in Plunderphonic work wherein retuning then seemed impractical.
[94] Ross Duffin, *How Equal Temperament Ruined Harmony: And Why You Should Care*, (New York: W. W. Norton & Co., 2007)

as a pitch system that could be called natural and universal. Here, I had missed a point: that no tuning system could be called natural in the human-exceptionalist sense, because the tuning system is inherently an abstraction. The harmonics may be in some sense “natural” to a monochord, but when applied to tuning a multi-stringed lyre, let alone a digital synthesizer, they are only a mimetic abstraction. It is true that they have certain unique acoustic and perceptual properties when played together, for example that harp strings that produce frequencies related in low-integer ratios will resonate in sympathy with one another. Nevertheless, I was becoming acquainted with various popular microtonal systems and writings, and finding it frustrating that, everywhere I looked, the harmonics were seen as an unmusical problem for tuning theorists to solve, to abstract a proper scale from. As well as this coming from the need to square the circle with western harmonic ideas, as I suggested earlier, it also seemed that people wanted a scale to be defined as a finite set of pitches, to repeat around the octave or occasionally around some other just interval. All of this rubbed me the wrong way, and so I think there was a certain element of wanting to prove those restrictions unnecessary that motivated my harmonic series music, since the harmonic series is both infinitely long and non-repeating when measured logarithmically. That same frustration also led me to develop what I called the *infinitely compact scale*, described in part 3.4, which *was* octave repeating but instead proposed there be an infinite number of pitches in between any two pitches. In attempting to imagine a “universal” and “natural” system, mathematical *completeness* seemed an important factor, if one was to choose a set of frequencies to work with, it should be a set preordained by set theory as a fundamental building block of number. The harmonic series is the set of all frequencies proportional to the set of all positive integers (indeed, the set known as the natural numbers, $\mathbb{N}$), and the infinitely compact scale, in its octave repeating extension of the Farey series (the series that iteratively includes every fraction between 0 and 1), plus one, was the set of all frequencies proportional to the set of all positive rational numbers, $\mathbb{Q}$, an ordered system containing every possible just intonation pitch, without the standard framework of prime limits.

My first compositional use of the harmonic series as a scale had been *Forwards*,[95] for which I was, at university, obliged to write a commentary explaining my decisions, and so looking back at this text gives an insight into my reasoning for adopting the harmonics. The full project *Backwards/Forwards* was intended as a comment on hauntological music, in which *Backwards* consisted of sampling material I deemed the positive utopian images of the past, which today existed as hauntologies, unrealized utopian dreams; the Afrofuturism of Parliament Funkadelic, Sun Ra, and late Coltrane; the cosmic synth music of Laurie Spiegel, Tangerine Dream and The Space Lady; Christian Wolff's *Changing the System*, and a few more. *Backwards* was composed of loops of these samples, as an attempt at suggesting that the hauntological mindset was stuck in a loop of memories. The idea was then that in *Forwards*, these ideas would be ‘updated’, reimagined following two criteria I deemed appropriate for a contemporary utopian musical approach. The first was that they would be digitally synthesized, to have a ‘perfect’ mathematical waveform,[96] a rejection of the nostalgic embrace of wow and flutter, and the instability of analog oscillators, and therefore, though I did not make this connection at the time, I was considering the tendency towards hypertuning, discussed in the previous chapter, as a fundamentally future-minded drive – although ironically, this was at odds with certain aesthetic sonic preferences I held at the time, and so the intent was really negated by the heavy use of a chorus effect. The second

[95] Wilf Amis, *Backwards/Forwards*, (2018) : https://wilfamis.bandcamp.com/album/backwards-forwards-ep

[96] ‘A move towards utopia is a move towards perfection and undoubtedly, the functions used in oscillators generated by computers are precise mathematical functions’.

criterion was expressed thus: in 'the pursuit of "perfection", the use of "pure", perfect harmonic intervals is a logical decision in the treatment of pitch material, but besides this, can be explained by distinctions between what is "western", "human", and "universal"', going on to claim that western music is in equal temperament, human music is confined to logarithmic pitch perception, but universal music is possible only in the harmonic series, in which we could even imagine an alien with linear pitch perception hearing the musicality. I didn't stop to ask whether linear pitch perception was a mathematically meaningful concept (it isn't), but let's put a pin in that, we'll be meeting some more alien ears later. Today, part of my issue with this approach, in which the harmonics are seen as the natural, universal, and perfect utopia, is also manifest in the structure of *Forwards*. The "utopian" samples are transcribed into the harmonic series, to represent parallel streams of utopian thought; over the course of the piece, each of these melodies mutates iteratively towards a common goal, with them all ending up in unison. I would today prefer progression not towards unison, but towards new harmonies, with space to nurture a diversity of systems. As I wrote at the time in my commentary on *Backwards/Forwards*, 'a move towards utopia is a move towards perfection', this was partially coming from my mathematical background. I was attempting to see history, and by extension the future, as a mathematical model of limits – that is, to say that the perfection of utopia is impossible, but nonetheless, with the right formula, we can tend ever closer to it, until what seems today like a negligible *epsilon*, a small injustice, could be zoomed in on, and addressed just as well as we might address gross injustices today. This was supported, I felt, by Wilde's assertion that 'progress is the realization of utopias', and that once arriving there we 'look out and, seeing a better land, set off once more' towards that.[97] But, really, the strength of the sampled utopias was not their malleability, to be reshaped under a common manifesto, but in their particular concerns and imaginations – imaginations brought alive in speculative fiction. What is needed is not a new monolithic scripture but a new living folklore, abundances of intersecting narratives capable of expanding the popular imagination.

If there is a validity to the foundationalness of the harmonics, I would today argue that it is not as an end point, but as a starting point. The harmonics would make for a far less prescriptive and Eurocentric basis for beginning to learn music theories than the current standard practice of teaching Renaissance or Baroque choral harmony, species counterpoint and the like on the stave. A history of western tonality taught only on the stave is a dishonest one, as it tells the story as if Palestrina and Schoenberg were dealing with the same pitch set, when really this history was an ever evolving tripartite dialogue between technology, temperament and what happened on the stave. If such a history need be taught with such a priority at all, the harmonics would contextualize it more accurately, whilst being a simultaneous anchor for the other classical theory pursuits such as orchestration, which relies heavily on the harmonics as the core of timbral understanding. This is the argument for the harmonics as music theory's foundation from a reformist perspective. More urgently, though, the necessity stems from what we aren't taught at all, that is, the musical languages outside the dominant common practice, including non-western pitch and timbre systems as well as various methods of synthesis. Yet, natural as they might seem, we should not push the harmonics as a new sacred and unquestionable natural law. After all – and this is the second key reason for ending my obsessive exclusivity with the harmonic series – we should be vigilantly aware of the nature fallacy: the mistaken assumption that what is natural is inherently good. Even where nature's superiority is not assumed, naturality is often conflated with neutrality. The argument might be made, for example, that the harmonic series is a

[97] Oscar Wilde, "The Soul of Man Under Socialism", in *Fortnightly Review* (1891).

good basis for music education because, in its naturality, it is a neutral choice: it says nothing of where the musician should follow their practice to, whether western or otherwise, tonal or otherwise, acoustic or otherwise. But this is not the case, whilst it may seem neutral with regard to some factors, it is also a very specific deeply scientistic[98] frame through which to approach music. There is no universal or neutral frame through which to interpret or create music. The response to this power vacuum, so far, has been overwhelmingly to justify the imposition of a clearly non-neutral frame, 12-EDO, to fill the apparently essential role of the universal language. But the exciting alternative would be to simply embrace the non-universality, and instead support a proliferation of musical languages, including those which are non-scalable.

The nature fallacy is so prevalent, and its role in maintaining the 'natural order' so powerful, that it has necessitated the building of an ideological current in direct response, anti-naturalism. From the fin-de-siècle Symbolists and Decadents such as Joris-Karl Huysmans and Oscar Wilde who detailed the domination of art over nature, to the Posthuman Feminism of Donna Haraway a century later, writing that:

> Located in the belly of the monster, I find the discourses of natural harmony, the nonalien, and purity unsalvageable for understanding our genealogy in the New World Order, Inc. Like it or not, I was born kin to Pu[239] and to transgenic, transspecific, and transported creatures of all kinds; that is, the family for which and to whom my people are accountable. It will not help – emotionally, intellectually, morally, or politically – to appeal to the natural and the pure.[99]

Since the 1990s, the increasingly unignorable climate catastrophe has made inevitable and necessary just such a form of anti-naturalism, that stands in practical solidarity with what was previously called nature (fellow organisms and ecosystems) against the category of nature itself as something existing outside of the human subject, and over which humanity holds dominion. Towards this end, object-oriented ontology (OOO) has constructed a narrative in direct opposition to the centrality of the human subject. This includes, for a practical example, the questioning of practices that measure a generalised nature with regard to its relation to a specific human subject, for example to measure an individual's carbon footprint. In Graham Harman's words, 'OOO challenges the notion of nature as holistic, viewing the world instead as a partially non-communicating system in which only certain *specific* relations yield dangerous positive feedback loops.'[100] Or indeed, as Timothy Morton posits it, that the whole is not greater but less than the sum of its parts, which means abandoning the standard understanding of the meadow as an abstract shell in which all of its constituent plants, soil and creepy-crawlies can be replaced without changing the nature of the meadow itself.[101] This may hold implications for the Harmony of the Spheres, and more generally the notion of proportion. The "undermined" image that Pythagoras creates implies that harmony is an entirely proportional relation, and so the ratio

[98] scientistic meaning a zealous pop-science attitude of general celebration of the wonder and fixed unquestionability of science that fails to account for the healthy uncertainty, extreme abstraction, and constant evolution of ideas involved in the scientific method.
[99] Donna Haraway, *Modest_Witness@Second_Millenium*, (New York: Routledge, 1997), p. 62.
[100] Graham Harman, *Object-Oriented Ontology: A New Theory of Everything,* (New York: Penguin, 2017), p. 247.
[101] Timothy Morton, "Subscendence" in *E-Flux #85*, (2017) : https://www.e-flux.com/journal/85/156375/subscendence

(or interval) 5:4 is the same object whether it is describing the orbits of planets or the vibrations of lyre strings.

Meanwhile, the Xenofeminist (XF) collective Laboria Cuboniks sees the enshrinement of the natural in a perpetual now as something that requires active undoing. As Helen Hester writes, 'XF is an anti-naturalist endeavour in the sense that it frames nature and the natural as a space for contestation – that is, as within the purview of politics. Any political project based upon nature as a pseudo-theological limit, a cartography of the untouchable, or a space of incontaminable purity risks lending huge conceptual resources to the conservative punishment of radical difference.'[102] This ever dangerous dichotomy, purity versus contamination, identified as core to the ideological content of nature by Hester and Haraway alike, weasels its way into tuning discourse constantly, with just intonation frequently referred to by its synonym, pure intonation.

Pure (pyʊə r) adjective

- *free from anything of a different, inferior, or contaminating kind; free from extraneous matter: pure gold; pure water.*
- *unmodified by an admixture; simple or homogeneous.*
- *of unmixed descent or ancestry: a pure breed of dog.*
- *free from foreign or inappropriate elements: pure Attic Greek.*
- *clear; free from blemishes: pure skin.*
- *(of literary style) straightforward; unaffected.*[103]

Without a well-defined contaminant, 'pure intonation' makes the most sense from 'pure' defined as 'unmodified by an admixture; simple or homogeneous', which rather lays bare the issue: the pure interval is only 'unmodified' if it is assumed as a default, to be defined in opposition to temperament. In other words, it assumes that any non-integer-ratio-based harmonies are approximations of the 'proper intonation'. It is a circular definition, when we say that a harmony is pure, all we are really saying is that other harmonies are not this. Historically this sufficed for numerically-driven systems where the tuning paradigm has long been in part defined by a battle between the "pure" just interval and the "impure" tempered approximation, but if we seek to reach beyond this historical precedent, we may find that this language limits us to these two frameworks, where others are possible.

Given how well established purity is as a synonym for just intonation today, it may seem a stretch to suggest that in tuning, purity is in the ear of the beholder, but if we look back to the crucial mid-nineteenth-century period in which 12-EDO was really beginning to gain traction as a singular standard in western Europe through education, we find evidence of just this. In 1832, renowned violin educator (and composer) Louis Spohr wrote: 'The teacher can indeed save himself a great trouble in the future if he insists with uncompromising strictness right from the outset on the absolutely pure intonation of the pupil's stopped notes'.[104] But here is the plot twist: 'By pure intonation is naturally meant that of equal temperament, since in modern music no other exists.'[105] In hindsight this reads as a strikingly transparent declaration of the intentions behind the standardisation of tuning. As Ross Duffin has pointed out, professional violinists of the time were not using a strict 12-EDO, but educators like Spohr would simply exorcise adaptive intonation from their

[102] Helen Hester, *Xenofeminism*, (Cambridge: Polity Press, 2018), p. 19.
[103] Dictionary.com
[104] Duffin, p. 94.
[105] Duffin, p. 95.

curriculum to make their own job easier. Spohr adds, 'The budding violinist needs to know only this one intonation. For this reason neither unequal temperament nor small and large semitones are mentioned in this method because both would serve only to confuse the doctrine of absolutely equal sizes of all 12 semitones.'[106]

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If nature need be referred to at all let it be the all that is possible, since all that is possible must be the past or potential result of those most foundational processes, the big bang and evolution. It would follow that the most "natural" pitch system is that which includes the entire continuum; for Ferruccio Busoni, 'Keyboard instruments, in particular, have so thoroughly schooled our ears that we are no longer capable of hearing anything else—incapable of hearing except through this impure medium. Yet Nature created an *infinite gradation—infinite!* '[107] Even this is unsatisfactory though, with its continued concern for purity and nature.

