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Modularity, Technology, and Geometry in Compositional Practice

A Portfolio of Original Compositions

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Abstract

This project, comprising of twelve original compositions and accompanying commentary, explores several key concepts that play a significant role in my creative practice, including the deconstruction and reassembly of materials; non-linear media; geometric construction of musical patterns; interactive audience elements; technology; and probability. Discussed across four chapters, these concepts lead to the development of unique compositional techniques and processes that feature heavily in my work. Chapter one focusses on deconstruction and non-linearity, from ensemble-led modularity to large-scale prerecorded compositions for radio. Chapter two is a study of how random elements and audience interaction can be facilitated through the use of technology, and takes examples from my generative audiovisual artworks. Chapters three and four cover geometry: introducing the mathematical concepts of perfect balance and aperiodic order, and discussing their use in my installations and compositions for orchestra. Throughout the project, a consideration of performance spaces and the audience experience is maintained, and the variety of ways a technique might be applied across different settings is explored.

Modularity, Technology, and Geometry in Compositional Practice: A Portfolio of Original Compositions

Introduction

Creative Practice and Compositional Aesthetic

When describing the process through which a piece of music is composed, a traditional viewpoint might be summarised by this quotation from Claude Debussy:

"The sound of the sea, the curve of some line on the horizon, the wind in the leaves, the cries of birds – such impressions accumulate within us. And suddenly, without requiring our consent in the slightest degree, one of the memories wells up from us and expresses itself in the language of music."[1]

Here three key ideas are introduced: the importance of external inspiration; the composer embodying a melting pot of ideas; and the almost unconscious and spontaneous act of musical creation. The final stage, when the memories 'well up' in the form of music, is often anecdotally described as happening suddenly, with an element of transience, forcing the composer out of bed and to the nearest piano or equivalent instrument.

The compositions contained in this portfolio cover a wide range of genres and performance settings, from chamber and orchestral music to electronic and installation. Many are written to a very specific brief, or are intended to serve a precise function for a particular audience. When considering what links these compositions, the most immediately obvious shared quality is the fact that they were not created via a process like the one outlined above. Instead, they were written according to a creative practice and compositional aesthetic that has emerged throughout my career and been consolidated during the years of my Doctoral research.

External inspiration remains an important element, although within this portfolio it appears less as something concrete, like the 'sound of the sea', and more in the form of an interactive device or a pattern of behaviour, a set of structuring principles or the idea of musical perspective. From one of these starting points, I begin investigating the chosen concept; exploring how it exists and testing different approaches to working with it. Musical elements are slowly added to generate potentially useful materials and a composition begins to take shape. In the case of some pieces, the audience is given the means to interact with the idea itself, allowing them to alter its behaviour and shape the final musical experience.

The concepts explored in my compositions cover a range of my primary interests, including the deconstruction and reassembly of materials; non-linear media; geometric construction of musical patterns; interactive audience elements; technology; and probability. From these topics, I develop unique compositional processes that put in place guidelines and

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[1] Claude Debussy, "Debussy and *The Martyrdom of Saint Sebastian* (Interview with A. Malherbe)," in *Claude Debussy* (Leningrad: Muzyka, 1964), 192. – Quoted in: Edison Denisov, "The Compositional Process," *Tempo* 105 (June, 1973): 2.

limitations for me as a composer. These compositional processes will be introduced in each relevant chapter, and summarised in the conclusion of this commentary.

Regarding the key contributions of this portfolio, it is important to state that it is not the broad approach to the act of composition itself that I believe to be unique, but the several techniques and processes I have developed throughout my research.

Mathematical ideas arise regularly in my work, and Emily Howard identifies two distinct approaches to composing with mathematics that I find useful when defining my creative practice and compositional aesthetic. Discussing her *Orchestral Geometries*, Howard says:

"When I'm thinking about maths in music, I'm always struck by: am I trying to be really true to the maths, or am I taking the maths as a starting point, and a catalyst, to completely jump off and let my imagination run wild?"[2]

Whilst Howard chooses to follow the latter approach, using the mathematical idea as a "lens through which [she's] thinking", I adopt the former.[3] Where properties or rules exist in the ideas I am exploring, I embed them within the emerging composition, meaning the resulting music is a sonic representation of the mathematical concept that created it, with proportions and behaviours intact. This approach has a lot in common with the work of Ryoji Ikeda, whose creative practice spans concert pieces, installations, recordings, and audiovisual art. Ikeda describes how:

"I use my palette – mathematical things, physical things, quantum mechanical – so [these are] my colours, you know?... I don't want to think about emotion for the audience because… if you think about emotion, you try to control or you try to give up."[4]

Although my music sounds very different from Ikeda's, I believe his compositional approach is useful to reference when introducing my own.

Performance Spaces and the Audience Experience

As previously mentioned, this portfolio features compositions that are intended to be experienced in a wide range of performance settings. Despite some inevitable overlap, I have grouped these settings into three main 'spaces': the concert hall space; the gallery space; and the virtual space.

Music heard in a concert hall space will traditionally be part of a curated narrative experience, with a beginning and an end, that is delivered to an audience whose involvement rarely extends beyond listening. There is, however, a strong sense of

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[2] Emily Howard, "Orchestral Geometries | Emily Howard Composer Q&A | NMC," uploaded April 24, 2023, accessed May 15, 2023. https://www.youtube.com/watch?v=Q5Ld206GDOI.
[3] Howard, "Orchestral Geometries."
[4] Ryoji Ikeda, "The immense electronic art of Ryoji Ikeda" (video biography by ABC News Australia), uploaded July 19, 2018, accessed May 22, 2023. https://www.youtube.com/watch?v=5y7WZk_IVqI.

'togetherness', as both the audience and performers hear the same music collectively and simultaneously.

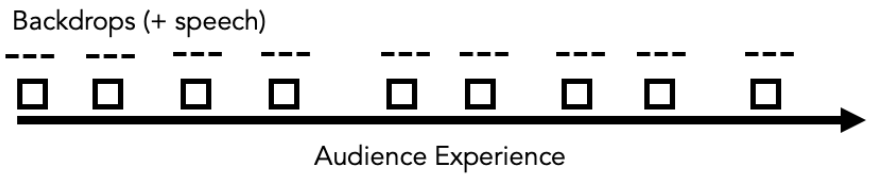
A gallery space provides the listener with a greater awareness of their ability to act within their environment: a greater sense of agency. In an interview with Marcella Lista, Ryoji Ikeda talks about adapting his concert piece *Datamatics* into a series of installations. He describes how the installation format is "opposite to that of concerts, where time has a beginning and an end for a fixed spectator. In the installation situation, the structure is open; people can enter and leave at any time."[5]

The virtual space is one of contradictory extremes: as pieces are free from the need for physical space, they have the potential to reach a much larger audience, however the listening experience is generally an isolated one.

Given the diversity of these spaces, I think it is useful to centre the discussion of my compositions around the audience experience, and keep in mind the intended performance context for each. For example, *Making Space* is a 7-minute piece commissioned specifically as a concert opener. For the audience, it was the first music they heard that evening, but it formed only a small part of a much longer musical experience featuring several pieces by other composers.

By contrast, four of my compositions were displayed simultaneously as part of a single gallery exhibition. The listeners travelled freely between each piece and would have heard some overlap as they moved to the next one.

Lastly, my piece *Backdrops* is used as short snippets of music beneath speech, spread throughout an entire 90-minute episode of the BBC Radio 3 show *Night Tracks*.



[5] Ryoji Ikeda and Marcella Lista, "Patterns of the Unknown," in *Continuum* (Paris: Éditions Xavier Barral, 2018), 159.

These widely contrasting contexts were considered at the start of the compositional process for each piece, and influenced how each composition took shape.

List of Compositions

I have grouped the twelve compositions contained within this portfolio into four main chapters, according to the concepts that form the external inspiration for each group of pieces. Links to scores, recordings, and videos can be found at the end of this commentary.

The compositions will be discussed in the following chapters, in this order:

Deconstruction and Non-linearity

Day One

Duration:	c. 8′
Performances:	24/04/22, Milton Court, Barbican Centre, London
	15/05/22, St. George's, Bristol
	22/05/22, Lighthouse, Poole (+ video livestream)
	05/06/22, Town Hall, Birmingham
Performers:	National Open Youth Orchestra conducted by Doug Bott

Backdrops (Volume 1)

Duration:	c. 20′ (submitted excerpts)
Recorded:	19/09/19, Abbey Road Studios, London
Performers:	BBC Concert Orchestra conducted by Lev Parikian
Broadcasts:	BBC Radio 3 Night Tracks (since the show launched on 30/09/19)

Backdrops (Volume 2)

Duration:	c. 50′ (submitted excerpts)
Recorded:	12/10/20, Watford Colosseum
Performers:	BBC Concert Orchestra conducted by Lev Parikian
Broadcasts:	BBC Radio 3 Night Tracks

A Slow Breath

Duration:	c. 8′30
Recorded:	22/02/22, Watford Colosseum
Performers:	BBC Concert Orchestra conducted by Ben Palmer
Broadcasts:	09/05/22, BBC Sounds - The Music and Meditation Podcast
	18/05/22, BBC Radio 3 Night Tracks

Technology: Probability and Audience Interaction

A Single Point In Time

Duration:	c. 6′
Released:	09/09/20, Bandcamp and Youtube

Blocking Measures
Duration: c. 2′ (submitted excerpts)
Exhibitions: 19/01/22 – 31/01/22, IN/FINITE Exhibition, Liberty House, Bristol
14/04/22 – 28/05/22, Made for the Rhythm, Pound Arts, Corsham
Performers: Harriet Riley (percussion), Georgie Ward (synths)

Forest Fire
Duration: c. 4′30 (submitted excerpts)
Exhibitions: 19/01/22 – 31/01/22, IN/FINITE Exhibition, Liberty House, Bristol
14/04/22 – 28/05/22, Made for the Rhythm, Pound Arts, Corsham
Performers: Lloyd Coleman (clarinets), Georgie Ward (synths)

Geometry: Perfectly Balanced Rhythms

Balance
Duration: c. 5′40
Exhibitions: 01/10/18, Britten Theatre, Royal College of Music, London
01/11/18, Digital Catapult Office, London
Performers: Matthew Wilsher (clarinet), Harriet Riley (marimba), Georgie Ward (piano), Kasia Zimińska (violin), Carola Krebs (cello)

Ocean Avenue
Duration: c. 7′
Performances: 14/07/22, Recital Hall, Royal College of Music, London
Performers: Beth Stone (flute), Rowan Jones (clarinets), Toril Azzalini (marimba), Emily Hoh (piano), Pietro Genova Gaia (violin), Shizuku Tatsuno (cello)

Turning Points
Duration: c. 3'40
Performances: 30/01/20, Symphony Hall, Birmingham
29/01/23, Symphony Hall, Birmingham
Performers: CBSO conducted by Mirga Gražinytė-Tyla (30/01/20)
CBSO conducted by Clark Rundell (29/01/23)
Broadcasts: 04/02/20, BBC Radio 3 in Concert

Geometry: Aperiodic Order

Waveforms
Duration: c. 1′30 (submitted excerpts)
Exhibitions: 19/01/22 – 31/01/22, IN/FINITE Exhibition, Liberty House, Bristol
28/06/22 – 29/06/22, The Open University, Milton Keynes
Performers: Harriet Riley (percussion)

Supergolden Approximations
Duration: c. 4′20
Exhibitions: 19/01/22 – 31/01/22, IN/FINITE Exhibition, Liberty House, Bristol

	28/06/22 – 29/06/22, The Open University, Milton Keynes
Performers:	Lloyd Coleman (clarinets), Harriet Riley (marimba), Georgie Ward (piano)

Making Space

Duration:	c. 7’20
Performances:	05/05/22 Queen Elizabeth Hall, Southbank Centre, London
Performers:	BBC Concert Orchestra conducted by Anna-Maria Helsing
Broadcasts:	13/05/22, BBC Radio 3 in Concert
	02/08/22, BBC Radio 3 Breakfast

TOTAL DURATION: c. 2 hours 10 minutes

Deconstruction and Non-linearity

The first compositions to be discussed were commissioned to a very specific brief regarding their structure. These pieces had to be delivered in a deconstructed, modular state, allowing them to be adapted and reorganised to fit future performance settings.

In his book *The Open Work,* Umberto Eco describes compositions by Karlheinz Stockhausen, Luciano Berio, Henri Pousser, and Pierre Boulez as being handed to the performer "more or less like the components of a construction kit."[6] This is a fitting analogy for the pieces discussed in this chapter, where several elements of the music's construction, from instrumentation to linear progression, are not within my control. Referring to Eco's book, James Saunders adds that "by loosening relationships between a work's elements the possibility of unforeseen yet interesting and valid combinations of material might occur, albeit often within carefully defined boundaries."[7]

Writing in this way familiarised me with the concept of allowing aspects of the compositional process to be handled by external influences, either human or technological, which is a key feature of my creative practice that appears throughout my research.

Day One

Day One was the second commission I received from the National Open Youth Orchestra (NOYO), an ensemble formed of disabled and non-disabled young musicians. They rehearse in smaller groups at regional centres before joining together for concerts.

The first piece I was asked to write, *The Umbrella*, was composed specifically with the individual members of the group in mind. The range of instruments in NOYO is wide and changes every year as players join or leave the ensemble. It combines standard orchestral instruments with electronic ones such as the Linnstrument, and the specially developed Clarion instrument. Because of this, NOYO's Musical Director Doug Bott asked if the second piece I wrote for the group could be adaptable to suit any future line-up of the orchestra.

One of NOYO's aims is to develop an accessible repertoire alongside their open ensemble, and to consider what forms this accessibility might take. Open Orchestras, a side project to NOYO that focusses on music in schools, describes how the pieces they provide to schools are "broken down into musical building blocks that can be reimagined into whatever your students want [them] to be."[8] When writing *Day One* I chose to do more than just write a piece for flexible instrumentation; I applied this 'breaking down' process to my own music

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[6] Umberto Eco, "The Poetics of the Open Work," in *The Open Work*, trans. Anna Cancogni (Cambridge, Mass.: Harvard University Press, 1989), 4.
[7] James Saunders, "Modular Music," *Perspectives of New Music*, Vol. 46, No. 1 (Winter 2008): 182.
[8] Jonathan Westrup, *Open Orchestras: Repertoire*, accessed May 20, 2022, https://www.openorchestras.org/repertoire/.

and provided the ensemble with musical building blocks from which they could construct the composition to suit the players and setting of each new performance.

Perhaps one of the most well-known and often-played compositions constructed in this way is *In C* by Terry Riley from 1964. 53 short musical phrases are played sequentially by an ensemble of unspecified size and instrumentation, whose performers are allowed control over several elements of the performance (e.g. how many times to play each phrase, which phrases to omit if any, when to re-enter) as long as they stay within a few phrases of each other. At the time of *Day One* being commissioned, there was a lot of attention given to making sure the NOYO performers went into each concert feeling prepared and aware of what the performance setting would be like. For this reason, we decided that the open and flexible elements of *Day One* would be explored and workshopped in rehearsals, allowing a fixed version of the piece to have emerged by the time of the concerts.

I believe that this is very often the case with compositions that present flexibility in their scores, but do not necessarily ask for live improvisation from their performers. In an article by Paul Hillier discussing Stockhausen's 1968 piece *Stimmung*, he describes how "although many elements in the piece's structure are free and, in theory, can be reconfigured for each performance, [Collegium Vocale] soon settled on one version, which they recorded twice."[9] He goes on to say that when preparing a new version of *Stimmung* for his ensemble Theatre of Voices, he preferred not to work too closely with the composer, stating that "the work had become somewhat fixed in Stockhausen's mind."[10] I sensed this happening to me when working with NOYO and composing *Day One*, and feel that in many ways the rescheduling of the performances due to the COVID-19 pandemic allowed the ensemble the freedom the piece asks for. Due to a postponement of over two years, the membership of the ensemble had changed significantly, and an essentially new version of *Day One* was devised and rehearsed without my involvement.

Whilst my first piece for NOYO featured a lot of rhythmic chordal writing, due to there being several excellent keyboard and tuned percussion players in the group, I chose to construct *Day One* around single-voice melodic lines, which would allow it to be interpreted by a wider range of instruments. For the opening section of the piece, I presented just a *Main Melody* and a *Sequence of Bass Notes*. The suggestion I gave was that the melody could be introduced note-by-note by several instruments in canon until it is completely revealed, and then reduced again by losing notes from the start of the melody.

One of the things I think is most effective about Riley's *In C* is how modulation is handled. The instruction that players should never stray further than two or three phrases from each other means that the introduction of the sustained F-sharp in phrase 14 is likely to coincide with the brief, passing F-naturals contained in the previous three phrases, but not clash with the sustained F-natural occurring six phrases previously. In *Day One* I wanted Part 1 to begin in an F major sound-world, and end in D-flat major. The *Sequence of Bass Notes*

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[9] Paul Hillier, "I felt a controlling hand take over," *The Guardian*, September 28, 2007, accessed May 20, 2022, https://www.theguardian.com/music/2007/sep/28/classicalmusicandopera1.
[10] Hillier, "I felt a controlling hand take over."

leads this modulation, but in the *Main Melody* the final note, a G, is replaced with an A-flat towards the end of the section. Depending on how the melody has been presented, there is a chance that the A-flat will coincide with the A-natural earlier in the melody, and the D-flat in the bass with the D-natural in the melody. As the section progresses, and the melody shrinks again, these dissonances will occur less frequently, and the music will settle into the new key.

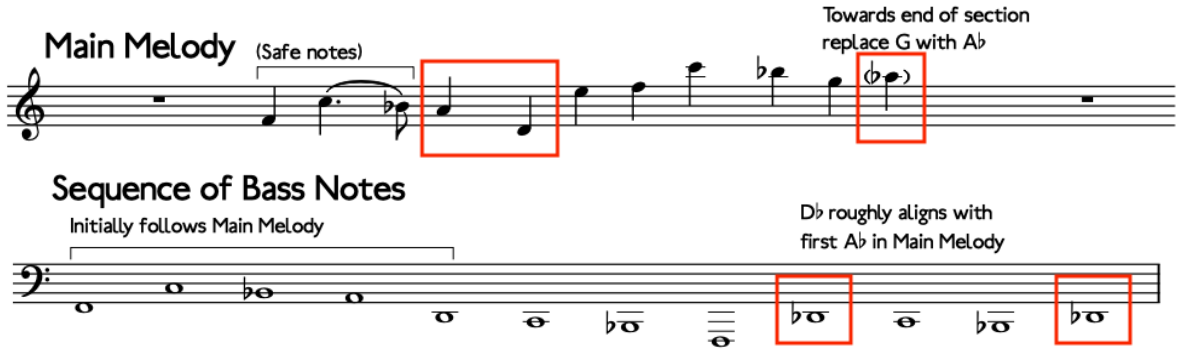

Figure 1: The materials given for Part 1 of *Day One*, with potential dissonances annotated.

Given that some members of the ensemble had had very little musical training prior to joining the group, I introduced the concept of 'safe notes' that could lie alongside the whole of Part 1, settling on F-natural only by the end of the section if required.

Part 2 of *Day One* was inspired by watching members of the ensemble who were able to hold a musical line very consistently against conflicting music and sounds happening around them simultaneously. Several of the players at the time were partially sighted and therefore couldn't see the conductor. They would rely on a strong pulse within the music but didn't necessarily need a down-beat. I wanted to write music that felt like it had no centre, where every musician could be heard to be on or off the beat at any time. The motifs in Part 2 do not easily fit within a regular framework of beats and bars, and several go out of phase with each other when repeated.

The *Main Motif* can mostly fit within a 4/4 framework but includes a triplet figure that dislodges the rhythm when two versions of the motif are played as a canon at the crotchet, as is suggested. The first three notes of the motif can act as safe notes (the same three notes as in Part 1 transposed up a semitone), and there is a suggestion that the motif can be transposed up a 5th to introduce the E-sharp that appears in the *High Chords* and the *Rising Melody*.

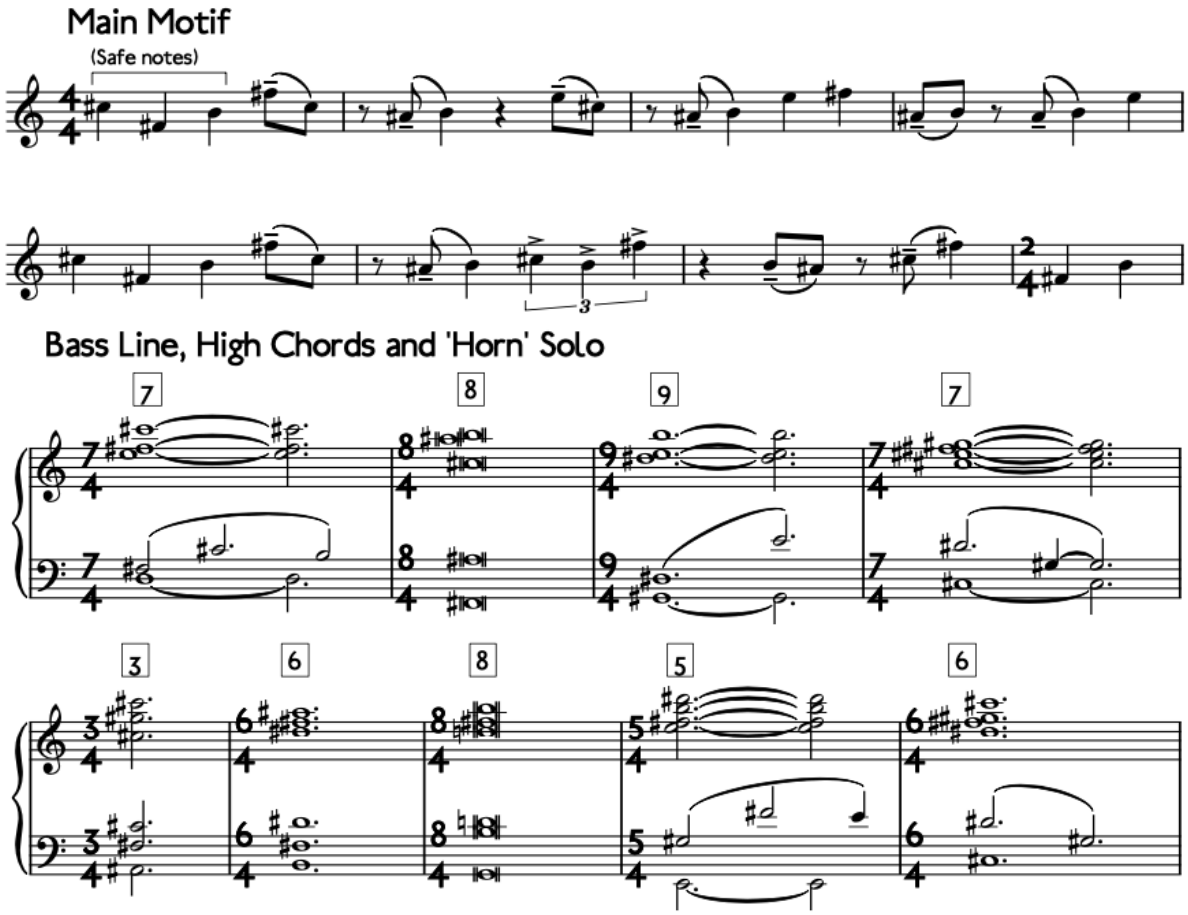

Figure 2: *Main Motif*, *Bass Line*, *High Chords*, and *Horn Solo* from Part 2 of *Day One*.

Whilst the *Main Motif* is intended to be heard in four-time, the *Rising Melody* is intended to be heard in three-time, and all other layers are meant to sit ambiguously against these lines.

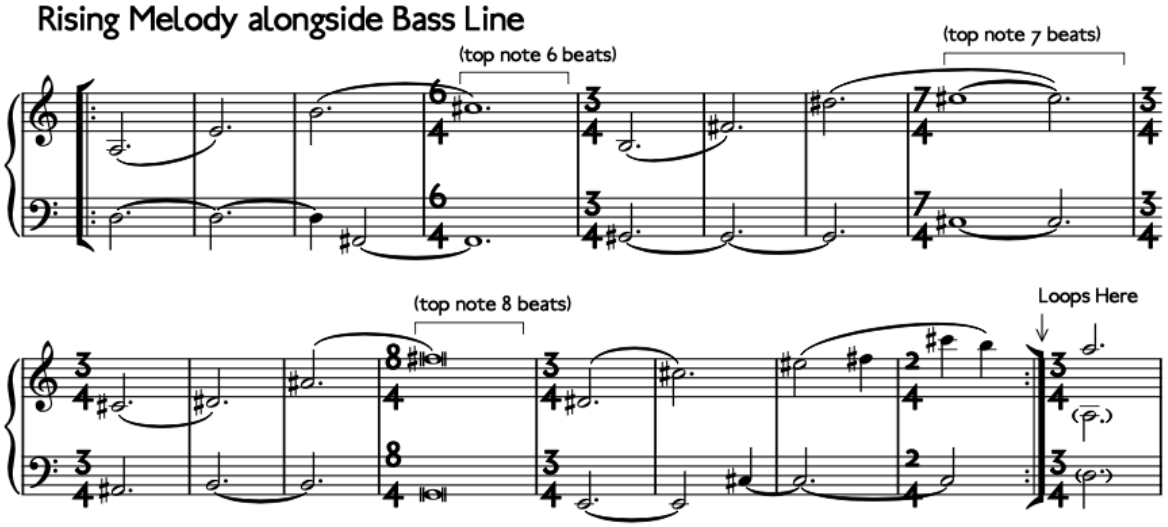

Figure 3: *Rising Melody* alongside *Bass Line* from Part 2 of *Day One*.

In the same way as the D-flat at the end of Part 1 is reinterpreted as the C-sharp you hear at the beginning of Part 2, the opening chord of Part 3 has the option of continuing straight on from the end of Part 2. It is comprised of a looping chord sequence drawn from the

Rising Melody and *Bass Line* of Part 2; a melody constructed from the *Main Melody* in Part 1; and ends with a quotation of the *Main Motif* from Part 2.

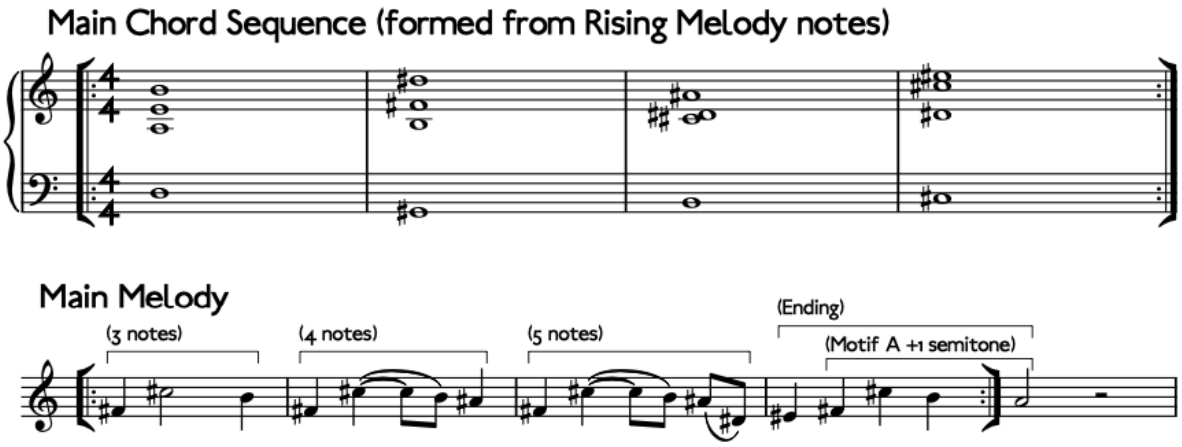

Figure 4: The materials given for Part 3 of *Day One*.

The compositional technique used in *Day One* is one of deconstruction, similar to some of the compositions that have been discussed previously: Stockhausen's *Stimmung* and Riley's *In C*. The score presents snippets of closely related music alongside suggestions of how they might be combined. This allowed the structuring and orchestrating of the piece to be decided by the Musical Director of NOYO, and the performers of the ensemble. It is the openness of this form, and its accessibility to players of varying ability levels that made it successful in this setting.

One of the few suggestions I make regarding the linear structure of *Day One* relates to the separation of the music into three parts, and the note at the start of the score that explains that "I have presented sections in the order I intended them to be played, but this too can be rearranged if it makes more sense that way."[11] The next composition we discuss, a piece written to be heard in a virtual space, removes even that level of structural guidance from my control. In this case, rather than the notated score being deconstructed and needing interpretation, the composition is formed of pre-recorded audio snippets that are combined with other music, manipulated, and recontextualised to form the final musical experience.

Backdrops (Volumes 1 and 2)

I was commissioned by BBC Radio 3 to write a large collection of music to be used in a new evening programme called *Night Tracks*. The idea was that this radio show would form a continuous musical listening experience, and my composition would be heard in between each played track, underneath the presenter's voice, joining everything together. The music I wrote had to perform a linking function, and also provide a sense of identity for the programme overall.

