THE CONSTRAINTS, AESTHETIC IMPLICATIONS, AND CREATIVE STRATEGIES OF COMPOSING FOR NETWORKED MUSIC PERFORMANCE

By

Rebekah Wilson

A Thesis submitted in fulfilment of the requirements for the degree of Master of Music in the New Zealand School of Music

Victoria University of Wellington, 2018

“This kind of perfume…”

- Ray Lustig

Abstract

Performing music together over a public network while being located at a distance from each other necessarily means performing under a particular set of technical and performative constraints. These constraints are antithetical to—and make cumbersome—the performance of tightly synchronised music, which traditionally depends on the conditions of transmission stability, ultra-low latency, and shared presence. These conditions are experienced optimally only when musicians perform at the same time and in the same place. Except for specialized private network services, public networks are inherently latent and unstable, which disrupts musicians' ability to achieve precise vertical synchronisation and create an environment where approaches to music performance and composition must be reconsidered. It is widely considered that these conditions mean that networked music performance is a future genre for when network latencies and throughput improve, or one that is currently reserved for high-end heavily optimised networks afforded by institutions and not individuals, or one that is primarily reserved for improvisatory or aleatoric composition and performance techniques. I disagree that networked music is dependent on access to advanced Internet technologies and suggest that music compositions for networked music performance can be highly successful over regular broadband conditions when the composer considers the limitations as opportunities for new creative strategies and aesthetic approaches. In this exegesis, I outline the constraints that prove that while networked music performance is *latent*, *asynchronous*, *multi-located*, *multi-authorial*, and hopelessly, intrinsically, and passionately *digitally mediated*, these constraints provide rich creative opportunities for the composition and performance of synchronised and resonant music. I introduce four aesthetic approaches, which I determine as being critical towards the development of networked music: 1) *post-vertical harmony*, where the asynchronous arrival of signals ruptures the harmonic experience; 2) *new timbral fusions* created through multi-located resonant sources; 3) a contribution to *performative relationships* through the generation and transmission of vital information in the musical score and through the development of new technologies for facilitating performer synchronisation; and 4) the *post-digital experience*, where all digital means of manipulation are permitted and embraced, leading to new ways of listening to and forming reproduced realities. Each of these four aesthetic approaches are considered individually in relation to the core constraints, through discussion of the present-day technical conditions, and how each of these approaches are applied to my musical portfolio through practical illustration.

Acknowledgements

I wish to thank my supervisors Michael Norris, John Psathas, and Kimberley Cannady for their insight and support as I articulated my ideas in text and musical form.

Thank you to Chris, Ray, and Sarah who gave me access to their wealth of practical knowledge through our conversations. Daniel, Alison, Wiek, Sjors, Ayelet, Dante, and Reiner: your musical performance contributions and observations in workshops and performances were invaluable in assuring me that my compositions were not only performable but enjoyable to play – the best feedback a composer could receive.

Thank you to Peter Fogarty, a professional editor who provided English language copy-editing and proof-reading services for the exegesis, and Alistair Gilkison, a professional music editor who provided copy-editing and proof-reading services for the music compositions. Both editors provided their services in accordance with the Editorial Advice Policy of Victoria University of Wellington.

I am indebted to Academia Alfonso X el Sabio for their gracious permission to use María Cegarra Salcedo's poem *Ausencia Total* in my music composition *Phase Not Phase.*

To my family and friends: *you are unwavering lights of guidance in my life and work*.

Table of Contents

List of figures

List of tables

INTRODUCTION

This exegesis seeks to illustrate four aesthetic approaches afforded by the primary characteristics of multi-located networked music performance and the strategies that come to play in relation to those approaches that can be exploited for musical composition and performance. Exposing the nature of those networked systems shows how these strategies are strongly compatible with the playful, imaginative creative processes that are both so satisfying to the musician and also so important to the experience of liveness so necessary to musical performance while being multi-located and connected via networked audio.

Increasingly, we are exposed to less liveness as technology allows us such advances as to pause an otherwise live event, make coffee, and come back to it a few minutes later. The experience of togetherness is heightened by liveness, such as when we are communicating with remote family and friends, sharing the thrill of your team's game, or getting excited with the inexplicable feeling of being-part-of-it when a worldwide event is happening. There is a strong correlation between the experience of liveness and the experience of togetherness and the growing ease of real-time communications over the public Internet and private networks encourage the exploration of new collaborative experiences.

Not so long ago, I would look forward to regular video chat sessions with my young nephews as they ate breakfast at the kitchen table in their family home in New Zealand while I ate my evening meal on the other side of the world. They quickly took to the game of taking me along for playtime and, in this manner, I saw their world through the view of a camera lens. I accompanied them alongside games of playing pirates, chasing the chickens, and hiding me under a pile of blankets. In that extraordinary way of children, there was no shortage of possibilities for play as long as our digital, oft-stuttering streams of audio and video maintained a sufficient representation of ourselves. Through these interactions, I came to fully understand that mediating remote presence requires the management of expectations, which can be creatively applied and interpreted. As experienced by my nephews, I *was there* and when I have the fortune to visit them in real life, we play no differently except in genre, be it a foot-chase around the house instead of a game of digital hide-and-seek.

This sense of togetherness that affords remote play is dependent on two key factors: liveness and reproduction fidelity. Composers or musicians can exploit these constraints by adopting the development of a musical stance that exploits the affordances of Internet-based networked music performance and generates and transmits information that promotes performance relationships. In the following chapters, I focus on and define the core characteristics of networked music performance that affect the composition of notated music for the live performance by multi-located[1] musicians via the public Internet. By defining networked music performance as being the interplay of three primary categories, I explore strategies that can come into play and investigate how these categories can be manipulated for musical purposes through the development of four aesthetic approaches.

My investigation into tool development and corresponding aesthetic techniques is facilitated by my two-decades-long experience in seeking technical solutions to address the problems of networked presence for real-time media practitioners. I began writing computer programs in the mid-nineties initially due to an interest in digital signal processing (DSP), but this quickly evolved into an instant and lasting passion for the Internet thanks to the knowledge and expansive world it brought to my immediate view. I spent two years as artistic co-director at STEIM in Amsterdam[2] from 2001–2003, which expanded my views on what music and technology was capable of, both in terms of technical possibility and expressive potential. In 2004, I became and remain co-founder and technical director of the Chicago-based tech company Source Elements,[3] which focuses on obtaining the highest degree of reproducibility for remote, low-latency audio communication over the Internet along with the corresponding workflows for remote collaboration in the field of sound. Thanks to this acquired knowledge, I am familiar with remote processes both as they are technically feasible today and as expectations of future developments, which will require significant effort, technological breakthroughs, or paradigm shifts.

Using a portfolio of notated music compositions, I demonstrate how the technical and performance constraints of networked music performance can be exploited for musical discovery and realisation. Having a particular musical fondness for the post-digital aesthetic, I bring my own expectations of embracing and anticipating digital and human failure and offer four approaches that can be used in today’s world of error-prone, best-effort Internet

---

[1] Multi-located is defined as being physically absent from each other with no natural means of communication.

[2] STEIM, the Studio for Electronic and Instrumental Music, is dedicated to the development and appreciation of where music and technology meet. https://steim.org

[3] See https://source-elements.com

and do not come with a demand for access to corporate- or academic-grade infrastructure. In the final chapter, I consider the aesthetic strategies that are explored during this exegesis and music portfolio and through these strategies, offer practical solutions for approaching the limitations and affordances of networked performance music. Finally, I touch upon future research and considerations in networked music performance from the perspective of my new practical knowledge.