Instead, we require active strategies for escaping the container of fixed nature. 'We need new affordances of perception and action unblinkered by naturalised identities.' Taking this closing statement of the Xenofeminist Manifesto perhaps intentionally too literally, 'the desire to construct an alien future' and to proliferate new narratives could be met through the artistic production of alien worlds. In fiction, anything can happen that can be expressed in a given medium. To stoke the imagination then, in an attempt to free ourselves from the perpetual now, we can approach world-building through possibilities beyond the confines of natural law – to place our science fictions within fictional sciences. A classic example of this is described in Sun Ra's film *Space is the Place:*

> Equation-wise, the first thing to do is to consider time as officially ended. We work on the other side of time. We bring them here through either isotope teleportation, transmolecularisation, or, better still, teleport the whole planet here through music.[108]

Such natures can indeed have far 'richer geometr[ies] than the aisle, the assembly line, and the feed', which, again, it is tempting to take more literally than Laboria Cuboniks may have intended it, especially given the ground already broken in the expansive multi-dimensional geometries of Erv Wilson's tuning systems.

[106] Ibid.
[107] Busoni, p. 24.
[108] Sun Ra, *Space is the Place*, dir. John Coney, (1974).
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3.2 Fiction

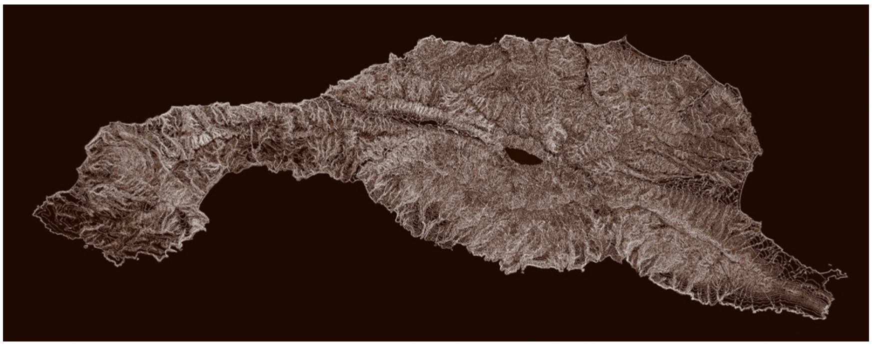
Lying, the telling of beautiful untrue things, is the proper aim of art.
***- Oscar Wilde,* The Decay of Lying**

In alternative universes, new equations can be written to govern acoustics. These equations might be mathematically rigorous or poetically nonsensical. New alien ears and brains can be designed with new frequency ranges and distributions, new ways of experiencing and relating to time and space, or otherwise new ways of reading the environment that might redefine the way music manifests, or if sound becomes to them an alien concept, some other form of sensory art is perceived. These new acoustics, new body parts, new technologies, and the social consequences that arise from them (*do they share our concepts of music and art?* If yes, *do they separate the audience and performers as we do?, Do they separate pitch and pulse as we do?,* and so on) can be composed for, from within the realm of the author. Even though we will never experience such works from the alien's perspective, we can do our best to simulate what they would experience, perhaps by audification, or simply allowing the results as they pan out in our universe to be the side of the work that is experienced here. At the concrete end of the scale, universes can resemble our own. Whole hyperplanes could be populated with histories, geographies and folklore, webs of musical styles and languages and how they relate to historical events, social movements and beliefs. At the abstract end of the scale, universes can bang and collapse in a moment, obeying geometries not approved by earthly cosmologists, they can be ever-shifting with surreal natures that change rapidly over time, or they can redefine or dispose of space and time entirely. The more abstract or different the nature gets, the more it may be difficult to convey with scientific precision, but since we are working in fiction, we can lean into this and allow the lack of sense to be a poetic feature, not a bug, as in the above *Space is the Place* quote, or in the sitcom *The Good Place*, where the nonlinear way that time functions is described simply as 'Jeremy Bearimy'. Already some project-specific possibilities have been hinted at. *What if there were ears that would perceive the pitch continuum not logarithmically but linearly?* This creature was my target audience when I used to claim that only the harmonics are universal. If we could project our way of listening onto them they would hear our harmonic series as if it were an equal division of the pitch space, and the fundamental would determine how wide that generating interval would be.

With common practice music theory's role recognised as forming the natural landscape that contains music, it might be unsurprising that creative music theory and creative world-building have a little history together, that is, beyond the ancient narratives of Pythagoreanism. Bebe and Louis Barron, tasked with scoring *Forbidden Planet* (1956), constructed what are widely considered the first circuits for generative synthesis (in the first fully electronic film score), this included composing from this new musical language, the ancient music of the Krell, an extinct advanced society found under the surface of the planet Altair IV. Eduard Artemyev used the highly microtonal (quasi-fluid-pitched) ANS synthesizer to score Tarkovsky's *Solaris* (1972). Generally futuristic and cosmic themes and titles are frequent in the works of microtonal artists Elaine Walker (a.k.a. ZIA), Kyle Gann, Dolores Catherino, Sevish, and plenty more. The system of frequencies known as Colundi, created by Grant Wilson-Claridge, comes with its own cult mythology of a sort, inspired by conspiracists' post-Tesla extrapolations about frequencies with magical abilities to heal the body, with Colundi itself seeming to take the form of a spirit, as its most renowned and prolific user Aleksi Perälä claims, 'For five years now, since I met colundi, I haven't made any music myself, I am merely a vessel for colundi. Colundi makes the music, it's like magic; all the ideas come from the other side.'[109] In 2015, Colundi users launched a crowdfunding campaign to release the album Colundi level 9 as a piece of land.

> Level 9 is to be released in the format of a part of our planet, an actual piece of land. A colundi Sanctuary. Embassy. Community. Example. Retreat. Festival, Hub etc. The third international hub could be in the South West of England, within or near to Cornwall, legendary home of King Arthur. The plan is for everyone to acquire such nodes on every "country" on Earth, so that they may be ultimately linked together and grow. colundi can encompass everything if we want it to, and vice versa.[110]

Figure 23 *Map of Anaphoria*



If it had been fulfilled, the land would have featured the tuning built into installations. The desire 'to acquire such nodes on every "country" on Earth' conjures up an imagined universality that I recognise from my harmonic series practice. Laboria Cuboniks offer a partially mended universalism – 'This non-absolute, generic universality must guard against the facile tendency of conflation with bloated, unmarked particulars—namely Eurocentric universalism—whereby the male is mistaken for the sexless, the white for raceless, the cis for the real, and so on'[111] – but in all of these cases the anti-Eurocentric universalism is formulated in the same old centre. I would prefer the Zapatista aphorism, generally credited to Subcommandant Marcos, which states: 'Our vision is a world in which many worlds fit, a world in which the only thing that is impossible is to dominate and oppress'. The likes of Terumi Narushima, Kraig Grady, and other such composers and theorists who might be called the followers of Erv Wilson, have built an online archive to document Wilson's teachings. This archive is situated on the fictional island of Anaphoria,[112] which is documented with maps, cultural customs and a list of government ministries (Ministry of Spirits and Ancestral Affairs, Ministry of Alphabetical Sequencing, Ministry of Deprogramming and Countercountercountercountercounter-Intelligence, and so on[113]). Colundi's fictionality remains undeclared, seemingly so that it is intentionally unclear whether it is a cult or a joke,[114] but Anaphoria addresses the question directly on its website:

> The most friendly and sympathetic have found Anaphoria a metaphorical place, even a metaphor for the world we call 'real'. This explains why it is too restless to entertain itself as a utopia.

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[109] 15 Questions Interview with Aleksi Perälä : https://15questions.net/interview/fifteen-questions-interview-aleksi-perala/page-1/
[110] https://www.kickstarter.com/projects/watmmofficial/the-colundi-sequence-level-9-colundi-everyone
[111] Laboria Cuboniks, p. 6.
[112] http://www.anaphoria.com/index.html
[113] http://www.anaphoria.com/offices.html
[114] The group's Bandcamp page declares: 'We fail to reliably express our precise thoughts and intentions using words. Consequently, you may fail to understand us. We apologise for the effects of such misunderstanding.' : https://colundi.bandcamp.com/

> The less sympathetic call it a fabrication, yet all borders and territories are man-made, and the overlay over geographical features should not distract us from their falsehood.
>
> Anaphoria is a fiction only to positioning itself to accommodate facts outside the conceit of prevailing philosophical assumptions. Anaphoria is a meta-culture domain, an island of exiles of the globally disintegrating remnants of what were once cultures, salvaged in what it sees as a natural demand.[115]

At once then it does not accept full fictionality, whilst using its ambiguity in this regard as a comment on violently imposed artificial borders. Nonetheless, it follows through on the metaphor to provide the image of a fully formed state, complete with a Hogwarts-esque mystic bureaucracy of ministries. Anaphoria embraces its contradictions in presenting a dream of non-violent borders, under the implied dominion of a 'Ministry of Barter, Trade, Equity, Immigration and Esotourism'. It emphasises that it is a land of 'expatriates':

> Known even to its inhabitants as the "Isle of Exiles" because it has so long been home and host to expatriates from all over the globe, Anaphoria's myths and history are replete with examples of heroes/heroines reappearing from distant lands in time to ward off perceived dangers - usually threats of foreign intervention. Researchers are often baffled to discover even inhabitants who have never been off the island referring to themselves as "foreigners".

Anaphoria especially is a manifestation of Xenharmony that emphasises the *xen* prefix as *foreign*, over its related meanings as *other* or *alien*.[116] It is framed as a refuge but explicitly not a utopia. Yet removing the implications of heavenly perfection from recent extrapolations of the meaning of *utopia*, such a refuge as does not exist in the world today seems to fit in the same image of utopia as I had echoed after Oscar Wilde, simply as a reimagined social system which exists on a positive horizon – in Wilde's words: 'A map of the world that does not include Utopia is not worth even glancing at, for it leaves out the one country at which Humanity is always landing. And when Humanity lands there, it looks out, and, seeing a better country, sets sail.' In the image of More's *Utopia*, both of these lands (Anaphoria and Colundi level 9) are positioned *along the surface of the earth*, in semi-fictions that semi-seriously throw esoteric poetry into the politics of nations, borders and land enclosure. Both invoke the image of the embassy as an outreach program bridging between their fiction and our reality. Both are imaginative ways to situate musical language in an extramusical context. But at my least charitable, I would argue both risk reproducing the problematic New Age orientalist, and that a future-minded project might, by contrast, situate its imagined worlds in the forward and outward realms.

Post-irony I would define as the state of fiction as possessing an indeterminate number of layers of irony, with that irony functioning as a shield rather than an arrow. For example, to create a hyper-marketised aesthetic, place it within an art context in which

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[115] http://www.anaphoria.com/about.html

[116] As an aside, the shared prefix with Xenofeminism is entirely coincidental, although we xenharmonicists could perhaps learn something from the way they use it, to mean *alien* or really *alienated*, although their unconventionally positive reconstruction of the idea of alienation remains a little under-explained, their alienation seems to hint at the possibility of a sort of technologically-enabled inauthenticity, as opposed to human attempts to be natural. This could be considered a form of positive alienation, reflected, for a musical example, in the trend towards hypertuning that we have seen since the beginning of digital music making.

rejection of marketing is expected to gain the aesthetic assumption of irony, and then sell the aesthetic creation back to the advertising industry wholesale. This "post-irony", in an era of internet-enabled rapid spread of ideas, poisons its ancestor, irony – which when placed online has no typeface, no clear signifier, and so can be used carelessly, or intentionally to obscure dangerous currents. This time around, fascism has reprised in the form of – not in spite of – the ironic. And so where we use fiction, let us declare it explicitly.