This was the first composition of mine intended to be heard in a purely virtual space, and as a result it contained several contradictory elements: my music would be pre-recorded, and

[11] Liam Taylor-West, Introductory notes to *Day One* (self-published, 2018).

therefore fixed, but its appearance within the radio programme would be entirely within the control of the show's producers, including the possibility of electronic manipulation (time-stretching, pitch-shifting, filtering, delay, etc.); the programme would go out to a large audience simultaneously, but their listening experience would be mostly as individuals; my music would be the most frequently heard on the programme, but I would remain anonymous to the listeners.

The technique used in *Day One*, applied here on a much larger scale with over two hours of music written, seemed to be a good approach to achieve an identity for the programme whilst having no control over the final use of the music during the experience. Suzanne Ciani, who wrote the music and sound design for the 1980 pinball game *Xenon*, has been described as providing the game "with much of its identity, and thus, its contemporary status as a classic and historically important game."[12] Ciani explains how she "was very interested in getting the whole composition to work… To think of the pinball as actually playing the piece."[13] Chris Reeves points out that "while the composition has been pre-recorded, it is nonetheless indeterminate, the sounds being dictated by the variable action of the pinball game player."[14] When the soundtrack to *Xenon* was released in 2021, it was presented not as a continuous composed experience, but as individual musical moments spread across three tracks: *Long Effects*, *Vocal Effects*, and *Short Effects*.

A modern equivalent of this form of composition is Anna Meredith's *Bumps Per Minute: 18 Studies for Dodgems*. The music was released as an album of 18 short pieces, but the composition was written to be experienced as part of the 2021 installation *DODGE* in collaboration with Yinka Ilori and Nick Ryan. In *DODGE*, each collision between dodgem cars triggers a different piece from Meredith's composition that runs until the next collision. Whilst the technique of presenting a composition as a library of smaller components is similar between *Xenon*, *DODGE*, and my piece *Backdrops*, the final experience for the listener is very different. The rate of collision events occurring in a pinball game, or a dodgems ride, is so fast that the result in *Xenon* and *DODGE* is a high-paced, cut-and-change, collage-like experience. The intention for *Backdrops* was for the piece to create a sense of calm, intrigue, and spaciousness, and for it to be broken up by the other musical pieces heard on the radio programme.

The 2016 video game *No Man's Sky* allows players to explore a vast universe of planets that are procedurally computer generated, meaning that each world visited is likely unique, and the game is essentially infinite (the game developers claim there are 18 quintillion possible worlds).[15] The band 65daysofstatic, who composed the soundtrack to the game, created

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[12] Chris Reeves, "Multiball and Multiplicity: Suzanne Ciani and The Voice of Xenon," in *Video Game Art Reader, Vol. 4*, edited by Tiffany Funk (Amherst: Amherst College Press, 2022), 45.
[13] Suzanne Ciani, "Omni: The New Frontier," (documentary), directed by Riva Freifeld, 1981, uploaded February 16, 2018, accessed August 4, 2022, https://www.youtube.com/watch?v=Cb2W75VbYCM.
[14] Reeves, "Multiball and Multiplicity: Suzanne Ciani and The Voice of Xenon," 49.
[15] Simon Parkin, "No Man's Sky: the game where you can explore 18 quintillion planets," *The Guardian*, July 12, 2015, accessed August 04, 2022,

both a standard 15-track album of music and a huge library of individual stems that the game would combine in the same way as it would generate worlds, constructing an essentially infinite and always-changing composition. 65daysofstatic band members Joe Shrewsbury and Paul Wolinski compared the album music to the in-game music at the 2016 EGX Develop Sessions using the following table:[16]

Album	In-Game
Finite	Infinite
Linear	Non-linear
Focussed	Responsive
Standalone	Context-aware
Event-based composition	State-based composition
Can use the whole mix	Has to co-exist with SFX

Table reproduced with the permission of Paul Wolinski.

My composition *Backdrops* is written to be experienced similarly to the in-game version of 65daysofstatic's soundtrack. *Backdrops* relies on the radio producers to construct the final output in the same way as the *No Man's Sky* in-game soundtrack relies on the computer's procedural generation methods. The producers working with *Backdrops* are aware of the context in which it is being applied and are using it to create a sound-world that provides an identity for the programme. In the context of the show the composition is state-based, rather than event-based, and must co-exist with the presenter's speech. It is within this framework that I think *Backdrops* should be heard; as a construction kit that allows the *Night Tracks* producers to give the programme a clear identity across a wide range of different contexts.

Backdrops was recorded by the BBC Concert Orchestra conducted by Lev Parikian. Volume 1, recorded at Abbey Road Studios, is largely a collection of single note stems and chords played by different sections of the orchestra that would act as an initial layer from which other details could be added. The producers wanted music to appear in a variety of different keys so that seamless transitions from one piece on the programme to the next could be achieved. Beyond the chords and held notes, I discussed with producers the idea that the music should have a finely textured detail and sense of sparkle to it, despite an overall feeling of slow harmonic movement and stasis. The most effective, and often used, music in Volume 1 were the *Five Textures* (numbers 10-14), which went on to be the primary influence for much of *Backdrops* Volume 2.

The *Five Textures* are scored for percussion, harp, celesta, and strings and require individual players to perform short phrases of music within a free-time section of the score. This adds a further element of freedom to the composition, with the performers becoming

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https://www.theguardian.com/technology/2015/jul/12/no-mans-sky-18-quintillion-planets-hello-games.

[16] Joe Shrewsbury and Paul Wolinski, "How 65daysofstatic created the No Man's Sky soundtrack," (video of conference), uploaded September 26, 2016, accessed May 21, 2022, https://www.youtube.com/watch?v=Y3Jm8hDbPO8&t=311s.

co-creators to a certain degree, choosing when to place their notes and repeating or shortening phrases as they choose. The idea was for the music to feel alive, like a swarm of creatures communicating with each other, without becoming too busy or intense, and maintaining the harmonic stasis that would allow the listeners to feel settled. For the strings this meant giving the moving lines to a couple of solo players, reducing the orchestra down to an ensemble of seven performers, each listening and responding to the others above a held chord bed.

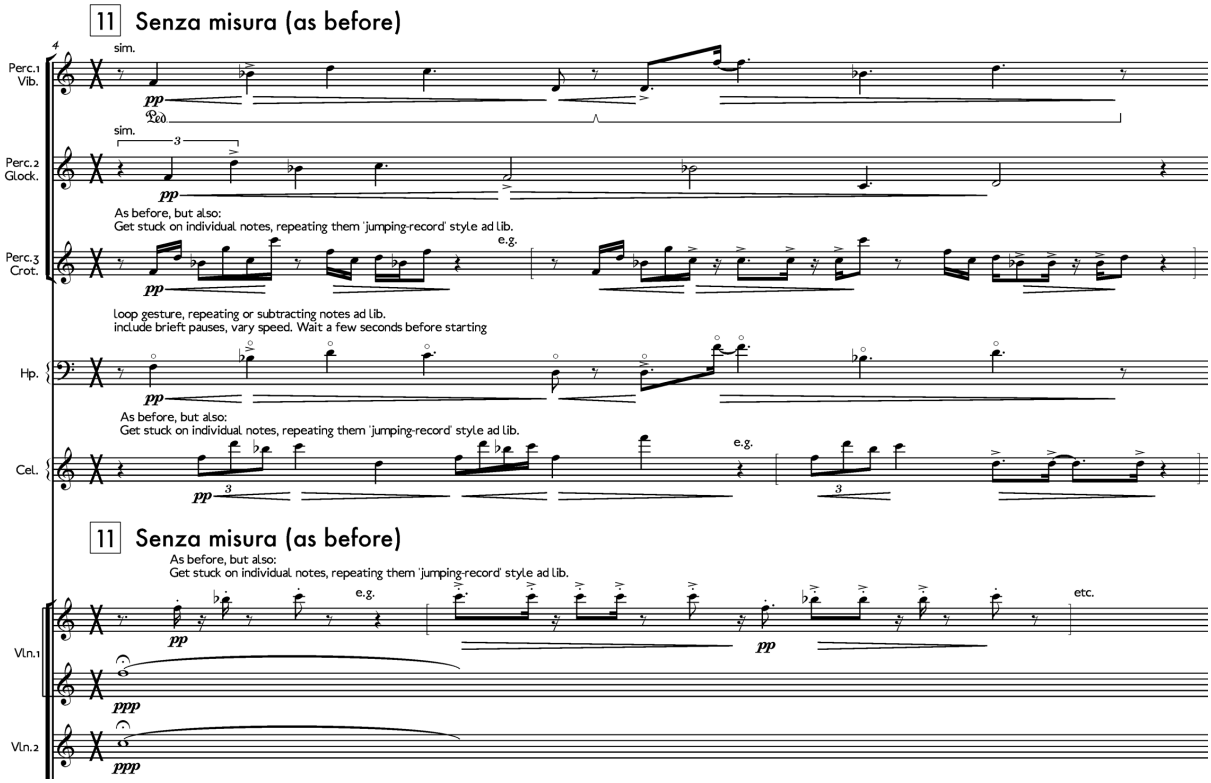

Figure 5: Score excerpt for *Five Textures (No. 2)* from *Backdrops* Vol. 1 showing free-time material.

Backdrops Volume 2 was recorded at Watford Colosseum during the COVID-19 pandemic when restrictions on live music were still in place in the UK. Due to social distancing measures, it was scored for a reduced orchestra of flutes, clarinets, percussion, harp, keyboard, and strings (with flutes and clarinets never being used at the same time as percussion, harp or keyboard). The focus for Volume 2 was to record more free-time textures like those in Volume 1, along with several short pieces with some sense of direction, tonal ambiguity, or interesting musical detail for the listener to focus on.

Fifteen Textures, recorded for Volume 2, added a greater variety of ways in which the music creates a sense of both movement and stasis simultaneously. Some of the textures were also given a sense of direction; ending somewhere slightly different from where they had started. As well as solo players acting as interpreters of the flexible elements of the music, as had been the case in the *Five Textures* of Volume 1, I also treated the string section as a massed indeterminate organism, with players moving to new notes freely as individuals, creating a blurring effect as one chord shifted to the next.

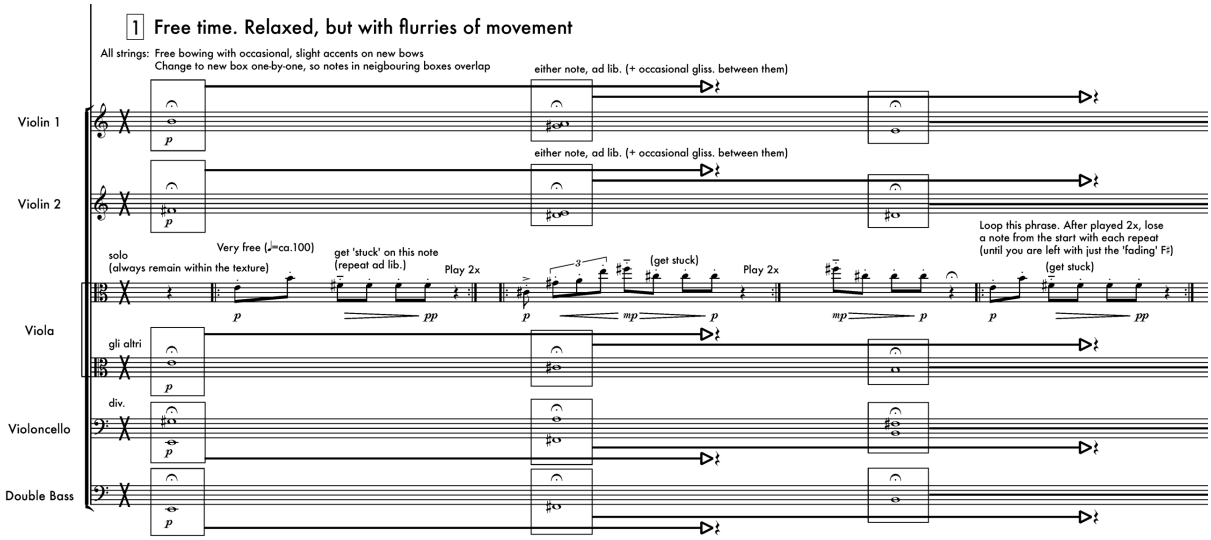

Figure 6: Score excerpt for *Fifteen Textures (No. 1)* from *Backdrops* Vol. 2 showing blurring effect in the strings.

Something I discussed with the producers is the fact that *Night Tracks* up to the point of recording *Backdrops* Volume 2 had always played bell sounds as midnight arrived. This seemed important, as it was something that brought the remote audience together for a moment and made them aware of the 'liveness' of what they were hearing. We decided that Volume 2 should contain a collection of music that would synchronise roughly with the second hand on a clock to mark the passage of time. These pieces (numbers 16 to 29 in Volume 2) kept the same instrumentation as the free-time textures but served a completely different purpose with their rigid timekeeping.

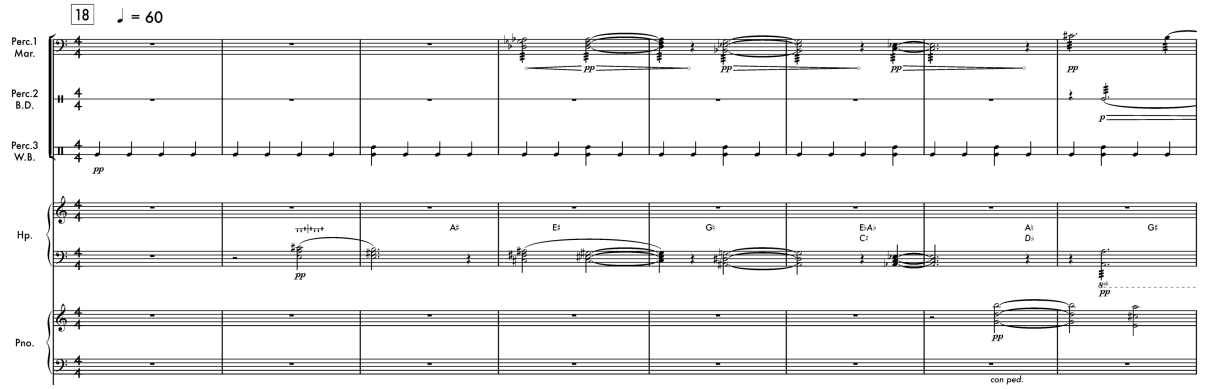

Figure 7: Score excerpt for *Music for Midnight (No. 18, The Endless Descent)* from *Backdrops* Vol. 2.

Backdrops presents a variation on the deconstruction approach used in *Day One*. The materials to be organised and shaped into the final musical experience exist as recorded audio, rather than notated music on a page, and the person reassembling the piece is not the performer, whose work has become fixed during the recording process, but the producer putting together the radio show. Additionally, the audience experience of listening to *Backdrops*, within the context of *Night Tracks*, includes hearing the music of other composers embedded within the composition, and sometimes layered on top of it. Whilst this might seem strange at first, I consider it not so different from the situation of a traditional concert hall experience, where a single composer's work might occupy only a few minutes of a musical experience lasting an hour or more.

So, if *Backdrops* was written to provide a sonic identity to the show *Night Tracks*, what happens if some of the recordings that comprise *Backdrops* are taken out of their intended context and heard elsewhere. Does this new musical experience become a version of *Backdrops*, or is it something different? The next piece investigates this question further, and is an example of me using a collage-like approach to composition, reassembling a selection of the deconstructed materials from *Backdrops* into a new linear structure.

A Slow Breath

I was commissioned to write a piece of music to accompany a guided meditation featured on a new BBC Sounds podcast *The Music and Meditation Podcast*. The composition had to be around nine minutes long and would underscore speech. Given that at the time of writing the piece no speech had been recorded, and there was no script written, there was always the possibility that my music would have to be adapted by the show's producers to fit with the voice.

Because of this I decided to construct the piece, *A Slow Breath*, using layered and overlapping recordings of the music from *Backdrops*, to create a composition that was a continuous wash of sound that would be easy to loop, or shorten, or crossfade into itself. The piece was going to be recorded by the BBC Concert Orchestra, so I would be able to match the orchestration of *Backdrops* exactly if I wanted to, and could experiment with how different chords and textures would sound when placed against each other. This was a new writing approach for me: to create an original piece from layered, pre-recorded audio excerpts. I saw myself as one of the radio producers working with *Backdrops*, reorganising the fragments to make something new.

The first of Cornelius Cardew's *Three Winter Potatoes* is a fully notated, fixed composition, created from his earlier, indeterminate work *Octet '61 for Jasper Johns,* a piece constructed of 61 musical 'signs'.[17] It is interesting to see how Cardew handles the question of 'identity' that is raised in the notes to the original composition. The answer lies in the '↗' sign in *Octet '61 for Jasper Johns* that means "out, away; something completely different," and which "should be interpreted only once in any performance of the piece."[18] Cardew claims that the "identity of the piece is given once for all by the sign ↗: the piece will be known and remembered (if at all) as 'the piece where something peculiar happens in the middle'."[19] In his own interpretation, the sign is represented by the performer inserting a screw "between the strings of middle D which at the moment of preparation during performance usually produces a grating (and therefore memorable!) sound."[20]

In the case of *A Slow Breath*, the interpretation process is taken one step further than with Cardew's *Winter Potato No. 1*. After reorganising the pre-recorded excerpts from *Backdrops* into a fixed audio recording, I transcribed the music back into score format to be

[17] John Tilbury, *Cornelius Cardew: A Life Unfinished* (Matching Tye: Copula, 2008), 157.
[18] Cornelius Cardew, "Octet '61 for Jasper Johns," *The Musical Times* (January, 1962): 35.
[19] Cardew, "Octet '61 for Jasper Johns," 38.
[20] Tilbury, *Cornelius Cardew: A Life Unfinished*, 157.

re-recorded by the BBC Concert Orchestra. This recording was then taken by the producers of *The Music and Meditation Podcast* and adapted as necessary to create the final musical experience within a virtual space.

A Slow Breath is scored for wind, percussion, harp, celesta, and strings. The piece is constructed from a wash of overlapping string chords and textures from *Backdrops*, with the wind used to fill out the harmonies, blur the transitions between chords, and highlight individual notes. The percussion, harp and celesta add a brightness to the top of the musical texture; provide points of focus for the listener to turn their attention to; and add the occasional sense of movement. The approach of transcribing the piece from a recording led me to explore new scoring techniques, like the controlled staggering of chord changes to get a sense of different moments fading in and out from each other.

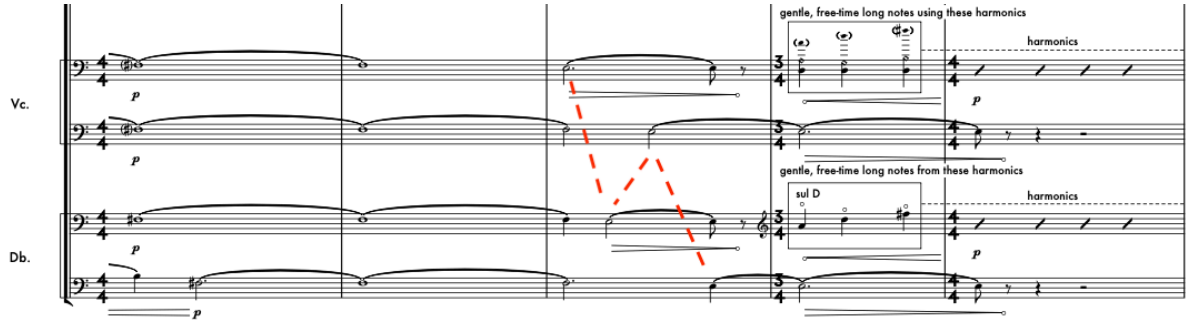

Figure 8: *A Slow Breath* bars 48-52 score excerpt with staggered bass note change from F-sharp to E annotated.

The tremolo texture that appears at the opening and closing of *A Slow Breath* is based on the first chord of *Backdrops* Volume 2 No. 57, scored for first violins and cellos. The first swelling gesture that enters at Figure A is taken from *Backdrops* Volume 1 No. 34, scored for violas and double basses. This combination of excerpts already provided *A Slow Breath* with an identifiable sound-world and left the second violins free to hold a chord that added warmth to the overall sound.

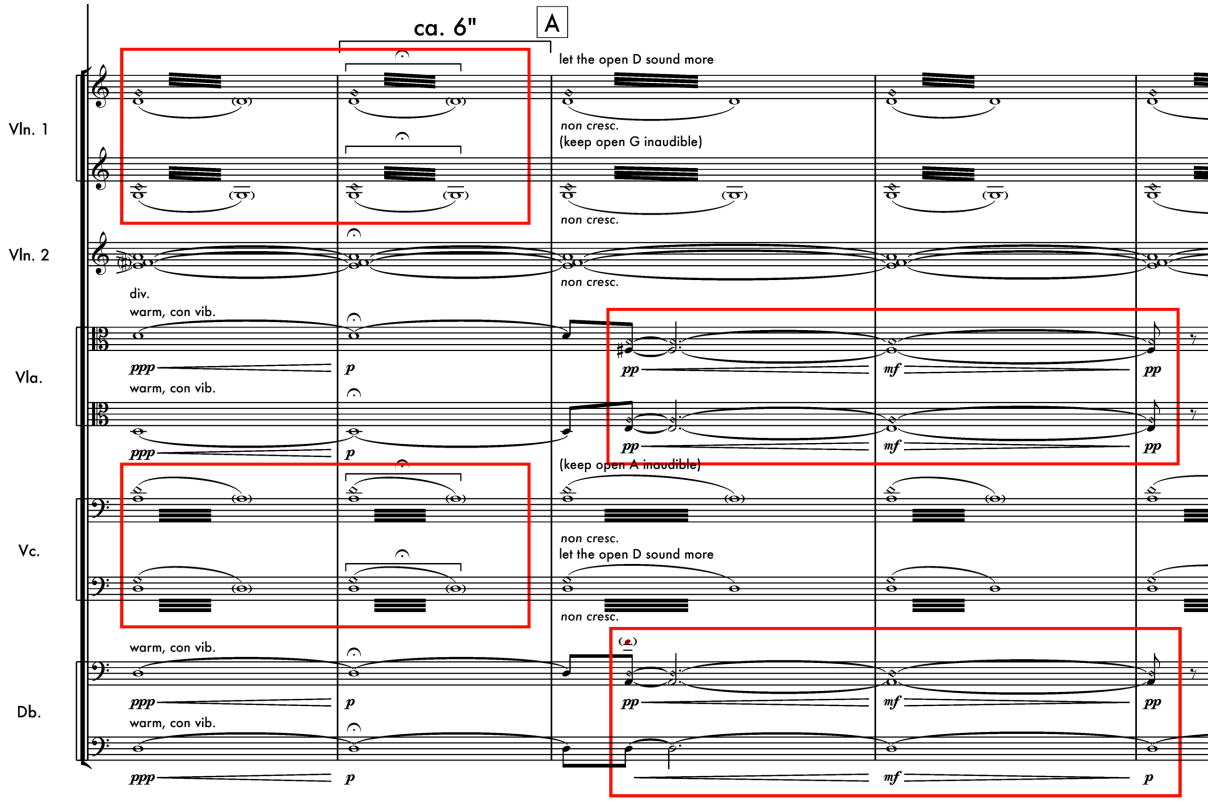

Figure 9: *A Slow Breath* bars 4-8 score excerpt with music taken from *Backdrops* annotated.

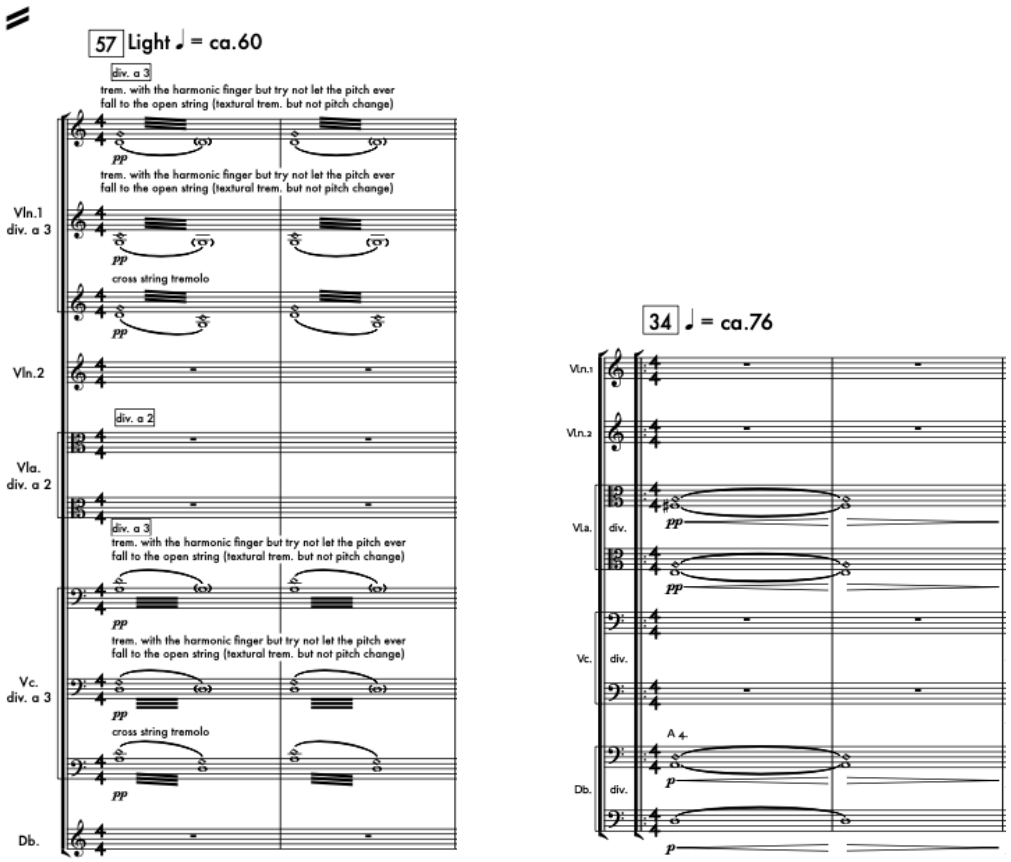

Figure 10: Score excerpts from *Backdrops* Volume 2, No. 57 (left) and *Backdrops* Volume 1, No. 34 (right) to show the moments from *A Slow Breath* annotated in Fig. 9 in their original settings.

Another way this approach to composition altered my writing was how chords were scored across the string section. I decided to give entire chords to individual sections rather than spread them across the full string ensemble as I might have done normally. This made it easier to score numerous very slow crossfades; gave each chord a subtly different tone colour; and created a spatial separation of chords in the stereo recording.

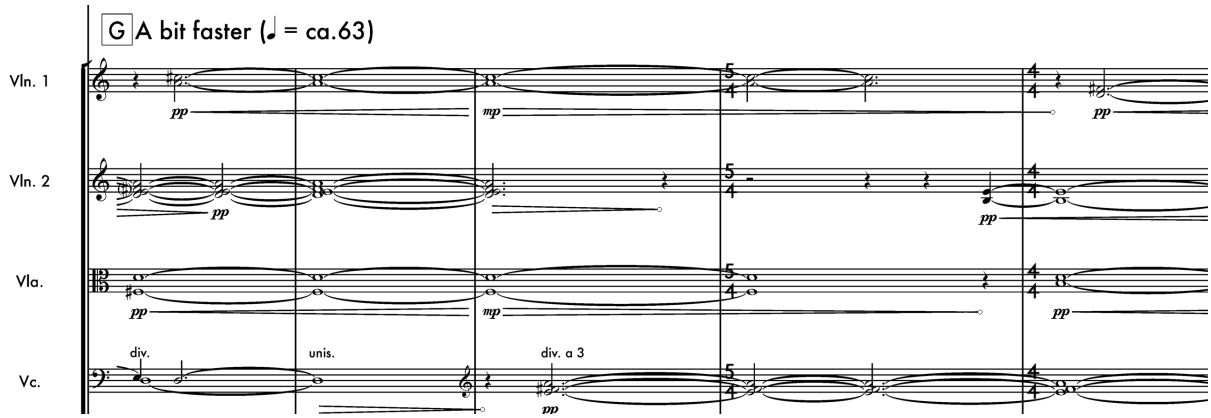

Figure 11: *A Slow Breath* Figure G score excerpt showing string divisi and crossfade approach.

Figure E is an example of a moment where two contrasting ideas are combined in a way that they might not have been were it not for the collage-like approach to composition. Some of the strings begin playing long harmonic notes in free time, taken from bar 3 of *Backdrops* Volume 2 No. 58, which accompany the first real sense of pulse provided by the harp's crotchet figure.