CHAPTER ONE: BACKGROUND AND CONTEXTS

"I haven't lost that wonder about what happens"

- Chris Chafe

Networked music performance offers a rich wealth of emerging potential for new aesthetic approaches. As a method of reproduction, it embodies Gibson's (1986) concept of an affordance machine in the way that it directly informs us about the environment in which the music is created. Furthermore, as an artificial, highly manipulable method of reproduction, it adds a powerful extension to Reybrouck's (2014) idea of music's ability "to bring together productive and experiential aspects of musical affordances … that prompts the listener to experience the sounds as if they are involved in their production" (p. 17). If the listener can imagine herself physically reproducing the sounds made by the pianist before her, she can equally imagine herself inhabiting the remote space of the pianist, which is 'not here' and is perhaps on the other side of the world. And, if the composer is doing any imaginings at all, it is soon highly likely she will start wondering what new uses she can put this technology to.

Music technology evolves rapidly and as it does so it has an undeniable influence on the creation of new musical forms. Throughout history, musical development has been tightly linked with advances in instrument technology, which has led to new genres and musical expressions. Entire new forms of performance and composition have been heralded thanks to technical inventions, such as the 1780s arrival of the pianoforte, which "urged composers towards more intense kinds of expression" (Swafford, 2014, p. 59).[4] New mechanical instruments that extend performance ability, simulation, and realisation make undeniably clear the definition between human and machine agency, arriving at the modern day where

[4] "New kinds of figuration, written articulations, pedal effects, and dramatic contrasts of volume began to appear in keyboard music, which in turn urged composers towards more intense kinds of expression" (Swafford, 2014, p. 59). Beethoven's playing was the "result of years of not only practising the pianoforte but also thinking about how it should be played, as distinct from the harpsichord or clavichord" (Swafford, 2014, p. 121). Further, Beethoven insisted that pianoforte manufacturer Stein extended the keyboard length, thereby forcing others to buy new instruments to play his new work.

instruments create what Nick Collins (2002) terms 'impossible music', music that could not be created without technical means.

In the last two decades with the Internet's extended reach of global broadband access and the development of media transmission technologies, music became producible and reproducible in unimaginable ways, leading to explorations of performing music together over the network. Regardless, for all the technical developments of the recent decades, no mainstream movement exists for networked music performance. Musicians use the Internet primarily as a file-transfer service for offline collaboration.[5]

While new digital technologies have had a deep impact on production and distribution (Poole, 2011) and a considerable number of networked music performances have been staged, "after a few years of experiments through the Internet, the interest has shifted toward the use of [networked music performance] for composition only and advancement in avant-garde music practice" (Gabrielli & Squartini, 2016, p. 1).[6] Compromises made by the designers of the public Internet have had long-lasting effects on networked audio and other real-time media streams: i.e., for massive amounts of data to be transferred, that data is packetised and decentralised, which causes latency—the time it takes for data to be transmitted—and 'network jitter', where data packets may arrive late and out of order. Networked audio can mitigate errors by implementing transmission protocols and codecs that compress and retransmit data, yet ultimately, latency and jitter are unavoidable over the public Internet. The result is 'best effort', where uncertainty must be designed for.

Latency affects time-keeping and human-level rhythms, properties that most would consider to be core in the act of making music as an ensemble. Lazarro and Wawryzynek (2001) declare that "the total latency must be kept reasonably short for the networked music performance system to be usable" (p. 157). I disagree, and argue that latency affords its own

---

[5] Observing my own daily interaction with sound professionals, real-time audio is mostly used for monitoring when working with music; e.g., a composer will listen to an orchestra or musician perform alongside a guide track or score to provide feedback as the performance occurs. Recorded files are then transferred after the listening session back to the composer for local mixing and editing.

[6] For a comprehensive overview of the history of music technologies and performance over the Internet, see *Wireless networked music performance*, chapter 2.2, A Brief Timeline, pp. 6–19.

creative opportunities. While the technical limitations of the Internet may disrupt traditional musical performance, the potential for making music together over the Internet remains to be fully realised; i.e., new aesthetic forms and genres remain to be seeded, “opening up a wide field for invention, intervention, and surprise” (Rohrhuber, 2007, p. 154) where networked music performance offers “a means of reflection for the artists and the composer over new media technologies” (Gabrielli & Squartini, 2016, p. 3). Accordingly, I suggest that networked music performance tends towards an aesthetic where “the resulting sound is born of the use of instruments in ways unintended by their designers” (Cascone, 2000, p. 396) and that basing a practice on the fragility of the networked experience leads to “situations resulting from the on- and off-line network interconnection experience” (Beiguelman, 2006) where the digitised signal provides co-ordination of “multiple and simultaneous readings of contents mediated by countless uncontrolled variables” (Beiguelman, 2006). For me, the potential for new forms and genres for suggests exciting opportunities for research, particularly in generating and transmitting ‘vital information’ by musical and technological means. Nevejan (2007) suggests that “when in trouble, one needs good information and good communication; i.e., one needs ‘vital information’” (p. 175), which is information that “supports survival for a specific person in a specific place at a specific time” (Nevejan, 2007, p. 175). Vital information in networked music is crucial in facilitating synchronisation, in contrast to the traditional performance setting, where ensemble musicians rely on low latency audio and visual communication. These considerations, which require “an interdisciplinary approach, evaluating both aesthetic and technical issues” (Gabrielli & Squartini, 2016, p. 3) form the basis of this exegesis.

1.1 METHODOLOGY

This chapter determines the primary characteristics of networked music performance from which I arrive at four aesthetic strategies that exploit those characteristics. In chapter 2, I explore those characteristics in detail through conversation with expert practitioners. Chapter 3 discusses tool development and strategies towards enacting the aesthetic approaches, after which I provide an analysis of the practical application of those approaches in my composition portfolio. Concluding with a review of the implications of the network on music performance, I offer my thoughts and hopes for future developments in the field.

To extract the key issues faced by participants in networked music performance, my research is grounded and richly informed through the interviews, workshops, and conversations with expert practitioners who are experienced in realising works for the medium.[7] Through these conversations and the research directions they inspired, I anchor my technical and musical knowledge in functional and practical terms to open up ways in which novel aesthetic strategies and musical ideas might develop. I understand my analysis of the material is situated as belonging to the "aesthetic interpretive subject" in Joanna Demers' (2010) concept of "an observer who reflects critically, albeit imperfectly, about what these disparate communities share" (p. 5). While it is fairly straightforward to categorise and formalise the technical constraints and characteristics given their procedural nature (Gill, 2015), talking about aesthetics is acknowledged as being highly subjective. I am indebted to the tacit knowledge research of Michael Polanyi, which I discovered via Satinder Gill and Leonard Meyer. It provided me with an aesthetic point of "knowing from" where "knowledge of style is usually 'tacit', it is a matter of habits properly acquired or internalised and appropriately brought into play" (Meyer, 1989, p. 10). Thus, how we approach music changes according to certain contexts; i.e., we can analyse contextual constraints and the relationships between constraints with the aim to make explicit the reasoning behind aesthetic choices.

1.2 PRIMARY CHARACTERISTICS OF THE MEDIUM

In this section, I provide a definition of networked music performance with a view to discussing the technical and aesthetic potentials in the following chapters, which I derived from the analysis of my gathered research with participants, workshops, and literature review within the context of contemporary classical composition. According to Meyer (1989), styles and the constraints governing them can be related to one another as hierarchically organised by the classes of "laws, rules and strategies" (p. 13). Laws are universal, primary constraints. Historically, they include structural constraints such as physics, instrument materials, and architectural limitations, but also cultural laws such as women being excluded from professional orchestras until well into the twentieth century.[8]

---

[7] These interactions were conducted in accordance with the policies of the Victoria University Human Ethics Committee, approval number 23345.