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As in the big bang, creation stories mark the founding moments at which nature's confines are defined. Many of our existing creation stories, like those situated in the Garden of Eden or the Hobbesian state of nature, take this opportunity to set out clear boundaries between humanity and nature. The anti-naturalist instead might prefer a nature with no confines. Happily, such a nature exists – it is called fiction. Of course this sounds like escapism, and if fiction were suggested as a response to material needs, it would be. But the vector of escapism points outwards; moving from reality to either fiction or music is an outward move of escapism, but moving from music to fiction is arguably in the opposite direction. It is a move from the abstract to the narrative, in order to be able to play around with reality. This possibility of playing with reality may be just what is required for a future-minded project. Mark Fisher describes Capitalist Realism as a form of 'consciousness deflation',[117] I would consider the same for all other interrelated elements of the perpetual now, including nature. The Neoliberal project, he posits, was designed with the aim of crushing what he categorises as three forms of consciousness which were expanding in the sixties and seventies – class consciousness, psychedelic consciousness, and group consciousness. It is 'psychedelic consciousness' (which, though accelerated by the Beatnik LSD culture of the time, 'expanded far beyond those who were actually using the drug') that is most shaped by the arts. Fisher points to the unprecedented celebrity of The Beatles: 'so you've got a popular modernist culture with something like The Beatles who basically trained people to expect things to get more and more experimental the more popular they got, [...] And what they mainstreamed was this psychedelic consciousness, with its key notion of the plasticity of reality, the exact opposite of what I was talking about at the start, that things are fixed, they're permanent, they can't change, reality is just something we have to adjust ourselves to.'[118]

This consciousness was also built on space age dreams, the belief that the space race would not simply be the brief historical episode culminating in the expeditions of Gagarin and Armstrong, but the start of a whole new interplanetary age. In such a time, science fiction presented ideas which held enormous power over culture. A decade ago this dream was apparently forgotten but in recent years we have seen the founding of Trump's "Space Force" and the extraordinarily successful PR around the privatisation of space travel – indeed, we have seen perhaps the most effective work of science fiction of all time, the spinning of fictional sciences and fictional technologies into a speculative investment bubble propelling Elon Musk to becoming the richest person on Earth.[119] And in a pincer motion seemingly by extension of that same PR team, the 2010s' rise of aestheticised post-irony has permitted the dystopian aesthetics of Grimes, in association with the eventually barely released video game *Cyberpunk 2077*, to lay the conditions for a transition from the state

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[117] Mark Fisher, "From Upper Crust to FOMO", talk given at CCI Collective's *All of this is Temporary,* (2016) : https://youtu.be/deZgzwOYHQI
[118] Ibid.
[119] "Elon Musk becomes world's richest person as wealth tops $185bn" in *BBC News*, (2021) : https://www.bbc.com/news/technology-55578403
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of fiction where dystopia functions as warning (with *Black Mirror* taking a stranglehold on sci-fi, leaving us with no image of the future but of one with more of the worst elements of now: more alienation, more surveillance, more social competition, bigger monopolies, and so on), to swiftly in the last few years replacing the negative warning with the amoral aesthetic, the fiction with the real, a (Nick) Landian nightmare of right-libertarian blockchain-saviourism, Mars colonisation, and robocops. Capital requires a fictional future to nourish today's investors with its assumption of perpetual growth tomorrow. Atomising individualism has been enough to distract from the lack of such a future since the eighties, but it may not sustain the illusion indefinitely in the midst of ecological collapse. Today the perpetual now is a grotesque blister ripe for bursting, but like with the fascist turn of the Italian futurists of yestercentury, that potential risks being hijacked by an anti-change futurism which marries cyber-dystopian aesthetics with the full force of capital, made possible by the same force of accelerationist post-ironic detachment that led the darlings of hypnogogic pop to Washington DC in time for January's coup attempt.[120] This contemporary current, like Italian futurism before it, holds new technologies to the same false assumption of being inherently good as we have tended to hold nature, and uses those those new technologies in defence of the "natural" order. It is partially in response to this tendency that I assert the urgency of positive future-minded fictions that treat the boundaries of nature as malleable.

3.3 Mapping

> ***Tortoise:*** *Why did you not have to turn the dials at all, the first time we saw a subjunctive instant replay?*
> ***Crab:*** *Oh, that was because I was tuned in to a channel which is very near to the Reality Channel, but ever so slightly off. So every once in a while, it deviates from reality. It's nearly impossible to tune EXACTLY into the Reality Channel. But that's all right, because it's so dull. All their instant replays are straight! Can you imagine? What a bore!*
> ***Sloth:*** *I find the whole idea of Subjunc-TV's one giant bore. But perhaps I could change my mind, if I had some evidence that your machine here could handle an INTERESTING counterfactual. For example, how would that last play have looked if addition were not commutative?*
> ***Crab:*** *Oh me, oh my! That change is a little too radical, I'm afraid, for this model. I unfortunately don't have a Superjunc-TV, which is the top of the line. Superjunc-TV's can handle ANYTHING you throw at them.*
> ***Sloth:*** *Bah!*
> ***Crab:*** *But look - I can do ALMOST as well. Wouldn't you like to see how the last play would have happened if 13 were not a prime number?*
>
> ***- Douglas Hofstadter,*** **Gödel, Escher, Bach**

Given the desire to present Anaphoria as a metaphor rather than fiction, it may be helpful to explore the distinction. A metaphor is in some sense an analogy (A is like B) minus the separation for poetic effect (A is B). The minus is implied by it being a metaphor, so it could also be read as: *A is B but it isn't really*. Fiction is not so easy to distil. A fiction can be a story, a world, or a statement of untruth. Stories unfold linearly. Worlds unfold expansively. Untruths are simple Boolean results.

[120] David Renshaw, "Ariel Pink and John Maus spotted during D.C. Trump riot" in *Fader*, (2021) : https://www.thefader.com/2021/01/07/ariel-pink-john-maus-trump-capitol-building

Douglas Hofstadter describes *Contrafactus*, the dialogue quoted above, as being 'About how we unconsciously organize our thoughts so that we can imagine hypothetical variants on the real world all the time.' In it he builds a world in demonstration of the counterfactual, that is, the subjunctive or hauntological – that which could have happened but did not.[121] But really this is not the whole image of the counterfactual, since it is not necessarily restricted to a growing-block model of time. Time is a confusing place-holder here because of the possibilities offered by quantum many-worlds interpretation. Hofstadter's Subjunc-TV scans through an array of other possible pasts but is there any practical distinction here between histories and realities? If Subjunc-TV were replaced with the idea of multiversal broadcast, the outcome would be the same. That is unless our imagined worlds become recursive so that we must discuss worlds imagined with imagined worlds, which might reconfigure dimensions in such a way that history becomes meaningless.

Hofstadter's work deals in creative analogy making, which he claims to be the primary tool in the functioning of cognition.[122] Analogy is the tool that enables comparisons of all kinds, it can define relations between ideas as similar, connected or proportional, it is the basis of translation, whether by dictionary (linguistic) or pentagraph (geometric), it can construct categories, and webs of ideas which form words by extending and evolving existing metaphors. *Harmony* comes from the root *harmos,* meaning (shoulder) *joint* or *fitted together*, theoretically traced back to the Proto-Indo-European *ar* (to fit together), a shared etymological ancestor with arithmetic, rhyme, army and aristocracy all of which are analogous only really in that they share the idea of fitting together – with analogies, too, being expressions of fitting together or relatedness.[123] Harmony in its current form is used to mean the juxtaposition of pitches, the peacefulness or fluctuating sense of social cohesion within a group (to be *in tune* with each other is to share complimentary world-views), as well as forming the basis of other such metaphorical extensions as in a Pythagorean Harmony of the Spheres. Whilst the harmonic-astronomical models of Pythagoras and Kepler after him have scientifically expired, they have since evolved into orbital resonance (scientifically in-date) which observes, for instance, that three of Jupiter's Galilean moons synchronously orbit almost perfectly in a 1:2:4 ratio of periods, as a result of their gravitational pull on each other. This obeys the same model for synchronous motion as the sympathetic resonance of a zither. Here, resonance is not only a linguistic web of metaphors which share the property of periodic self-reinforcement, but a scientifically modellable idea in that these analogous scenarios share a set of equations.

Mappings are analogies which imply two variable parameters are related. Constructing such mappings between "nature" and music has been an aim for musicians since long before the Platonic coining of "mimesis". The appeal to nature and maths to justify tuning systems, discussed earlier in this chapter, is an example of this prevalent today. Along with these, we will also see how mapping is done in sonification, audification, and science

[121] Note that whether or not we accept the subjunctive past possibilities, and future possibilities as a part of nature has considerable implications for the perpetual now. If nature is defined by the growing-block concept of time, then nature excludes the way the world *could be* in favour of the way the world *is*, and so is inherently opposed to change.

[122] Douglas Hofstadter and Emmanuel Sander, *Surfaces and Essences: Analogy as the Fuel and Fire of Thinking* (Basic Books, New York: 2013)

[123] The American Heritage Dictionary Indo-European Roots Appendix : https://www.ahdictionary.com/word/indoeurop.html

fiction music – by which I mean music shaped by its context within an imagined world. It will become apparent that mappings are fictions of a kind too – fictions which exist to serve narrative functions.

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Sonification[124], applied to creative composition, gets an understandably bad rap. Generally, what is involved is the mapping of one or more dimension of data to one or more musical parameter. Frequently, its proponents express their findings (or have them expressed by click-hungry media outlets) as the "sound of…" some natural phenomenon. For example, a 2017 interview with Mark Ballora in *Science* has the headline: 'Meet the scientist who turns data into music – and listen to the sound of the neutron star'.[125] The issue with this is that the neutron star does not make a sound as we can detect, what Ballora does is simply take the numbers from measurements of neutron stars, rescale them arbitrarily, and map them to unrelated synthesis parameters. Asked how he decides 'the type of sound to use for a specific data set', Ballora explains: 'When I was working with solar wind, I created a shifting shimmery sound. For tropical storms, I needed a swirling noise that would sound like a tornado.' The method then is to start from thinking what it should sound like in order to match the listener's pre-conceived ideas, construct a musical system that will create that result no matter what data you plug in, and then plug the data in. Composers import wholesale a reference to some source of scientistic wonder – and map it to a set of 12-EDO pitches with which we have a socially trained relation to the intended emotion (major = happy; minor = sad), to elicit a: *wow, isn't nature/science/maths beautiful?* In short, the issue is that there is no meaningful rigour to the process of sonification, and so it instead becomes a way to tell the subjective story they wanted to tell, but with an inflated air of scientific authority.

When a physical phenomenon is sonified, it meets many of these issues of arbitrary parameter scaling, but how about pure mathematical structures? In the justification of the 432Hz conspiracy (the advocacy for a tuning reference standard of A = 432Hz rather than 440Hz on the basis that 432Hz possesses magical healing qualities that we are intentionally kept from by nefarious interests who wish to contaminate us into social disharmony) proponents have pointed to multiple properties that show 432 is a special number which deserves a mystical Pythagorean-esque elevation: including it being the sum of four consecutive primes, a multiple of 144 (which is a round number, being 12^2), and that its square root is the area of an equilateral triangle with its perimeter equal to its area. The problem is that Hertz is a measure of cycles per second, and the second is an entirely human unit derived from divisions of a day, which is not a universal unit but one specific to the current rotational period of Earth. The neglect of units is frequent in the sonification of data.

A more rigorous approach might be to map only across units that share the same physical reference. For example, beats per minute (BPM) and cycles per second (CPS, or its equivalent, Hz). This mapping is core to many of my systems. BPM, as a measure of tempo is concerned with musical events and implied rhythmic feel, whereas CPS is concerned with the periodicity of a waveform – these are quite different events, but they share a single physical reference unit, the earth day. In this case, the two measurements are usually applied

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[124] Sonification is the interpretative translation of extra-musical data into sound.

[125] Giorgia Guglielmi, "Meet the scientist who turns data into music – and listen to the sound of the neutron star" in *Science*, (2017) : https://www.sciencemag.org/news/2017/07/meet-scientist-who-turns-data-music-and-listen-sound-neutron-star
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on very different time scales, but when this is breached more connections can be observed. For example, Extratone is a style of hardcore techno that takes the tempo up to around 1000 BPM and above; converting this to beats per second (BPS), it deals in tempos of 16.7 BPS and above, up into the audible spectrum. At this point, the distinction between Hz and BPS begins to breakdown: it becomes clear that whilst 'cycles' are simplified in acoustic models to refer to sinusoidal peaks and troughs, it is equally applicable to any periodic waveform, including that of a looping drum sample, and so beats and cycles become one. At the other end of the time scale, that of typical musical tempo, say 120 beats per minute, a pulse wave of 120 cycles per minute would also be an accurate description of a one-beat-long loop of a short clicking sound.

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Analogies formalised as A : B :: C : D (A is to B what C is to D) resemble ratios as commonly used to describe justly tuned intervals. In practice they function in a similar way: given a fundamental of 100Hz, the interval 5:4 (a just major third) is, in a sense, shorthand for "5 is to 4 what 500Hz is to 400Hz". Note here that the added clause 'given a fundamental of 100Hz', is also establishing a ratio, 1:100Hz, a scaling factor which could in its full context be shorthand for the analogy "1 is 100Hz what 4 is 400Hz and 5 is to 500Hz". And so the harmonic ratio 500Hz:400Hz is, in usual discussions of tuning practice, broken down into two dimensions – *proportion* (5:4) and *scale* (1:100hz). Note that the units are defined in *scale* only – the separation of proportion from the question of what it's measuring is a decision which paves the way for extrapolation (extrapolations themselves forms of analogies) to many other forms of proportion. A tuning system consists of more than one interval, and so, whilst scale comes to be a one dimensional ratio, proportion can encompass a multi-dimensional web of relationships between multiple nodes. More information is therefore contained in proportion, creating a cognitive hierarchy of proportion over scale, which is clear in the example of a street-map. A map is incomplete without a scale factor, conventionally written as a ratio (for example, all Ordnance Survey 'Explorer Maps' use a scale of 1:25000)[126]. Without this, the proportional representation of a city cannot represent all of the information needed to navigate. Yet we tend not to need to look at this scale because we have looked at maps and moved around cities throughout our lives, and so we have a learned idea of what that scale is likely to be, even if we can't intuitively put a number on it. Viewing the map as a miniature parallel world, the proportion is everything that is diegetic to the miniature world, whilst the scale is the relationship between the real world and the world inside the map.