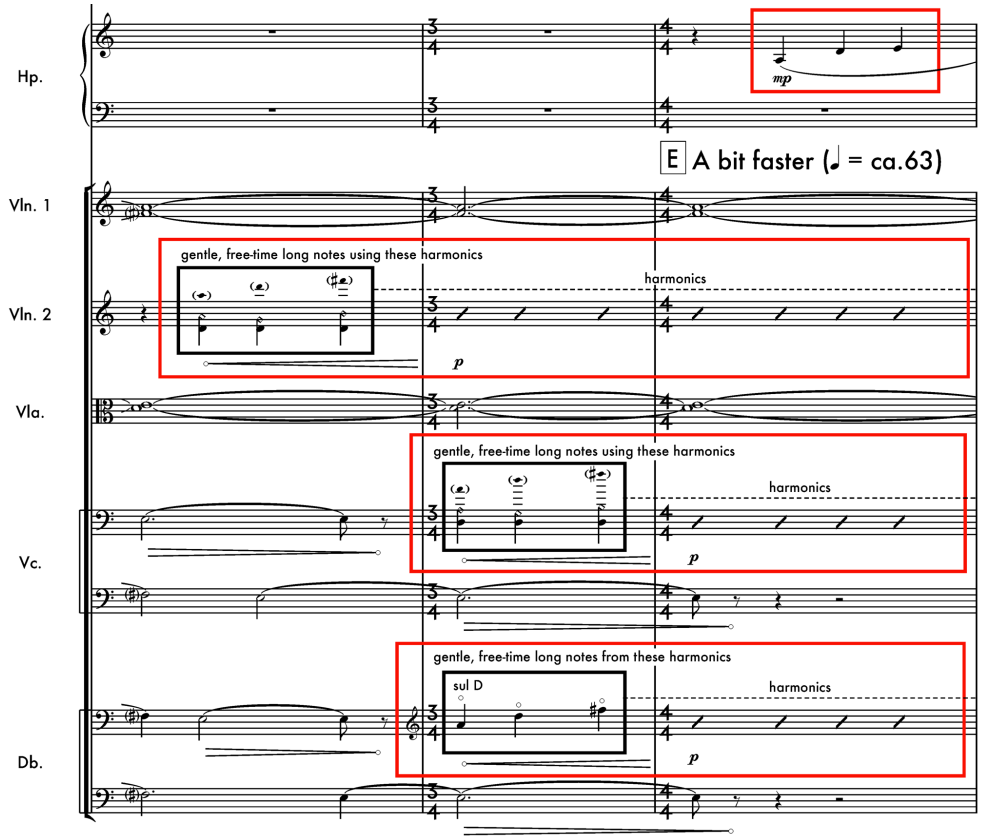

Figure 12: *A Slow Breath* Figure E score excerpt with free-time harmonics and crotchet movement annotated.

Because *A Slow Breath* was created via my own reassembly of materials from *Backdrops*, it has a clear similarity to the earlier composition in terms of its mood and timbral characteristics. As a result, it could be considered an additional part of the *Backdrops* composition, or the continuation of a modular working practice, described by James Saunders as the "possibility of renouncing the composition of individual works in favour of developing a single generative meta-composition."[21] Despite this, I regard *A Slow Breath* more as a standalone piece, with its own name, in the same way Cardew's interpretation of *Octet '61 for Jasper Johns* is retitled *Winter Potato No. 1*. Importantly, whilst *Backdrops* is a composition that exists as pre-recorded audio, the process of transcribing the recording back into notated form when composing *A Slow Breath* has resulted in a piece that could be played by an orchestra in a concert hall, and have a life outside of its use in the meditation podcast.

[21] James Saunders, "Modular Music," *Perspectives of New Music*, Vol. 46, No. 1 (Winter 2008): 188.

Technology: Probability and Audience Interaction

One important aspect of my creative practice is the significant role technology plays as part of the compositional process. In the compositions discussed in this chapter, technology acts in two key ways: it facilitates an element of interactivity, which allows the audience to become co-creators of the musical experience, and acts as a generator of random events, providing probabilistic tools that add a level of indeterminacy and openness to the compositions. Audience interaction is a theme that will appear again in later chapters, so probability will take more of a focus in this one.

Technology in the following compositions acts as the source of chance events that can be manipulated by the listener to alter the resulting musical experience. This approach differs from John Cage's adoption of chance events in the composition of pieces such as *Music of Changes*. Here the music is "indeterminate with respect to composition," but "determinate with respect to its performance."[22] In my pieces, I view the composing stage as taking place prior to the chance events, which in turn take place in the moment of performance, allowing for the element of audience interaction to take place.

This method of using random events as probabilistic tools that can be adjusted live (within set parameters) by a listener is summarised well by Brian Eno when he gives the following definition of an 'experimental composition':

"I hope to show that an experimental composition aims to set in motion a system, or organism that will generate unique (that is, not necessarily repeatable) outputs, but that, at the same time, seeks to limit the range of these outputs. This is a tendency toward a 'class of goals' rather than a particular goal, and it is distinct from the 'goalless behaviour' (indeterminacy) idea that gained currency in the 1960s."[23]

A Single Point In Time

In the first UK lockdown following the outbreak of the COVID-19 pandemic, when most of the music projects I had been involved in were put on hold, I began composing music to be generated and performed entirely on a computer. Having been writing pieces like *Day One* and *Backdrops,* where certain elements of the composition are intended to be shaped by someone else, I wanted to explore how a similar approach could be achieved using a computer generating random events.

Iannis Xenakis' 1956 composition *Pithoprakta*, which translates as "actions through probability," is modelled around the kinetic theory of gases, where the random movements of individual molecules are averaged out and an overall directional trend can be viewed

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[22] Christoph Cox and Daniel Warner, "IV. The Open Work: Introduction," in *Audio Culture: Readings in Modern Music*, edited by Christoph Cox and Daniel Warner (New York, London: Continuum, 2008), 165.

[23] Brian Eno, "Generating and Organizing Variety in the Arts," in *Audio Culture: Readings in Modern Music*, edited by Christoph Cox and Daniel Warner (New York, London: Continuum, 2008), 227.

when a vast number of molecules are observed.[24] When discussing Xenakis' music in the context of probability theory, Christopher Butchers relates it to the appreciation in modern science of the "general characteristics of entities on a macrocosmic plane, the precise properties of the micro-components of those entities being irrelevant."[25] Put more simply, the behaviour of a large collection of events can be predictable, even if those individual events themselves are not. In the case of *Pithoprakta*, Xenakis creates a sense of general movement across the ensemble that wouldn't be discernible if following a single instrument's line.

Tristan Perich takes this handling of the large-scale behaviour of many random events even further in his composition *Noise Patterns* from 2016. As with his previous piece, *1-Bit Symphony*, the music in *Noise Patterns* is created directly from the on-off operations of a small number of chips installed on a circuit board.[26] In *1-Bit Symphony*, Perich instructs each chip how many times a second to swap between on and off, therefore creating a digital square wave at a certain frequency. In *Noise Patterns*, each chip is instead given a probability of swapping between on and off at any moment in time. Perich describes how "a high density, or a high probability of switching back and forth randomly between 1 and 0, sounds a lot like white noise… As I lower the probability, as I make it less dense, more sparse, it sort of sounds like an EQ filter sweep, white noise down to a rounder wash of sound. As I lower that even more, it turns into a crackle, a sparse crackle. As it goes down even farther it just becomes sporadic pops."[27] Given the huge number of possible swaps between on and off each second, providing the probability of a swap occurring creates a predictable quality of resulting sound.

Whilst I didn't want to reduce the random events in my composition to as homogenous a mass as the white noise used in Tristan Perich's *Noise Patterns*, I wanted the overall texture of my music to have a similar swarm-like quality to it. I was also interested to see if random events could not only dictate the pitches and harmonies of the music, but the way the piece would progress through time as well.

The piece I composed, *A Single Point In Time*, is a 64-channel composition, with each channel generating a sawtooth wave. In the background of the piece, inaudible to the listener, an audio sample of a double bass playing a 4-note bass line (C-sharp, G-sharp, B, A) is played as a loop by 64 voices at slightly different speeds. The speeds that each of the 64 bass lines are played at are selected randomly from within a range of 3% above and below a fixed tempo. This means that at the start of the piece the bass lines are roughly in the same place as each other, but as the piece progresses they move further and further apart. With each new performance, the speeds of each bass line will be different, and the progression of the piece will differ slightly.

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[24] James Harley, *Xenakis: His Life in Music* (New York, London: Routledge, 2004), 12-13.
[25] Christopher Butchers, "The Random Arts: Xenakis, Mathematics and Music," *Tempo*, No. 85 (Summer, 1968): 2.
[26] Tristan Perich and Mark Weidenbaum, "The Circuit Board Record Album," *Disquiet*, June 23, 2016, accessed May 22, 2022, https://disquiet.com/2016/06/23/tristan-perich-noise-patterns/.
[27] Perich and Weidenbaum, "The Circuit Board Record Album."

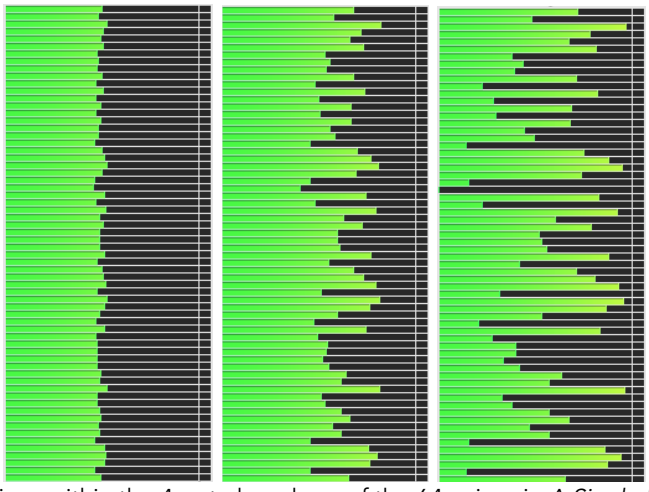

Figure 13: Relative positions within the 4-note bass loop of the 64 voices in *A Single Point In Time*. Snapshots taken towards the start (left), middle (middle), and end (right) of the piece, showing the dispersion over time.

To translate the audio from the sampled bass line to the sawtooth wave generators, the program takes short 'snapshots' of the audio, and attempts to guess the frequency of the sound it is hearing. This is where the double bass sample is important: it contains a lot of non-pitched sound, like bow scratch, which means that the computer's frequency prediction is not always accurate, which provides complexity and variation to the music. Once each of the 64 audio channels has been converted to a frequency (therefore, a number), that frequency is multiplied by a random whole number between 1 and 15, which creates a new frequency from the harmonic series of the original frequency: a partial. It is the frequency of these partials that are then delivered to the sawtooth wave generators that create the pitched sound that is heard.

The rapid pace of the music is generated by the rate at which the program takes a new snapshot and makes a new prediction of the bass line frequencies it is hearing. With each snapshot, 64 frequencies are taken from the 64 bass line audio samples (each playing at a slightly different speed), which are then multiplied by 64 different random numbers between 1 and 15, generating 64 unique frequencies that form the chord the listeners hear.

To help identify what was happening in the music, I created a visual analogy of a grid of 64 coloured squares, each representing one of the 64 audio channels. Each bass note is associated with a colour (C-sharp, G-sharp, B, and A are blue, red, green, and yellow, respectively), and the higher the partial associated with that bass note (from 1 to 15), the brighter the colour. At the start of the piece, when the 64 bass lines are still roughly in the same place as each other, the grid displays different shades of a single colour. Towards the end of the piece, when the bass lines are totally out of time with each other, the grid displays a patchwork array of different colours, representing the partials from the four different harmonic series you are hearing.

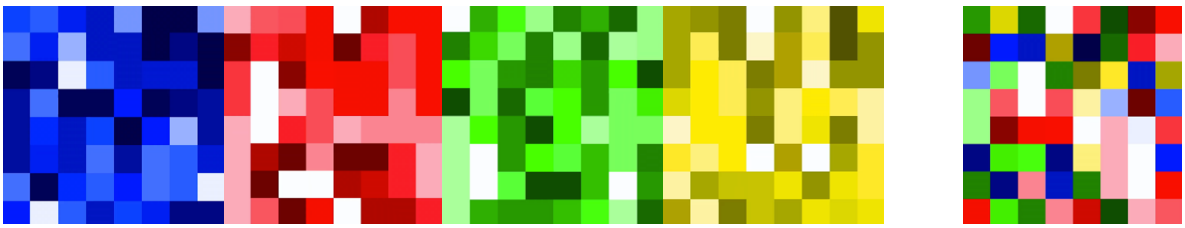

Figure 14: Four moments from the start of *A Single Point In Time* with each colour representing a bass note, and one from towards the end where all the bass notes have combined.

To analyse the harmony of *A Single Point In Time*, you need to look at the first fifteen partials of the harmonic series for each of the four bass notes. When the grid shows a single colour, you are hearing the harmonic series on a single note, which is a harmony we are mostly familiar with. As soon as colours start mixing, the harmony we are hearing will be taken from two or more harmonic series. The interval between each pair of neighbouring bass notes is different, meaning that each colour combination will provide a different mixture of harmonic series. Blue and red represents harmonic series on C-sharp and G-sharp, which are a perfect fourth apart; red and green are G-sharp and B, which are a minor third apart; green and yellow are B and A, which are a major second apart; and yellow and blue are A and C-sharp, which are a major third apart.

Looking at the harmonic series below you can see that even if neighbouring series share common notes, they are unlikely to have the same tuning. The number below each note in the series indicates the partial numbers which create that pitch, and the number above each note shows how the tuning of that pitch differs from equal temperament in cents (100 cents is 1 semitone). The C-sharp and G-sharp series are probably the most harmonious pair, given that the note G-sharp appears regularly in both series, and the 2-cent difference in tuning is essentially inaudible. Despite this, the combination of these two series still has the potential to create a rich array of complex chords, and features some audibly different tunings of shared notes, like the 55-cent difference between the tunings of the two high E-sharps.

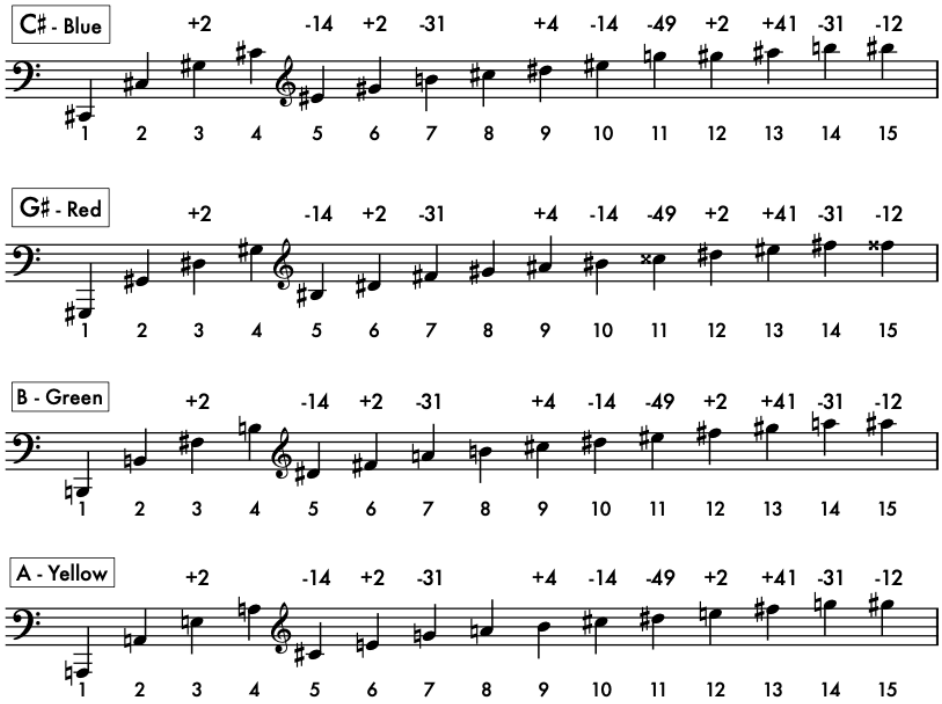

Figure 15: The pitches used in *A Single Point In Time*, taken from four harmonic series.

As the piece progresses, some large-scale operations are applied to the entire 64-voice ensemble. Firstly, after a couple of cycles of the 4-note bass line, individual voices are 'frozen' one-by-one until a dense static chord is formed and held, before all voices are released again simultaneously. Because of the random variation in the speed of the 64 bass lines; the possibility for error in prediction of the bass note frequency; and the random selection of partials that each voice will be playing; there is an almost infinitely small chance that any chord would be formed twice, and therefore in practice each chord heard is unique.

About halfway through the piece, all voices are suddenly forced to the same partial: number 6. Depending on where within each of the 64 bass lines each voice is at that moment, the pitch generated from partial 6 will be G-sharp, D-sharp, F-sharp or E. From this point on, a second 4-note sequence is superimposed onto the music, as voices are forced to certain partials, and then released, in the order: 6, 4, 6, 4.5 (an octave below the 9th partial). As the bass lines get further and further apart from each other, and the piece becomes increasingly dissonant, the forcing of all voices to a certain partial helps return harmonic clarity to the music, as the notes of the original 4-note bass line are now stacked on top of each other to form chords.

My original intention for *A Single Point In Time* was to have the piece displayed in a gallery space, with audience members able to enact the large-scale operations on the artwork themselves as a form of interaction. In the end, as the COVID-19 pandemic extended, and the opportunity to develop the piece into an installation piece didn't arise, I decided to create a video of one of my own performances of the piece and release it online. At the time this felt like a fitting space for the work to be heard in. Many other forms of musical performance were being broadcast and heard in a virtual space, and given the purely

electronic method of the piece's creation it seemed a suitable match. I am still hopeful that an opportunity will arise for *A Single Point In Time* to be translated into an exhibition piece and shown to a live audience.

Blocking Measures and *Forest Fire*

Shortly following the release of *A Single Point In Time*, in September 2020, I was employed as Artist-in-Residence at the University of Bristol School of Mathematics. The purpose of my role was to help introduce an audience with no background in mathematics to some of the concepts being studied by researchers at the university. I thought that creating audiovisual compositions based on mathematical ideas and presenting them as interactive artworks would be a good way to achieve meaningful engagement with the audience. My assumption when beginning the project was that each piece would be based on a certain mathematical process, and that the audience could be given control of this process's development, shaping the final musical, and in this case visual, experience.

Among the researchers I was working with were Márton Balázs, who specialises in stochastic interacting particle systems, and Edward Crane, who studies self-organized criticality. These collaborations introduced me to structures based on random events that were much more complex than my technique of generating random numbers in *A Single Point In Time*, and led to the creation of pieces with more interesting behaviours.

The residency culminated in an exhibition of four of my compositions, each of which were able to be interacted with by their listeners. I wanted the pieces based on probability to have visuals that were directly related to the music being heard, as *A Single Point In Time* did, and for their structures to be shaped by both the audience and the random events. My aim was for the listeners' control over the mathematical processes to help them better understand and appreciate the mathematics taking place, and the music being created.

Angela Bulloch is an artist who works with colour, light, and sound, and finds ways for the audience to interact with her pieces. "*Pixel/Sound Stack* responds to both audience and environment, listening in to the changing soundscape it inhabits. Working with the spectrums of both light and colour, it pixelates in different colours according to changes it detects in the surrounding sound."[28] I wanted my artworks to have a similarly conversational approach to Bulloch's *Pixel/Sound Stack*, where audience members were aware of the changing colours and sound created by the artwork, but also of how the artwork would respond to their interaction.

The two interactive artworks I created based on ideas of probability were *Blocking Measures* and *Forest Fire*. Both used a visual language of coloured squares similar to *A Single Point In Time*, but this time they existed outside the virtual performance space and were represented using 3D-printed LED matrices designed and created by the University of Bristol Faculty of Engineering Technicians.

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[28] Angela Bulloch, "Angela Bulloch," in *Sonic Boom*, edited by David Toop (London: Hayward Gallery, 2000), 18.

Figure 16: A photo from the exhibition, showing *Forest Fire* (left) and *Blocking Measures* (right).

Blocking Measures

Blocking Measures was created in collaboration with Márton Balázs. The piece exists on a horizontal strip of 60 squares. Nine of these squares are coloured either red, green, or blue: three of each. The coloured squares represent particles that can move randomly left or right along the line. The particles can't pass each other and so get 'blocked', creating areas of congestion at certain points. The system shows the complex behaviours that can emerge when large numbers of simple random events are combined, and has real-world analogies in situations like traffic jams. The audience has control over the probability of a particle travelling left or right when it moves, and through this can affect the overall movement of the group.

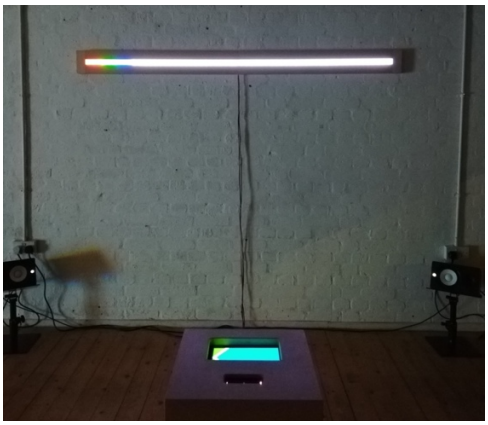

Figure 17: *Blocking Measures* on display during the exhibition.

Having experimented with several texturally dense musical sound-worlds like the one created by *A Single Point In Time*, I decided that the music generated from this mathematical process ought to match what the audience was seeing, which was the fast movement of a group of nine particles moving left and right randomly. Each group of particles represents an instrument group: red and blue are two different synthesizers, and green is percussion. Each time a particle moves, a pre-recorded note on that instrument is triggered. To begin to build complexity into the music, and reflect the behaviour of the system, the further apart each of the synth particles get from their neighbour within the same group, the higher the pitch of the triggered note is, with pitches taken from a

predetermined scale. This means that it is clearly audible when those groups of particles begin to spread apart. The percussion particles do not change pitch, but each particle is assigned to a different roto-tom. Every note heard in *Blocking Measures* was recorded several times with a range of dynamic and timbral variations to stop the performance sounding overly repetitive. Additionally, there is a background chord that grows louder as the overall group of particles spreads out, and a note that changes depending on how far left or right the average position of the total group is.

What is effective about *Blocking Measures* is that you can clearly hear the multitude of events occurring within the artwork, whilst also watching as the ensemble of particles slowly shifts its position from one location to another. Additionally, the audience interaction is not always intuitive. For example, a 60% chance that the particles will move to the right still includes regular movement of individual particles to the left and it can take quite a long time before the whole group has travelled to the right of the artwork. This is interesting when considering the audience's expectation of their own role within the performance, as they are not given total control of the artwork, and there is a sense of the piece having a life of its own beyond their influence.

Forest Fire

Forest Fire was created in collaboration with Edward Crane. It is based on the forest fire mathematical model; an example of self-organized criticality where interactions between random events fall into a regular pattern, and the system achieves a state of equilibrium overall. *Forest Fire* exists on a 10x10 grid of squares. As time passes, there is a random chance that a tree will grow in one of the squares, represented in the artwork as a green light. As more trees grow, the density of the forest increases. There is also a random chance that lightning will strike and, if it hits a tree, set the tree on fire. A burning tree will spread the fire to any neighbouring trees and disappear (I used the Von Neumann neighbourhood of only the four adjacent squares, not diagonal neighbours). Depending on the probabilities of trees growing and fires starting, the behaviour of the system can change dramatically. In my *Forest Fire* artwork, audience members are given control over these two probabilities.

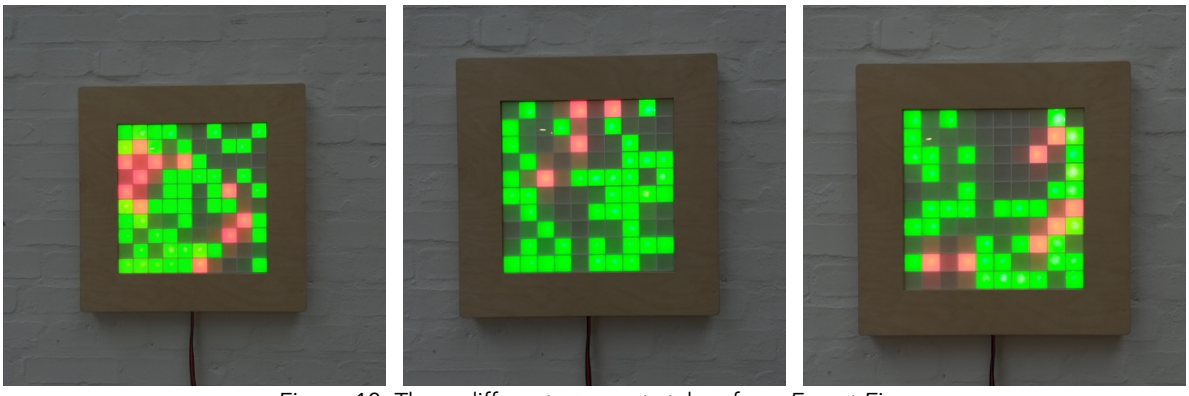

Figure 18: Three different moments taken from *Forest Fire*.

Like *Blocking Measures*, the musical components of *Forest Fire* are extremely simple, and it is the complexity of the overall system that creates the variation in the music that is heard. I wanted each of the 100 squares to be its own voice that would join the ensemble whenever

it was displaying a tree or a fire. When a tree grows in a square, a slow rising melodic line starts playing using a recording of either a synthesizer or a clarinet (50 of the squares are one, 50 are the other). When lots of trees are heard together this melodic line forms a dense chord that keeps climbing and bending upwards. This creates a real sense of anticipation for an incoming fire outbreak and adds an element of tension. To reflect this, when a tree first grows, the light on the grid is pure green, but as time passes it slowly changes colour to yellow. This helps the audience identify which trees have been on the grid for longer, and which have just started growing.

In contrast to the trees, which are sustained events that remain on the grid and slowly fill up the available space, the fires are short and fast outbursts that spread rapidly across neighbouring trees and disappear. Musically these are represented by an accented staccato bass note (performed by both bass clarinet and synthesizer) that can be strung together depending on how long the fire spreads for, creating a driving semiquaver rhythm. Like *Blocking Measures*, there are also overall behaviours in the system that affect the music in *Forest Fire*. When the density of the forest has climbed above 50%, the bass note shifts to the next note in a sequence of three notes. This means that there are times when the harmonic foundation of the music hardly changes and the piece feels quite static, and others where each fire outbreak has a new bass note attached to it, and the music is given a sense of forward momentum and progression.

I believe *Forest Fire* is a good example of how very few musical elements can be reorganised to form a wide variety of different outcomes. The piece can range from huge, bending chords with occasional fire sweeps, to non-stop bass notes looping a 3-note sequence, with the melodic sequence of the trees never able to progress beyond the first note. All of this is generated through random events, with the audience able to control the likelihood of those events happening and shape the piece accordingly.

Given that both *Forest Fire* and *Blocking Measures* were composed to be heard in an exhibition setting, where the audience are in control of the time they spend with the pieces, I decided not to impose any narrative structures on either of them. They begin when the computer is turned on and end when it is turned off. The musical narrative between those points is determined by the audience's interaction with the probabilities at the heart of each composition, and the computer's construction of the music based on those probabilities.

Geometry: Perfectly Balanced Rhythms

In the process of discussing experimental music, Brian Eno describes the traditional classical orchestra as being organised as a "ranked pyramidal hierarchy of the same kind as the armies that existed contemporary to it."[29] When exploring the implications of this hierarchy he makes an interesting statement:

"Ranking has another effect: like perspective in painting, it creates 'focus' and 'point of view.' A listener is given the impression that there are a foreground and a background to the music and cannot fail to notice that most of the 'high-responsibility' events take place in the foreground, to which the background is an ambience or counterpoint. This is to say that the number of perceptual positions available to the listener is likely to be limited."[30]

I was interested in the concept of a flexible musical experience where this sense of foreground and background is no longer inherently built into the composition; where the number of perceptual positions available to the listener is unlimited and they are given full control over their own perspective of the piece.

When discussing Alexander Calder's mobile sculptures, Earle Brown describes "a flexible situation that subjects the original relationships to constant and virtually unpredictable, but inherent, change," and identifies that this 'change' is created both by the "movement of the units as well as the movement of the viewer."[31]

A musical equivalent to this 'flexible situation' in sculpture is the type of experience in which the musicians are spatially dispersed, and the audience is free to roam throughout the performance space. John Luther Adams describes his 2009 composition *Inuksuit* as "a concert-length work for percussion, in which the performers are widely dispersed and move throughout a large, open area. The listeners, too, may move around freely and discover their own individual listening points."[32]

This approach appears to remove the built-in musical foreground and background described by Brian Eno in the quotation above. There are however several other aspects of *Inuksuit* that add elements of indeterminacy to the performance such as the locations and movement of the performers; the flexible size of the ensemble (from 9 to 99); the construction of the score; and the duration of the piece. For the exploration of audience agency in my own creative practice I wanted to fix down these other elements, allowing the listeners to be fully aware of the part they are playing in shaping the musical experience.

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[29] Brian Eno, "Generating and Organizing Variety in the Arts," in *Audio Culture: Readings in Modern Music*, edited by Christoph Cox and Daniel Warner (New York, London: Continuum, 2008), 226.
[30] Eno, "Generating and Organizing Variety in the Arts," 227.
[31] Earle Brown, "Transformations and Developments of a Radical Aesthetic," in *Audio Culture: Readings in Modern Music*, edited by Christoph Cox and Daniel Warner (New York, London: Continuum, 2008), 189-190.
[32] John Luther Adams, Introductory notes to *Inuksuit* (Taiga Press, 2009).