[8] Women were non-existent in most major music symphony orchestras up until the 1960s (Collins, 2015).

In networked music, the primary characteristics are defined by technology and the imposition of that technology on participants: i.e., the network introduces latency through transmission. Network latency cannot be removed—it is a property of the natural laws of physics—and it cannot be reliably predetermined or fixed at a certain value, even during the duration of a performance. Therefore, latency and uncertainty are primary characteristics. Secondly, networked music requires at least two participants who are multi-located and multi-authorial, each inhabiting their own distinct acoustic space and influencing a musical result that is experienced distinctly by them. The third core characteristic of networked music is the digital mediation of presence: i.e., networked music is performed over a digital network where the signal is digitally encoded, transmitted, and decoded. Performative relationships are managed purely by the means of this digital transmission. In practice, the characteristics of latency and uncertainty can be applied to networked music transmitted via analogue means, such as radio broadcasts or copper phone lines; however, listeners are less frequently listening to analogue radio transmissions as they migrate to the Internet, satellite radio, and podcasts. In addition, digital fibre optic and wireless installations are replacing the old analogue telephone infrastructure.[9] Given the increasing level of digital communication technologies, transmitted data should be assumed to be subject to compression and the network effects of packetisation, which are the core digital mediation parameters that I explore in chapter 3.

Secondary properties are defined as musical relationships such as rhythm, harmony, and timbre. In networked music performance, these properties are directly affected by how the composer negotiates the primary characteristics: e.g., latency affects the ability of musicians to be temporally responsive to each other, and a multi-located performance removes eye contact as a visual aide for synchronisation. These constraints thereby necessitate new strategies in musical synchronisation.

Tertiary properties are the parameters and consequences of how certain rules are applied to those parameters; i.e., the ways in which the composer can personalise her music according to the way she realises a constraint's rules. This includes concepts such as

---

[9] The New Zealand Telecommunications (New Regulatory Framework) Amendment Bill of 2017 aims to allow telecommunications companies to actively discontinue support for analogue copper phone services by removing service regulations.

manipulating or accommodating the variable amount of latency between network participants, or sending unexpected data to the codec for the purposes of exploiting timbral potential. How the composer approaches the secondary strategies is determined by her aesthetic.

Lazzaro and Wawrzynek (2001) defined networked music performance as the "practice of conducting real-time music interaction over a computer network" (p. 4). For the purposes of this exegesis, I added to this definition of networked music performance in line with my own personal interpretation, which I derived by way of, and subject to, the three primary characteristics extrapolated above in relation to the following three conditions:

1. I refer to the network exclusively as the public Internet, which is prone to latency *and* uncertainty.
2. I apply the concepts of multi-located and multi-authorial, which refer to music made between multiple spaces and multiple human participants, respectively.
3. The means of communication between participants is encoded and transmitted by digital network technology; therefore, communication is digitally mediated.

Within the boundaries of these characteristics, I consider the limitations and affordances of how we perform music over a network. When we communicate with each other via technology, we are experiencing mediated presence: i.e., a networked performance mediates human presence by exchanging 'vital information' via technology. Mediated presence is partial, it lacks the full-sensory experience of real-life interactions. The information we expect to have during an interaction is limited; therefore, synchronisation becomes difficult and we easily misunderstand each other. When performing music over a network, we need to generate and transmit vital information that tells performers where we are together in the score to address the disruption of the normal exchange of musical communication, which is available to musicians who are present with each other in composite space.

We further accommodate mediated presence by adapting our expectations and 'orchestrating' or 'performing' presence (Gill, 2015) actions that permit the synthesis of new modes of communication and expression, which are often converted to more abstract forms that are transmitted easily. The way in which the composer manipulates presence by making technical or musical choices in turn affects the relationship between participants: i.e., the performative relationship is the dance between a constraint and acting on that constraint.

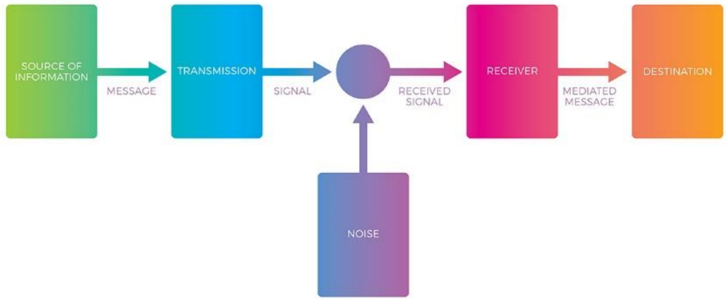
My understanding of performative relationships via mediated presence is heavily influenced by Nevejan's (2007) YUTPA (i.e., being with You in Unity of Time, Place, and Action) framework. Nevejan describes how the "four dimensions of time, place, action and relation have different values between You and not-You, Now and not-Now, Here and not-Here, Do and not-Do" (Gill, 2015, p. 148). These dimensions are useful for understanding the constraints, artificial or otherwise, that are created when presence is mediated by technology. Nevejan's (2007) research shows that such relationships can be measured and categorised and through this process we can create vital information and expose new aesthetic strategies by the exploitation of the fabrications, synthesises, and synchronisations of presence as influenced by digital mediation.

In the following section of this chapter, I introduce the aesthetic approaches that I will focus on in chapter 2, where I give a detailed analysis of the constraints of each primary characteristic towards a full comprehension of the technical, performative, and aesthetic potential of those constraints.

1.3 STRATEGIES AND APPROACHES

As a composer and network technologist, my interest in preparing this exegesis is to encourage musicians and composers' desire to play music together from a distance. To encourage remote participation, it must be shown that networked music performance is an invigorating and satisfying musical pursuit with achievable aesthetic challenges and a rich circumstance of affordances for future work. As outlined in the previous section, networked music performance involves three primary categories: latency and uncertainty, digital mediation, and multi-location. In a reading of Moles (1984), Rohrhuber (2007) describes the artistic expression, in reference to Shannon and Weaver's (1948) mathematical theory of communication (Fig. 1), as a "message transmitted by an artist (the transmitter) to another individual (the receiver) over the systems of perception (the channel)" (p. 145).

Figure 1. Shannon and Weaver's (1948) schematic diagram of a general communication system



These categories of message, transmission, and reception work together to comprise the vital information that continuously forms the musical experience as encapsulated by the sound image in which musical participants interact. The ability to manipulate the sound image by generating and modifying both the message (as sound) and the way the messages are transmitted reassures us that: a) we can be participatory with the remote sources and b) we can imagine and apply strategies towards an aesthetic of networked music performance.

1.3.1 AESTHETIC CREATION CONTEXTS

I use the term 'aesthetic' in the way John A. Walker (1987) defines it, as in "the aesthetic quality of a work that is not determined by the motives of its maker" (p. 26). The French curator Nicholas Bourriaud (2002) defined the term as "a set of artistic practices which take as their theoretical and practical point of departure the whole of human relations and their social context, rather than an independent and private space", where artists facilitate rather than make, and consider art as information to be exchanged between the artist and viewer. Through reading Polanyi, via Gill (2015), I understand aesthetics as a personal act of knowing involving 'tacit knowledge', which is the "way we are aware of our neuronal processes in terms of perceived objects. This has a mediatory structure, hence we know more than we can say" (p. 21). From this position, I apply the term 'aesthetics' to denote both a way of knowing and a way of doing.