The Harmony of the Spheres – when interpreted as an analogy of proportion between the ratios of frequencies of the vibrating strings of a lyre and the frequencies of the orbits of celestial bodies – is a foundational example of this parametric hierarchy, just as with the map and the just intonation theories, the analogy is drawn with a silent scale ratio, that ratio between the frequency of the pitch fundamental and the frequency of the orbit of the reference planet. Pythagoreanism lives on as the cult of the absolute importance of proportion. Given that "perfect pitch" (absolute pitch memory) is relatively rare, whilst all who can hear, can hear "relative pitch" (comparative pitch memory), it should be no surprise that we have tended towards this spirit in tuning theory. However, there are many ways that can we can extend the *scale : proportion* analogy in music, since music is made up of frequency references and related proportions on multiple time scales. We can formulate these as:

[126] https://getoutside.ordnancesurvey.co.uk/guides/understanding-map-scales/
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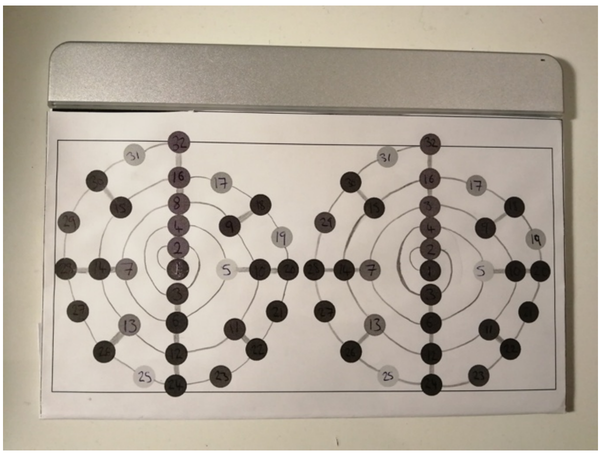
Rhythm	:	Tempo	::	Proportion	:	Scale
Modulation	:	Key	::	Proportion	:	Scale
Harmony	:	Pitch	::	Proportion	:	Scale
Timbre	:	Pitch	::	Proportion	:	Scale

This draws attention to other perhaps underexplored relationships. Especially, given that they analogously share a relationship to pitch: *what is the relationship between harmony and timbre?* Timbre, understood through the model of Fourier analysis, is the vertical arrangement of audio-rate frequencies; harmony too is the vertical arrangement of audio-rate frequencies. The missing distinctions in this statement are that, for timbre, the frequency arrangement strictly follows the harmonic series (with inharmonic variance in real world acoustic scenarios), and for our conventional understanding of harmony, "frequencies" are really "notes", which tend to have overtones of their own. To make artistic use of breaking down these distinctions then, we could begin by tuning our keyboard to the harmonic series (using variations on Erv Wilson's spiral design) as I had done for a couple of years, and then use only sine waves to remove the distinction between frequency and "note". Here we have reduced harmony and timbre to their lowest common denominators and then combined them. Rather than reducing the "note" back down to a simple sine tone, we could instead take direct control of the overtones by implementing additive synthesis – timbre determined by the vertical arrangement of sine waves, simply reversing the Fourier model. Using the harmonic series as a tuning and additive synthesis as a timbral framework, we are playing with the harmonics of the harmonics, a recursive system. At first, this additive synthesis was controlled through a mixer-like interface of sliders and knobs, typical of additive synthesis. I found that adjusting these overtones individually meant only ever slowly changing timbres, and so I soon changed approach, opting to define four presets of frequency distributions and their different amplitudes, as well as positioning those overtones in a quadraphonic space, with each preset then placed in each corner of a two-dimensional parameter space, a joystick could then be used to morph quickly between different states. This is the form taken by the Polyharm. This does provide a much more performable instrument, but as it continues to follow the convention that a keyboard should be used to control harmony, whilst the joysticks control timbre, there is still a clear parametric hierarchy which it could be interesting to further deconstruct.

The solution would be to control harmony and timbre alike with keyboards. Since the relationship of note to overtone is one of multiplication (which is commutative[127]), and both hands are dealing in the same set of integers, really there is no functional difference between the two – the hierarchy has dissolved such that either hand can play either function, even thinking of those functions as separate is just one model for how this instrument could be played. On such an instrument – which I have named the *Recursive Harmonic Organ* – this multiplicational relationship is extended out

Figure 24 *Recursive Harmonic Organ*



[127] Commutative meaning for example that 3×2 = 2×3.

into polyphony such that each of the integers pressed by the left hand are multiplied by each of the integers pressed by the right hand. Given 'the tyranny of the five-fingered hand',[128] this means a maximum of 25 frequencies result, to be understood as a matrix (fig. 1). Additive synthesis and expressive polyphonic touch-keyboard playing (as with MPE) alike do not set the amplitudes of their frequencies as simply on or off, but as continuously variable. Therefore, the amplitudes of each of these (up to) 25 frequencies are to be determined by the touch pressure from each side of the sum also multiplied together so that neither hand has sole command of the envelope of a gesture. See video example 4 for a demonstration.

Figure 25 *a snapshot example of the resulting frequencies and their matching amplitudes when three keys are played with the left hand and four with the right hand. The frequencies are written as harmonics of a common fundamental, and the amplitudes have the continuous range [0,1]*

FREQUENCIES

		RIGHT HAND			
		5	**13**	**18**	**31**
LEFT HAND	**1**	5	13	18	31
	3	15	39	54	93
	7	35	91	126	217

AMPLITUDES

		RIGHT HAND			
		0.7	**0.5**	**0.1**	**0.9**
LEFT HAND	**0.9**	0.63	0.45	0.09	0.81
	0.4	0.28	0.2	0.04	0.36
	0.3	0.21	0.15	0.03	0.27

This is a two-dimensional frequency system in that giving only one position will not define a frequency, the frequency is a function of the left and right hand positions together. Or A future extension of this concept could include exploring different binary operations beyond multiplication, not only standard mathematical ones like addition or indices, but also each key could produce a tone and the binary operation could be one from the realm of electronic music: ring modulation, frequency modulation, convolution, or just plain mixing. Extending this further, there could be more than two input keyboards, there could be a whole schematic flowchart of operations. This is getting further from the initial premise but with multiple touch keyboards and multiple performers, each with different binary or even more complex operations, this could be the basis for a form of modular environment – a multidimensional frequency system that requires the inputs of several performers to produce a tone. Indeed, why restrict ourselves to the integers that give us the harmonics? Different keyboards could be used to give different numerical sets as inputs to these functions. For now, though, these more complex possibilities are only future plans since they would require several polyphonic pressure-sensitive keyboards, which would be an extravagance for now, since I am yet to find as much musicality in the initial simple form as I hope it may offer over a longer period of exploration.

Returning to the open ended question '*what is the relationship between harmony and timbre?'* as a prompt for frequency system design, we have already offered some solutions: to derive tuning from timbre (by using the harmonics as a scale), or to neutralise the distinction between harmony and timbre (as in the Recursive Harmonic Organ). One extension of the first of these would be to include the modelling of inharmonicity extended into the harmonics as a scale, so that moving up the octave equivalence lines of the spiral keyboard would not give an octave but something a little – or drastically – flatter or sharper. Alternative takes on deriving inharmonic tunings from inharmonic timbres have been done

[128] Partch, p. 423

through spectral analysis of recordings of bells and the like by Wendy Carlos[129] and some spectralist composers, as well as being the basis for extensive theoretical developments by William Sethares, including the development of the Hyperpiano, an instrument built in the frame of a piano that uses strings of thicknesses that vary along their length in order to achieve especially inharmonic timbres, and then tunes the strings of the Hyperpiano according to what would be harmonic for these strings.[130] Indeed, Scott Wilkinson suggests that this adaptation of tunings to inharmonic timbres was happening even prior to the development of tools for accurate spectral analysis, with gamelan instruments being mainly inharmonic metallophones, these inharmonicities influenced the intervals found in each slendro or pelog – this would be another non-electronic example of technology-driven approaches to tuning.[131]

A further outcome of the attempt to blur or cross-pollinate harmony and timbre is the symbiosis of MPE and spectral analysis. When playing an MPE instrument like the octave ribbon controller on the Morph, our hands can produce gestures of (high-resolution quasi-) continuous pitch and amplitude information. When we use a tool such as SPEAR to perform spectral analysis, we are also attaining (high-resolution quasi-)continuous pitch and amplitude information. Even though they are recording very different physical occurrences – tactile gesture and sound – the analogy from the data collected is uncanny. The implications of this are, firstly, that spectral analysis data could be converted to MPE in order that it could be resynthesized not simply as sine waves but with any other kind of synthesis engine. MPE protocol today has space for only 15 voices of polyphony, and so this would not be a high fidelity resynthesis of the sound but perhaps, with MIDI 2.0 protocol all agreed and expected to come into common use in the next few years, there may be many more voices available in the future. Which brings us to the second implied possibility, that MPE data could be treated like a sound file, that is, it can be used with time-based effects such as echoes and granular processing, as well as the ability to modulate the amplitude and frequency. My design for a Granular MPE Looper must balance the number of possible overlapping grains with the number of voices of polyphony that should be available to record; for example, if you play with 5 voices of polyphony, you get up to 3 overlapping grains, and that would be even less if you want the ability to overdub, but again perhaps MIDI 2.0 will bring the potential for lots more. For now, implementations with more voices and more grains can be simulated outside of a MIDI environment. The Granular MPE Looper makes use of MPE's ability to control the amplitudes of each voice separately to enable each grain to have an envelope as is typical in the audio domain. It could also granularize multiple dimensions of control changes for parameters outside of plain old frequency and amplitude. The purpose is that we might want the textures that result from the rhythmic layered enveloping of granular synthesis whilst controlling a synthesizer rather than playing back a sample. It also doubles up as what I described in chapter 2 as a *sustain cheat* – a way to get a musical use out from the nuances of your own physical gestures in music when your chops aren't great, and/or you want to control other things with your hands some of the time, like knob twiddling, playing a second instrument, or layering loops from the same instrument. Audio example 13 demonstrates an early prototype in which two looping grains with changing envelopes chop up a gesture on the multi-ribbon keyboard.

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[129] Scott Wilkinson, pp. 49-51.
[130] Kevin Hobby, William Sethares and Zhenyu Zhang, *Using Inharmonic Strings in Musical Instruments*, (2017)
[131] Ibid.

This closer relationship of harmony and timbre also invites the realisation that our classic synthesis algorithms (such as subtractive, additive, frequency modulation, and west-coast) in their basic forms are monophonic, with polyphony as an afterthought achieved by having multiple voices mixed at the end of the signal chain. We don't tend to apply harmony earlier in the algorithm than what we think of as the end of the synthesis process. Rethinking this framework could start with a shift of perspective on existing synthesis systems. John Chowning (or Yamaha DX7)-style frequency modulation synthesis could be framed as a network of harmonic ratios applied to the tuning of an audio-rate fluid pitch gesture, and the supersaw as a microtonal cluster chord. Building on this we can hack tuning ideas into existing synthesis procedures in other ways. Harmony is far more than the stacking of multiple discrete pitches, it is the ongoing interaction between those pitches – the phase relationship, the beatings, and so on. Though usually relegated to psychoacoustic afterthoughts by the logic of the stave, these effects can provide a wider palette of sounds if considered earlier in a signal chain. Audio example 14 shows an alternative take on west coast synthesis.[132] Just as the psychoacoustic effects of harmony might seem to come alive when placed in the reverberations of a real space or simulated reverb, wavefolding and distortion do likewise in a less "natural"-sounding way, although as we are used to the sounds of distorted and feedbacking guitars it ends up sounding perhaps more "real" than the initial sine wave instrument. As electric guitarists tend to find out, since distortions amplify upper harmonics, chords that go beyond the simplest integer ratios, power chords (5ths), into "jazzy" 7ths, 9ths, 11ths or 13ths will create a very "muddy" sound from all of the interacting harmonics. We get not only a brightened timbre but an exaggeration of dissonance. The system proposed is really no different from running a synthesizer or guitar through a distortion pedal, except in the use of sine waves or even simple additive functions, along with the ability to play fluidly with the tuning in real time – but the alternative mindset it lays out is the invitation to play certain harmonies not because of their tonal functions but because of their timbral effects, to be found in the way they interact with the distortion. Minor variations on common synthesis methods like this are potentially only an initial step towards more novel synthesis methods that involve consideration of harmony from the start.

The LYRA-8 is just such an instrument, as it takes eight manually tunable oscillators, wavefolds them together in pairs, and then routes these pairs into other pairs to cross-frequency-modulate them, before processing the results through delay and distortion. The architecture of the synthesizer allows different oscillators to interact with each other in different stages relating nodes in subsets of 2, 4 and 8, it treats each oscillator as a node in a reconfigurable network rather than a parallel array of independent voices. And so harmonies are played by the performer, but when cross-frequency-modulating they do not unfold in the clear parallel way that we are used to, but rather as if the device has a mind of its own. The LYRA-8 is described by its makers as an 'organismic synthesizer', as Vlad Kreimer would relate its architecture to the complex behaviours of insects who even with relatively few neurons, far surpass the complexity possible in digitally implemented neural networks because the neurons communicate in analogue states. The result of an analogue network of cross-modulation is, according to its manual, 'a bizarre animal that twists and turns under your fingers, rather than a precise mechanism.'[133]

The symbiosis of harmony and timbre is one of many possibilities for remapping certain musical parameters to other musical parameters. When these parameters are

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[132] West-coast synthesis being the method developed by Don Buchla, in which you begin with a dull sine tone and wavefold (or distort) it into a brighter tone.
[133] Vlad Kreimer, *LYRA-8 User Manual v 2.0*, (2020) : https://somasynths.com/lyra8_specs/

understood through the framework of proportion, the proportions found in one domain can be translated to different time-scales – a 3:2 polyrhythm sped up to audio rates (that is, temporally rescaled) is heard as a 3:2 harmony, a justly tuned perfect fifth. Few have been so captivated with this proportional approach than Henry Cowell. In *New Musical Resources*, Cowell argues that the history of musical innovation has been a history of moving up the harmonic series (first the fifth battled to become accepted, then the third and so on up to the point where the 15th harmonic giving the major seventh chord and the 15:16 semitone, had been accepted as valid harmonic material), and that a modern music would embrace the harmonic series at the core of every domain, not only harmony.[134] Therefore, of rhythm, he lamented that 'we have limited ourselves to [rhythms divided in] half notes, quarters, eighths, and further division by halves, but we do not divide by thirds, fifths, sevenths or ninths and we have no means of notating such divisions.'[135] To meet this lack, he invented two tools: a system of notating "third notes", "fifth notes" and so on using different shaped noteheads on an otherwise conventional stave, and the Rhythmicon, an early electronic instrument commissioned from Léon Theremin in 1930. The Rhythmicon uses a Halberstadt keyboard on which each key plays not a pitch, but a steady pulse, so that, for example, playing the fifth, C and G, and would produce a 3:2 polyrhythm. The proportional analog in harmony would have been a just intonation scale.