Balance

Balance was composed as part of a project funded by Digital Catapult to design new artistic experiences using virtual reality technology. I collaborated with producer Emma Hughes and technology company All Seeing Eye Ltd to create a recording of a piece of music that was mapped to 3D space and could be explored physically by its listeners. The concept relied on the HTC Vive virtual reality system that could pinpoint very accurately the position and orientation of tracking devices within a mapped-out area. These tracking devices were small enough to attach to the top of a pair of headphones, meaning that an audience member could be provided with a live-updating audio feed based on their location within a performance space. The recorded audio for each instrument involved in the piece would be spatially dispersed across the mapped-out area and the listeners would hear them as coming from a specific point in the room. Instruments and music stands were placed around the real, physical space to guide listeners to the places the recordings were located at.

Figure 19: Performance of *Balance* at the Royal College of Music's Britten Theatre on 01/10/18.

There were several interesting things about this idea, and the way a piece of music written for this setup would be heard and engaged with by its audience. Given that the listeners were able to move around the space and draw nearer to each instrument individually, dynamic control and a sense of instrumental balance was essentially left for them to decide. The further away they moved from the clarinet, for example, the quieter it would get in their headphones. This allowed situations where a musical line played fortissimo could be heard as a quiet, background accompaniment to an instrument playing pianissimo much closer to the listener. The result was that the listeners had a very intuitive sense of their role within the experience, as their slightest movement would change the music they were hearing in a way that they would immediately know how to control. Additionally, the listening experience exists somewhere between an individual experience and a communal one. Each

audience member wears a pair of headphones, which are associated with isolated, individual listening, but they are joined by up to four other people in the performance space, moving around the room together and hearing the music simultaneously.

One of my inspirations for this type of presentation of a piece of music, which allows an audience the freedom to explore the composition, is Janet Cardiff's artwork *Forty-Part Motet*. This installation is an inward-facing circle of speakers on stands, playing a recording of *Spem in Alium* by Thomas Tallis, with each voice in the choir coming from a single speaker. Audience members can choose between listening from the centre of the ring of speakers, hearing a balanced sound of the overall choir, or focussing in on a single vocal line by moving closer to an individual speaker. This hands control of the listening experience to the audience and creates a vast number of perspectives from which *Spem in Alium* can be heard. When discussing her audio walks, Cardiff describes how "every person will have a different experience of the piece depending on what happens around them or where and when they walk."[33] The concept of 'when' a listener is in a certain place was important to me when composing music for the virtual reality experience, as I had to deal with the possibility that some elements would not be heard if an audience member was not in a certain place at a certain time.

Because the music I was writing was going to exist in a virtual space, and be heard via headphones, I could have much greater control over the sonic environment of the room than is the case in *Forty-Part Motet*. Using the program designed by All Seeing Eye Ltd, a sound could be made to be inaudible from less than a metre away, or could be present at equal volume everywhere in the space. Because of this, we were able to create a much greater sense of discovery in our experience; giving listeners access via their headphones to a hidden sonic landscape. This approach is similar to Christina Kubisch's sound installation pieces, where specially designed headphones translate electro-magnetic fields carried by cables into music. Describing these installations, Kubisch says:

"The audience is able to move freely between various acoustic fields distributed throughout the sound zone, enabling the listener to discover ever new and individual sound combinations. These sound-zones are often created in the open air: in woodland glades for instance, or in buildings that were not constructed to act as concert halls, such as deserted factories, shipyards and cellars."[34]

It is in this discussion of performance spaces that my approach differs most from Kubisch's, as the venue for our installation was a concert hall (The Britten Theatre at the Royal College of Music in London) that had been designed to look as though a performance was taking place. Instruments, stands, and sheet music were set up, and stage lighting was synchronised with the music. We wanted the experience to feel as much like a concert performance as possible, but with five roaming audience members present instead of musicians, and all the music being created in a virtual space and delivered via headphones.

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[33] Janet Cardiff and Atom Egoyan, "Janet Cardiff," *BOMB*, No. 79 (Spring, 2002): 62.
[34] Christina Kubisch, "About My Installations," in *Sound by Artists*, edited by Dan Lander and Micah Lexier (Toronto: Art Metropole, Banff: Walter Philips Gallery, 1990), 72.

What I wanted to create in *Balance* was a piece that had no clear 'ranking' of instruments, and no inherent sense of 'foreground' and 'background', to return to the terms used in Brian Eno's essay on experimental music discussed earlier.[35] Instead, by repositioning themselves within the performance space, listeners would be able to choose their own perspective of the music and shape the musical experience.

As the audience experiencing *Balance* would be able to focus on each individual instrument at a time, I wanted the music to be built from layered melodies containing contrasting pulses that would give the impression that the music existed in different metres, or had multiple possible downbeats, depending on what perspective you had of the piece. I began searching for compositional methods that could achieve this effect whilst maintaining a sense of cohesion in the piece overall.

I was introduced to the concept of 'perfectly balanced' rhythms through the music creation software *Xronomorph* and several papers written by its developers.[36] On their website they state that "a rhythm is perfectly balanced when the mean position (centre of gravity) of all its rhythmic events, when arranged on a circle, is the centre of that circle."[37] This is demonstrated more clearly using the analogy of a bicycle wheel to represent the musical bar, or loop. Imagine the bike is placed upside down so the wheel is free to rotate. If you were to place a weight on the edge of the wheel, representing a beat within the loop, the wheel would rotate until that weight was vertically below the axle. This is because the wheel's centre of gravity has been shifted away from the centre and it has become unbalanced. To re-balance the wheel, you would have to place more weights on it: for example, an identical weight directly opposite the other one, creating an even pulse of two beats within the loop. This is the easiest way to ensure that all rhythms you create within the loop are balanced: to build them up from even pulses of notes or, to use a visual analogy, regular polygons within the circle. Polyrhythms are therefore perfectly balanced, as are rhythmic patterns where one of the groups of pulses in a polyrhythm has been displaced within the loop (or the shape has been rotated around the circle) so that the two pulses never coincide with each other.

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[35] Eno, "Generating and Organizing Variety in the Arts," 227.

[36] Andrew J. Milne, David Bulger, and Steffen A. Herff, "Exploring the space of perfectly balanced rhythms and scales," *Journal of Mathematics and Music* 11(2) (December, 2017): 101.

[37] Andrew J. Milne, "Perfectly balanced and well-formed rhythms," *Dynamic Tonality*, accessed May 28, 2022, https://www.dynamictonality.com/xronomorph.htm.

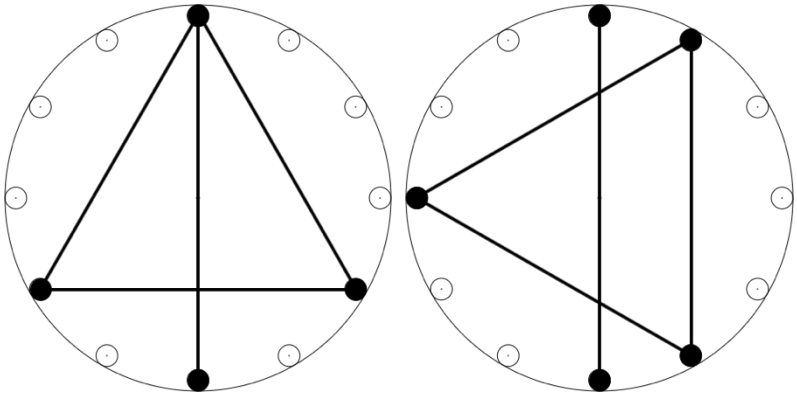

Figure 20: Two perfectly balanced rhythms created from even pulses of 2 and 3 beats within a 12-beat cycle. The left one is a standard 3-against-2 polyrhythm, with two pulses aligning at the top of the circle, and the other has the 3-beat pulse rotated one beat around the cycle.

Steve Coleman uses a technique in his music where rhythmic patterns are shifted around a loop, changing their position in relation to other musical elements and altering the listener's perspective of the music. His piece *Cardiovascular* is rhythmically structured around a fixed clave and a 4-note drum pattern. Throughout *Cardiovascular*, extra bass drum hits are occasionally added, shifting the 4-note pattern one beat later in relation to the clave.[38] The equivalent visual representation of this is the rotation of one shape clockwise around the circle, while the other shape remains fixed. This sets up an ambiguity for the listener regarding where the true pulse of the music, if there is one, should be felt.

Figure removed due to copyright

Figure 21: The three positions of the 4-note drum pattern against the clave in Steve Coleman's *Cardiovascular* (my transcription).

Nik Bärtsch has talked about being inspired by the music of Steve Coleman in an interview with Yogev Gabay. When talking about playing his own compositions he describes how "finally your feel is in all the beats, so you feel the seven, the five, or the four, and you feel

[38] Steve Coleman, "Steve Coleman – Cardiovascular – Rhythmic Voice Leading – Habana, Cuba" (video talk on Steve Coleman's piece *Cardiovascular*), uploaded February 20, 2017, accessed May 29, 2022, https://www.youtube.com/watch?v=NiuCafYOmb4.

the resulting patterns, and the topography of the piece just grows all the time."[39] To take an example from Bärtsch's music, *Modul 29_14* has a section built from combining pulses of two, three, four, and five semiquavers.

Despite the large number of different rhythmic layers in *Modul 29_14*, each pulse is easy to distinguish as it is played by a unique and identifiable instrument. The only exception in the example below is the bass clarinet, which performs a melody combining both a 5-semiquaver pulse (the G-sharp) and a 4-semiquaver pulse (the F-sharp). When the two notes coincide, the G-sharp is prioritised. I liked this approach of creating melodies from layered pulses and thought that in the context of *Balance* it would give the music a different metrical feel depending on where in the performance space a listener was located.

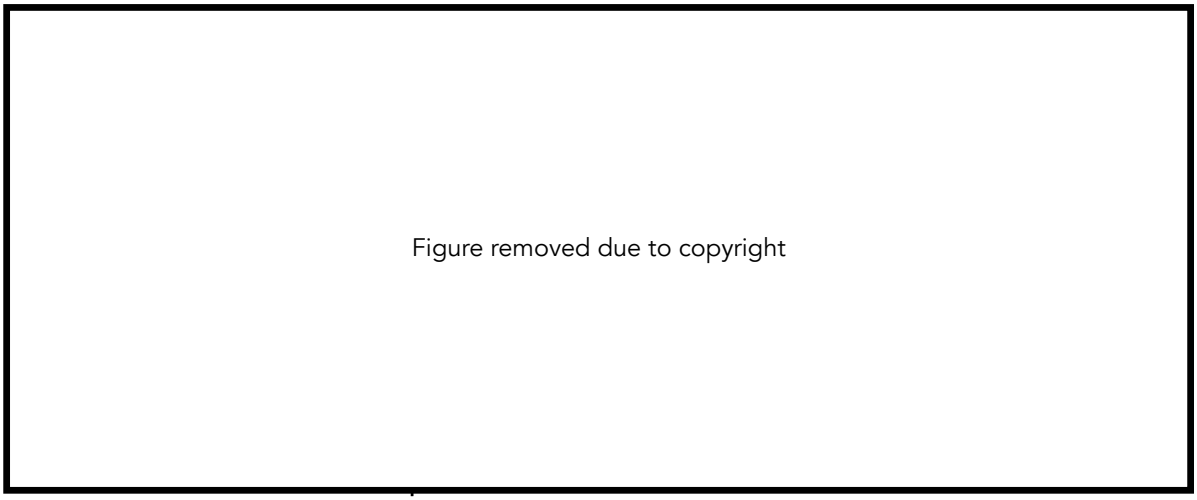

Figure 22: Excerpt of Nik Bärtsch's *Modul 29_14* from 2'02 in ECM 2464 (my transcription).

Following the approach of layering even pulses to create perfectly balanced rhythms I composed a simple rhythmic motif that would form the foundation of *Balance*. It was made from five 2-beat pulses existing within a cycle of thirty beats. In *Balance*, these beats are quavers, and the cycle is notated as five bars of 3/4. This framing of the thirty beats into bars of crotchets means that each pair of pulses has one beat landing on a crotchet on-beat, and its connected beat landing on a quaver off-beat. I labelled the beats arriving on the crotchet on-beats as the primary beats of each pulse (labelled with numbers in the diagram below) and the beats connected to them as secondary beats.

[39] Nik Bärtsch and Yogev Gabay, "A conversation with Nik Baertsch" (video interview), uploaded January 1, 2021, accessed May 29, 2022, https://www.youtube.com/watch?v=4BO6JcBs2GE.

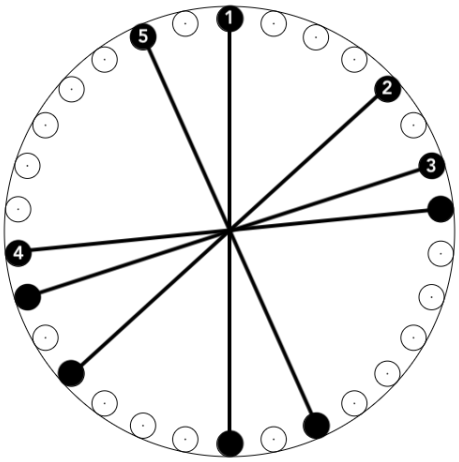

Figure 23: The rhythmic motif forming the foundation of *Balance*, shown as a perfectly balanced rhythm created from five pairs of pulses within a 30-beat cycle. Primary beats (landing on on-beats) numbered 1 to 5.

Figure 24: The rhythmic motif forming the foundation of *Balance*, shown as a rhythm spanning five bars of 3/4. Primary beats (landing on on-beats) numbered 1 to 5.

To generate melodic material, I distributed a 5-note chord (bottom to top: B, E, F-sharp, B, D) across the rhythmic motif as a rising line. By placing the low B on each of the five pulses I was able to create five different melodic shapes from which to develop the piece.

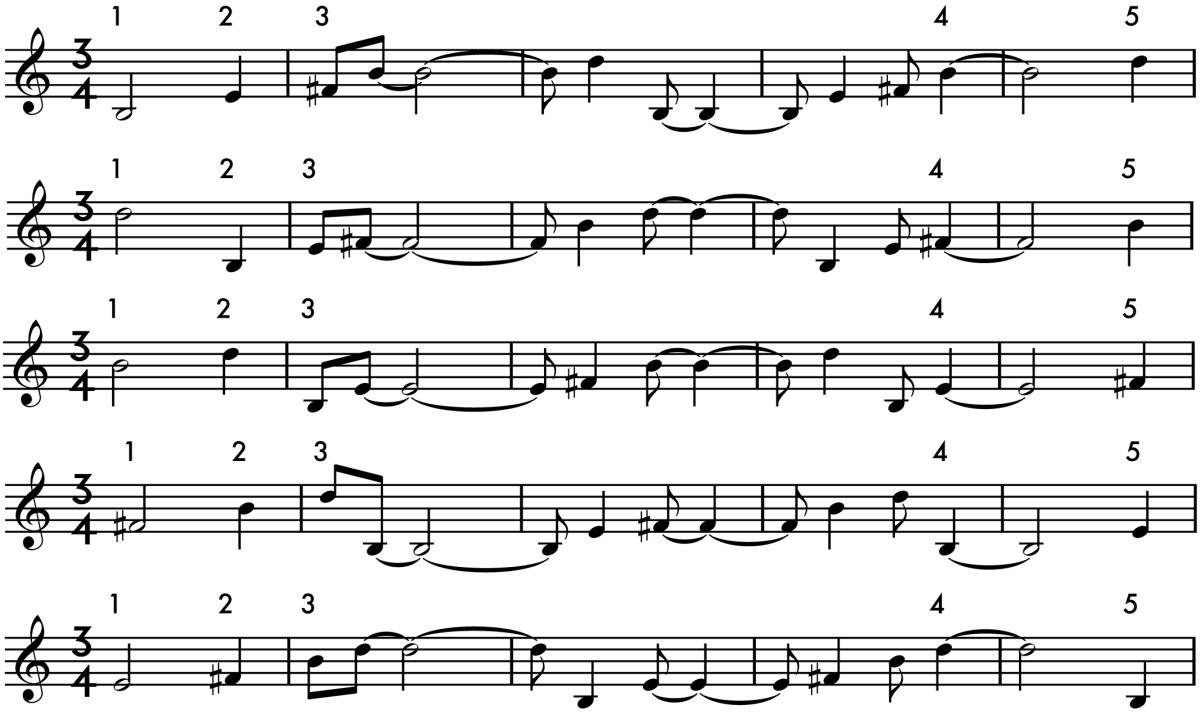

Figure 25: Five melodic outlines created by spreading a 5-note chord across the original rhythmic motif with the lowest note placed on a different pulse in each example (from top to bottom the lowest note is placed on pulses 1 to 5).

Balance opens with the gradual introduction of the five instruments, each slowly unveiling one of the melodies above, with the notes eventually shifting as the harmony changes. The idea was that from the very outset, depending on which instrument they were nearest, the audience would hear a different melody as the primary 'theme' of the piece, whilst everyone would hear the same basic rhythm.

As the piece progresses, the music is created from variations of the above melodies using pulses that occur increasingly frequently within the cycle. For example, imagine that instead of occurring only twice within the cycle, the fourth pulse occurred three times. Using the polygon notation, this could be shown as an equilateral triangle dividing the cycle evenly into three. This creates a variation on the original melodies and begins to shift attention away from the original rhythmic motif and towards the contrasting pulses. The clarinet line at Figure B (bar 38) is a demonstration of this variation, with some notes adjusted to fit the harmonic context.

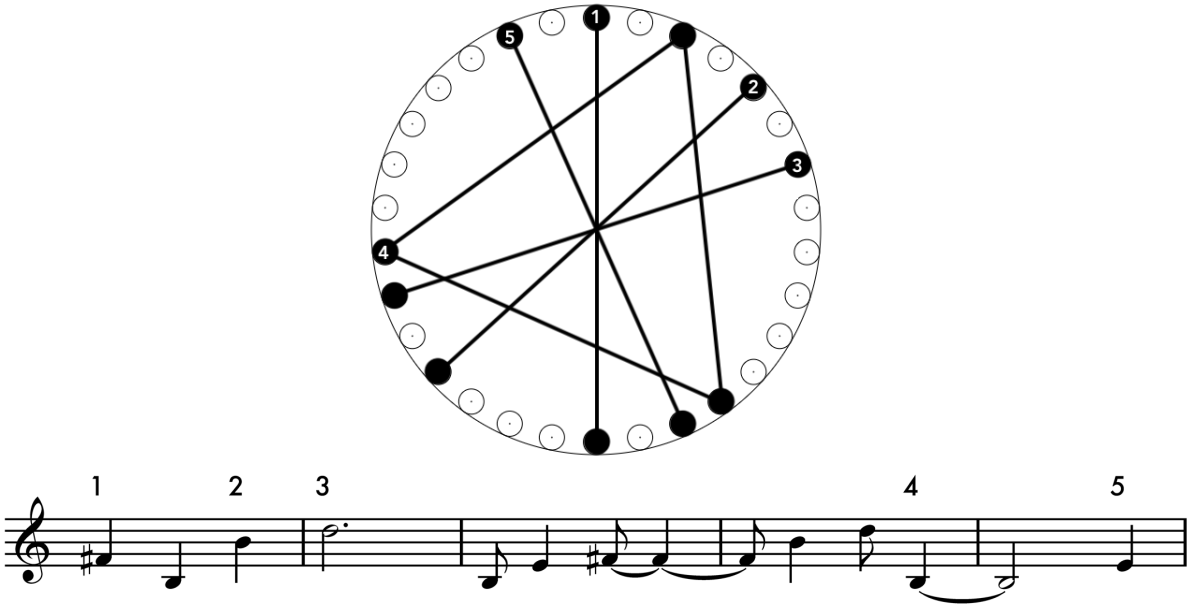

Figure 26: A variation on the original rhythmic motif, with the 4th pulse occurring three times within the cycle, and the melodic variation that is created as a result.

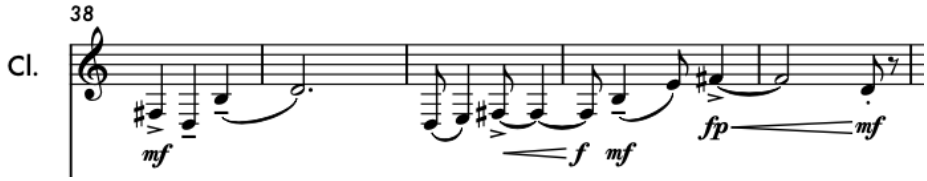

Figure 27: The appearance of this variation in *Balance* at Figure B (bar 38), with some notes adjusted to fit the harmonic context.

My intention was that as the piece progresses, the audience's perception of the music would be gradually drawn away from the original rhythmic motif, being played across all the instruments, and towards the pulses getting faster as the cycle is divided into increasingly small amounts of time. The position within the cycle of these pulses would differ across each instrument, creating a metrical ambiguity depending on which instrument was most present in a listener's headphones.

The section that develops from Figure I (bar 124) in *Balance* is a good example of this concept of conflicting pulses beginning to become more important than the original rhythmic motif. Each instrument enters playing a different variation on the original melodies created by dividing the 30-beat cycle evenly into six.

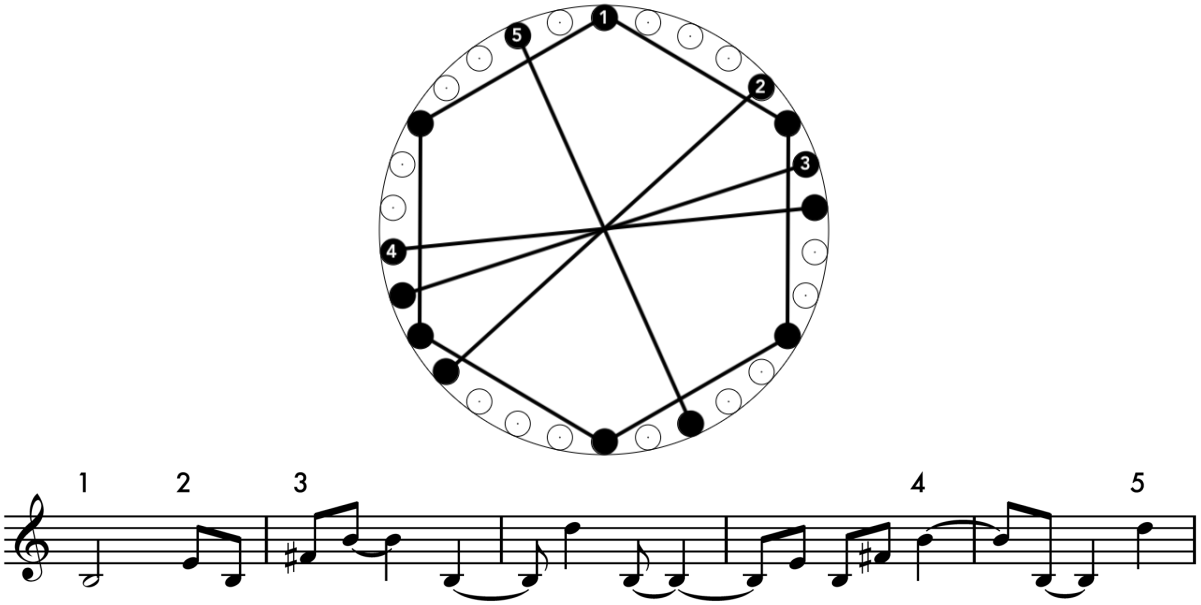

Figure 28: A variation on the original rhythmic motif, with the 1st pulse occurring six times within the cycle, and the melodic variation that is created as a result. The cello material at Figure M (below) is based on this pattern.

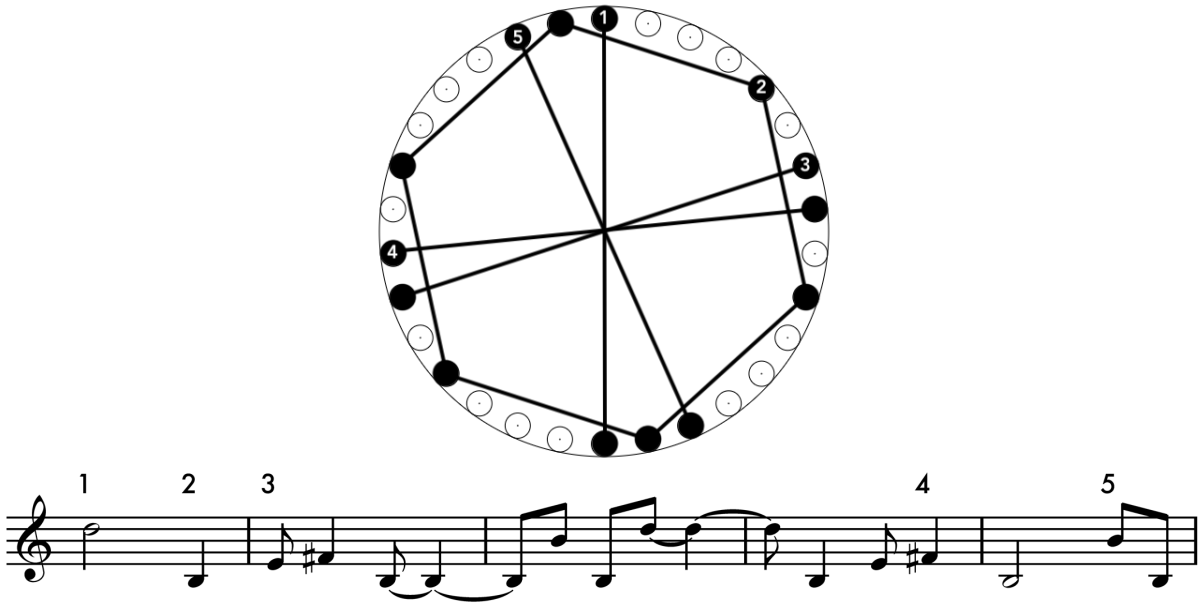

Figure 29: A variation on the original rhythmic motif, with the 2nd pulse occurring six times within the cycle, and the melodic variation that is created as a result. The piano material at Figure M (below) is based on this pattern.

What is satisfying about this structure is that none of the pulses coincide with any of the others, meaning that each instrument has their own unique pulse (each beat being five quavers long) that slots in with the original melodic material. The example below from Figure M (bar 156) shows the original rhythmic motif, shared across the whole ensemble, in

blue boxes, and the pulses dividing the cycle evenly into six, unique for each instrument, in red boxes.

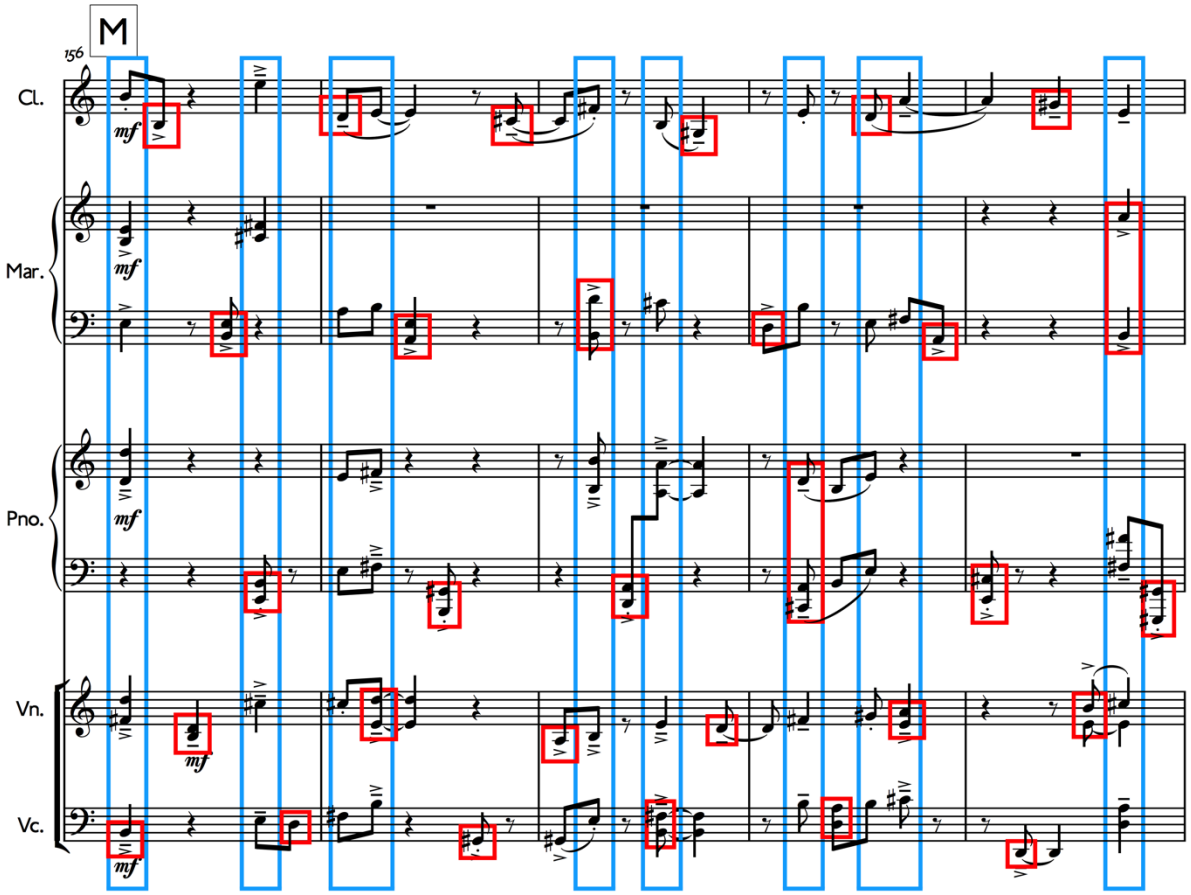

Figure 30: Figure M in *Balance*, with the original rhythmic motif shown in blue boxes, and each instrument's individual pulse of five quavers shown in red boxes. The only notes that exist outside of this structure are the additional cello note at the start of bar 158 and the displaced piano quavers in bar 159.