An aesthetic is created by poiesis[10] through the combination of decisions made according to the real-time experience of what is happening now in play with tacit knowledge: i.e., "poiesis, as it pertains to the distance collaboration" means "creating with intentionality" (Pignato & Begany, 2015, p. 119). Aesthetics exposes musical relationships, which to date are largely built on the assumption of musicians who share the same space. The introduction of latency and multi-located digitally mediated presence requires a departure from the traditional musical strategies of vertical harmony and synchronous rhythmic relationships towards aesthetic strategies of liveness and uncertainty.

The concept of liveness is used to distinguish between music that is in the act of creation and has not previously existed in its complete form, as opposed to music that has already been created. Through liveness we experience participation and interactivity, which engenders resonance between stimulus and action, thereby strengthening social connections. I appeal to Auslander's (2012) premise of liveness being a "historically variable effect of mediatisation" where "prior to the advent of these technologies (e.g., sound recording and motion pictures), there was no need for a category of 'live' performance" (p. 3) and I continue this idea to suggest that the arrival of networked music requires approaching liveness from new angles. Latency disrupts liveness, which unsettles the naturally developed tendency for musicians to sound together; therefore, vertical harmony and synchronous rhythms are laborious. For most musicians, this is a most profoundly disorienting experience and causes many to state that you cannot play music together over the Internet.[11] Flipping this assumption by saying you can play new kinds of music together over the Internet opens up opportunities for listening and experiencing music in new ways.

The twentieth century gave a wealth of understanding that music is not limited to harmony and melody, and that rhythm and timbre mean more than experiencing a beat and a determinable audio source. By the time the twenty-first century arrived, music refused to be

---

[10] Nattiez (1990) defines poiesis as "the *link* between the composers' intentions, her mental schemas, and the result of this collection of strategies: that is, the components that go into the work's material embodiment".

[11] From private conversations with many musicians over the years during my time working with networked audio. This exegesis is valuable to me personally because I am finding ways to describe in musical terms that indeed, you *can* play music together, just not in the traditional forms of music that you usually experience.

categorised at all except as that which is audible[12] during an act of listening; i.e., it is intentional. If a genre of networked music performance might be imagined, it would be the set of creation contexts marked by nomadism (sources of sound arrive from anywhere), failure (failure of the network, failure of equipment, or failure to respond performatively), the boundary between logistic optimism and pessimism, limits of technical virtuosity, and the exploitation of human-level rhythms in a multi-located and multi-authorial environment mediated by networked presence.

1.3.2 FOUR AESTHETIC APPROACHES

An aesthetic strategy of networked music performance is a complete, categorisable expression of the application of music given the primary characteristics and constraints I lay out in this chapter; i.e., a set of principles underlying the stylistic choices made during the creative process. I refer to Curtis Roads' excellent *Aesthetic Foundations* for a relevant discussion on aesthetics as it applies to computer music. Roads (2015) further defines aesthetics as an "inspired choice" or a "particularly satisfactory choice given the context" (p. 15). My take on this is that the more informed a composer is about her tools, the more choices for inspiration she has available. In the remainder of this chapter, I extract key aesthetic considerations to apply as a basis for the following chapters on aesthetic approaches to music and network technology.

1.3.2.1 APPROACH 1: POST-VERTICAL HARMONY

Harmony is a vertical property, where multiple voices sound together at the same time to create an experience of simultaneous complexity. Counterpoint and melody are *horizontal* properties that create complexity over the temporal, horizontal plane. I introduce the term 'post-vertical harmony' because the experience of harmony, counterpoint, and melody as known in traditional music is disrupted when time-keeping is unstable. Post-vertical harmony

---

[12] Or not! See Cage's *4′33″*, a work of no audible sound, "one of the most controversial, inspiring, surprising, infamous, perplexing, and influential musical works since Igor Stravinsky's *Le sacre du printemps*" (Gann, 2010, p. 3).

means embracing a time-shifted skewed listening experience; i.e., the experience of knowing that the harmony you are hearing is the result of network latency.

To the listener, a completely different harmonic experience happens with each permutation shown in Figs 2–4. Such an effect of harmony shifting over time is familiar through works such as Ligeti's 'micropolyphonic' webs based on constant transformation (Roig-Francolí, 1995) and the mensural canon effect of an unfolding melody that expands underneath itself creating harmonic density, a modern example being the opening movement in Shostakovich's fifteenth symphony.[13] There are fundamental harmonic processes that are compatible with a networked aesthetic: e.g., detached layers of sound, macrostructured to allow for unstable internal motion. Where "polyphony is what is written", says Ligeti, "harmony is what is heard".[14] I have no doubt that these composers would feel completely at home given the latency constraints of the network. Nebulous compositions such as Ligeti's 1967 *Lontano* and Xenaki's 1953 *Metastasis* embody processes that would translate directly to multi-located performance because these works depend on conceptualising time instead of a melodic theme.

Figure 2. Opening bars of Bach's Choral BWV639

[13] From rehearsal number 27, *Symphony No. 15* in A major (Opus 141), Dmitri Shostakovich.

[14] Ligeti, *Lontano* LP program notes, 1984, as cited by Bauer and Kerékfy (2017).

Figure 3. Each line is 375 ms ahead of sync of the previous line (typical latency)

Figure 4. Each line is 375 ms out of sync after the previous line

1.3.2.2 APPROACH 2: RESONANCE AND MULTI-LOCATED TIMBRAL FUSION

Networked music performance mirrors the electroacoustic experience of Schaeffer's (1977) reduced listening, "which strives to strip sound of distractive visual presences" (McKinnon, 2007, p. 1). When the sounding body is not present and transmission is digitally mediated, we have no obligation to reproduce the signal as it is received. This challenges the expectation of liveness further: e.g., without being present at the moment of sound-making, the listening experience becomes detached. The result is that the sounds created by remote spaces are fused together to be experienced as new timbres—new instruments—as "we forget about what agent, object, or action made the sound or what the sound signifies; we focus only on the musical properties of the sound – its internal rhythms, its timbres and textures" (Andean, 2013).

In networked music, latency affects both the rate of succession and therefore the timbre of the source sound: e.g., two flutes sounding the same note in 'composite space'[15] are now different because the attacks and envelopes are even more asynchronous than occurs naturally with non-machine performances. Latency can be exploited to further detach musical harmonies and rhythms: i.e., asynchronous timbres, loudnesses, and pitches have the potential to create a fusion of succession of sounds when overlapped in quick repetition, much in the way that film when played back at twenty-four frames a second is perceived as a seamless image (Seashore, 1936). Music psychologist Carl Seashore's studies on vibrato were instrumental in considering the timbral implications of networked music performance and the ability to create entirely new sounding instruments that echo and shimmer between the networked locations, where distinct sources are perceived as forming fused timbres. Seashore (1936) claimed that timbral deviations, such as vibrato, create an auditory illusion which result in our hearing something entirely different than that which is performed. This illusion is the sound world that happens in the act of creation.

1.3.2.3 APPROACH 3: VITAL INFORMATION AND PERFORMATIVE RELATIONSHIPS

While the Internet has been transformative in many fields, including the arts, music collaboration and creation over the Internet remains largely non-real-time. Given that musicians are highly collaborative and readily embrace new technologies, this lack of real-time music creation and experimentation suggests that distinct issues must be resolved before a wider group of musicians embrace networked music performance as part of their repertoire. Presence that is mediated over the network disturbs human-level rhythms (Gill, 2015) by interrupting life-long musical practices of playing music together and rhythmic synchronicity, which interferes with honed musical abilities for virtuosic performance based on traditional ensemble dynamics. Networked music performance clearly creates extra-musical demands on the participants as they attempt to achieve temporal stability through their performance. Critical information must be created and exchanged in ways other than the traditional cues

[15] "Composite space" is a borrowed term from Sarah Weaver (2016). It refers to participants being present in the same physical space as opposed to being in multiple, separate spaces and connecting over the Internet.

used by musicians in composite space. Nevejan (2007) states that "for information to be vital, it has to touch upon our natural presence physically or socially. Mediated presence, which generates vital information, will also ultimately have this effect" (p. 174).