In Cowell's 1936 work *String Quartet no. 4 "United Quartet"*, which he describes as executing 'the unity of form, rhythm and melody', takes the simple stress pattern - - ˘ - ˘ and from it derives material at every parametric level. As Stephanie Stallings explains:

> On the macro-level, it represents the overall stress pattern of the five movements, based on overall dynamic level of each movement (loud, loud, soft, loud, soft) and the corresponding ground tones for each (C, C, G, C, G).
>
> On a smaller level, the pattern is evident within the individual form of each movement. It is the most obvious in the first movement, which exhibits the form A A B A B. As well as in formal sections, the pattern appears in the corresponding dynamic markings for each phrase: *ff, ff, f, ff, f* in the A section, and *p, p, pp, p, pp* in the B section. Each measure also contains the stress pattern in the form of actual accents.[136]

Figure 26 *analogy for the development of the stave*

Cowell described the *United Quartet* as 'an attempt toward a more universal musical style'.[137]

This notion of the unity of a musical system, in which one source would be mapped to every parameter, entered western music with Ruth Crawford Seeger in the early 1930s,[138] and entered into common Serialist practices in the 1940s. The Seegers extended by analogy the notion of harmonic dissonance to include 'dissonant rhythm',

[134] Henry Cowell, *New Musical Resources*, (Cambridge: Cambridge University Press, 1996)
[135] Stephanie Stallings, *"New Growth From New Soil": Henry Cowell's application and advocacy of modern musical values,* (Tallahassee: Florida State University, 2005), p. 15.
[136] Stallings, pp. 37-38.
[137] Ibid.
[138] Evident in *String Quartet* (1931).

'dissonant dynamics', and 'dissonant accents'.[139] In the use of analogies to redraw connections between long lost relatives such as harmony and rhythm, what these early modernists were coming up against was the patchwork logic of the stave, with its rigid parameterisation of music. What had happened over the history of the development of the stave was that each element as potentially codified in score – structure, tempo, rhythm, metre, tuning, pitch, harmony, timbre, dynamics, envelope, spatiality – all with complex relationships to one another, entered the domain of composition more or less one by one, with the result that each was forced to take on a logic entirely perpendicular to what was already there, in order not to confuse the reading of the systems that were already a part of the code. What results today is the outcome of a millennium of attempted backwards compatibility. Given this patchwork nature then, many continue to see the benefits of this established code precisely on the merits of its modularity. Score-based practices – from the simplicity of Dolores Catherino's colour-coded Polychromaticism, to the complexity in the artistic embrace and extension of the chaos of extreme parameterisation in avant-garde concert music especially since the eighties – continue to tack new parameters onto this existing code perpendicularly with a good deal of success.

Just intonation theories, with their emphasis on proportion, lend themselves to the pursuit of music from a single system, not only in that the same proportions could be rescaled to appear at every time-scale and otherwise translated to every frequency-related parameter, but also in that every time-scale could be encompassed within a single system by all sharing a fundamental whilst covering not only the audible frequency range, but all the way down to the sorts of durations that would make for an entire piece of music. In *2048*, Sóley Sigurjónsdóttir's work for wave field synthesis system, the harmonics are treated as just such a system stretching to every scale at once. '*2048* is a fixed media piece based on a mathematical system that deals with ratios and the relationship between frequencies and pulses. The system is applied to all factors used; time, space, the spectral content and the pulse. It is an exploration on sound perception and psychoacoustics.' The piece lasts 2048 seconds and consists of pulses of noise periodic at 2Hz, 4Hz, 6Hz, 8Hz and so on up to 64Hz (that is, a harmonic series from 1-32 crossing from what humans perceive as pulse to pitch). For each of these voices, 1-32, the 2048 second timeline is divided into as many segments as its voice number, and then flips from on to off or back at the start of each segment so that voice 1, at 2Hz, is heard the whole time, whilst voice 8, at 16Hz, is intermittently silent in chunks of 2048 ÷ 8 = 256 seconds. Whilst there are still some different levels going on then, each of the frequencies used on the level of macro and micro-structure and in the pulses/pitches themselves, could all be called harmonics of the fundamental that is the length of the piece, $1 \div 2048 = 2^{-11} \approx 0.000488...$Hz. These proportions are also brought into the filtering and spatialisation of the pulses, for example the bandwidth of the filter processing the 32nd voice (pulsing at 64Hz) covers $\frac{1}{32}$ of the audible spectrum. In 2048, the system is unified as a single system that spans across every frequency scale at once without respect for the usual division of parameters that have been constructed in musicology as a result of the combined limitations of the human ear and the stave.

Parameters may be seen as filters through which music is comprehended, as well as modelled in the scientific sense of isolating variables in order to systematise the workings with axioms and formulae. In the examples from the Recursive Harmonic Organ, to the Rhythmicon, to *2048*, we have seen have the harmonics relied upon to provide a

[139] Judith Tick, *Ruth Crawford Seeger: A composer's search for American music*, (New York, Oxford University Press, 1997), p. 203

reunification of these arguably over-isolated elements, and indeed much of my work in the Infinitely Compact Scale does likewise with just intonation systems as we shall see in **3.4**. And this is perhaps the constructive and forward-looking response to such an atomisation. However, this question also seems to offer an additional compositional directive – what I am calling a cross-parametric detournement of common practice music theory. Towards this aim, musicians could return to common practice music theory but jumble up its mappings. This idea began with recognition of somewhat of an oversight in how the Rhythmicon is interpreted today into a scale variable demonstration of the relationship between polyrhythm and harmony, a 3:2 polyrhythm is played and then sped until it is heard as a perfect fifth.[140] Presented in this way, as might also be interpreted from the simple Halberstadt presentation of the original Rhythmicon, what is missing from such a lesson is that the perfect fifth on our keyboard is not 3:2 but a 12-EDO approximation a couple of cents flatter. And so rather than take this as yet another reason to adopt just intonation so that our harmonies would match our polyrhythms, we could instead match the polyrhythms to the harmony; hence my first exercise in the *cross-parametric detournement of common practice music theory* was to make a 12-EDO Rhythmicon. Three audio examples are provided, demonstrating: a fifth (audio example 15), a major third (audio example 16), and a minor third (audio example 17). The 12-EDO fifth at audio rate sounds very similar to the justly tuned fifth with the addition of a slow beating effect that might easily be mistaken for a periodic timbral modulation, but slowed down to a rhythmic relationship, the "out-of-tune" nature of the 12-EDO fifth is heard very clearly as a phasing effect where the two patterns drift out of and then eventually back into phase, reminiscent of Steve Reich's tape works. The more "out-of-tune" a 12-EDO pitch is in comparison to simple just intervals of similar size, the faster it will complete such a phase shift. Creating such an instrument is very simple, since it can be achieved by taking the algorithm for a standard polyphonic 12-EDO synthesizer with pulse or sawtooth wave oscillators and shifting it down a large number of octaves. Rather than the click that this would produce, samples could also be looped in the same ratios for more varied artistic exploration of this system.

A second exercise along the same lines is to work with what we might call metric tonality – that is the mapping of the rhythmic durations used in a piece of music to frequencies. Again it would serve to point what might be considered a shortcoming of common practice, here, that as Cowell has pointed out we have limited ourselves to rhythms that, built as they are of halves, quarters and eighths, and sometimes tied combinations of these, are restricted to very simple ratios, almost always with a denominator of the form 2^n. By bringing such simple ratios into harmony, the simplicity to which the conventional use of the stave confines rhythm is brought to the foreground. A third exercise would be dynamic-marking pitch. In such a system, the vague loudness zones of pianissimo, piano, mezzopiano, mezzoforte, forte, fortissimo, and so on, would be mapped to pitch to give a pitch set of the vague pitch zones ..., ***lll, ll, l, ml, mh, h, hh, hhh,...*** (lowlowlow, lowlow, low, mezzolow, mezzohigh, high, highhigh, highhighhigh). In this case, we are mapping across two domains, frequency and amplitude, which do not share a unit or physical reference to a natural phenomenon and so there is no clean proportional analogy possible. But in this case the subject of the analogy is the mapping of a continuum. Just as with pitch classes, the dynamic markings here take a continuous spectrum and map it to a limited set of categories, with any fluid motions in between (portamento for pitch or crescendo for loudness) limited to markings which give no indication of the nuances of the contour of that slide. Nonetheless, a more directly comparable but equally vague (and Italian) scale exists in the temporal

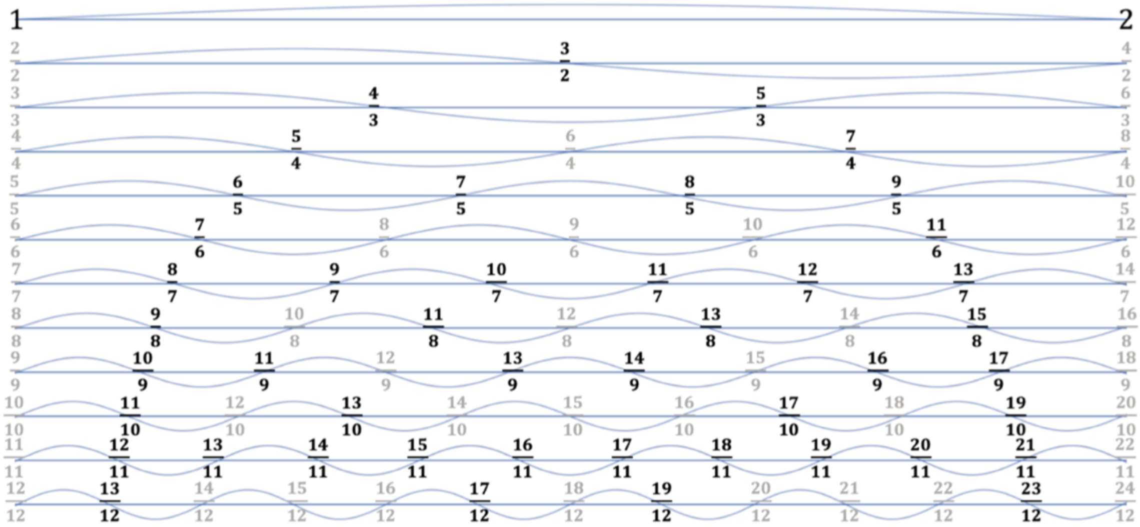
[140] As in Adam Neely's talk on polyrhythms at Ableton Loop 2017 : https://youtu.be/JiNKlhspdKg

domain, that of pre-metronomic tempo markings: adagio, andante, allegro, and so on. To use these terms as pitch classes would complete the detachment of these terms from their original meanings that began with leaving them untranslated as international units in their own right. What is satirised about the notation system and the language it represents in this approach is not the vagueness of these systems – vagueness can be a useful tool – but only how its Frankenstein nature has formed a language in which pitch works on the basis of modular arithmetic, rhythm on rational proportion, and dynamics on vague zones, along with a dozen other intersecting complexities each with their own logics. The intent of all of these exercises is to highlight the many very different approaches to communicating parallel streams of information, all present at once in the conventions of the notational system we have inherited. The notation system provides parameters by which we might inappropriately isolate the variables of music, and so here we create music by inappropriately isolating the variables of the notation system. In other words, we can comment on the model of music-as-data by sonifying that data as music.

For the followers of Erv Wilson, his artistic medium which Stephen James Taylor describes as 'sculpting with numbers' is the key to new musical horizons – 'with Wilson's imaginative use of number logic, a composer can now embrace the sonic sky in its totality.'[141] Yet for Aleksi Perälä, 'Music all started going wrong with Pythagoras, when they started dividing strings into octaves, a very mathematical approach. The actual important thing, I find, is the frequencies themselves; it's more about what feels good to people on this planet, and what's effective?'[142] The truth is we need both, given that harmonic ratios can describe a very particular effect, the beatless combination of pitches, mappings from numerical systems to pitch systems always offer their own particular sonic identities, but we also need a parallel desystematisation. In the now, we have inherited the standard of a singular rigidly systematised approach – to offer alternatives would be both: to produce new systematic approaches, and simultaneously to assert the licence to be entirely unsystematic, to make unrigorous mappings, and to tell 'beautiful untrue things'.