From Figure O (bar 178), the original rhythmic motif is desynchronised between instruments for the first time, losing its unity across the ensemble and allowing the pulses within each instrumental line to take the focus. The pulses have now sped up to beats of three quavers each, dividing the cycle evenly into ten, with the occasional stretching of the perceived tempo using pulses of four quavers (a pulse that can't be created from an even division of the 30-quaver cycle).

The example below shows the melodic variation arising from the first pulse occurring ten times within the cycle, and its appearance in the piano line during the final moments of Balance. The other instruments are annotated to show where the original rhythmic motif exists in their parts (with beats numbered 1 to 5), and where their pulses lie. The original rhythmic motif is boxed in blue, the 3-quaver pulse in red, and the stretching of the pulse to a 4-quaver beat is shown in green.

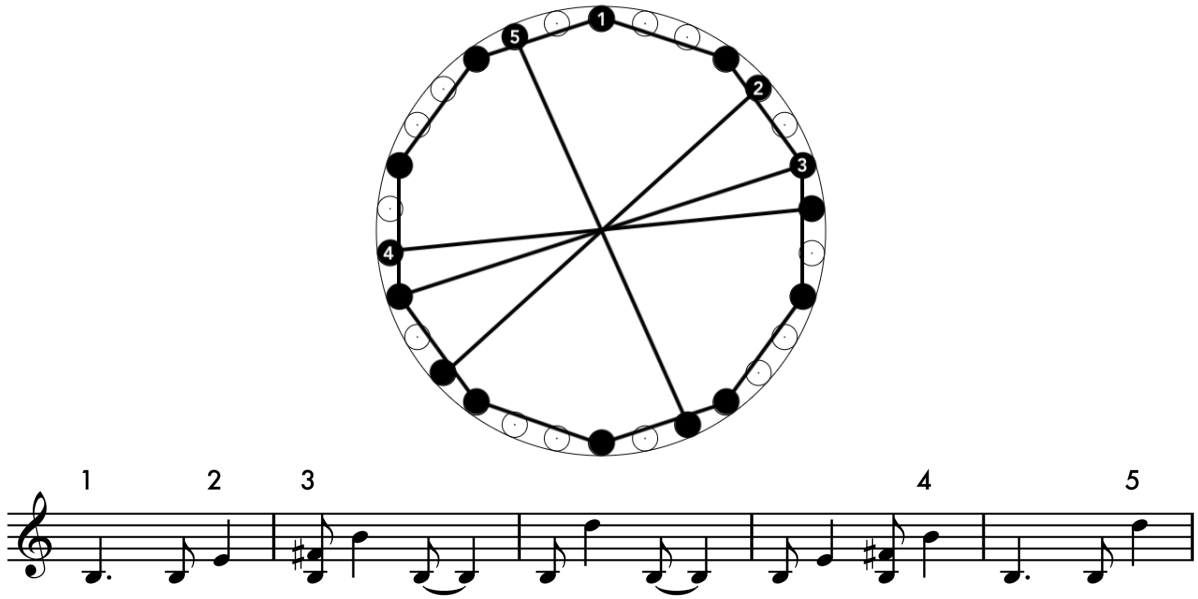

Figure 31: A variation on the original rhythmic motif, with the 1st pulse occurring ten times within the cycle, and the melodic variation that is created as a result. The piano material at bar 186 (below) is based on this pattern.

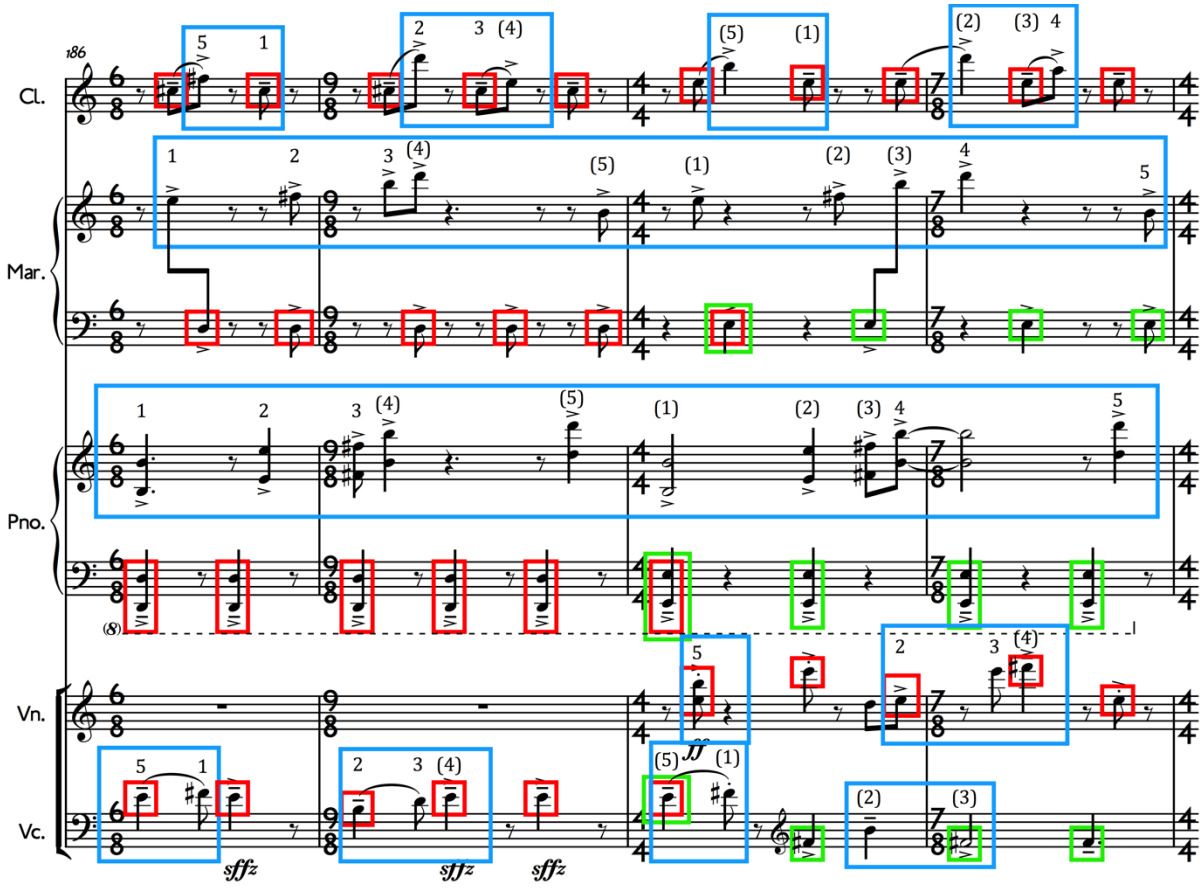

Figure 32: Bars 186-189 in *Balance*, with the original rhythmic motif shown in blue boxes, and each instrument's individual pulse shown in red and green boxes.

Although the *Balance* installation was well received by listeners, there were several things I wanted to change going forward. We had asked audience members to book a 15-minute time slot, which allowed them to experience the piece once before we welcomed the next group. This was a lot of extra work for our team and meant that listeners did not get a

chance to fully explore the installation for longer than the music's duration, or easily leave early if they wanted to. This was the first piece I had written to be heard in a gallery space and going forward I made the decision to present any fixed-duration music as an endless loop, or write music that had no clear beginning or end, for this setting.

The other thing I hadn't anticipated was how sparse and empty the listening experience of *Balance* was, given the spatiality of the ensemble's layout, and the focus placed on individual instruments. As a result of this, I decided that the overall textural density should be increased in future compositions written for this type of experience. *Ocean Avenue*, discussed below, applies the perfectly balanced rhythm technique more loosely, allowing greater flexibility in the placement of layered melodies, which in turn creates a bigger contrast between the different perceptual positions available to the listener.

Ocean Avenue

I was provided funding by the Bliss Trust to study with Nico Muhly in New York for two months in 2019. During this time, I worked on a new composition, *Ocean Avenue*, that was intended to be heard within the same virtual reality experience that had been developed for *Balance*. However, the opportunity to record *Ocean Avenue* in the format that would allow it to be used in the virtual reality system is yet to arise (each instrument needs to be recorded individually), and so the recording submitted as part of this portfolio is from a concert performance of the piece at the IMA Maths in Music Conference hosted by the Royal College of Music in London on 14/07/2022.

The question is therefore raised as to whether compositions written to be heard by a roaming listener can create successful musical experiences when presented in a traditional concert hall context, or whether they lack the sufficient foreground and background elements normally required for that setting.

When considering this question, I have found it useful to turn to descriptions of music performed using a traditional concert hall format (without dispersed performers or roaming audience) that nonetheless use analogies relating to the concepts of audience agency we have been discussing. When describing the music of Jürg Frey, Jennie Gottschalk talks about how the listener metaphorically "moves around within the space created by [Frey's] sounds and silences in a way that has more to do with thought than with acoustics, physical placement, or the passage of time."[40] This suggests that there is a sense of space created by Frey's music, and that the navigation of this space is achieved by the listener purely through the focus of their attention.

Frey enables this by giving his music both "structure (a space to occupy) and empty space (room to move around)."[41] I feel that a concert-style presentation of *Ocean Avenue*, a piece written to be experienced using the virtual reality system, creates almost the opposite effect, as the 'room to move around' was intended to be provided by the technology rather

[40] Jennie Gottschalk, *Experimental Music Since 1970* (New York: Bloomsbury Academic, 2016), 108.
[41] Gottschalk, *Experimental Music Since 1970,* 108.

than the notes on the page. The listener's navigational tool in this case is perhaps better described by a process of mentally filtering out some musical lines in order to focus on others.

The source material for *Ocean Avenue* is created from four groups of pulses within a cycle of thirty beats. Two similar patterns were used to form synchronised melodic lines, both with three groups of pulses occurring twice within the cycle, and one group of pulses occurring five times within the cycle. I kept very strictly to the rhythmic structures of the melodies but allowed myself more freedom when choosing the notes. From this point onwards, unlike in *Balance* where the source materials are used mostly unchanged in the piece, I used these two melodies as a reference point from which the rest of the piece was written. Throughout this writing process I kept in mind the desire to maintain a high pace and textural density within the music, given the general emptiness experienced when hearing *Balance* as part of the virtual reality installation.

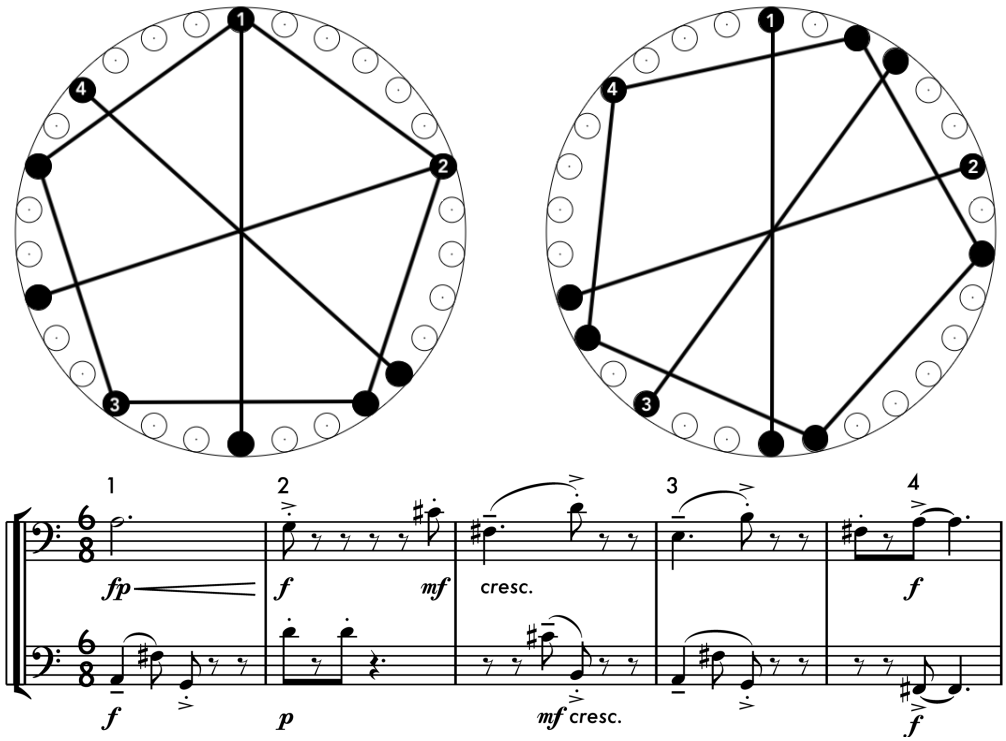

Figure 33: The two perfectly balanced rhythms, and the melodies that act as source material for *Ocean Avenue* (left to right = top to bottom).

Below you can see how the piano part at the opening of *Ocean Avenue* is a variation on the two melodies created as source material from the perfectly balanced rhythms.

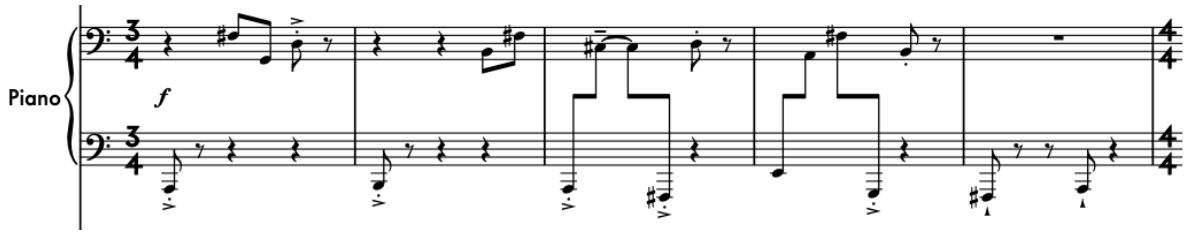

Figure 34: Piano part at opening of *Ocean Avenue*, composed as a variation on the two melodies shown above.

The rest of *Ocean Avenue* is largely created from the exploration of layers of music that exist simultaneously to the piano figure shown above. In particular, the introduction of musical material that is more, or less, energetic than the piano figure, or that implies a pulse that is faster or slower than the one heard at the opening. Figure 3 (bar 41) shown below is a good example. The marimba, piano and cello play material developed from the music heard at the opening that maintains a similar sense of pace. The violin introduces material that increases the sense of pace and energy of the composition, whilst the flute and clarinet glide over the top with a musical line that implies a minim pulse. Throughout *Ocean Avenue* this pulse-layering approach is used frequently.

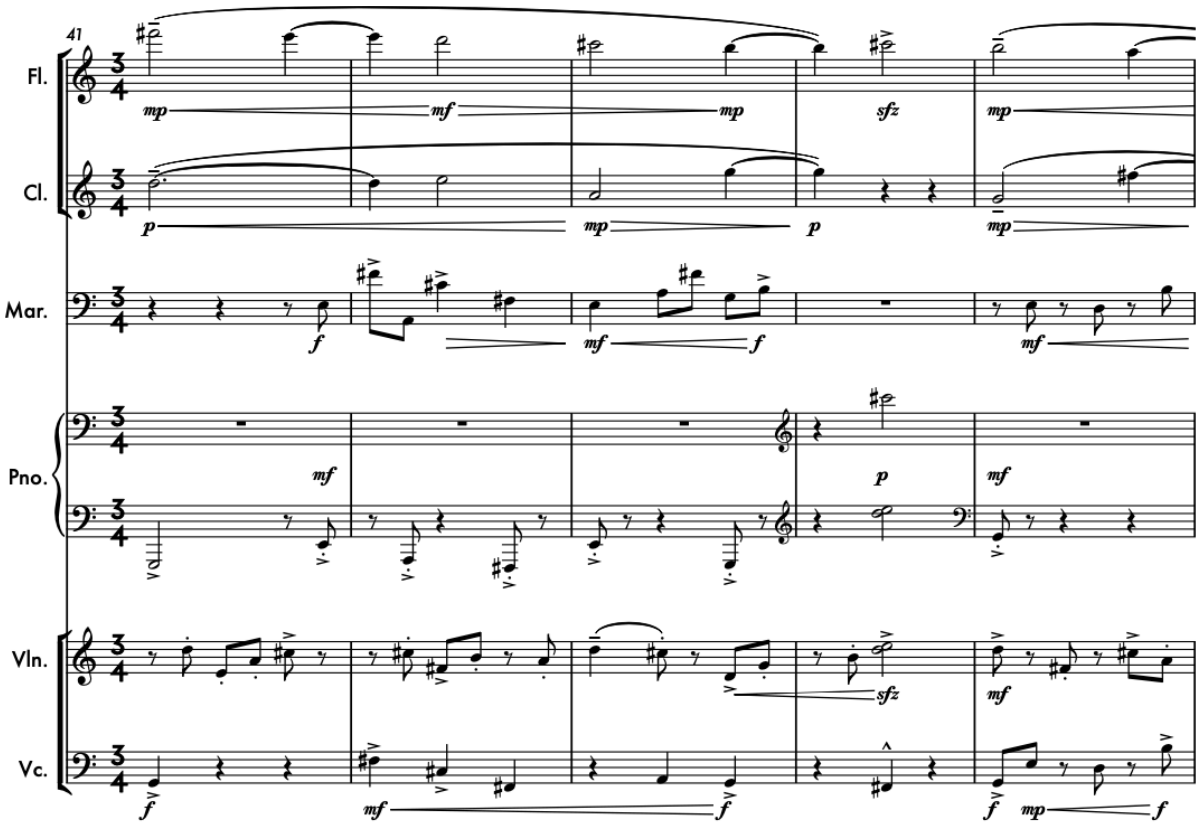

Figure 35: Figure 3 (bar 41) in *Ocean Avenue*, showing the introduction of high-energy material in the violin, and a smooth even minim pulse in the flute and clarinet.

Of the compositions contained in this portfolio, *Ocean Avenue* is the one written using a method that most closely matches Emily Howard's description of "taking the maths as a starting point, and a catalyst, to completely jump off and let [her] imagination run wild."[42] Whilst there is material based on perfectly balanced rhythms at the core of the composition, most of the music is composed freely in response to that material, with the aim of filling audible space and creating multiple contrasting layers taking priority.

Although it is yet to be recorded and heard within the same virtual reality platform as *Balance*, I think *Ocean Avenue* is a more successful piece for that style of musical

[42] Emily Howard, "Orchestral Geometries | Emily Howard Composer Q&A | NMC," uploaded April 24, 2023, accessed May 15, 2023. https://www.youtube.com/watch?v=Q5Ld206GDOI.

experience. I believe that there is more to explore within the piece for a listener, and a greater number of possible perspectives from which to hear the music.

Turning Points

I was commissioned by the City of Birmingham Symphony Orchestra to write a short orchestral piece that would act as an 'encore' for a concert in January 2020. Using perfectly balanced rhythms to generate musical material had worked well when writing the installation pieces *Balance* and *Ocean Avenue*, and I was keen to apply the approach in a new context with a larger ensemble. The multi-layered quality of the music written using this technique would lend itself well to being orchestrated, and the contrasting pulses contained within the rhythms would create music that could divert suddenly and surprisingly into a new metre.

Unlike in *Ocean Avenue*, where I used the perfectly balanced rhythms to generate source material from which to compose more freely, for *Turning Points* I chose to base the music very strictly on the patterns themselves. I composed a selection of highly complex perfectly balanced rhythms, featuring a dense array of pulses and contrasting layers, that would form the backbone of the piece. Where a pattern could be established and maintained, I kept the pitches consistent, meaning individual notes could be focussed on and regular pulses could be drawn out of the texture.

Turning Points opens with the presentation of a pattern outlining a perfectly balanced rhythmic cycle lasting thirty semiquavers. To view the opening pattern more clearly, it is helpful to split it into the pulses that occur twice within the cycle, and those that occur three times.

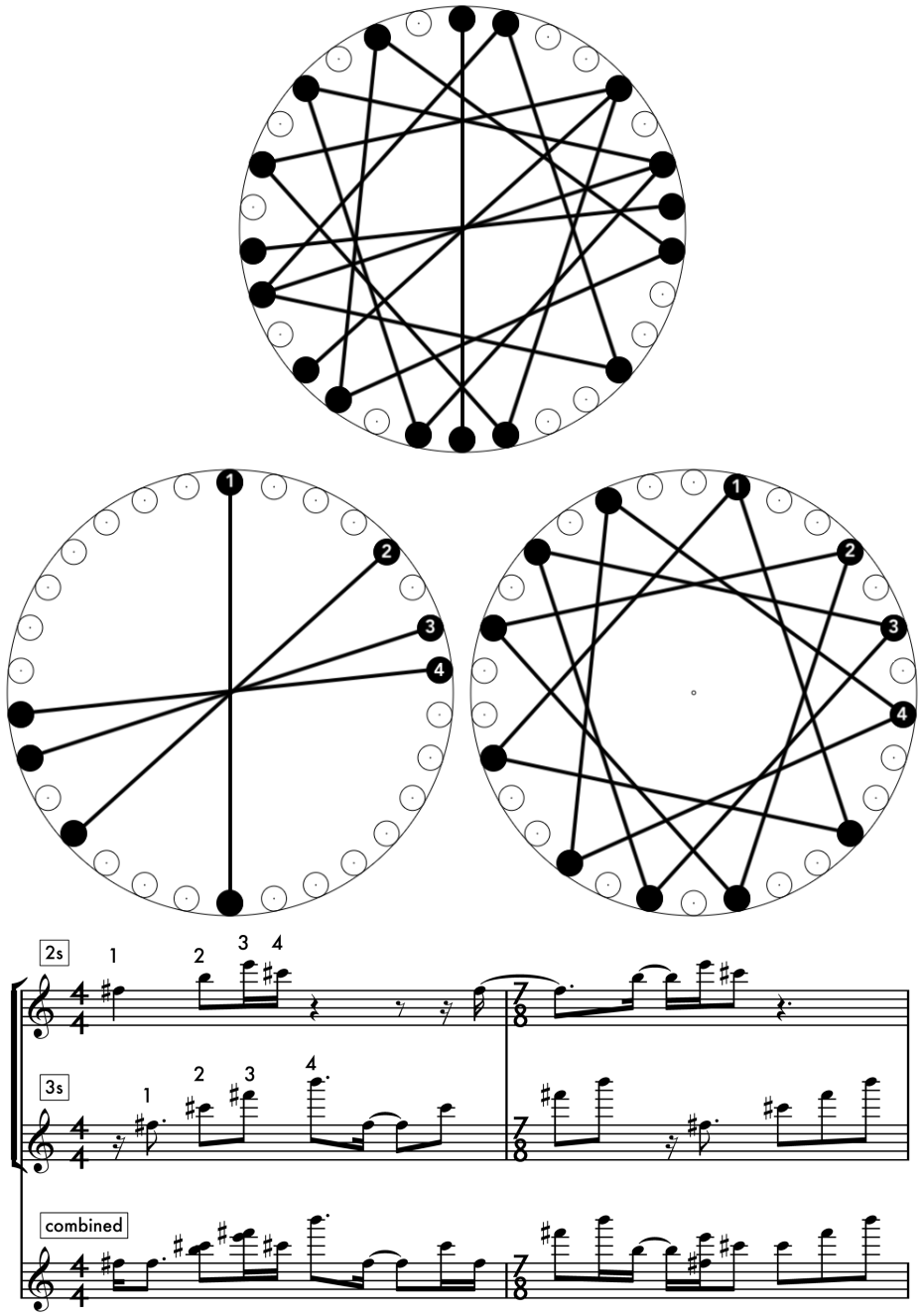

Figure 36: The perfectly balanced rhythm heard at the start of *Turning Points*, shown in its complete form (top), and then split into four pulses occurring twice within the cycle (middle left), and four pulses occurring three times within the cycle (middle right). The separate and combined notation is also shown (bottom).

The statement of the pattern at the opening is immediately followed by a variation created by increasing the number of times two of the pulses occur within the cycle. The B and C-sharp that had previously occurred only twice within the cycle now occur five and six times, respectively. The beat lengths of these two new pulses, with notes being played every six and five semiquavers, become two characteristic features in the rhythmic language of *Turning Points*.

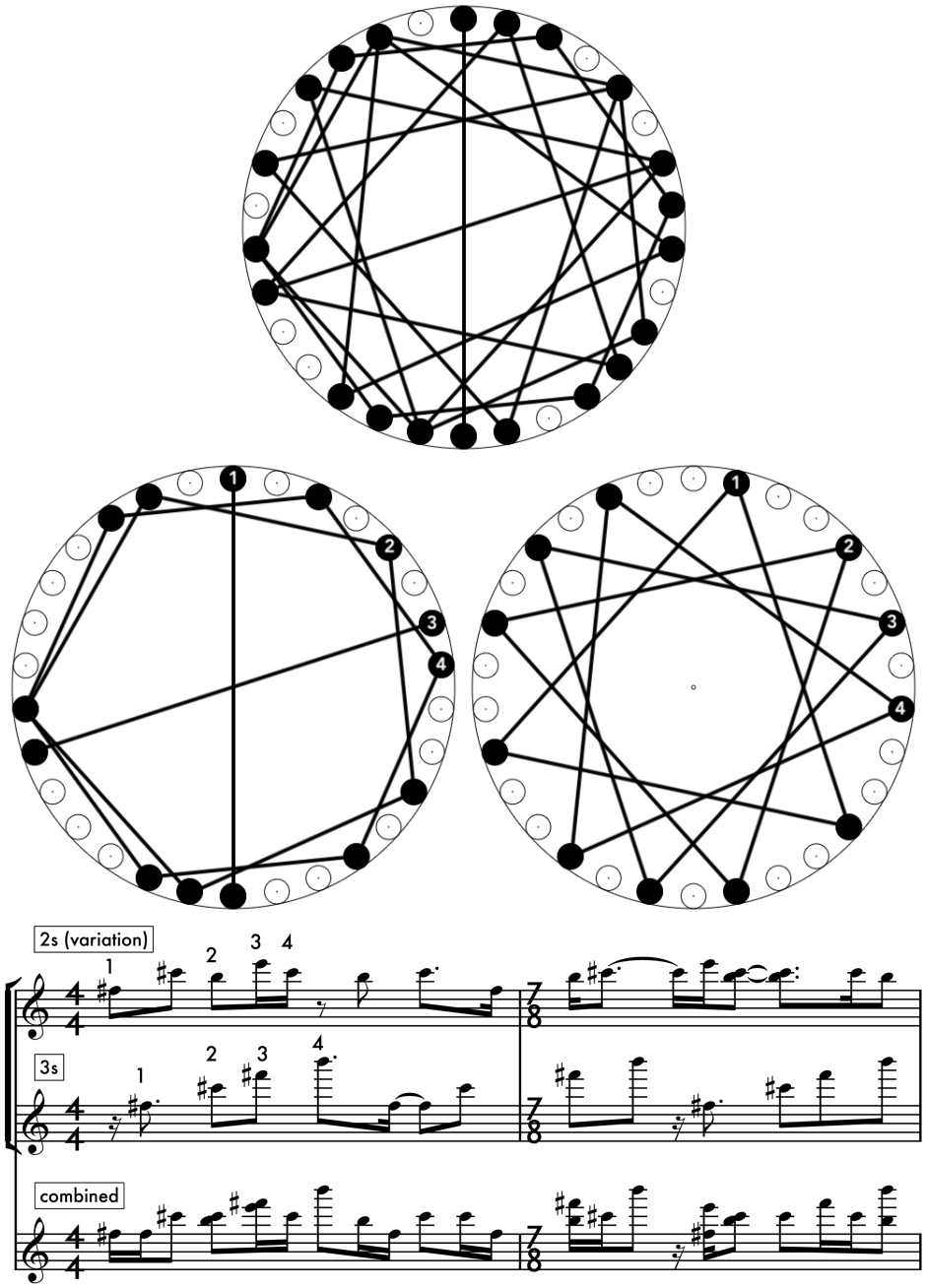

Figure 37: A variation on the opening pattern, treated as an answering phrase to the original. Two of the pulses previously occurring twice each cycle are now occurring five and six times. As before: complete pattern (top), separated patterns (middle), and notation (bottom).