I propose that the vital information that facilitates performative relationships over a network can be created and transmitted as musical information. The understanding of how vital information is used in a networked music context is of high value: e.g., we can make use of notational music events in the score and implement technical solutions that reproduce and communicate clock and event messages. By providing this vital information, the composer creates an environment that mitigates synchronisation concerns for musicians, leading to the development of new performance structures.

1.3.2.4 APPROACH 4: A POST-DIGITAL APPROACH

Inspired by Nicholas Negroponte's 1998 comment, "the digital revolution is over", Cascone (2000) coined the term, 'post-digital', in commenting that the "revolutionary period of the digital information age has surely passed. The tendrils of digital technology have in some way touched everyone" (p. 12). Cascone's (2000) thinking follows Walter Benjamin's thesis that "mechanical reproduction results in fundamental and traumatic derangement of the senses, which anticipated certain aspects of [Marshall] McLuhan's idea that media technologies constitute new extensions of the sensory organs of man – *outerings* of the body" (Taylor & Harris, 2007, p. 24). All of this means to say that technology that reproduces reality does not reproduce it in human ways, but it decimates it to pieces, duplicates it, destroys much of it, encodes and decodes it, transmits it, stores it, deletes it, and reproduces it with or without the grainy veil of decompression. This can be taken as a cautionary tale: i.e., reality can be spliced at the will of machines and we should all take care not to believe any of it, or this can be taken as a great opportunity for messing with reality. This exegesis looks at some of the ways in which networked music performance can manifest itself via a post-digital approach as Cascone (2000) notes, "technological failure is often controlled and suppressed" (p. 13). In the case of networked music performance, failure is largely uncontrolled. Even when not faced with packet loss, time-stretching, or changes in latency during a performance, the "uncertainty of causation is often an integral part of the aesthetics" (Rohrhuber, 2007, p. 148). The resilience and musical creativity of the participants is paramount when facing latency and multi-located considerations.

In chapter 2, I extract the parameters, both technical and performative, from the primary characteristics that can be manipulated and addressed to find new ways of playing music remotely. In chapter 3, I present a summary of technical tools and devices that can be manipulated for creative purposes. In chapter 4, I describe my composition process and subsequent portfolio that has been created alongside this exegesis. Chapter 5 reviews the entire body of this work, offers practical strategies for the composer, and suggests future areas of research.

CHAPTER TWO: PARAMETERS FOR EXPLOITATION

"We're dealing with different models of time"

- Sarah Weaver

This chapter extracts and discusses in detail the three primary characteristics as determined in the previous chapter and how those characteristics lend to the evolution of a networked music performance aesthetic. In this chapter, I introduce Chris Chafe, Sarah Weaver, and Ray Lustig, who are musicians and composers with whom I explored in conversation their performative and aesthetic experiences in working with networked music performance. Through the discussion of their performed musical works, which was approached through the lens of the primary characteristics, I conceptualise a concrete foundation for aesthetic and technical discovery in subsequent chapters. Speaking with these experts gave me access to their complex, thoughtful approaches in consideration of their direct experience in working with network technology in a performance setting and how that influenced their compositional decision-making process. Each expert is introduced in Appendix I. In chapter 5, I present a comprehensive review of techniques discussed in this exegesis in the form of an aesthetic toolbox.

Being digital, the means of transmission is highly manipulable. Being music, what is transmitted is highly expressive. These two premises offer strategies for approaching the aesthetic considerations outlined above in networked music performance. I summarise below the primary characteristics:

- **Latency and uncertainty**: the unavoidable artefact and unstable property of the network transmission.
- **Multi-located, multi-authorial**: the collision of sound images that exist on multiple temporal planes, creating new timbral experiences and questioning perceptions of authorship and ownership.
- **Digital mediation**: the deconstruction and reconstruction of the sound image, permits reproduction in any form.

I consider the musical affordances of the primary characteristics using these four aesthetic approaches:

1. Post-vertical harmony.
2. Vital information and performative relationships.
3. Resonance and new timbres through multi-located fusions.
4. The post-digital aesthetic.

I argue that everything else that addresses the sound image, be it as perceived by participants, listeners, or the concerns regarding DSP[16] or placement of audio speakers[17] has been addressed with sufficient depth in other texts.

2.1 LATENCY AND UNCERTAINTY

Latency—the time difference between sending and receiving data over a network—is fundamental to the experience of networked music performance. To gain insight into how composers and performers manage latency, I spoke with Sarah Weaver whose decade-long experience in composing, conducting, and performing with music over a network is currently culminating in her PhD on networked music. Sarah's interest in the medium began in 2006 with early collaborators Pauline Oliveros, Chris Chafe, and Mark Dresser. Oliveros (2009), a pioneer of early networked music performance, stated that as "the technology improves exponentially and ubiquitously then eventually there will be no reason not to perform music at a distance" and "making music together makes friends" (p. 2).

Latency is the essential grain of networked music performance that articulates the physical limits of a system and cannot be programmed away. It is a technological implication that cannot be solved by technology. Sarah (Weaver, 2016) explains that something new happens when we traverse distance with technology because humans remain analogue even when we use communication technology that works on a radically different timescale.

[16] Digital signal processing (DSP) is the method by which signals, such as sound, that have been encoded into digital form are intentionally manipulated (Thon, 2003).

[17] Sound projection or 'diffusion' is the active practice, originating with the French acousmatic tradition, of redirecting sound to loudspeakers (Emmerson, 2017).

Latency can be experienced as a site-specific phenomenon; e.g., as reverberant artificial structures or cavernous natural spaces. It can be introduced purposefully with electronic means, such as network latency or analogue delay. It can also be produced through musical intentions such as "groove" elements, grace notes, rubato, and free tempos. Sarah is familiar with performing networked music over ultra-low-latency systems, such as Internet2,[18] and observed that latency's "threshold is key in creating a perception of 'synchrony'" (Weaver, 2016).[19] I interpret Sarah's observations as referring to the properties of latency as vital information. The delay and jitter values tell us critical information about the environment that directly affects the way we respond to each other musically.

While certain types of music-making over a network are complex or impractical due to the disruption of rhythmic expectations, other forms of music are well-suited and exquisitely distinct when composed with latency in mind and the audience's perception of latency is related to expectations. When surveying an audience after a networked music performance, Sarah "asked them if they experienced any delay or latency, and they almost unequivocally said, 'what do you mean', like they just didn't know that there was any delay because we had bridged it with the music" (Weaver, 2016).

The primary effect of latency is the unavoidable—and possibly unstable—counterpoint caused by both the network and the result of humans attempting to synchronise remotely. I conversed on this topic with Ray Lustig, a New York-based composer whose 2013 work *Latency Canons* approached latency as the focal characteristic for orchestra and four distributed ensembles. An audience member and reviewer noted that for Ray, latency was far from being an obstacle: "where many composers might bemoan a technical difficulty

---

[18] Internet2 is an institutional network that can "support phenomenal numbers of channels at long distance and low latency. As these linkages become more commonplace (and extend into communities outside universities) they will create an 'always on' real-time media web that includes a different kind of acoustical medium" (Chafe, 2009, p. 28).