3.4 The Infinitely Compact Scale

Figure 27 *Infinitely Compact Scale up to 12 (low to high pitches read left to right)*



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[141] *Surfing the Sonic Sky*, directed by Stephen James Taylor, (Los Angeles: 2012)

[142] Louis Pattison, *"Colundi" is Music Tuned to Frequencies That Heal the Body*, article on Bandcamp Daily, (2019) [https://daily.bandcamp.com/lists/colundi-aleksi-perala-interview]

The Infinitely Compact Scale (ICS) is a tuning system I first suggested in my 2018 bachelor's mathematics project *Measured Steps Towards Harmony: metrics for measuring consonance and their creative applications*. I have since found the same or similar structures, both based on the Farey series taken from pure mathematics, in the work of Erv Wilson who used it in installations in the nineties[143] and Rudolf Rasch who wrote a paper on it in 1988.[144] The system theoretically packs every possible positive integer ratio into an octave-repeating structure, but does so one iteration at a time in a structure that mirrors the Farey series, plus one. In mathematical terms we would say that the i^{th} iteration of the ICS is all of the fractions of the form $1 \leq \frac{n}{d} < 2$ where $d \leq i$, with the entire set being in its theoretically infinite form on the infinityth iteration, $i = \infty$. In musical terms, this means that the first iteration (ICS-1) is a single pitch and its octave equivalents, the second iteration (ICS-2) is the that first pitch (the tonic) plus a perfect fifth (3:2) above (and their octave equivalents), the third (ICS-3) is the scale $\left\{1, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}\right\}$ (tonic, perfect fourth, perfect fifth, and major sixth), the fourth (ICS-4) is $\left\{1, \frac{5}{4}, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, \frac{7}{4}\right\}$ which adds a major third and harmonic seventh, so on.

Over the course of this research, my largest compositional project has been to write a cycle of works exploring these iterations one at a time, up to some arbitrary limit, which turned out to be twelve. The idea for this cycle, however, did not begin with an abstract mathematical notion but from a series of non-numerical analogies coming together to form a narrative. In its initial plan, ICS has, in perhaps absurd ambition, set about telling the entire story of a universe, in two phases, from the big bang to now, and then from now to some form of spacetime singularity.

Phase 1

ICS-1 Bang
ICS-2 Birth of Energy
ICS-3 Birth of Matter
ICS-4 Birth of Antimatter
ICS-5 Birth of Atom
ICS-6 Birth of Sun
ICS-7 Birth of Birth
ICS-8 Birth of Voice
ICS-9 Birth of Fiction
ICS-10 Birth of City
ICS-11 Birth of Electricity
ICS-12 Birth of Network

Phase 2

ICS-12 Death of Nepotism
ICS-11 Death of Nationalism
ICS-10 Death of Specialism
ICS-9 Death of Work
ICS-8 Death of Money
ICS-7 Death of Meat
ICS-6 Death of Men
ICS-5 Death of Nature
ICS-4 Death of Pain
ICS-3 Death of Blood
ICS-2 Death of Death
ICS-1 Birth of Utopia

The scale of this project was underestimated, and over the two years since I began, I have not yet begun work on the second phase. The idea was born in the early stages of this research, and the period since has involved attempting to understand its every aspect as well as reaching a number of conclusions about future-minded tuning. It may then be appropriate that only after these revelations can I execute the half of the structure, the second phase, that is directly concerned with the future. The initial plan had been to work towards a series of performances presenting variably sized chunks at a time. In this, I have

[143] Warren Burt, "The Wilson Installations" in *Perspectives of New Music*, vol. 48, (2010)
[144] Rudolf Rasch, "Farey systems of musical intonation" in *Contemporary Music Review*, vol. 2, (1988)

performed extracts from the first phase on three different occasions, ICS-1-4 in November 2019, 5-8 in February 2020, and an updated version of ICS-5 in March 2021, all performed solo and semi-improvised[145] with live electronics, and I will soon premiere ICS-12 with an ensemble in a concert of network music. In the unforeseen circumstances of the pandemic, however, I have mainly shifted my focus to the medium of the fixed album, to cover the first phase in one project. Since the period over which I have been working on this has corresponded to and intersected with all of my other research in the fields of technologically-driven and narrative-driven approaches to pitch, including changes in my positions on the role of nature, fiction and utopia, the writing of the backward-looking historical phase has served as a sandpit for learning through experimentation how I might want to reconsider the story told, the way it is told, and the musical systems underlying the narratively more future-minded second phase. Therefore, evaluation of the work on the first phase will have direct consequences for the future composition of the second. Overall the characteristic of a non-continuous comprehensiveness is intended to be key to both levels, the narrative and the pitch system: for pitch this means that theoretically every rational number is available, with infinite compactness, but that there may be points in between even the infinitely compact points, (i.e. irrational numbers) which are not covered in the story. Of course, the infinitieth iteration is not possible anyway. This reflects the way histories are formed, like any other monolithic tellings of universal histories, from the Bible, to Yuval Noah Harari's *Sapiens*, to Bill Wurtz's video *History of the Entire World, I guess,* this historical phase is necessarily selective in what it tells. It is this selective framing of a creation story that defines the confines of nature within which its world's future will unfold.

Looking track by track we can see that each scale is associated with a particular force (for example, ICS-8 with voice). Some of these have intentional relationships, for instance ICS-2 is the "Birth of Energy" because the addition of the fifth, which turns the system from a single note to a set, makes movement and momentum possible for the first time. ICS-8 introduces the pitches $\frac{9}{8}$, $\frac{11}{8}$, $\frac{13}{8}$ and $\frac{15}{8}$, which, given octave equivalence, fall in the harmonic series, and so fittingly this section where the singing voice is first introduced is also where the harmonic series can first be explored beyond the tonic, major third, dominant and harmonic seventh. Up until ICS-3, at least, the pitches used are all within a small variance from the 12-EDO system we are used to, for those first movements of the cycle, the listener would be hard pushed to differentiate it as xenharmonic at all. As the universe's story goes on and its nature drifts further and further from our own, the tuning adds more and more unfamiliar intervals. Each force is born additively over generations, in that, for example, at the birth of energy, energy is added to the universe, and then at the birth of matter, matter is added whilst energy continues, and so on, just as the ICS iteratively adds a new layer without removing the previous layers. Over the larger structure, then, this adds up to an analogy of expansion – the tuning system, the available sonic palette, and the universe follow a process of expansion that involves adding ever more elements. At risk of explaining away the metaphors, there are analogous relations implied in the titles, "Birth of Voice" is really about the development of communication and language, "Birth of Birth" is really about the start of life in all forms not just those that reproduce through something we would call birth, and "Birth of Fiction" is really about the cognitive leap of the development of fiction as a source of social cohesion that, at least in Harari's view, allowed humans to break through to the next stage of evolution by circumventing the "natural" urge to organise around trust only in personal acquaintances,

[145] Semi-improvised here meaning with a performance setup and sometimes structural keyframes pre-composed but with moment-to-moment details determined live.

by constructing social fictions as common causes: folklore, divine rulers, nations, economies, rights, celebrities, currencies, monsters and scapegoats.[146] Whilst I am sceptical of any such claim of there existing some special characteristic that separates human from beast, in combination with the Wildean assertion that art is both fictional and unnatural, it does seem to at least partially explain some truths about art as going beyond one-to-one mimesis of nature into more complex webs of analogies capable of describing the emergence of hybrid beasts in Palaeolithic art. Whether or not it is the case, it is a compelling narrative to assume that what initially made the emergence of larger-scale society possible was the imaginative construction of fictional natures.

Unfolding as it was at the same time as my thoughts on nature and fiction, this universe remains confused. It began as a history of our universe, and therefore its structure follows a nature made up of energy, matter, antimatter, atoms and stars just like our own, and its society emerges likewise following historical stages that map cleanly onto our own history. Yet as imagined natures emerged as compositional directives, I sought ways to reframe this. One possibility comes from a wider plan I have been interested in, in music and writing alike, for situating fictions within – that is the notion of a realm of Gods who treat world building as art, and who go about doing mundane God-things like taking world design courses where they might discuss the aesthetics and practicalities of designing a universe – a literal God-complex reminiscent of Douglas Adams's Magrathea, the planet of planet builders where Slartibartfast and his colleagues designed the surface of the Earth in *The Hitchhiker's Guide to the Galaxy*. In reality, our own first world designs tend to be in the media of crayons or Lego bricks, and so ICS-1 begins where any world might begin, with the act of rooting around in search of the right plastic bricks. Granularised recordings of this act spectrally morph into the initial state of the universe, ICS-1, a simple drone. As this transitions into ICS-2, energy, with the additional fifth, is then introduced as a pitch-shifting reverb to process that drone. ICS-3, a four note scale, is the first to have the possibility of a conventionally harmonic identity beyond the skeletal open fifth. This also makes possible some simple form of melody, and with that the introduction of pulse and metre. This chord emerges not as a block but as a contrapuntal tapestry, with the layering of seven pitch-independent subtractive synthesizer melodies all pulsing monorhythmically but polymetrically, with slowly evolving phrases that often change metre – this is the first suggestion of a musical idea I keep coming back to throughout, which is to create phrases which are cyclical in that the same sort of contour repeats over and over, but free of strict metric periodicity, so each cycle may take a different length of time. This kind of free cyclical phrasing also describes ICS-4, where the contrapuntal texture smears and fades away to leave a clear melody to introducing the major third, and the piece's first clearly non-12-EDO pitch, the harmonic seventh. ICS-1-4 bring their tunings to different forces, resonant filtering in 1, pitch-shifted reverb in 2, subtractive synthesis in 3, and forms of Karplus-Strong synthesis and recordings of e-bowed zither and guitar in 4, but all map the tuning to each form in the conventional way, as a set of notes that sound with these frequencies as their fundamentals. Because they all transition into each other, the first four parts are together in audio example 18.

[146] Yuval Harari Noah, *Sapiens: a brief history of humankind*, (New York: Harper, 2015)

ICS-5, in its revised 2021 form, is the first attempt at interpreting the tuning as something beyond simply a gamut of notes. This meant mapping its ratios $\left\{1, \frac{6}{5}, \frac{5}{4}, \frac{4}{3}, \frac{7}{5}, \frac{3}{2}, \frac{8}{5}, \frac{5}{3}, \frac{7}{4}, \frac{9}{5}\right\}$ to a range of interrelated parameters within the design of an interactive generative synthesizer. With each movement's title determined by the overall structure before it is written, the predetermined subject, here the atom, is always the starting point. In this case, I decided to embrace the fictionality of sonification and proportional mapping. Atoms and their less balanced relatives, isotopes, are defined by the quantities and proportions of their subatomic components, and so, setting the numerator as the number of neutrons and the denominator as the number of protons, there is an isotope corresponding to each ratio in the scale. Where the neutrons significantly outweigh the protons, there will be radioactive decay. This decay is exponential, much like the decay envelope of a typical percussive sound, with each unstable isotope having a specific half-life. Gutting this of all other context then, as I have argued that working within fiction permits us to do, a look at the properties of these isotopes gifted me a set of ratios and their corresponding envelopes, the two main components of a Chowning-style frequency modulation system – although this would usually obey only the harmonic series and so importing these other justly tuned ratios changed the possible timbres without making the resulting sounds entirely inharmonic. Ordered from fastest to slowest decay, the algorithm was then a ten operator FM synth, with each operator modulating the one slower than it, and the four most stable isotopes (which since stability comes from a relative balance of protons and neutrons, would be the ratios that described the smallest intervals) would have no envelope but be constant. Typically, creative sonification takes the form of a piece of music, but in this case I wanted to begin by allowing the data to form an instrument to be improvised with, and so beyond the relationships offered by the isotopes, I wanted to leave plenty of room for variation. By giving the envelopes an entirely proportional relationship, so that the decay time of one operator and the next would always be in the same ratio, a multiplier could be applied to every envelope at once, and even an attack added occasionally obeying the same proportions. Each operator also had an individually controllable amplitude multiplier, or could be bypassed entirely – as well as an octave control, in keeping with the octave equivalence permitted in the ICS system. In this form then, there is often no clearly defined pitch, but when there is it is not necessarily that which you input, since the carrier which gives it its pitch is the most "stable" operator currently not bypassed. And so if I fed this algorithm an input frequency of 100Hz, but the first six operators were bypassed, that the result would be $\frac{7}{5} \times 100\text{Hz} = 140\text{Hz}$. And so, whereas the entire cycle stays in a single tonal centre, tuned to Bb in order to accommodate the tuning of the zither, ICS-5 yields pitches which are outside of its simple set of ten ratios applied to that tonal centre, it is capable of producing tones which given it is sent pitch material in the same tuning, are the ratios multiplied by the ratios, much like in the Recursive Harmonic Organ, except that when this is done with the harmonic series, the results stay within that series.

Figure 28 *ICS-5 ratios and their corresponding isotopes*

Ratio	**ICS-6 note**	**element**	**isotope**	**half-life**
1/1	C	Hydrogen	2H	Stable
6/5	D	Boron	11B	Stable
5/4	D#	Beryllium	9Be	Stable
4/3	E	Lithium	7Li	Stable
7/4	A	Beryllium	11Be	13.76 s
5/3	G#	Lithium	8Li	839.40 ms
7/5	F	Boron	12B	20.20 ms
8/5	G	Boron	13B	17.33 ms
9/5	A#	Boron	14B	12.5 ms
3/2	F#	Helium	5He	7×10^{-19} ms

This FM algorithm is the sound generating component receiving its pitches and rhythms from the Markov Chain Dissonance Generator. The Benedetti height of the interval from a starting ratio to each possible next ratio from a pool of two octaves of ICS-5 are calculated. To save computing time, with a finite fixed set like this the heights can be calculated prior to performance and stored in a matrix. The rhythm is controlled from this system, again only proportionally so that the performer has control over the fundamental rhythmic duration. If the Markov Chain Dissonance Generator yielded a 7:5, the duration of that step would be $\frac{5}{7}$ multiplied by that fundamental duration since duration has an inverse relationship with frequency. If we were following the usual logic of the Markov Chain Dissonance Generator to a monophonic melody, there would be a melody that jumps all over the place, with the same ratio as the rhythm and so a clear correlation between highness of pitch and shortness of duration; whereas I had an eventual sonic goal in mind that would be a little more minimal and chordal, and so I defined five chords of four pitches each by taking two octaves of ICS-5 and, with chords composed according to taste, split its pitches so that none would appear in more than one chord (fig. 29). When the sequencer yielded a 7:5, then, whilst the duration would be exclusive to that result, the resulting chord would be $\{\frac{5}{4},\frac{7}{5},\frac{7}{4},\frac{10}{3}\}$ for any of its constituent parts. In performance, alongside this especially designed instrument, the frequencies were applied to band pass filters used in a chaotic modular synthesizer patch, and the tuning of a zither, not only played with e-bows, but also used with a transducer pressed to its body, to have the output of the atom-inspired FM synthesizer vibrate through. The sympathetic resonances from this transduction made for a reverb-like effect shaped by the tuning itself (see video example 5). The same instrument is played but not transduced through a zither in audio example 19.