Although the pattern lasts thirty semiquavers, I notated the music in bars of 4/4, meaning that the variation on the pattern has a totally different feel given that it enters a quaver before the downbeat of bar three. I use this method throughout *Turning Points* as a way of making repetitive musical figures appear within a new metrical context.

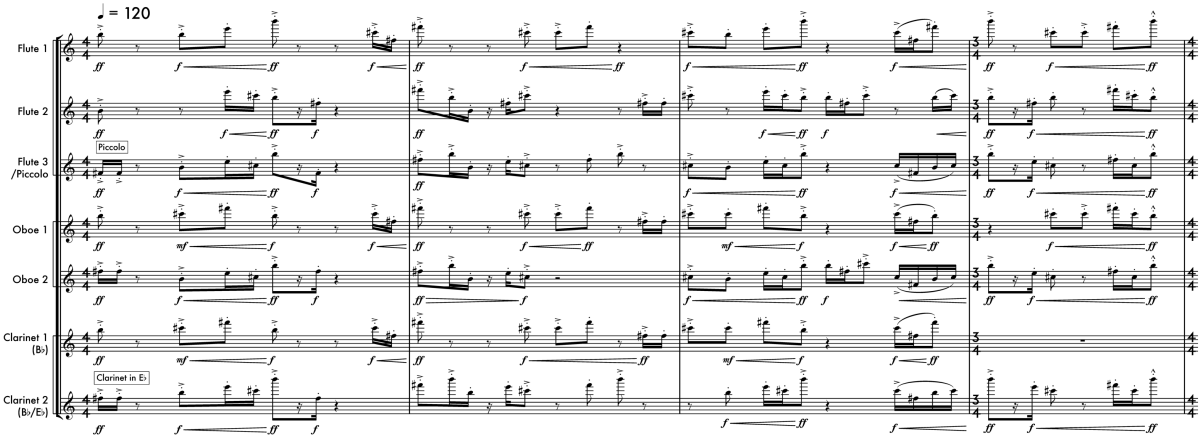

Figure 38: Score excerpt showing flutes, oboes, and clarinets playing the original pattern, immediately followed by the variation, at the opening of *Turning Points*.

The second pattern formed by the layering of many pulses is the rolling ostinato figure that enters at Figure C (bar 29). This perfectly balanced rhythm contains eight different pulses: three occurring five times each cycle, two occurring six, two occurring three, and one occurring twice.

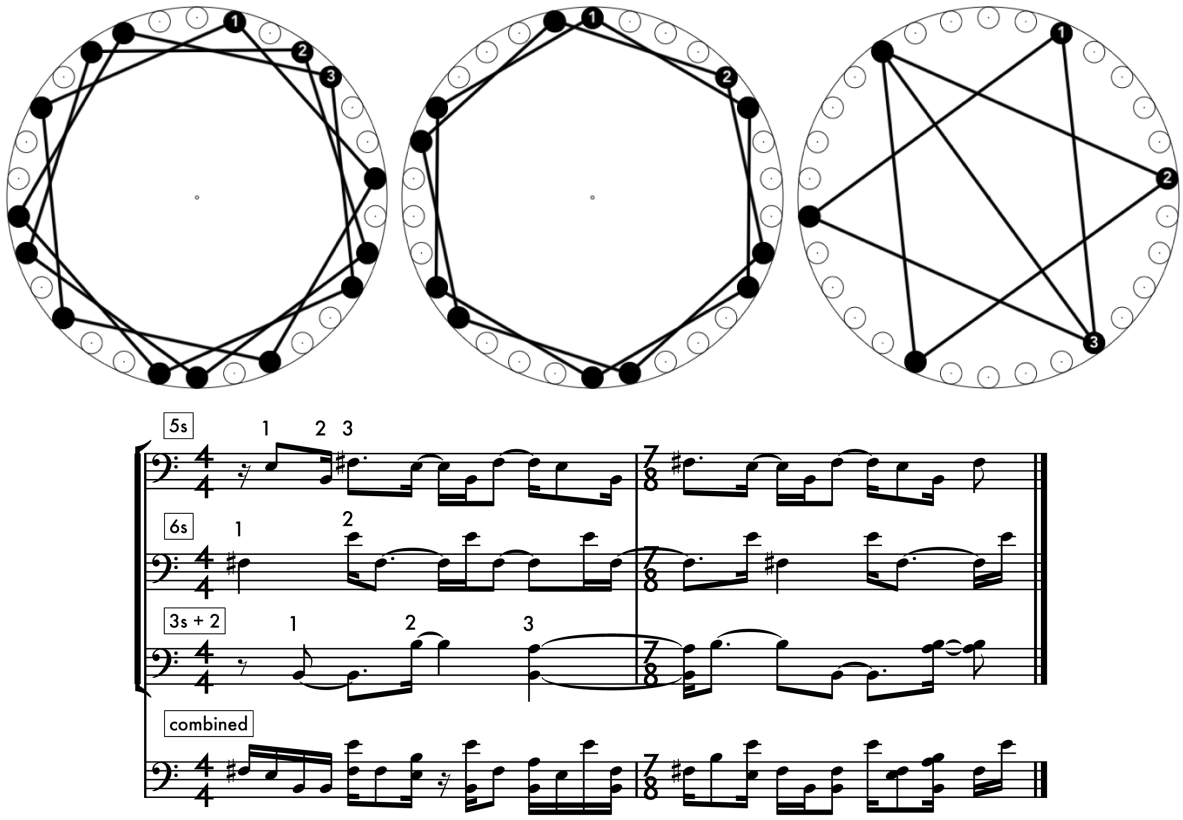

Figure 39: Three perfectly balanced rhythms, plus their musical notation, that together form the ostinato pattern entering at Figure C of *Turning Points* (left to right = top to bottom).

At first the ostinato pattern is accompanied by the bass drum outlining the conductor's pulse of straight crotchets (a pulse that is not contained within the pattern). Then, at bar 34, a pulse occurring every five semiquavers enters, disrupting the flow of the music and triggering a shift into a new perceived metre at the end of bar 35, where the bass drum

starts indicating a pulse of dotted crotchets. Throughout the piece the destabilising, momentary pulse of five semiquavers is used as a rhythmic cadence, rounding sections off and introducing new material.

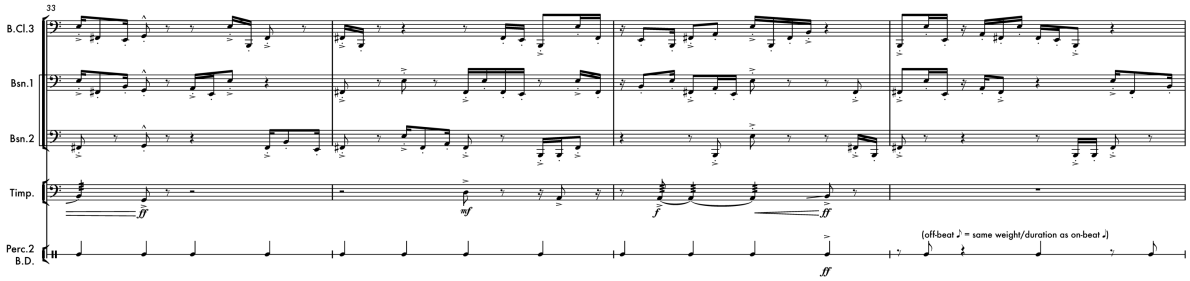

Figure 40: Bass clarinet, bassoons 1 and 2, timpani, and bass drum in bars 33-36 of *Turning Points*, showing the crotchet pulse in the bass drum, the five-semiquaver pulse interruption in the timpani, and the shift to dotted crotchet pulse at the end of bar 35.

At other moments in *Turning Points*, I placed several perfectly balanced rhythms alongside each other to act as interweaving contrapuntal lines. By forming these patterns from pulses occurring two and three times during the cycle, a sense of slight variation within familiarity is achieved, which works well when placing the patterns at different points within the bar each time they are repeated. The clarinet solo and accompanying lines at Figure E (bar 61) are each made from patterns of four groups of pulses: three occurring twice during the cycle, and one occurring three times.

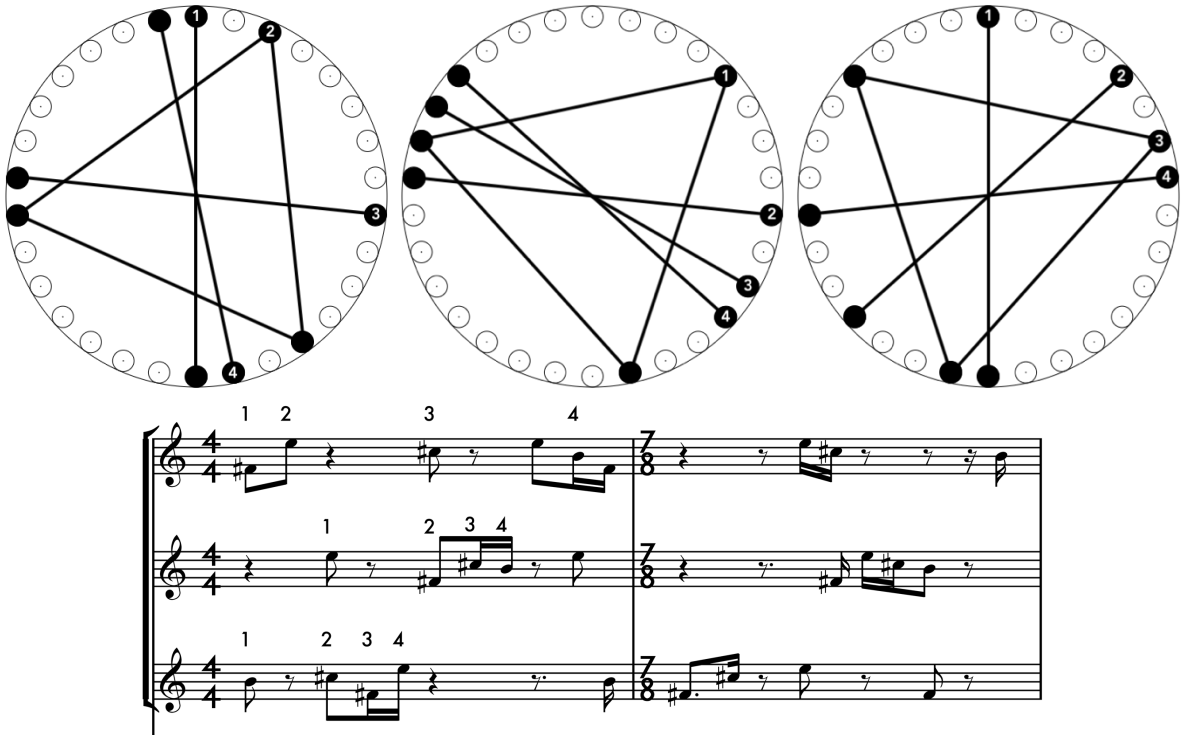

Figure 41: Three perfectly balanced rhythms formed of three pulses occurring twice within the cycle and one occurring three times, plus their musical notation (left to right = top to bottom).

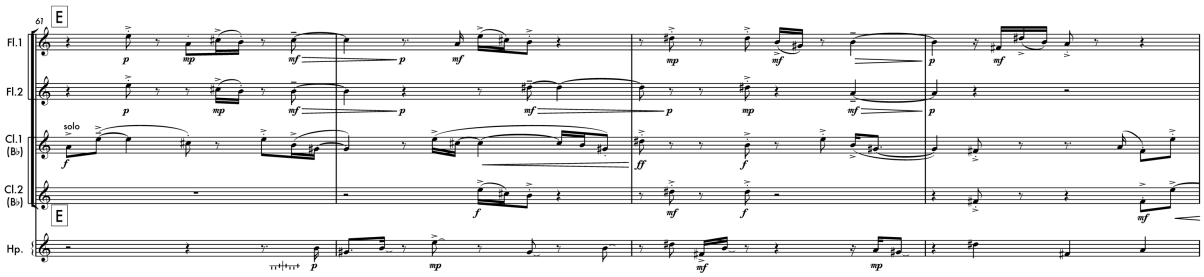

Figure 42: Flutes 1 and 2, clarinets 1 and 2, and harp at Figure E in *Turning Points*, outlining the three patterns shown above.

Overall, with *Turning Points* I was really pleased with how the compositional approach I had developed through a consideration of roaming audience and spatiality in *Balance* and *Ocean Avenue* had been adapted to form a technique for creating dense, polyrhythmic patterns in a composition intended to be heard in a concert hall.

Geometry: Aperiodic Order

As part of research into the audience experience as an "important measure of quality in the performing arts," Jennifer Radbourne, Katya Johanson, Hilary Glow, and Tabitha White use 'knowledge' as one of the four key components that has an influence on that experience.[43] They explain how the "rationale for utilizing a knowledge strategy is that the deeper the understanding of the performance, the greater the appreciation, leading to a richer experience."[44] Whilst the research goes on to discuss knowledge held by listeners prior to attending a performance, and knowledge disseminated via programme notes, I intend to focus on knowledge gained purely by interacting with a composition. The aim in this case is not so much to educate the audience as to spark their interest, opening the piece out in order to deepen the listeners' understanding of its construction.

As mentioned previously, from September 2020 I was employed as Artist-in-Residence at the University of Bristol School of Mathematics; a role that led to the creation of four interactive, audiovisual compositions. I wanted these pieces to have a clear method of construction that could be adjusted and manipulated by the listener. My intention was that by giving the audience control over the mathematical process at work in each composition, they would gain a better understanding of that process, and therefore a greater appreciation of the piece.

Two of the four compositions created during the residency, *Waveforms* and *Supergolden Approximations*, were based on research into 'aperiodic order', a field of mathematics that I will briefly introduce before discussing those pieces in more detail.

Introducing Aperiodic Order

I worked with three mathematicians researching aperiodic order at the University of Bristol: Demi Allen, Felix Flicker and Henna Koivusalo. Aperiodic order is the study of systems and structures that do not repeat but that display some sort of ordered form and predictability to them. It relates to other areas of mathematics such as fractals, and topics in physics such as quasicrystals. This was particularly interesting to me, as I had found that my music composed using perfectly balanced rhythms was always at risk of developing clear loop-based structures, given that so much of the material was created using fixed-length cycles.

My introduction to the topic was through infinite (never-ending), aperiodic (never-repeating) sequences that could be created using irrational numbers. Irrational numbers are numbers that cannot be expressed as the ratio of two whole numbers. Two of the better-known irrational numbers are the Golden Ratio (1.618…) and Pi (3.141…).

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[43] Jennifer Radbourne, Katya Johanson, Hilary Glow and Tabitha White, "The Audience Experience: Measuring Quality in the Performing Arts," *International Journal of Arts Management*, Vol. 11, No. 3 (Spring, 2009): 16-19.

[44] Radbourne, Johanson, Glow and White, "The Audience Experience: Measuring Quality in the Performing Arts," 20.

Polyrhythms can be thought of as a musical expression of the ratio of two whole numbers, as a unit of time is divided into two groups of even pulses. The three-against-two polyrhythm, for example, is a rhythmic representation of the ratio 3:2, which expresses the number 1.5, because 3÷2 = 1.5.

There are several ways that polyrhythms can be represented visually. One approach is to use the same notation we used earlier for perfectly balanced rhythms. Using this method, the three-against-two polyrhythm would be shown as an equilateral triangle and a line within a circle. Using a different approach described in a paper by Felix Flicker, the three-against-two polyrhythm could be shown as a path travelled over a regular grid of squares.[45] The two pulses of the polyrhythm are represented by the two dimensions of the grid, and if you imagine yourself travelling along the path, every time you pass over a horizontal or vertical line, a beat from that pulse would play. The three-against-two polyrhythm would be shown by a path that travels three squares up for every two squares along.

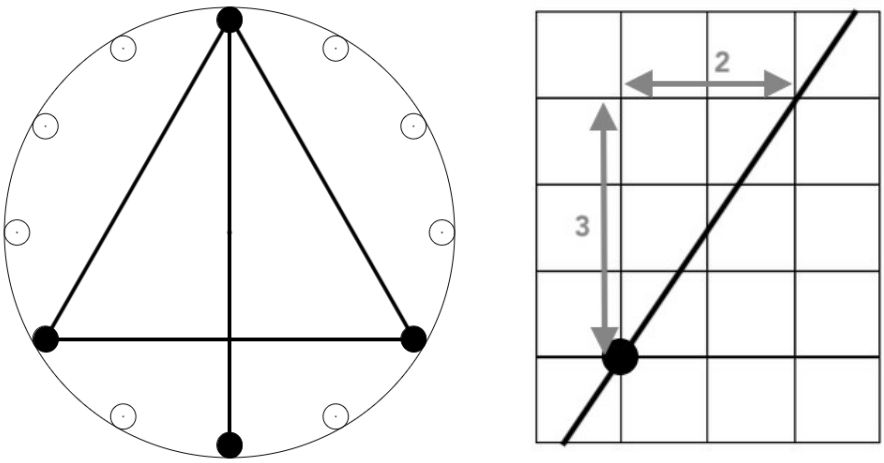

Figure 43: Two possible visual representations of the three-against-two polyrhythm: as a perfectly balanced rhythm (left), and as a diagonal path travelled over a grid of squares (right).

When following the diagonal path, the moment you pass over a crossroads, where the horizontal and vertical lines meet, is the moment that both pulses of the polyrhythm sound together, and the point at which the pattern repeats. Therefore, to create a pattern that never repeats, you would need to travel along a path that begins at a crossroads, but that never passes over another one. To do this you need to find a path that is irrationally sloped in relation to the horizontal line. Per Nørgård describes exactly this situation in an interview for *Tempo* where he compares harmonic intervals to polyrhythms using the ratio between the two frequencies that form the interval. He says:

"What about the rhythmic pattern? If the fifth is three to two, and the third is four to five, what is then the tritone? It's a rhythm where, if you start at the same time, they will never meet again; the impulses will never come together again. It makes a cycle in some way, but

[45] Felix Flicker, "Time Quasilattices in Dissipative Dynamical Systems," *SciPost Phys.* 5, 001 (2018), accessed August 12, 2022, DOI: 10.21468/SciPostPhys.5.1.001.

it's always changing a bit. That was very fascinating because it gives a totally new possibility of rhythm."[46]

Although Nørgård is comparing a fifth and third in just intonation to a tritone in twelve-tone equal temperament, which has a ratio of the square root of two (an irrational number) between the two frequencies, he is describing exactly the concept that was introduced to me by the mathematicians.[47] The infinity series discovered by Per Nørgård, which is used in several of his compositions, is perhaps the best-known example of an infinite, aperiodic musical sequence. By repeating a simple process over and over, each time using a newly generated set of notes, the infinity series remains self-similar whilst ensuring that it will never truly repeat and will continue to expand and develop forever.[48] Similarly, the infinite, aperiodic sequences of events formed by travelling along an irrationally sloped path over a grid of squares can also be constructed following simple instructions, called substitution rules.

Any sequence begins with a single event, 'A', which in musical terms could be anything from a note to a chord, a duration to a melody. To grow that event into a sequence you replace it with something else, following certain rules that will generate a sequence relating to an irrational number. The rules relating to the Golden Ratio are:

A > AB, B > A

When developing the sequence, the single event 'A' is replaced with two events 'AB'. Then, the first part of the new sequence, 'A', is again replaced with 'AB', and the second part, 'B', is replaced with 'A', so the sequence grows like this:

A
AB
ABA
ABAAB
ABAABABA

A sequence relating to the square root of two, imagined by Per Nørgård as the rhythm created from the ratio of a tritone, follows the rules:

A > AB, B > AAB

This sequence grows:

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[46] Per Nørgård and Martin Anderson, "Composer in Interview: Per Nørgård Recent and Early," *Tempo*, New Series, No. 222 (October, 2002): 10.
[47] Joe Monzo, "Tritone," *Tonalsoft: Encyclopedia of Microtonal Music Theory*, accessed June 1, 2022, http://www.tonalsoft.com/enc/t/tritone.aspx.
[48] Lawton Hall, "Per Nørgård's Infinity Series," *Lawton Hall: Music + Audio*, September 9, 2019, accessed June 1, 2022, https://www.lawtonhall.com/blog/2019/9/9/per-nrgrds-infinity-series.

A
AB
ABAAB
ABAABABABAAB

For each length of the sequence created using the substitution process, if you add up the number of 'A' events and divide by the total number of 'B' events you get an approximation of the irrational number the sequence describes. In the example above, 7 'A' events divided by 5 'B' events (7÷5) equals 1.4. The next step in the sequence's growth is:

ABAABABABAABABAABABAABABABAAB

In this section of the sequence, 17 'A' events divided by 12 'B' events equals 1.416666…, which is a closer approximation to the square root of two (1.4142…) than the previous section. As the sequences get longer, the approximations get more accurate, with the infinite sequence being the exact representation of the irrational number.

In Felix Flicker's paper on 'time quasilattices' the sequences were represented using the letters L and R.[49] This made them look very similar to drumming patterns that dictate which hand should play each beat, like the paradiddle: RLRRLRLL. I imagined these sequences being translated into drumming patterns, which is where the idea for my piece *Waveforms* began.

Waveforms

Waveforms is an interactive audiovisual installation that was displayed during the exhibition forming the culmination of my time as Artist-in-Residence at the University of Bristol School of Mathematics. This piece was used to introduce the audience to the mathematical process at work within the composition: the structured growth of aperiodic sequences. In the case of *Waveforms*, the listener can construct different drumming patterns by interacting with the mathematical process.

I recorded two drumming patterns, each with multiple versions of increasing complexity, representing the expanding lengths of two aperiodic sequences related to the Golden and Silver ratios. Rather than showing these growing sequences as an additive musical process, with one beat followed by two and so on, I decided to show them as increasingly small divisions of a fixed period of time. Both patterns begin with a single low-pitched beat. The listener is then able to smoothly mix in the other layers of complexity to the rhythm, as well as seamlessly cut back and forth between the two patterns. Each new layer introduces the next iteration of the substitution process described above.

To help the audience visualise the process, a stylised waveform for each pattern was projected onto the wall, with new layers of complexity growing vertically upwards as they get mixed into the audio. The 'A' and 'B' beats in each rhythm were given a different colour

[49] Flicker, "Time Quasilattices in Dissipative Dynamical Systems," 4.

in the waveform, corresponding to the colours used in two framed artworks displayed on either side of the projection. The framed artworks show a Penrose and an Ammann-Beenker tiling, two of the best-known aperiodic tilings that are created using the same ratios as those appearing in the drumming patterns.[50]

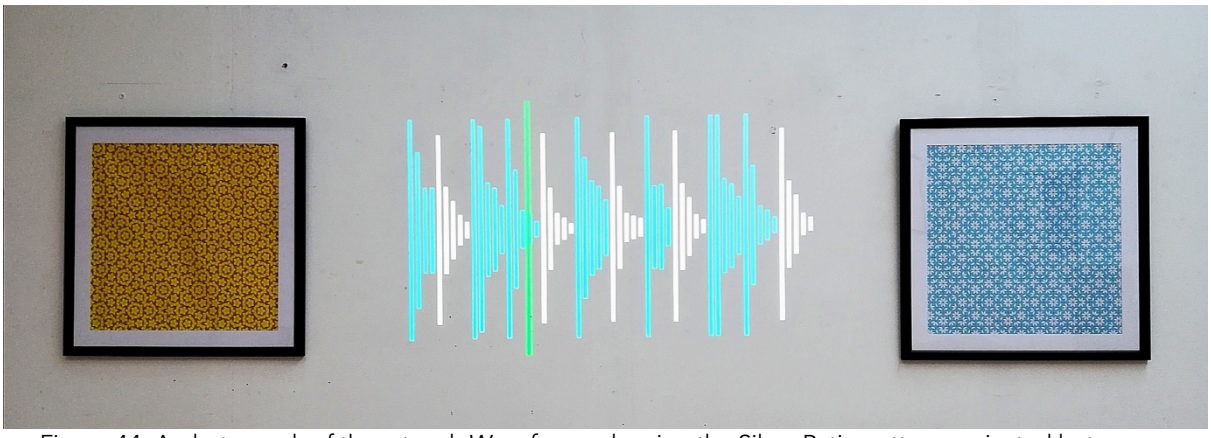

Figure 44: A photograph of the artwork *Waveforms*, showing the Silver Ratio pattern projected between a Penrose Tiling (left), and an Ammann-Beenker tiling (right). Reproduced with the permission of Josh Colclough.

As discussed earlier, the drumming patterns act as approximations of the irrational numbers they relate to via the frequencies of the 'A' and 'B' events in each section of the pattern. In the case of *Waveforms*, that approximation is also present in the ratio between the durations of each beat. In the Golden Ratio pattern, the best approximation reached is 5÷3 = 1.666…, as there are 5 'A' events and 3 'B' events in the most complex layer. This is reflected in the ratio of beat durations when there are only two beats present. As shown in the example below, at this moment in the Golden Ratio pattern the 'A' event lasts 5 semiquavers, and the 'B' event lasts 3 semiquavers. In the Silver Ratio pattern, the best approximation reached is 7÷5 = 1.4, as there are 7 'A' events and 5 'B' events in the most complex layer, and the ratio between beat durations when the pattern consists of only two beats is 7:5.

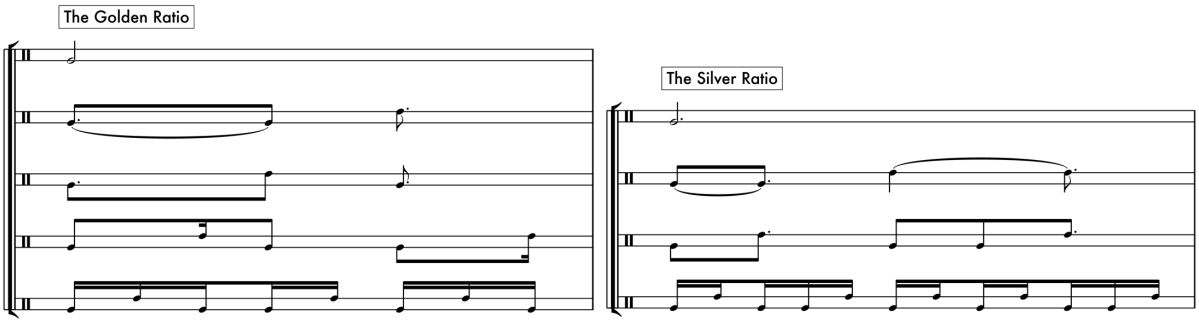

Figure 45: The rhythmic patterns in *Waveforms*, shown as layers of increasing complexity.

[50] The Silver Ratio is traditionally given the value of 1 + √2, whereas the irrational number that my 'Silver Ratio' drumming pattern approximates is √2. There is a full explanation of why this is the case in: Flicker, "Time Quasilattices in Dissipative Dynamical Systems." In short, there are two possible matrices with eigenvalues of the Silver Ratio (1 + √2), and each creates a different substitution rule and resulting aperiodic sequence. I have chosen to use the sequence that was demonstrated visually in the paper, which approximates √2, rather than the other which approximates 1 + √2.

What was interesting about the audience response to *Waveforms* was that they treated the two drumming patterns and their variations as materials from which to make their own piece of music. They could jump back and forth between the two patterns, changing the instrumentation from woodblocks to tom-toms, and dive between levels of complexity to provide moments of less or more activity.

Waveforms presented to the audience the mathematical ideas, and the musical realisation of those ideas, that would be used in another artwork in the exhibition: *Supergolden Approximations*.

Supergolden Approximations

Supergolden Approximations is a composition structured around the growth of an aperiodic sequence relating to the Supergolden Ratio (1.465…). The growth of this sequence is interesting as it relates to the Narayana's Cows sequence, first written about in 1356 by mathematician Narayana Pandita.[51] Narayana's Cows sequence presents a situation where a cow gives birth to one calf every year, starting in the fourth year of its life. If you begin with one cow in its first year, how many cows do you have as time progresses? The sequence begins with three consecutive 1s (as the first cow is not old enough to have a calf) and then begins to grow:

1, 1, 1, 2, 3, 4, 6, 9, 13, 19, 28, 41, 60, 88, 129…

Like the Fibonacci sequence, where the ratio between consecutive terms tends to the Golden Ratio the further along the sequence you go, the ratio between consecutive terms in the Narayana's Cows sequence tends to the Supergolden Ratio.

Tom Johnson's 1989 composition *Narayana's Cows* deals with this sequence and the question of growth in a very effective way. It is a piece for narrator and ensemble. The music progresses through the years; each year beginning with the narrator describing the makeup of the population of cows before the ensemble play a musical representation of that number. As Samuel Vriezen describes in the linear notes to Ensemble Klang's recording of the piece: "First you're listening to a lecture on mathematics with examples in sound, then, after a while, you suddenly realize it is actually music that you are listening to. In this case, with each generation, the musical phrases get longer as Narayana's herd grows larger, and so generation by generation the music becomes more important than the talk."[52] However, Johnson's musical representation is a highly repetitive and single-voiced approach, and I wanted my composition to reveal more of the interesting structure and depth that is contained within the sequence.

The substitution rules that create the Supergolden Ratio sequence are:

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[51] N. J. A. Sloane, "A000930," *The On-line Encyclopedia of Integer Sequences*, April 30, 1991, latest revision July 30, 2022, accessed August 15, 2022, https://oeis.org/A000930.