[19] Sarah Weaver (2016) uses 'synchrony' to suggest that "to connect live and perform together live is a different level of intimacy" and, given a set of musical instructions, remote participants can be musically synchronised. Gill (2012) also defines synchrony as "the period and phase-locking movement patterns or sound to an external referent. In other words, it is the capacity to move in time to the next expected regular beat from outside" (p. 112).

that must be overcome in the service of precision, Lustig saw an opportunity. What if he could make a virtue, even compositional principle, out of latency?" (Lowder, 2013).

Continuing my research, I discussed latency technology with Chris Chafe, professor and director of Stanford University's Center for Computer Research in Music and Acoustics (CCRMA). Chris is deeply familiar with latency and technology as one of the core motivators of networked music performance in the United States and author of widely used software for performance over broadband networks.[20] He notes that there is "content that could live at that time-scale",[21] and with sufficient vital information of the state of the network, musicians can not only mitigate unreliability with appropriate musical choices, but also enjoy the fault-prone means of transmission. Chris's 2001 work *Network Harp*, in which he generated tones using variable network delays, exposes the latency of network through sonification by "constructing feedback loops over Internet connections" (Rohrhuber, 2007, p. 154). Chris's application of the networks' vital information to directly inform musical content is an example of finding aesthetic inspiration in the machine, a by-product of the "immersive experience of working in environments suffused with digital technology" (Cascone, 2000, p. 12).

2.1.1 PARAMETERS OF CONTROL

For a successful networked music performance, the core compositional strategy is to accept that latency is elemental to the conditions. Latency over the public network cannot be made shorter until major physics breakthroughs occur.[22] Latency can be either a constant delay or it can be subject to unstable jitter, resulting in an inconsistent response time over the network. Latency cannot be decreased; however, it can be stabilised using a buffer, which in turn adds

---

[20] Chris Chafe is a major contributor to the JackTrip networked audio software, which demands ultra-high broadband services such as Internet2 due to its ability to transmit multiple independent streams of full-resolution audio at very low latencies (Chafe & Cáceres, 2009).

[21] Juan-Pablo Cáceres and Alain Renaud (2008) developed several techniques for playing network feedback with their *Net vs. Net* collective.

[22] With any physics breakthrough that affects space travel and all manner of human activities, music performance will be a much lesser concern for society!

more latency. The compromise between transmission fidelity and latency is integral for the experience of remote presence. Consider the last time you had a video chat call with the other side of the world, latency may have caused you and your conversation partner to talk over each other, and packet loss may have frustratingly interrupted your conversation. In a music setting, such transmission degradation can inhibit performance relationships, triggering decisions to mitigate failure. In general, except when working with the most remote or off-the-grid locations, high-fidelity audio is quite good at being transmitted as long as there is a suitable buffer in place.

In conversation with Chris, I asked if he could imagine any advances that would improve the experience of networked music performance and his immediate reply was "I guess we are presuming that speed of light isn't something we've figured out?" (Chafe, 2016). On a technical level, while we cannot shorten distances without breaking the laws of physics, we can attempt to stabilise the network, make incremental improvements in the transmission, and work to bring Internet2 services to universities and institutes around the world.[23]

The controllable parameters for latency are equally technical and musical. We can adjust the length of latency through technical means (though we cannot shorten it except by coming closer to each other) or we can develop musical responses both composed or improvised that interact with the network latency. Regardless, the composer must understand the networked environment so she can better develop compositional strategies and make use of the technical solutions available to her.

2.1.2 MUSICAL IMPLICATIONS OF LATENCY AND UNCERTAINTY

The remainder of this section looks at the musical implications of latency and the unstable transmission and what kinds of decisions might be made that respond to the four aesthetic

---

[23] Given that in the early 1990s I was unable to access non-New Zealand websites at my university console due to the sheer cost of international traffic at that time and now I have access to all the world's public data at my fingertips within a few seconds, it won't surprise me if we will all be connected at insanely high speeds and low latencies within my lifetime.

approaches introduced in chapter 1 of post-vertical harmony, performative relationships, resonance and timbre, and the post-digital experience.

2.1.2.1 APPROACH 1: SYNC WINDOWS

While musicians performing over a network may start at perceptually the same time, reception is delayed due to network latency, which means that instruments cannot be deterministically aligned for synchronicity. This misalignment creates a condition where we cannot compose music that relies on vertical alignment of notes. The disruption replaces simultaneous, vertical musical alignment with asynchronous, diagonal alignment, requiring what I term a *post-vertical* harmonic approach. While the effect of latency on harmony ruptures traditional harmonic progression, it creates two harmonic opportunities: i.e., counterpoint and blurring.

The ‘sync window’ is the sounding of a note in relation to another note according to both the intention and position of the composer and participants, and the latency created by the network. The distributed nature of the network means that there are as many permutations of the music experience as there are locations, which are primarily created by latency. A completely different harmonic experience happens with each permutation, according to the sync window, which I define as the perceptual vertical synchronisation of multiple remote sound events depending on the latency between the time they are generated and the time they are heard by remote participants. Fig. 5 shows the sync window in composite space where notes are aligned with insignificant delay and the participants perceptually experience their created notes as sounding at the same time, e.g., the way each player in a string quartet experiences the simultaneous sounding of all four instruments while at close range. Figs 6 and 7 demonstrate how the network creates misaligned sync windows where the alignment depends on the amount of latency.

Figure 5. Sync window in composite space

Figure 6. Sync window with some latency

Figure 7. Sync window with high latency

From a musical perspective, the sync window informs how consonance and dissonance is experienced. James Tenney (1988) defines consonance and dissonance as properties of sound that are caused by its partials. The close frequency of partials creates a beating, which is heard as roughness or dissonance, while the absence of beats is called consonance. I approach harmonic and timbral morphology in networked music performance by applying sync windows where alignment is dependent on the latency and acoustic properties of the performance conditions. While sync window alignment is determined by the environmental conditions, periodicity is manipulated through compositional elements. Periodicity "emphasises both the sensation of stability and smooth fusion in beat-less consonances as well as the regularity of intermittent pulsations causing roughness in dissonance" (Tenney, 1988). The following figures illustrate how the sync window in combination with periodicity creates dissonance. Fig. 8 shows a vertically aligned chord progression I V I V. With latency, the sync window alignment skews diagonally, but retains the essential harmonic progression (Fig. 9). With greater latency than the length of the chord, the performed music no longer matches the written intent (Fig. 10).