Figure 29 *two octaves of ICS-5 divided into five chords*

1 / 1	A	2 / 1	D	Chord A	Chord B	Chord C
6 / 5	D	12 / 5	B	1 / 1	8 / 5	5 / 4
5 / 4	C	10 / 4	E	3 / 2	9 / 5	7 / 5
4 / 3	E	8 / 3	A	8 / 3	12 / 5	7 / 4
7 / 5	C	14 / 5	E	14 / 4	6 / 2	10 / 3
3 / 2	A	6 / 2	B	Chord D	Chord E	
8 / 5	B	16 / 5	D	6 / 5	4 / 3	
5 / 3	E	10 / 3	C	2 / 1	5 / 3	
7 / 4	C	14 / 4	A	16 / 5	10 / 4	
9 / 5	B	18 / 5	D	18 / 5	14 / 5	

ICS-6: Birth of Sun is a simple solo zither composition still in progress. ICS-7: Birth of Birth, also in progress, themed as it is on the emergence of life, will lean heavily on the ideas of imagined natures and alien environments. Acoustic ecologies describe the way frequency zones are occupied, contested, and shared by particular species within an environment. ICS-7 will imagine an acoustic ecology tuned to the scale ICS-7, and artificially construct what should sound like a field recording, made from synthesized and recorded elements edited together. ICS-8: Birth of Voice will apply its tuning to autotune algorithms, pitch shifters, and samplers, to create a piece which centres vocal sounds, not unlike my initial performance of this in January 2020 heard in audio example 20. ICS-9, 10 and 11 are not yet fully formed ideas, whilst ICS-12: Birth of Network is written already as a score for a performance by ensemble members linked by live audio connections over the internet. The score is written in the form of story, to be read in appendix 2. Birth of Network might be considered the initial culmination of all of the ideas that have led me to the pursuit of science fiction music.

Building on the idea of acoustic ecologies, and exploring their analogous properties with democratic systems, radio communications protocols, forums on social networks, intellectual property enclosure and its alternatives, and the experience of social isolation when living in close quarters with practising music student flatmates – all of which are networks of participants, at the best of times, attempting to collaborate and decide things as a community without stepping on each other's toes, and which involve troubled balancing acts between the public forum and the need for privacy, between local devolution and wider cooperation. These social dynamics are reproduced in an alien form of network communication that, as acoustic ecologies and radio systems do, gain access to privacy in a public space by using only a certain frequency zone within the full spectrum. By contextualising this system within a fictional alien history, a simple network of band pass filters are turned from a dry sound processing environment into a living world in which the performers are nudged towards certain ways of exploring the system whilst leaving it to them to really define the system's logic. They are given a nature on which to attempt to collaboratively build a language and method of social organisation. Only repeated experiments will show just how deterministic this "nature" might be for its outcomes.

To return to the question of how to continue into the second phase of the cycle, we might assume, given the conclusions reached on the necessity of a diversity of musical systems, that faced with the possibility of changing system for the second phase, it would be desirable to embrace the approach of exploring as wide a range of unrelated systems in each iteration as possible. But given that the relationship between the music and the world it depicts is one of analogous representation and description of natural systems, rather than being used for music diegetic to that world, the implication is not that the story being told is the evolution of a tuning system, and so this needn't be a factor. Given how long it has taken so far, though, and if in tuning, as the adage goes, *variety is the spice of life*, and given that I am no longer exclusively concerned with mathematically ordained systems, I am interested in perhaps switching to other forms of infinitely compact scale. There are three variations that come to mind. First could be to take this just intonation form and remove its reliance on octave equivalence, so that, for example, ICS-2 $\{1, \frac{3}{2}\}$ would not expand around octaves to give $\{\dots, \frac{1}{2}, \frac{3}{4}, 1, \frac{3}{2}, 2, 3, \dots\}$, but instead follow the same rule that each iteration i is defined by all of the elements with denominators $\leq i$, but without confining to that 1-2 octave range, so for ICS-1: $\{1,2,3,4,5,\dots\}$, for ICS-2: $\{\frac{1}{2}, 1, \frac{3}{2}, 2, \frac{5}{2}, 3, \frac{7}{2}, 4, \dots\}$ (both of which are the harmonic series), and for ICS-3: $\{\frac{1}{3}, \frac{1}{2}, \frac{2}{3}, 1, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, 2, \frac{7}{3}, \frac{5}{2}, \frac{8}{3}, 3, \frac{10}{3}, \frac{7}{2}, \frac{11}{3}, 4, \dots\}$. The second might be an infinitely compact scale of EDOs, so that ICS-2 would be the tonic and tritone, ICS-3 the conventional augmented chord plus the tritone above the tonic, and so on with each iteration i layering i-EDO on top of previous iterations. Finally, and I believe this may be narratively most fitting and, as a compositional process, most engaging: a filtering down of the infinite array of just pitches that were tended towards in the first phase, this could involve a less systematic approach, to determine subsets of this grand set not by some mathematical rule, but by empirical listening. This reflects a narrative where in the first phase nature went unquestioned, birthing good and bad forces alike, whilst in the second, detrimental forces are actively removed. When confronted with such a projection of the future, the anti-utopian reflex is understandable, a future all laid out sounds dangerously deterministic. But, I would argue, we should not allow this reflex to prevent us from mapping out possibilities however far into the future. Taken in isolation they might appear as blueprints, but in the context of myriad other fictions, they should be taken as a part of a proliferation of future-minded folklore. And after all, the Infinitely Compact Scale is a universe which, diegetically speaking, was constructed by a child-God with Lego bricks – it needn't be perfect.

4 Conclusion

No project that aims to be future-minded can be entirely concluded. This research has aimed at a proliferation of possibilities, and, in that, opened more cans of worms than can be consumed in a two-year period. Many of the tools and instruments designed remain as prototypes, virtual versions of hardware intentions, works in progress, and initial concepts. Many of these ideas applied to composition, had skeletal demonstrative results which barely hint at the full musicality I hope to find over an extended period. As I have sought to develop both a design practice and a performance practice, I have found inevitably that the development of performance lags behind as it waits on the development of the instrument. The design process ought to be a dialogue back and forth between designer and user, which in this case, where I must not only familiarise myself with the unfamiliar device, but the unfamiliar musical system it offers, is a process that is just beginning. Nevertheless, as I had hoped with my assertions on the importance of play, it has not been unfruitful to play as a beginner on the fabric keyboards, and especially with the tunable keyboard, with which I have practised most often, I have found the playing experience comfortable, simple and expressive. It has offered me a level of tactility and harmonic versatility I have not experienced before. Despite the emphasis on the initial stages of education, I am curious to see where these practises can be taken over the next several years of performance experience, and what they might tell me about these designs. Through algorithmic composition and the design of generative sequencers, I have found ways to refocus on the 'nervous system' of electronic music. I have found this rewarding both in the sequencing itself, that is, in the generation of novel rhythmic, melodic and harmonic material, but also in the ability to bring an alien or hyper-real sound world like that of ICS-5 to life with a process that generates itself not on the basis of arbitrary random functions that might work when applied to the modular arithmetic of 12-EDO, but with functions that are directly tied to the properties of the ratios used.

During the final leg of this research, Khyam Allami's Leimma and Apotome projects were released and caught significant media attention with headlines like Pitchfork's 'Decolonising Electronic Music Starts With Its Software', reflecting the postcolonial focus of Allami's research and his much needed call for software developers to finally incorporate what so many have been asking for for so long.[147] It caused quite a stir online and I was therefore able to gather a wide range of reactions to many of the core concerns of my thesis, especially relating to the general neglect of tuning options in most popular music software. Many of these were objections over the limited kinds of implementations that would be possible over the top of an existing DAW, or questions over the idea that absolute decolonisation could occur through cultural matters, both concerns that I would categorise as setting perfect as the enemy of the good. Another reaction was to object on the basis that 'electronic music in it's essence doesn't deal with tuning nor rhythm as fundamental building blocks but with machine aesthetics'. Breaking this point in half, I would argue first that electronic music doesn't have a singular essence, and further that tuning here is the proverbial baby to 12-EDO's bathwater. I have in the past used the term post-12 as a catch all to unite both the Busoni (pitch) and the Russolo (noise) trajectories explored in experimental music throughout the previous century as two sides of the same phenomenon, a will to leave behind the baggage of an old standardised language. Secondly, I hope that the larger point here has been sufficiently addressed by my own research as indeed it is

[147] Tom Faber, "Decolonizing Electronic Music Starts From Its Software", in *Pitchfork*, (2021) : https://pitchfork.com/thepitch/decolonizing-electronic-music-starts-with-its-software/

precisely these 'machine aesthetics' that present a world of new tuning possibilities. Machine aesthetics or more importantly machine logics provide new possibilities by attempting, however futilely, to exit the anthropocentre, the subject, and establish fictional empathies with objects. It is these fictional empathies that connect the technologically-driven to the narrative-driven, as we seek fictional empathies with aliens and robots alike. From these empathies arise the musical systems that we imagine would please these aliens. This approach calls to mind the alien phenomonologies of Ian Bogost.

> Speculative realism really does *require* speculation: benighted meandering in an exotic world of utterly incomprehensible objects. As philosophers, our job is to amplify the black noise of objects to make the resonant frequencies of the stuffs inside them hum in credibly satisfying ways. Our job is to write the speculative fictions of their processes, of their unit operations. Our job is to get our hands dirty with grease, juice, gunpowder, and gypsum. Our job is to go where *everyone* has gone before, but where few have bothered to linger.
> I call this practice *alien phenomenology.* [148]

Literalising this, alien phenomenology can be about interrogating objects to find approximations of their desires as much as about literal alien experience. The relation of experience, especially sensory experience, and therefore phenomenology, to tuning is evident as tuning has been, for all I have avoided the matter in my research, inextricably linked to the experience captured in the human ear. The naturalised is truly baked into our default nature as listening to microtonal music even after years of exposure remains to me an alien experience. After Peter Blasser, I have offered robot-phenomenologies of a kind. These robot phenomenologies are valued not simply for their machine aesthetics but also for their limitations, and the frameworks that these suggest. Whilst a robot phenomenology which centres on the removal of limitations quickly begins to echo the runaway reaction of Landian accelerationism, a *cyborg* phenomenology might be one which centres the living whilst seeking to eliminate unnecessary "natural" boundaries. Instruments have always been our cyborg dreams, extensions our bodies allowing us to produce sounds we could not with only our hands and voice. But as cyborg, not robot, they offer also living tactility, and this I argue we should be more ready to present in its vulnerable imperfection, rather than with the mechanised accuracy of the virtuoso.