[52] Samuel Vriezen linear note to T. Johnson, *Cows, Chords and Combinations*, Keir Neuringer, Ensemble Klang (Ensemble Klang), 2010, EKCD2.

A > AB, B > C, C > A[53]

Starting with a single event, ‘A’, the sequence grows in the following way:

A
AB
ABC
ABCA
ABCAAB
ABCAABABC

I wanted to write a piece constructed from three clearly contrasting sources of material, A, B, and C, that would grow step-by-step in the same way as the sequence. It was important to me that the audience, who would have also experienced *Waveforms* in the same exhibition, would understand how the piece was developing according to this mathematical process. They would then be allowed control over that process, jumping forwards and backwards through the growth of the sequence in the same way as they had dived between levels of complexity in *Waveforms*. Additionally, I wanted the music that formed the source material to be built using the same sequence, meaning that there would be a fractal quality to the composition, with the same pattern existing at both small and large scales.

First, I explored whether I could extract any pitch information from the sequence. I started by taking a long chunk of the sequence:

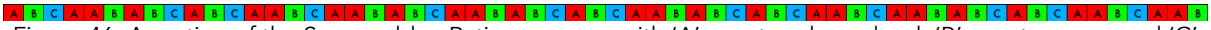

Figure 46: A section of the Supergolden Ratio sequence with ‘A’ events coloured red, ‘B’ events green, and ‘C’ events blue.

I was interested in the spacing between similar events in the sequence, and so looked at the distances between ‘A’ events. I found that there were only three possible distances between ‘A’ events, and if you labelled those distances ‘A’, ‘B’ and ‘C’, you found a stretched-out version of the original sequence:

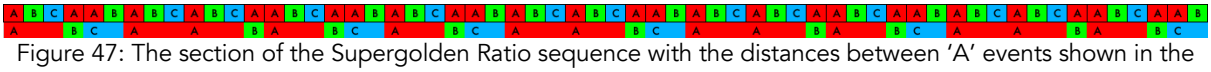

Figure 47: The section of the Supergolden Ratio sequence with the distances between ‘A’ events shown in the second row. There are 3 possible distances between ‘A’ events, labelled ‘A’, ‘B’, and ‘C’ and coloured red, green, and blue as before.

This was very interesting, as it meant that the sequence contained a stretched-out version of itself within the ‘A’ events. I decided to apply the substitution rule in reverse to this stretched-out version of the sequence, reducing it back to a single, very long, ‘A’ event:

[53] The Golden and Silver ratios are solutions to quadratic equations, so their sequences contain only two events: A and B. The Supergolden Ratio is the solution to a cubic equation, so the sequence needs to introduce a third event: C. Relating the sequence to a path over a grid of squares, the Supergolden Ratio sequence would be a path travelling through three dimensions rather than two.

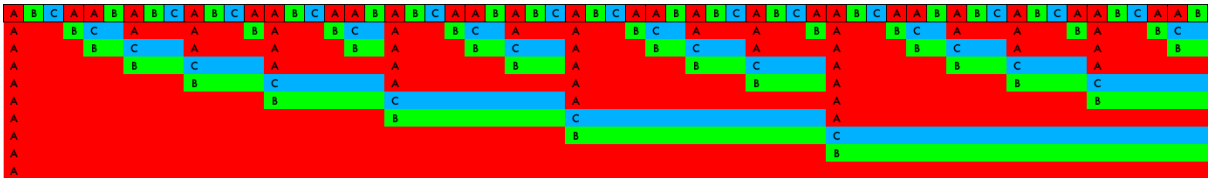

Figure 48: The section of the Supergolden Ratio sequence, with the distances between 'A' events shown in the second row, and a reverse substitution process taking place in each row below that; reducing the sequence back to a single 'A' event. All events remain coloured as previously.

I then counted down through the rows below each 'A' event in the original sequence, to give each 'A' a numerical 'weight'. The first 'A' was the heaviest, with nine events beginning in the rows beneath it, followed by a very light 'A' with only one, and so on. The result was this:

Figure 49: The section of the Supergolden Ratio sequence with each letter 'A' replaced with a number corresponding to the weight of that event (explained above). The numbers contained in the red 'A' events read from left to right: 9, 1, 2, 3, 4, 1, 5, 1, 2, 6, 1, 2, 3, 7, 1, 2, 3, 4, 1, 8, 1, 2, 3, 4, 1, 5, 1, 2.

Next, I looked at the distances between each of the 'B' events, and found that they too created an even more stretched-out version of the original sequence:

Figure 50: The section of the Supergolden Ratio sequence with the distances between 'B' events shown in the second row. There are 3 possible distances between 'B' events, labelled and coloured as before.

I applied the same reduction technique, and was able to give a weight to each of the 'B' events in the original sequence:

Figure 51: The section of the Supergolden Ratio sequence with each letter 'B' replaced with a number corresponding to the weight of that event. The numbers contained in the green 'B' events read from left to right: 8, 1, 2, 3, 4, 1, 5, 1, 2, 6, 1, 2, 3, 7, 1, 2, 3, 4, 1.

Finally, I did the same for the 'C' events in the original sequence. By this point I was not surprised that the spacings between 'C' events created an even more stretched-out version of the original sequence. Applying the reduction technique again I was able to give a weighting to every event in the original sequence:

Figure 52: The section of the Supergolden Ratio sequence with each letter 'C' replaced with a number corresponding to the weight of that event. The numbers contained in the blue 'C' events read from left to right: 7, 1, 2, 3, 4, 1, 5, 1, 2, 6, 1, 2, 3.

To hear what this sequence of numbers would sound like, I related each number to a pitch within the scale of C major, scored the sequence for three clarinets playing either 'A', 'B', or 'C' events, and added some phrasing. The result was a beautifully weaving sequence of notes that, due to the self-similarity of the three lines, acted as a sort of canon at three different speeds. Other than their very first note, each clarinet plays an identical melody at a unique speed that creates an interlocking pattern of notes that is very satisfying. I decided that this would form the basis of the A material in my composition.

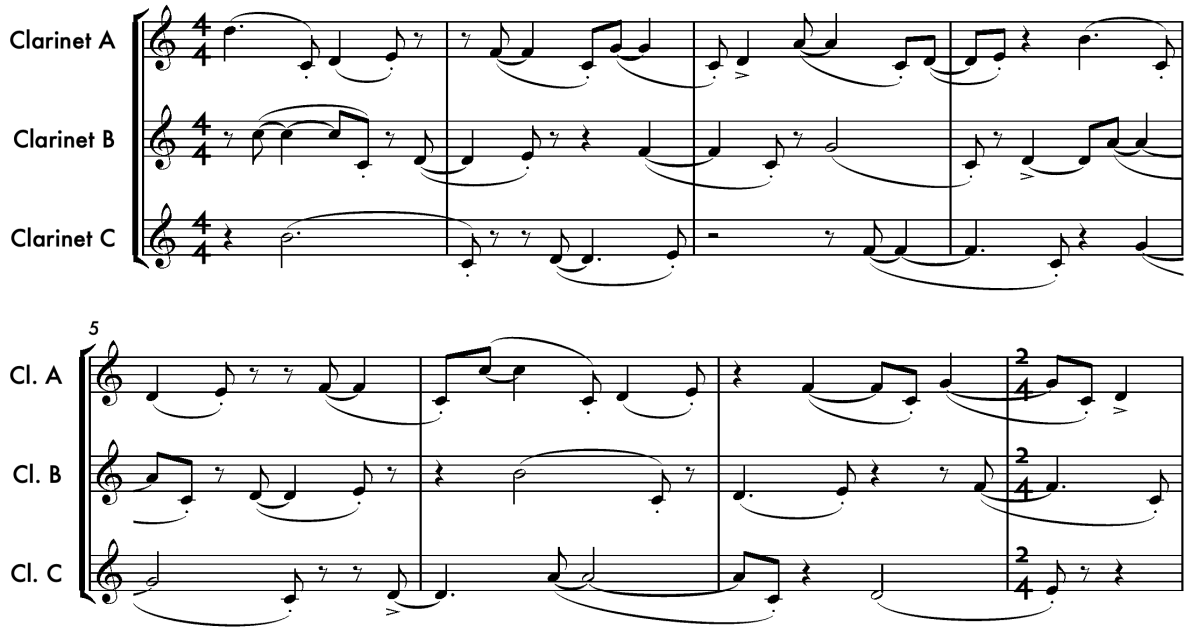

Figure 53: The A material for *Supergolden Approximations*, with each clarinet playing either 'A', 'B', or 'C' events from the sequence, and pitches determined from the weighting given to each event.

Having dug so deeply into the sequence to find the A material for the composition, I wanted the B material to provide a stark contrast to the weaving and interlocking lines of the clarinets. I decided upon a percussive stream of notes, with each 'A', 'B', and 'C' event given a certain pitch. Event 'A' was given the pitch D, event 'B' was given the pitch B, and event 'C' was given the pitch C. The resulting string of notes makes the aperiodic nature of the sequence clearly audible, as it refuses to settle into a predictable repeating pattern.

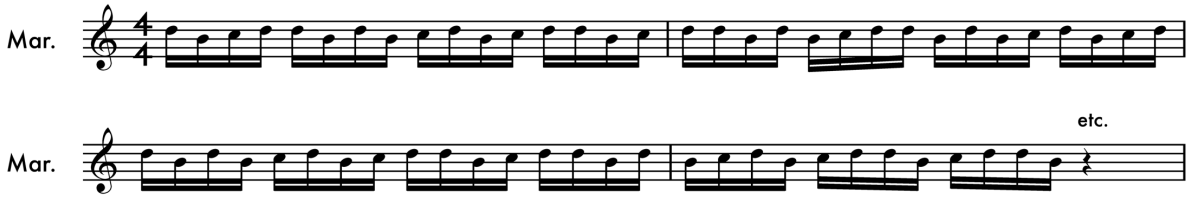

Figure 54: The B material for *Supergolden Approximations*, with each event from the sequence given a specific pitch (Event 'A' = pitch D, 'B' = B, 'C' = C).

For the C material, having explored contrapuntal melodies and fast passages of limited pitches, I chose to compose a series of held chords whose durations would be dictated by the clarinet playing the 'A' events in the A material. Each chord would coincide with the clarinet notes that fall to the low C. This sequence of durations also follows the Supergolden Ratio sequence, with chords representing the 'A' events lasting 9 quavers, those representing the 'B' events lasting 4 quavers, and those representing 'C' events lasting 6 quavers.

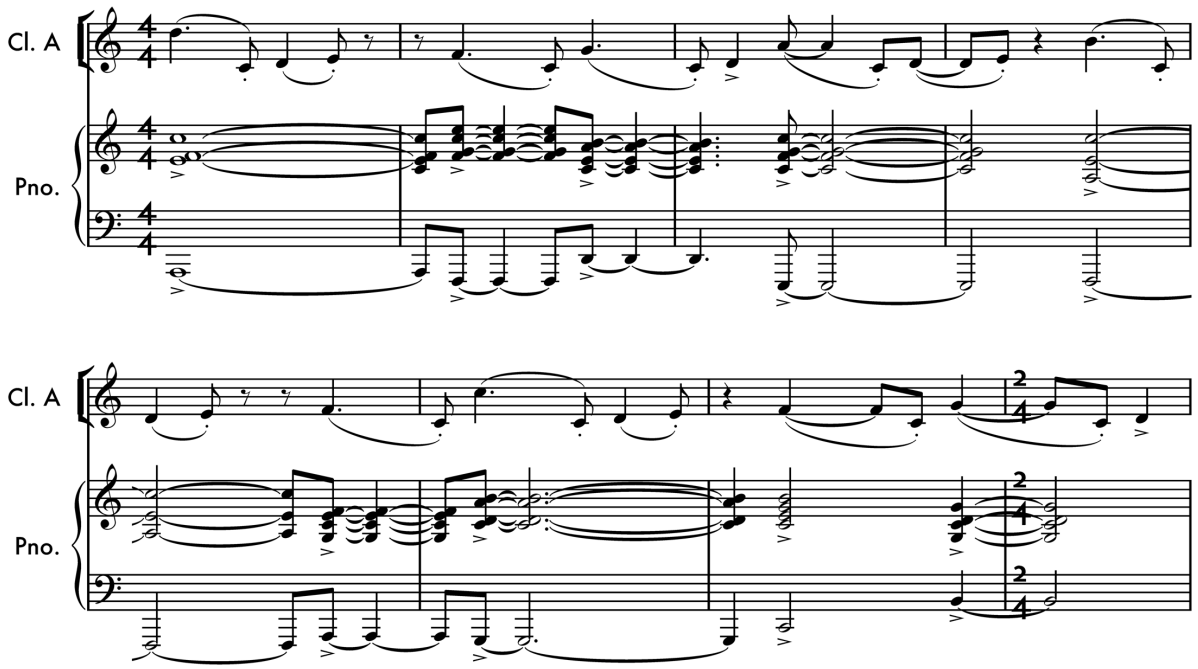

Figure 55: The C material for *Supergolden Approximations*: a series of chords with 3 different durations, aligning with the clarinet playing 'A' events in the A material.

The piece is then constructed in the same way as the aperiodic sequence develops. It begins with a single event, 'A', and each subsequent rehearsal figure introduces a longer segment of the sequence in the following way:

Opening (bar 1):	A
Figure A (bar 3):	AB
Figure B (bar 5):	ABC
Figure C (bar 9):	ABCA
Figure D (bar 15):	ABCAAB
Figure E (bar 29):	ABCAABABC

The section of C material reached at bar 56 represents the end of the longest section of the sequence used structurally in the piece. The music modulates, using the only note from outside the key heard so far, C-sharp, as a mirror line, across which all the material is reflected. The C-sharp continues to appear as a dissonance in the new key, but is respelled as D-flat. Moving forward, the sequence begins to shrink again, and at times sections flow into each other more seamlessly:

Figure F (bar 61):	ABCAAB
Figure G (bar 75):	ABCA
Figure H (bar 89):	ABC
Figure I (bar 106):	AB (the sequence starts just before Figure I)
Figure J (bar 108):	A

The piece is constructed as a continuous loop, and after a final statement of the sequence starting to regrow at bar 110 the music jumps back to bar 5 and the cycle of expansion and

contraction continues. Giving the composition a looping quality gave me the option to have it playing continuously in the gallery and acted as a further invitation for the audience to interact with the music and create a new structure for themselves.

Within each of the sections of A, B, and C material in the piece, the expansion and contraction of the sequence happens in a similar way on a small scale as it does in the overall structure of the composition. The first appearance of A material, right at the start of the piece, is itself a statement of the sequence in the form ABCA. The next appearance, at Figure A (bar 2), shows the sequence after a further expansion, in the form ABCAAB. The following section of B material outlines the same length of sequence.

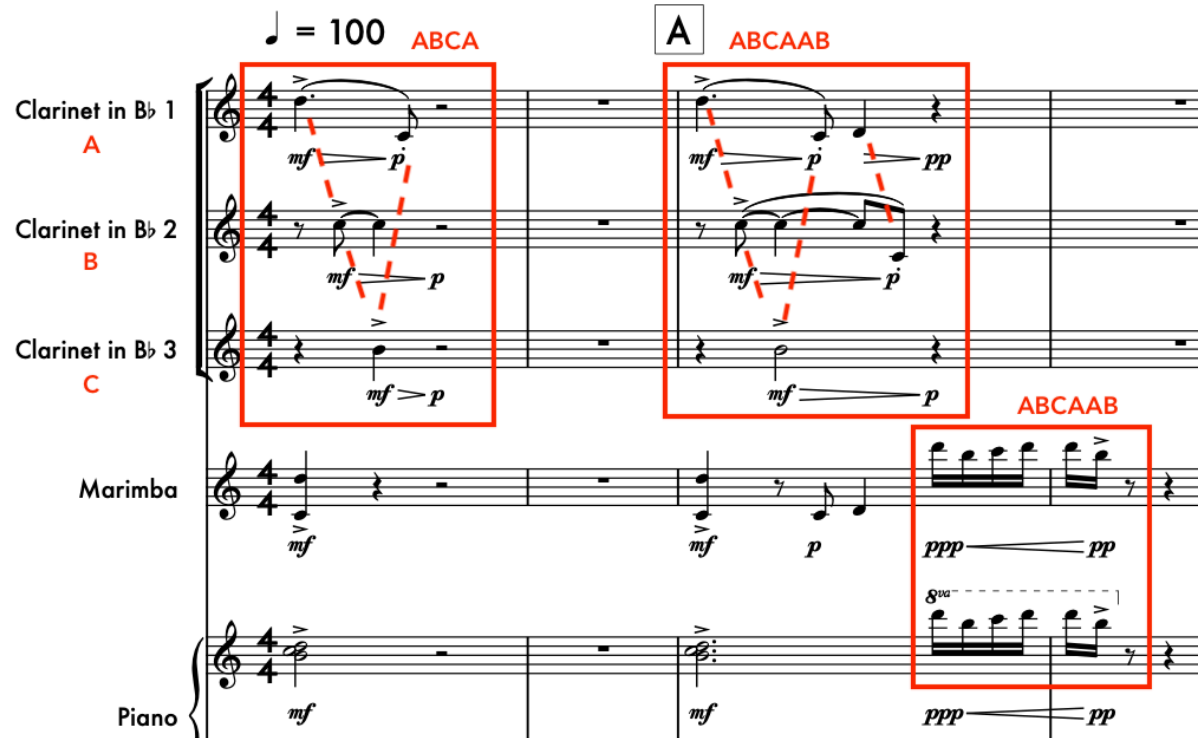

Figure 56: Score excerpt of the opening of *Supergolden Approximations*, showing the growth of the sequence.

At Figure B (bar 5), when the first C material is introduced, it enters with just a single chord, representing the sequence in its shortest form, A. By this point the A and B materials have lengthened to represent the sequence in the form ABCAABABC.

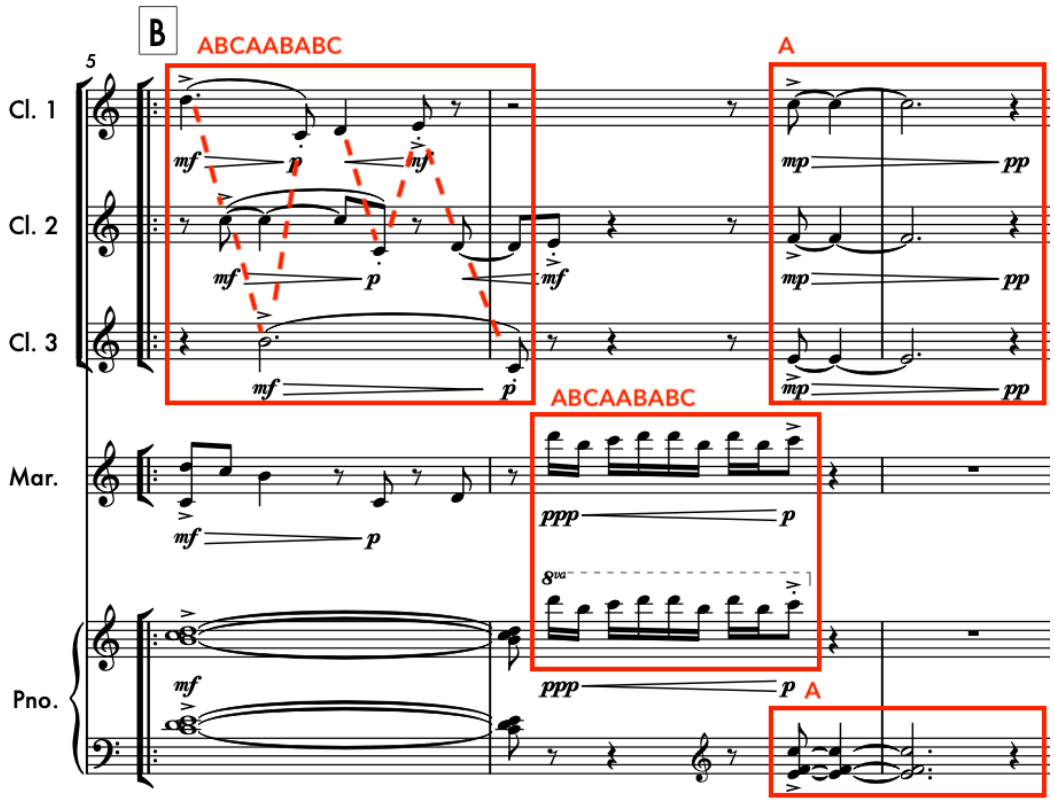

Figure 57: Score excerpt of Figure B of *Supergolden Approximations*, showing the longer sections of the sequence in the A and B material, and the introduction of C material.

This process of lengthening continues throughout the piece with the longest sections of A and B material appearing within the longest structural section of the sequence, ABCAABABC, starting at Figure E. After this point, the sections of A and B material start reducing in length again. In the case of the C material, however, the sequence continues to grow throughout the duration of the piece. This shifts the narrative of the music away from a simple expand/contract loop and, as in Tom Johnson's *Narayana's Cows*, the chordal C material slowly comes to the forefront of the music as time progresses.

In the exhibition, *Supergolden Approximations* was presented as part of a pre-recorded audiovisual installation that encouraged interaction from the audience. The volume of the audio was used to control the brightness of a large 3x3 grid of lights. Each row of lights represented an instrument group, with marimba at the top, clarinets in the middle, and piano at the bottom. Each column of lights represented the moments within the music that related to the 'A', 'B', or 'C' events in the sequence, displayed from left to right. The colour of the light represented whether the composition at that moment was playing A material in red, B material in green, or C material in blue. Despite the structural outline of *Supergolden Approximations* being very clearly defined, snippets from each of the source materials appear at times in the other sections, bringing cohesion to the overall piece, and adding a sense of complexity as the music builds towards the central moment.

Figure 58: A photo of *Supergolden Approximations* as it was presented within the exhibition.

Similar to how the rhythmic patterns in *Waveforms* were related to visual tilings created using the same irrational numbers, the audience's interaction with *Supergolden Approximations* related the music to a tiling that would grow and reduce as the piece progressed. The listeners were able to scroll through the piece of music, jumping between levels of complexity as they had done with *Waveforms*. As they did so, a tiling discovered by Ed Pegg Jr. would divide itself into increasingly complex forms.[54] The substitution rules creating the structure of the music are shown clearly in the development of the tiling, where one tile splits into two, or changes colour. This allowed the audience to keep track of how far they were into the piece and watch as the sequence expanded and contracted again.

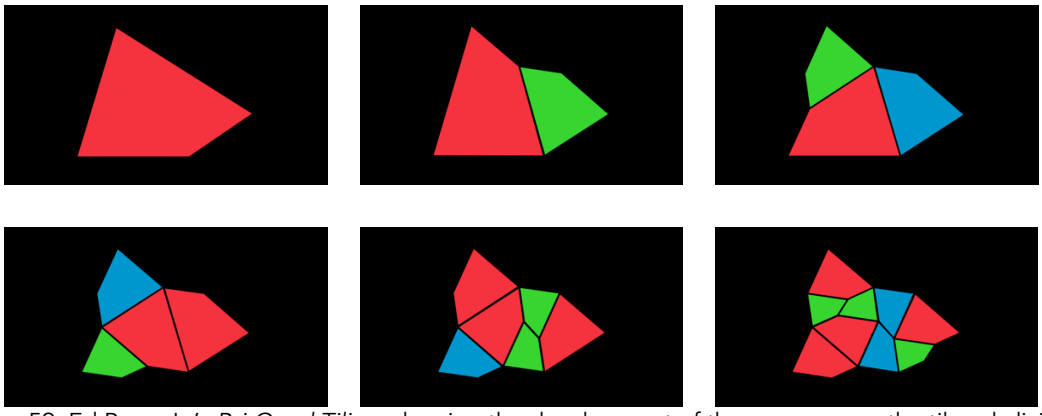

Figure 59: Ed Pegg Jr.'s *Psi Quad Tiling*, showing the development of the sequence as the tile subdivides. Reading the top row left to right: A, AB, ABC. Bottom row left to right: ABCA, ABCAAB, ABCAABABC. Reproduced with the permission of Ed Pegg Jr.

My intention with *Supergolden Approximations* was for the audience to construct a new musical experience, in the same way they had with *Waveforms*. The composition process had seen me write a cyclical piece following a mathematical process, with the aim of making that process clear to a listener who would be interacting with the composition. This was an experience I carried forward when given the opportunity to write *Making Space*: a linear composition on a larger scale, based on the same mathematical concepts.

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[54] Ed Pegg Jr., "Lots of substitution tilings," *Wolfram*, accessed June 3, 2022, https://community.wolfram.com/groups/-/m/t/1679969.

Making Space

Making Space was commissioned by BBC Radio 3 as a concert opener to be performed by the BBC Concert Orchestra and Anna-Maria Helsing. I wanted to continue investigating the behaviour and growth of aperiodic sequences and see if I could apply them in a concert hall setting, with a seated audience and none of the interactive elements that had been available when presenting *Waveforms* and *Supergolden Approximations*.

Supergolden Approximations explored the linear growth of the Supergolden Ratio sequence through the expansion of musical lines in a traditional way: by adding more music to the end of the sequence you already have. Henna Koivusalo compared this approach to the way in which physicists think about the growth of quasicrystals. By contrast, she said that mathematicians studying the fractal structures of aperiodic sequences tend to imagine their growth as being the result of the original elements of the sequence being pulled apart, as if you are zooming in on the sequence to view it more closely, and the newly formed events appearing in the gaps. This related to the videos I had seen of large-scale zooms on fractal structures such as the Mandelbrot Set that revealed the infinite detail existing at deeper and deeper levels.[55]

I wanted to write a piece using this approach, where the music at the beginning of the composition was stretched apart to make space for new material, and that process continued throughout the piece. I chose to base the music around the aperiodic sequence related to The Plastic Number, which has the following substitution rules:

A > AB, B > BC, C > CAB

The sequence expands in the following way:

A
AB
ABBC
ABBCBCCAB
ABBCBCCABBCCABCABABBC

To generate my source material, I started with the section of the sequence that is nine events long: ABBCBCCAB. I chose three chords to represent 'A', 'B', and 'C' events, which created the first layer of the music. Whilst creating the source material I scored the music for a reduced ensemble of bass clarinet, bassoon, and strings.

[55] Mathigon, "Mandelbrot Zoom Sequence," (youtube video), uploaded April 2, 2020, accessed June 03, 2022, https://www.youtube.com/watch?v=b005iHf8Z3g.

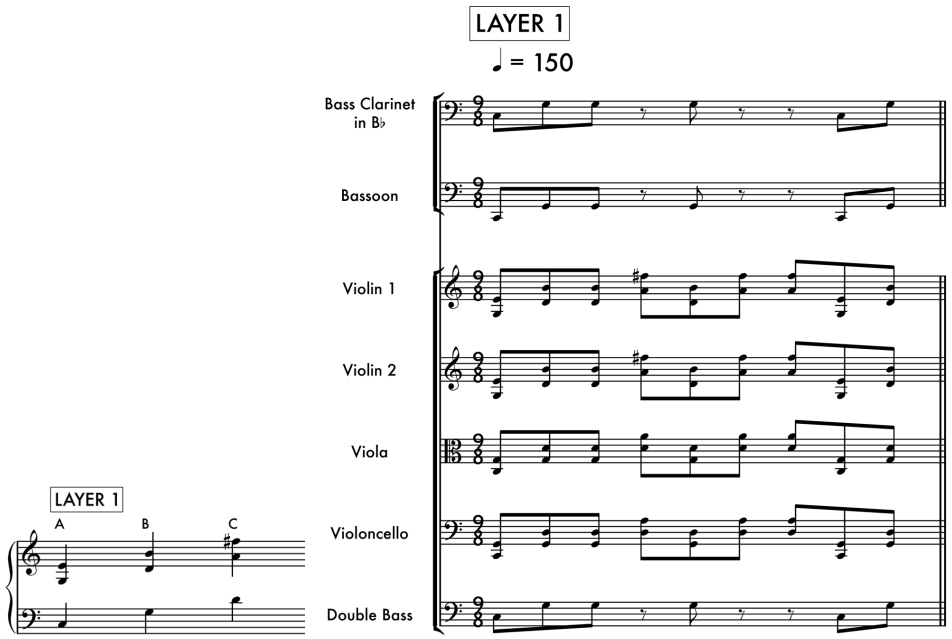

Figure 60: The three chords representing the events 'A', 'B', and 'C' in Layer 1, and their appearance as part of the Layer 1 sequence (ABBCBCCAB) in the source material for *Making Space*.

To make sure the piece would develop in an interesting way and keep introducing new ideas, I decided that each subsequent layer would have a new set of notes or chords representing events 'A', 'B', and 'C'. To create Layer 2, I stretched apart all the chords in Layer 1 and placed the new notes after each chord following the substitution rules. Given that the rules were:

A > AB, B > BC, C > CAB

- Each 'A' originally in Layer 1 would be followed by a new 'B' in Layer 2.
- Each 'B' originally in Layer 1 would be followed by a new 'C' in Layer 2.
- Each 'C' originally in Layer 1 would be followed by a new 'A' and 'B' in Layer 2.