Figure 8. Vertically aligned consonant chord progression

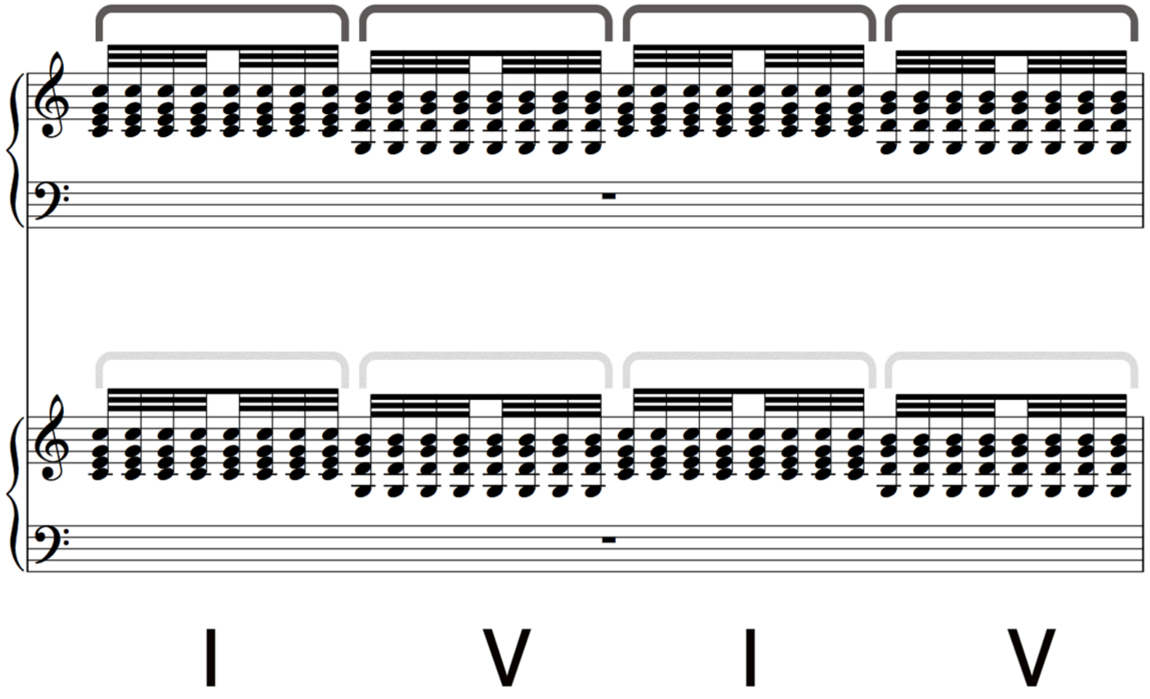


Figure 9. Harmonic progression is blurred at edges but retains consonance

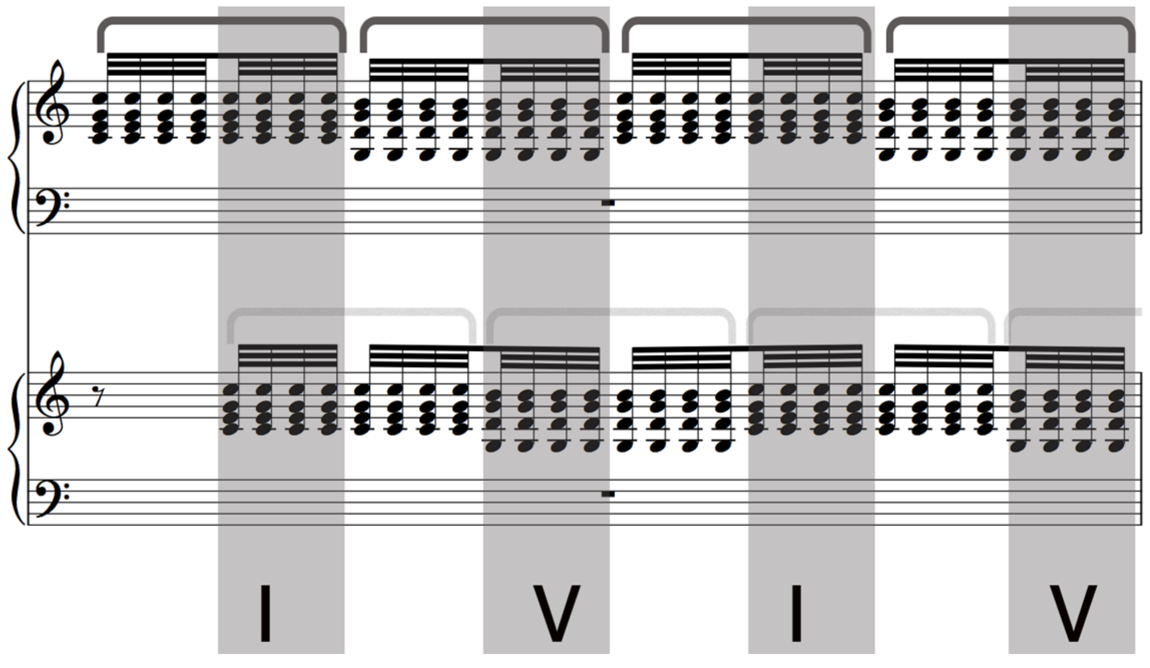
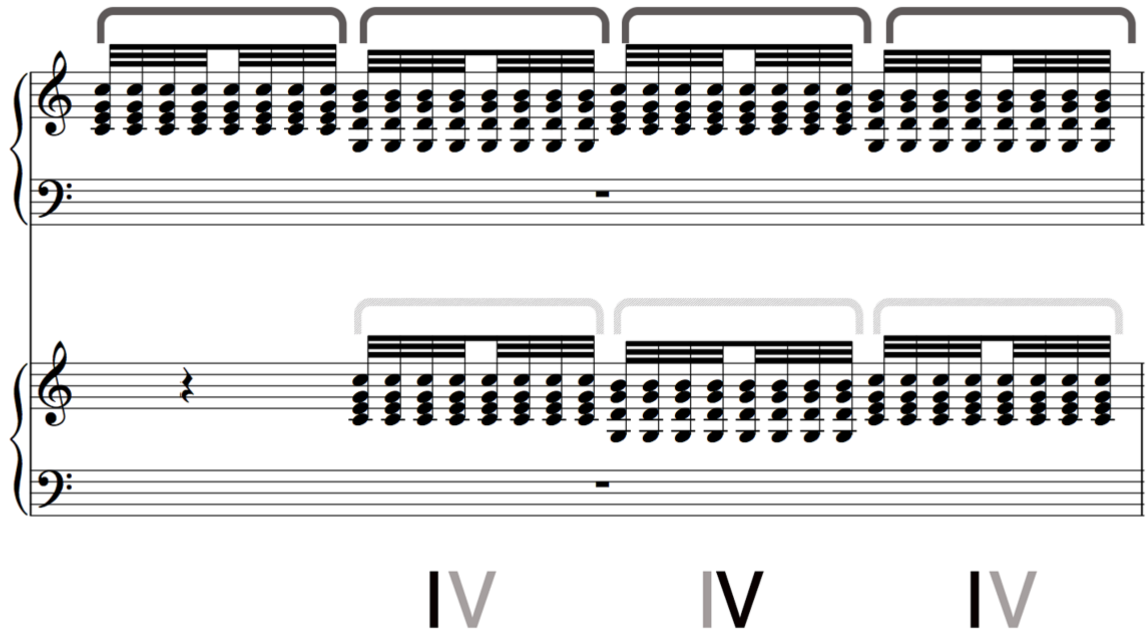


Figure 10. Wide sync windows cause harmonies to be disrupted



Overlapping sync windows present an opportunity for harmonic blurring and timbral development through resonance. Ray's trans-Atlantic performance of *Latency Canons* took place in 2013 between multiple ensembles located in New York and Manchester. Ray was in New York during the event and described how "if the delay got longer with Manchester, then the sequence would become really out of whack with itself and you'd have this beautiful pile-up of chords" and even simple music can be "made beautiful by this process" (Lustig, 2016). Wider sync windows as shown in Fig. 10 can be exploited to manipulate and disrupt harmony completely, where a "performance is heard as a blurring, as echoes, a wash of musical material" (Lustig, 2016). Audio's latent arrival over the network extends well into the application of the musical ideas of counterpoint, ideas such as canon, heterophony and stretto, where audio material echoes upon itself creating textural and harmonic layers. In practice, these echoes cannot be relied on to be consistent in either dynamic or length as Ray noted during the performance of *Latency Canons*, "some of the delays were short, and some of them were long and so we would always sort of have this kind of perfume of the music" (Lustig, 2016).

2.1.2.2 APPROACH 2. MITIGATING DISRUPTION WITH VITAL INFORMATION

The networked environment is subject to latency and uncertainty, which are factors contributing to participant anxiety because of the constant possibility of losing synchronicity.