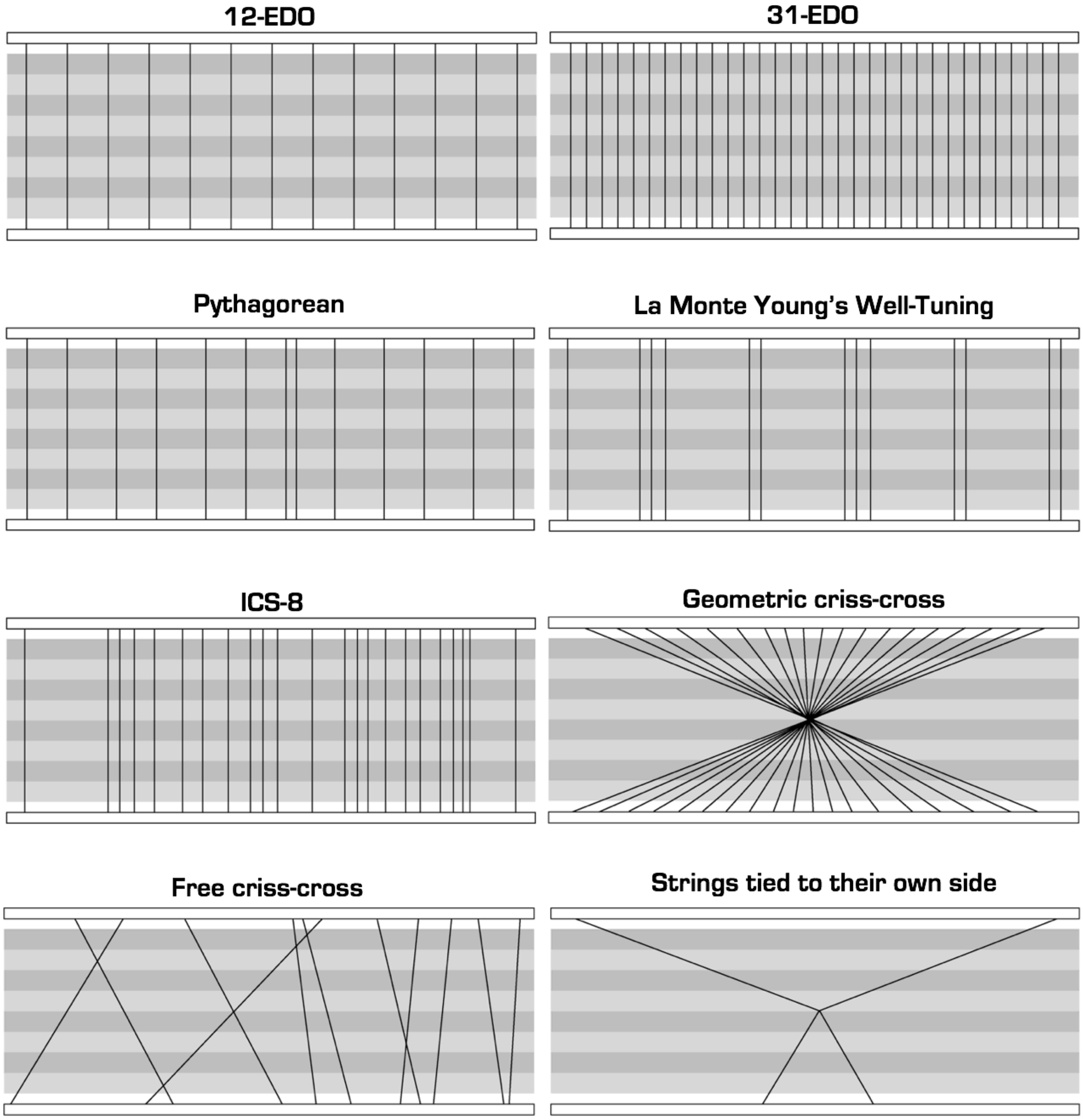
This embrace of living tactility as an alternative to virtuosity would free up space for generalism, that is, the opposite of specialism. In youth the future feels a strange manifestation. We are born with maybe a century ahead of us, and then over the first two decades of life, the future turns from meaning a time of spaceships, to meaning the waged profession we are preparing ourselves for. We begin to narrow our already non-comprehensive study to keep cutting out subjects throughout our teens until we are left with one specialism. This is a source of immense alienation both from the product (by making us act as a single cog in a Babbage-Fordist machine), and from each other, as we lose the time for leisure and we end up doing things that are too niche to really talk about them with friends and family. Musicians, authors, linguists, philosophers, mathematicians, scientists, circuit designers, programmers, luthiers, and other engineers, architects, choreographers, fine artists, sportspeople, educators, all have knowledge and skills worth bringing to the table of musical language. It may in fact be an under-discussed factor in the

[148] Ian Bogost, *Alien Phenomenology: or what it's like to be a thing*, (Minneapolis : University of Minnesota Press, 2012), p.34.

cultural freezing of tuning that we are living in an epoch uniquely extreme in its division of labour. Guan Zhong, Pythagoras, Eratosthenes, Ptolemy, Ho Tcheng-Tien, Vincenzo Galileo, Christian Huygens, Hermann von Helmholtz, Alexander Ellis, all played influential roles in shaping the history of tuning, and all are considered polymaths. More recently, Julián Carrillo, Adriaan Fokker, Harry Partch, Clarence Barlow, Erv Wilson, Wendy Carlos, John Chalmers have brought together multiple disciplines in their tuning research. This correlation is in part because of the importance of analogy making to the design of music theories. Today it is also because a xenharmonic composer must be not only composer but theorist, instrument builder, mathematician, and acoustician. A pedagogy that is oriented towards generalism, that aims at drawing connections between subjects to encourage creative analogy-making and therefore critical thought, is not one that lends itself to the usual aim of generating an obedient workforce. However, a future-minded pedagogy may find that as necessary specialisms are increasingly automatable there may be more space for such an approach as socialising, leisure, research and art become more and more central to everyday life and we seek to intellectually connect with our neighbours whilst exiting the age of dogmatic individualism.

Such a generalistic approach will inevitably generate ideas, and so I have attempted to follow this. Though I have many unfinished projects, I can be satisfied that so many such projects have sprung from this research, and I hope that these can add to, or at least, through other artists presented in this thesis, highlight some proof that there are in waiting vast underexplored musical universes relating to tuning and its interrelated phenomena. And therefore to have offered some semblance of a hope in my arguments that perpetual stasis and revivalism is probably just a phase and that the future can be resumed. After Pythagoras, and after the twelve tones, we will find that frequency has plenty left to say.

5.1 Fretting examples for String-fretted Multi-Ribbon Keyboard



5.2 Score for ICS-12: Birth of Network

Welcome to the panmultiversal cultural communications institute of Earth.

In about a year, we are going to meet some fellow creatures with what might seem to us a strange way of communicating. Rather than the sonic salad of our old world, in theirs, sounds are transmitted and received in narrow frequency bands. You're loudest early-rising or late-night flatmate does you no harm because they are listening on a different band. Their hearing is structured around the Infinitely Compact Scale, which is to say that they can distinguish between rational (numerator/denominator) pitches with theoretically infinite resolution, which they interpret through a framework much like the Farey series, but repeating around the octave. All will, I hope, become clear. Let's start with a little history lesson.

Measured in earth years, we'll start 1195 years before now. Well, not "now" exactly (we are, after all, reaching across into another universe a different age than our own) but since we cannot travel in the temporal dimension, whenever our heads pop through the wormhole into their universe seems like good time to call "now". You see, back then, they too existed in a sonic salad much like our own. They too communicated by making mono sounds out of their eating holes on the front of their heads, and listening in stereo through little drum membranes, with sounds in continuous frequency and amplitude ranges very similar to ours.

They too laboured for a tiny class of overlords, on threat of violence and being left out to die in the cold air. Understandably, many weren't too keen on this setup, and formed resistance groups. Our story begins with the first law in a series that later came to be condensed into the preventative anti-terrorism act. It stated that *red* pigments, paints, inks, dyes, waxes, and so on would be banned outright. Visual artists faced a strange task, to reinvent their language in a narrower spectrum, to find something fresh in a blue-green world. Inevitably, at first, irony dominated. Blue and green were after all now the state mandated hue of all art, and so, besides a few radicals who chose to bleed their own redness onto their canvases, and so inevitably faced incarceration, it seemed the only way to resist was to maintain plausible deniability by ensuring that every image was to have one more layer of irony than the last. As the layers stacked though, the meaning faded. A growing contingent of artists operating within the equatorial resistance found themselves disillusioned with the ironic response. They, instead, said that, if the overlords were going to keep narrowing the spectrum of possible perceptions, they would have to develop new ways of perceiving colour through technological means, such that a narrower range was capable of expressing just as much as, if not even more than, before. And so began what became known as the perceptual revolution.

The next law was the first to address sound. This time it was not a ban, but an active program of sonic weaponry to be implemented in all urban spaces not frequented by the overlords. The idea was modelled on the tone generators of old, ringing out around 18kHz, which had been used to disperse anyone considered vermin, including the youth of their own species. These *new* weapons were a couple of octaves lower, and a good deal louder. Overnight, they appeared everywhere at once, and the following morning the whole world's underclass woke up to a freshly delivered package, and in it a set of earbuds. The earbuds were capable of producing inverse signals that could cancel the tones within the ear canal. This function came with a 32-day free trial. On average, those who didn't opt in went deaf in two days.

Those who had worshipped the overlords were mostly already supporters of the blue-green art their lords had been commissioning for decades before, so had welcomed the red law zealously. Now, whilst the truest loyalists of course insisted that quiet was well worth renting, they were, for the first time, in the minority. In eight days, the resistance grew from 14% to 63% of the population. In sixteen days, it was 81% and the overlords had all retreated to the walled desert. On the thirty-second day, the overlords left the planet for good.

But they left behind something terrible – a sound bomb of unimaginable scale. For a thousand years it boomed and echoed. White noise filled the atmosphere. All were deafened.

Whilst the perceptual revolution was still in its infancy, within a few years of the blast, the first attempted prototypes had emerged for new sonic communication devices. Soon, the consensus that took hold was that they would simply have to raise the volume at which they communicated until the bomb became nothing but an imperceptible noise floor. Within seventeen years of the bomb, there had been successful experiments in which sensors could be placed on the major components of the vocal apparatus that would allow their movement to be synthesized into sound, and with amplification and transduction powerful enough to be just noticeable through the noise. However, it used an astoundingly unsustainable amount of energy to make even the shortest of sounds. And no one could build a listening apparatus to match. Moreover, if such a system were to be adopted amongst an urban population, everyone would hear everyone, always; there could be no private sonic communication.

The solution eventually adopted was not in the form of an electronic device, but an organ of flesh and blood, cartilage and nerves, to be grafted onto the forehead. It consisted of three main muscular components that might be best translated as the multiplying pendulum, the dividing pendulum, and the main stem. By being rocked back and forth at high frequencies, this organ was capable of transmitting and receiving vibrations of rational frequencies at extraordinary loudness with little energy. Hence, with listening now occurring at a specific frequency, those living in close quarters would be able to communicate at these extreme loudnesses whilst still maintaining the possibility of privacy. Over time the noise faded, and since only a few hundred generations passed in this circumstance, the old hearing organs did not greatly evolve over the millennium, and so recent generations have been reintroduced to the old forms of hearing. But in the nine centuries of living with these organs as the only mode of sonic communication, without the old overlords, an extraordinary society developed. I'm not sure that human language is really capable of expressing the structures that emerged, of the new forms of classless democracy, or the incredible artistic, scientific, and technological collaboration that occurred. Rather, it would be best that we begin by learning to communicate through the system of frequency isolation that they did, and to consider what emerges from our attempts at this novel form of communication.

Our emulation:

Using web-based network communication for the benefit of sonic isolation, we will each be able to choose any one frequency at a time from eight octaves of the twelfth iteration of the infinitely compact scale, with each octave containing 46 possible frequencies. We will be making sound and listening through band pass filters centred on these frequencies. Since these filters are not as exact as the real organs, our simulation will be a little easier in that it will likely be possible to hear a fellow creature transmitting on a frequency band next door to yourself. Another function we will emulate of their system, is the possibility of making a sound broadcast across the whole spectrum. In reality, this required a great deal of amplification, using a level of current which could not run through diodes – the consequence of this was that if someone in your neighbourhood was broadcasting at full spectrum, and you attempted to interrupt them, your amplifier would explode. Consequently, whilst full spectrum communication will be possible (that is, the full spectrum of the sound you make into your microphone will be broadcast, although the others will only hear it through their own frequency band), if you interrupt someone else who is already communicating on full spectrum, you will not be permitted to communicate on full spectrum again.

I have set us some exercises...

The non-technical preparation:

- Please bring to each practice or performance, a unique question for each of your ensemrades. It could be something that invites a yes/no answer, something that invites a short answer, or a more open question.
- Please also bring a secret, not something you don't want anyone to know, since there will be a recording and/or broadcast of the output that captures the entire audible spectrum, but something you wish to express in the knowledge that the others will not hear. It could be a fact, a story, a poem, a song, an idea, anything that can be expressed with the voice alone.

For part 1 of the exercise/performance we will have 8 minutes to:

- find the answers to each of our questions;
- express our secrets;
- and, as a whole group, to decide on one change to the rules, to be implemented in future performances (a full performance meaning part 1 and 2, so the rule is not implemented immediately).

For part 2 of the exercise/performance we will then have 8 minutes to freely explore what we have learned about the system with the use of musical instruments.

5.3 Audio Examples

1–11 Raw Data Sonifications

12 Quotient Generator (Just Intonation)

13 Granular MPE Looper

14 Tunable Keyboard with Distortion (Harmony earlier in the algorithm)

15 12-EDO Rhythmicon – Fifth

16 12-EDO Rhythmicon – Major Third

17 12-EDO Rhythmicon – Minor Third

18 ICS parts 1-4

19 ICS-5 Birth of Atom (Improvisation)

20 ICS-8 Birth of Voice (Live at Studio Loos, 2020)

5.4 Video Examples

1 99 To 5

2 Polychromatic Keyboard (configured as 48-EDO)

3 Tunable Keyboard

4 Recursive Harmonic Organ

5 ICS-5 Zither Transduction

5.5 Figures

Figures provided by the author are excluded.

1 Ciat-Lonbarde Tocante: https://www.matrixsynth.com/2015/12/ciat-lonbarde-tocante-zenert-phashi.html

2 Mike Page's Just Touch Synth: diagrams and image provided by Page.

5 Lissajous curves: https://mathematica.stackexchange.com/questions/189440/fine-tuning-plotlabel-graphics-lissajous-curves

6 Yamaha DX7 Algorithms: https://encyclotronic.com/synthesizers/yamaha/yamaha-dx7-digital-programmable-algorithm-synthesizer-r1/

9 Neo-Riemannian Tonnetz: https://commons.wikimedia.org/wiki/File:Neo-Riemannian_Tonnetz.svg

12 Erv Wilson's harmonic spiral diagram: http://www.anaphoria.com/harm&Subharm.pdf

16 Note 'Dha' with inflections in raga: Harsh Vyas, Suma S. M., Shashidhar Koolagudi, and Guruprasad K. R., *Identifying gamakas in Carnatic music*, (2015)

17 Score for James Tenney - *Cellogram* (1971): https://blogthehum.com/2016/05/31/james-tenneys-postal-pieces/

23 Map of Anaphoria: http://www.anaphoria.com/map.html

26 Analogy for the development of the stave: Meme, source lost in the ether.

5.6 Bibliography

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