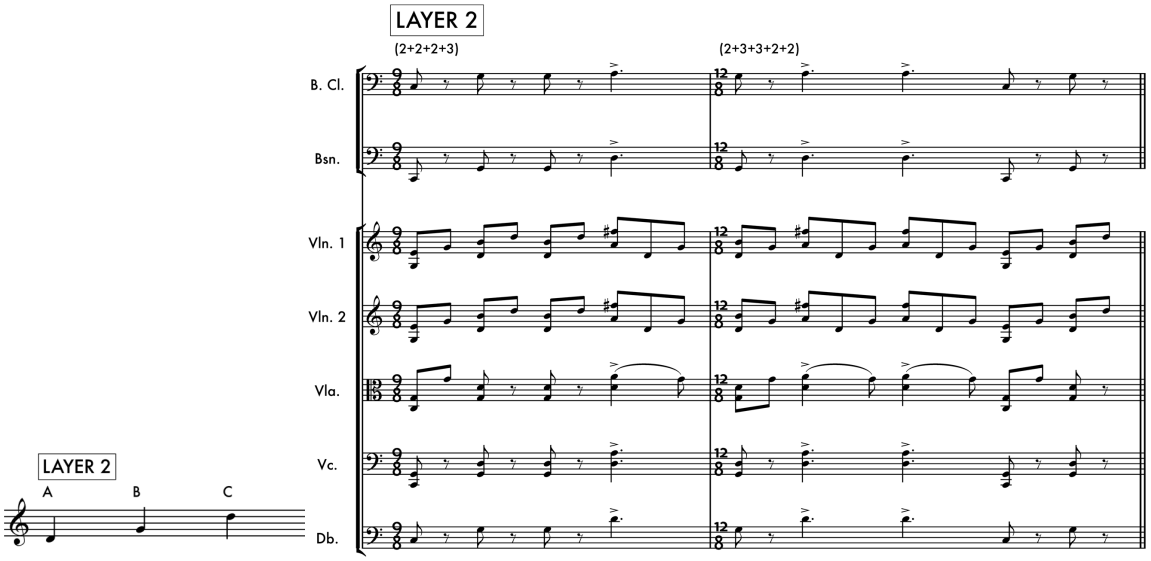

Figure 61: The three notes representing the events 'A', 'B', and 'C' in Layer 2, and their appearance as part of the Layer 2 sequence (ABBCBCCABBCCABCABABBC) in the source material for *Making Space*.

What was immediately noticeable was the rhythm built from groups of two or three quavers that appeared when the Layer 1 material was stretched out. It had a folk-like quality to it, and the resulting pattern wouldn't fit into regular bars of simple or compound time. I continued stretching the sequence apart, adding higher notes for Layer 3.

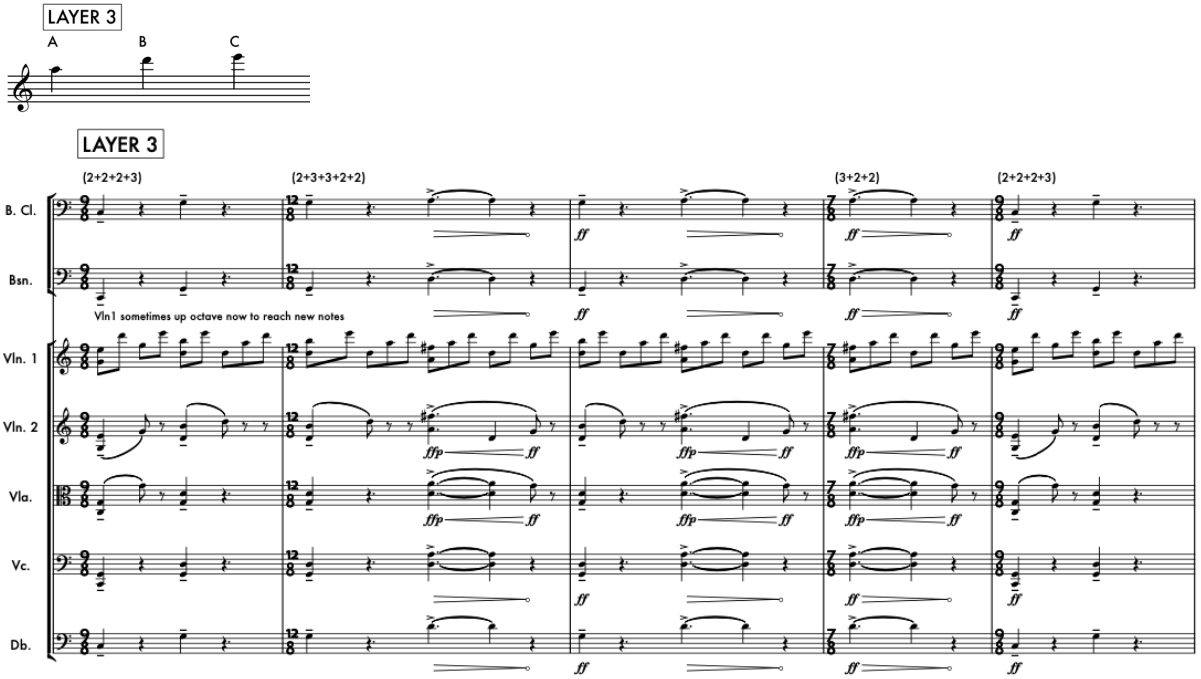

Figure 62: The three notes representing the events 'A', 'B', and 'C' in Layer 3, and their appearance as part of the Layer 3 sequence (ABBCBCCABBCCABCABABBCBCCABCABABBCCABABBCABBCBCCAB) in the source material for *Making Space*.

From this point on, the layers began expanding quite rapidly, as they would more than double in length with each stretching process. From Layer 4 onwards, the original chords from Layer 1 acted more like harmonic changes underpinning the rest of the music.

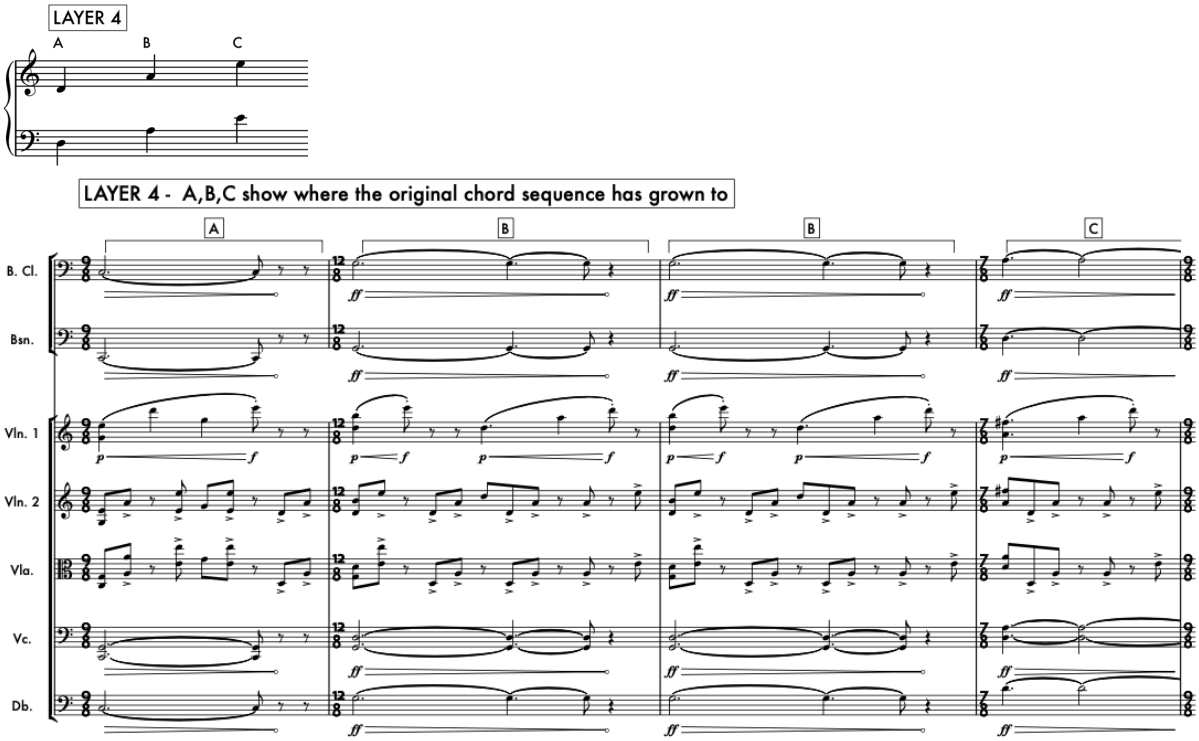

Figure 63: The three notes representing the events 'A', 'B', and 'C' in Layer 4, and their appearance as part of the Layer 4 sequence (not fully shown) in the source material for *Making Space*.

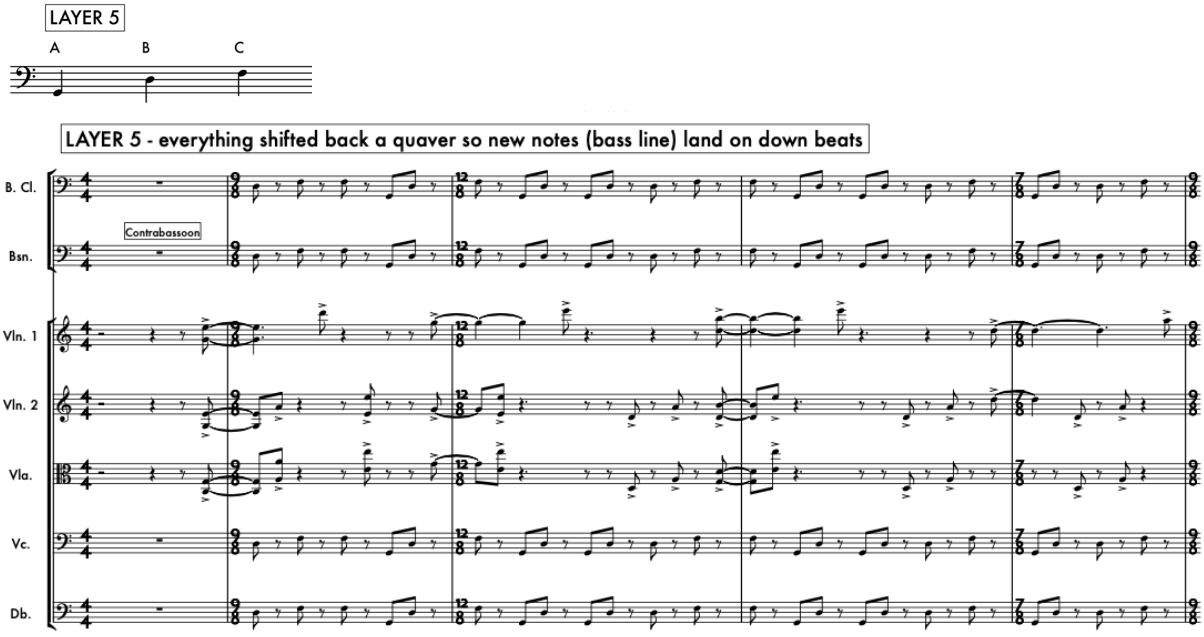

Figure 64: The three notes representing the events 'A', 'B', and 'C' in Layer 5, and their appearance as part of the Layer 5 sequence (not fully shown) in the source material for *Making Space*.

I then began composing *Making Space*, referring to the layers of source material as five sections that the music would pass through. Some layers ended up appearing almost unchanged in the final piece, whilst others were altered or recontextualised to provide a wider variety of different textures.

The piece opens with the constant looping of the 9-quaver Layer 1, with the music notated in a crotchet pulse to give every other repetition of the sequence a different weighting. The

chords being outlined by the pattern change at bar 9, and from Figure A (bar 17) the pattern begins to be stretched in places, with quavers becoming crotchets or dotted crotchets depending on which events in the sequence they represent. This momentary expansion and contraction of the sequence prepares the listener for the introduction of Layer 2 at Figure B.

From Figure B (bar 33), the sequence runs seamlessly, diving between Layer 2 and Layer 1 as it goes. The annotated score below shows the wind section from Figure B and the appearance of events relating to Layer 1 and Layer 2 of the sequence. The events outlining Layer 1 are labelled in red, and the events appearing only in Layer 2 in blue. The points at which the original 9-event sequence (ABBCBCCAB) restarts are also labelled. This shows the amount of melodic and rhythmic variety that can be achieved by diving into and out of Layer 2 at different points within the original sequence. This method of jumping between layers was inspired by the experience of watching audiences interact with *Waveforms*; shifting between moments of high and low complexity to create a musical phrase that contains elements of both.

The final bar in the example, bar 44, shows the start of the Layer 2 sequence being played in canon between clarinet 1 and bassoon 2. This treatment of the sequences as part of a close canon is used regularly throughout *Making Space*.

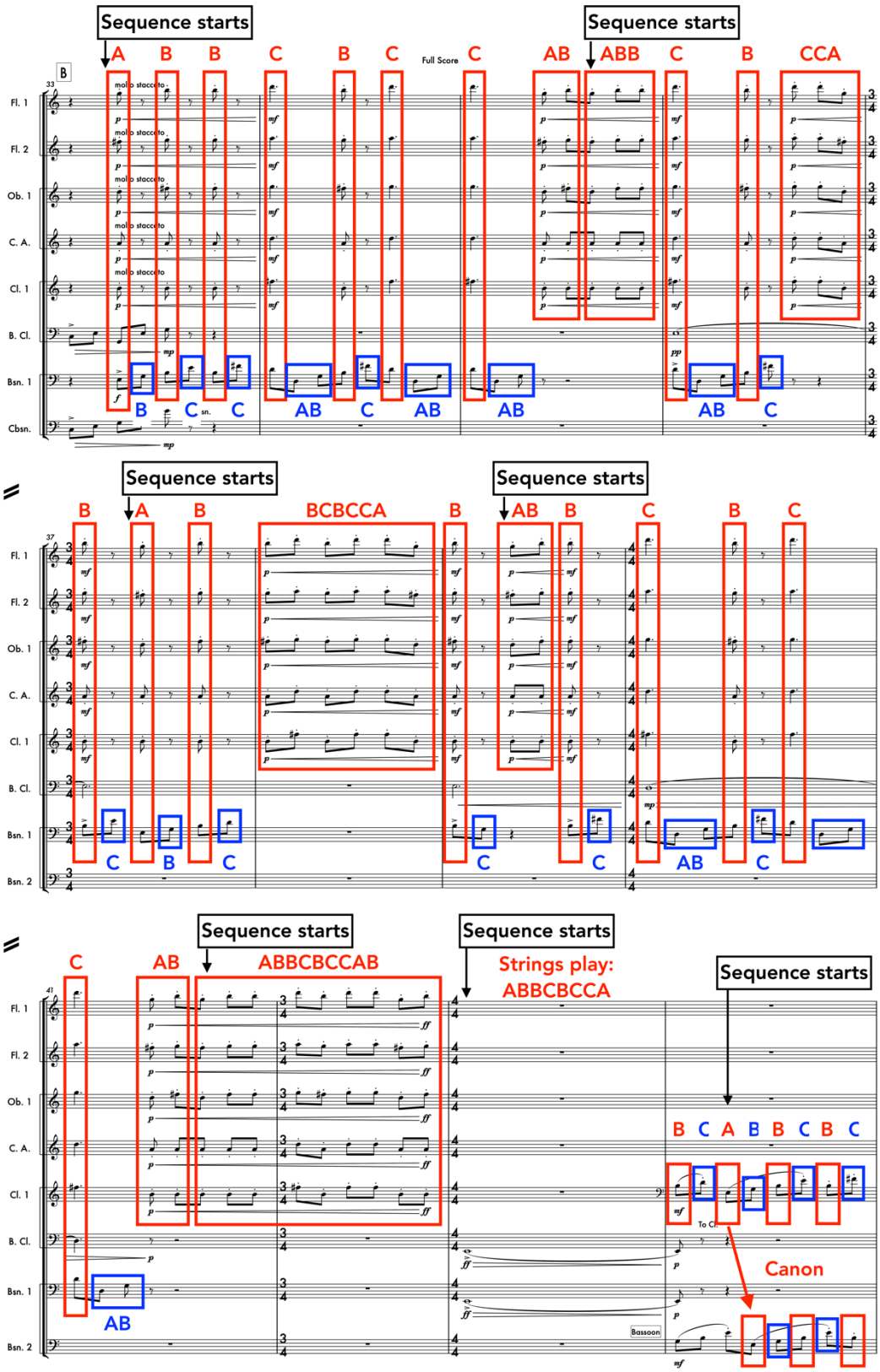

Figure 65: Annotated score excerpt showing the wind section from Figure B of *Making Space*, outlining the events that relate to Layer 1 (red) and Layer 2 (blue) and the points at which the original sequence restarts.

The stream of quavers relating to material from Layers 1 and 2 continues, with occasional moments where Layer 1 in its original form is heard alongside Layer 2 (bar 57, and bar 68). The music starts stretching apart again at bar 71, introducing notes from Layer 3, now a

perfect 5th higher than they were in the source material, as the music has modulated. Layer 3 begins properly at Figure E (bar 78), with the sequence starting a quaver before the barline so that the newly introduced material begins on the downbeat. All notes that had existed previously, from Layers 1 and 2, are removed at Figure E to thin out the texture. 'A', 'B', and 'C' events are played by oboe 1, flute 1, and piccolo respectively, and the rest of the high wind instruments join with occasional flourishes of Layer 1 material.

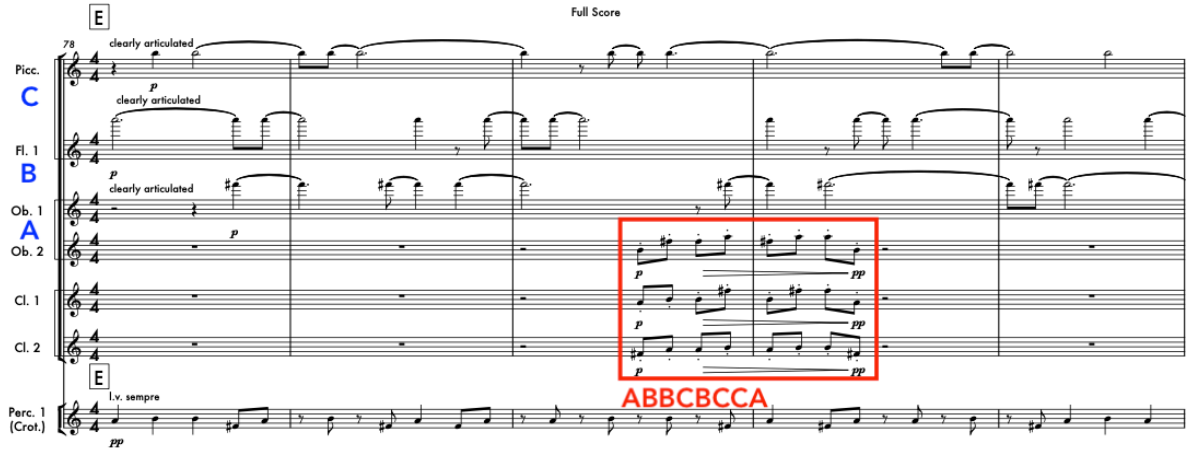

Figure 66: Score excerpt from Figure E of *Making Space* where oboe 1, flute 1, piccolo and crotales play the new notes added for Layer 3, with all previous material from Layers 1 and 2 removed. Clarinets and oboe 2 enter sporadically with material related to the sequence in Layer 1.

From bar 103 the stretched-out material from Layers 1 and 2 begins to be reintroduced with its characteristic rhythm of crotchets and dotted crotchets. This builds until Figure G (bar 134) where the music contracts back to Layer 2 again before gradually stretching further and further apart until the introduction of Layer 4 at Figure I. The melody from Figure I (bar 164) appears almost exactly as it did in the second violins and violas in the source material but transposed up a 5th. It is built from events from Layers 1, 2, and 4, with the rests occurring where notes from Layer 3 would have been. The example below shows the melody played by clarinet 2 at bar 166, accompanied by the vibraphone playing the chords from Layer 1, now spread across several beats.

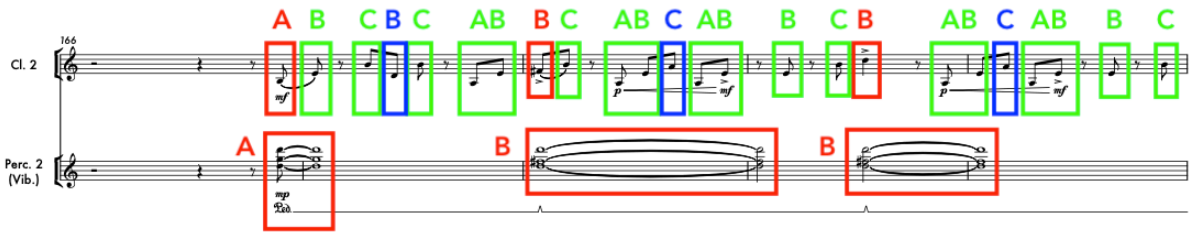

Figure 67: The clarinet 2 melody and vibraphone accompaniment from bar 166 of *Making Space*, showing events relating to Layer 1 in red, Layer 2 in blue, and Layer 4 in green. The rests in the clarinet melody show where the events from Layer 3 would have been placed.

This pattern continues until the introduction of Layer 5 material at Figure M (bar 224). All the newly introduced material is played by the bassoons, cellos, and double basses, with their accented notes and simultaneous brass chords outlining how spread out the original notes from Layer 1 have become. The cor anglais and upper strings outline snippets from the stretched out previous layers.

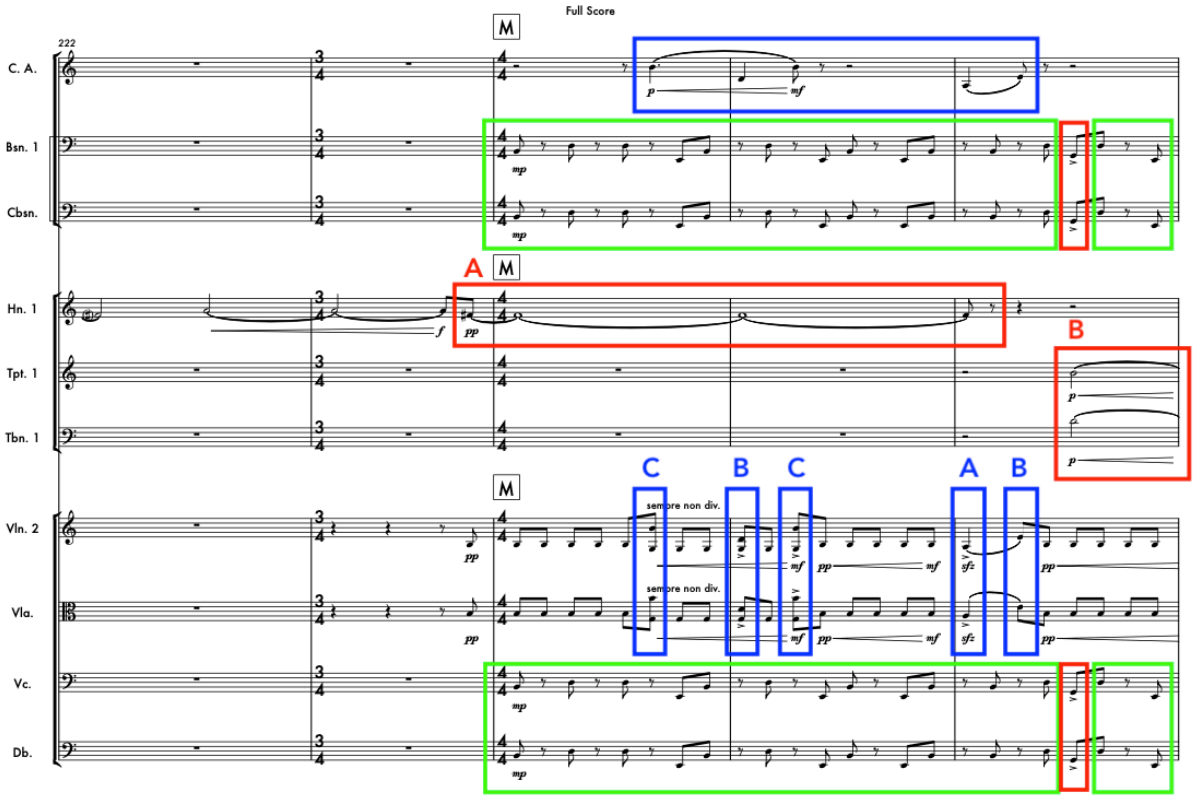

Figure 68: Reduced score of *Making Space* from Figure M showing the original Layer 1 material in red, stretched out notes from Layers 2-4 in blue, and new material from Layer 5 in green.

From this point, melodies that were introduced with the entrance of each new layer begin to get stacked on top of the Layer 5 texture, appearing in reverse order. Layer 4 material appears in the flute and piccolo at bar 230; Layer 3 material is introduced by the xylophone at bar 233; Layer 2 material enters at Figure N (bar 239), played by the violins, oboe 1 and clarinet 1; Layer 1 material arrives in the upper strings at Figure O (bar 252). The music has reached maximum density at this point, and material from lower layers is being heard against itself at different durations across multiple layers. The final expansion, at bar 260, tears the entire ensemble apart and introduces semiquaver and triplet rhythms that haven't been heard yet in the piece. It is supposed to represent the endless depths of complexity that could be contained between each of the notes if you were only to zoom in and listen closely enough.

As had been the case with *Turning Points*, I felt that *Making Space* was a successful application to a new performance setting of compositional techniques I had developed when writing music for interactive compositions in gallery-style spaces.

Conclusion

The compositions in this portfolio are the outcome of explorations into concepts ranging from deconstruction and non-linear media to audience interaction and probability. I composed them using a variety of techniques, which were developed as part of these explorations, and applied across a range of genres and performance settings.

Introduced as part of the discussions about each composition, the ideas and techniques relating to each chapter can be summarised as follows:

Deconstruction and Non-linearity

Compositions in this chapter were written to a specific brief that removed several elements of the music's construction from my control. They are presented as collections of musical material to be reassembled by someone else, either in modular score format, or as pre-recorded audio excerpts. I explore the concept of musical identity, especially in the absence of a fixed narrative form, and adopt a collage-like approach to composition, where the deconstructed materials from one piece are rearranged to make another.

Technology: Probability and Audience Interaction

These compositions explore the interactions of many random events contained within broad parameters and controlled by audience members. They demonstrate the complex and varied behaviour that can emerge from simple rules and limited source materials. I create pieces that aim to realise a "class of goals", with the understanding that each performance is unique, given the vast number of possible outcomes.[56]

Geometry: Perfectly Balanced Rhythms

Compositions in this chapter investigate the idea of sonic foreground and background, and consider the effect of roaming listeners who are able to choose their own perspective of the piece. I use the concept of perfectly balanced rhythms to develop a technique for creating musical materials that suggest multiple metres via contrasting pulse-based elements. Melodic variation is achieved using perfectly balanced rhythms, and this process is introduced to the concert hall space with a fixed audience.

Geometry: Aperiodic Order

These compositions explore the idea that complex mathematical processes can be engaged with by audience members who, in doing so, alter the musical outcome. The music is built from layers of varying detail, and the listeners are invited to switch between layers as they choose. I study the structures contained within infinite, aperiodic

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[56] Brian Eno, "Generating and Organizing Variety in the Arts," in *Audio Culture: Readings in Modern Music*, edited by Christoph Cox and Daniel Warner (New York, London: Continuum, 2008), 227.

sequences, and apply these structures to compositions written to be heard in gallery and concert hall spaces.

As mentioned in the introduction to this commentary, it is not my compositional approach itself that forms the key contribution of this portfolio, but the techniques and processes I have developed. These techniques are used across a wide range of performance settings, and are adapted to fit the expectations of the audiences that inhabit those settings.

Before Edison Denisov turns to the Debussy quotation used at the start of this commentary, he describes how "sometimes, what grips a composer is a vague idea which [they] cannot always fully comprehend. Only at some later time – and perhaps years later – does that idea take shape and its substance become clear."[57] This is perhaps the perfect description of the compositional approach I have adopted throughout my Doctoral research. Each of the concepts outlined above were unfamiliar to me when I started studying them. They represented the unknown, or contained unpredictable elements. By exploring these concepts, developing compositional techniques from them, applying those techniques across a variety of performance settings, and allowing others to interact with the music, I am attempting to give shape to the idea. Whilst there will always be some remaining mystery (as Ryoji Ikeda says: "you need some mystery"), I believe this portfolio takes steps towards clarifying the substance of the ideas that have inspired me over the past five years, and has broadened my creative practice in the process.[58]

[57] Edison Denisov, "The Compositional Process," *Tempo* 105 (June, 1973): 2.
[58] Ryoji Ikeda, "The immense electronic art of Ryoji Ikeda" (video biography by ABC News Australia), uploaded July 19, 2018, accessed May 22, 2023. https://www.youtube.com/watch?v=5y7WZk_IVqI.

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Composition Materials

Links to scores and recordings were provided to examiners