When vertical alignment is made unfeasible, complexity in time-keeping arises. The implications of latency means that tightly synchronised rhythms and musical events cannot be precisely timed, e.g., as would be demanded for a Mozart string quartet. Instead, participants accept that note alignment is not possible and make use of other forms of information in the score or via technical aids to maintain synchronisation on a phrase level. A single piano note to be played simultaneously between two pianists is no longer a single piano note but a delayed, reflected note with echoes and refractions that have no determined arrival time.

Musical interaction in composite space assumes a stable one-way latency of less than 25 ms between two rhythm-based instruments (Gabrielli & Squartini, 2016). Latencies higher than this creates a “fat beat” or an “expanded feeling” (Robinson, 2013). According to Robinson (2013), the 25 ms round trip time (RTT) “acts as a special kind of threshold at which music performers feel that they can, or cannot, play in synchronous time together as if you are in the same space”. The spectrum of rhythmic movement in music swings between the mechanical reproduction of a digital beat, and the groove expressions of a rhythmically expressive musician or group of musicians. Latency interrupts the expression of tightly coupled rhythms; thus, the strategy for composing rhythms for network performance involves the anticipation of syncopation. Intuitive syncopation occurs musically given a known delay (Nevejan, 2012). Sarah (Weaver, 2006) relates a performance situation by composer Mark Dresser between Seoul and NYC where, “we had two drum set players, one in each location, and they were able to blend in a way that created a larger sense of time, make that bridge to the wider beat”. In another performance, between New York, Seoul, and Beijing, the musicians had “an accented pattern and they were able to play at the tempo of the latency and what happened was that it was the accents were displaced. It wasn’t necessarily intentional that that happened but they were able to lock it in on a more intuitive level”. Sarah affirms that while an ensemble is disrupted in its ability to remain “in time” due to asynchronous latent transmission, “depending on the content you can bridge the time”.

Furthering my understanding of how latency affects performative relationships, Chris described his work *Chopper* to me. Involving three saxophonists in three separate locations, the first improvises to a fixed-media electronics score and the other two respond to the first’s musical events. For example, if the leading musician plays a slap-tongue on a saxophone, the responding musicians find some musical equivalent. This interaction becomes “something in the arsenal of the lead player where they can trigger off these remote echoes and that’s a major part of the piece, … it's increasing the lead player's palette, they know that they are going to get this response so it becomes a distributed hydra-saxophone" (Chafe, 2016). Chris explained how in such a composition, "you actually don't hear the network at all, you hear the response time of the humans and it depends on their attention". Our dialogue introduced an important concept in my own thinking, to understand that a musician's response time is not only dependent on the latency in the transmission, it is equally dependent on the musician's ability to respond. Chris explains that the "response time is variable depending on their attention and what they hear, but it's way longer than the network delay" (Chafe, 2016).

In *Chopper*, the vital information that informed the performance relationships was the audible traces of network latency as articulated by the lead musician, showing that compositional parameters can encourage performative relationships. Where precise note placement is not possible due to latency, the composer can provoke or encourage these relationships by shifting the articulation level from the note level to the phrase level. Chris cites an experience where the score indicated an accelerando over a long phrase length which "focused the ensemble's attention away from the difficulties of playing synchronously under such temporal separation and onto the shape of the phrase. The result was a perfectly synchronised arrival at the end of the phrase" (Chafe, 2009). Chris surmised that "longer time shapes (from phrasing, arrivals, cadences, etc.) seem to have less trouble synchronising, just as slower rhythms also seem to be less affected by difficult delay conditions" (Chafe, 2009).

Ray experienced "much uncertainty about whether it might work when it all comes together" (Lustig, 2016) during the process of creating *Latency Canons*. Given the technology available, Ray decided to adopt a synchronous, centralised approach whereby the hall that housed the orchestra and audience was the central hub, and each ensemble had a conductor to follow the orchestra, sending independent signals to be mixed in with the orchestra as a live feed. This functional approach means that while the orchestra and audience had a successful performance, each ensemble did not get to experience the work as a whole.

By using specific scoring technique and telemetrics, we can provide vital information to participants about the state of the network; e.g., we might construct music that provide event markers in the way of dynamics and note articulations. Or we might measure latency and provide a digital metronome for the musicians that updates as latency changes. Once the networked system is designed to transmit sync information, rhythmic syncopation becomes a characteristic for exploitation rather than an unavoidable product of uncertainty.

2.1.2.3 APPROACH 3: TIMBRE THROUGH ASYNCHRONOUS TRANSMISSION

The formation of timbre from remote sources is possible due to the experience of 'sonance', which Seashore (1936) defines as "that aspect of tone quality which results from fluctuations in pitch, intensity, and timbre within a tone" which "represents the body of the tone as a whole for the period of its duration" (p. 20). Much like the frames of a film which when viewed in quick succession appear seamlessly as a smooth series of images, the sonance potential of sound as it arrives from multiple locations to be heard as being created by a single, larger source leads to new timbral possibilities. Not only are we hearing the natural resonance of a musician's instrument, or the ensemble, but also the room frequencies of those instruments and how the sound waves collide and dissipate. Over a network, we introduce additional room resonances, phasing, and latencies (both networked and human), which creates a "continuous flux in the structure of the tone … The result is a fusion of all these changes, a sort of average timbre, pitch and intensity" (Seashore, 1936, p. 20).

Helmholtz (1912/2009, p. 28) stated that "the quality of tone should depend upon the manner in which the motion is performed within the period of each single vibration", essentially defining timbre by the spectral envelope of the sound.[24] Houtsma et al. (1990, p. 61) further define timbre as "the subjective correlate of all those sound properties that do not directly influence pitch or loudness. These properties include the sound's spectral power distribution; its temporal envelope … rate and depth of amplitude or frequency modulation, and the degree of inharmonicity of its partials". This analysis enables us to better describe the effect heard in Ray's *Latency Canons*. As each remote signal arrives, it merged into the orchestra through monitors. Rather than being perceived as individual signals, the composer's intent in combination with the natural acoustic blending creates a new instrument completely, one which is latent, reverberant, and asynchronous. Ray describes his experience with latency as "a delay with crisp edges and [you] can feel the sort of refractoriness of the sound, it's kind of like looking into a crystal and seeing an image in different places and different angles" (Lustig, 2016). For Ray, it's "also in the twenty-first century, the nature of time itself, time is this kind of fluid fabric that we're on, and on a fluid fabric the same piece of music, it's kind of an expression of that". Ray's observations of his work's creation and performance

---

[24] Latency variation on the spectral envelope has been show to affect the pitch change response (Ritter et al., 2007).

gave me valuable insight into the technical affordances and challenges in networked music performance, which I discuss further in the next section of this chapter.

Sarah intuitively employs texture building using spectral qualities by using "a wide variety of instruments and also instrumentalists that have … extended languages on their instruments, particularly ones that identify with spectral language" (Weaver, 2016). Instruments with a rich spectral quality to them work well over networked performance because the timbres unfold over time: i.e., a string continues to resonate or a flute's multiphonics changes mid-breath. It could be said that a latent response serves to enhance and tease out spectral content, as Murail (2005) comments, "it seems to me that the entire range of complex sounds can be integrated functionally within a musical logic, rather than used as a startling daub of colour, or only for expressive ends, for their anomalous or paroxysmal qualities. With [a computer's] help, timbres are split into harmonies, harmonies fuse as timbres" (p. 135). Sonic aesthetic opportunities have exploded since the advent of computer analysis. I propose that the network offers additional opportunities to deconstruct and examine the contents of a sound because it arrives asynchronously and may be recreated in a completely different space than that from which is was disseminated, which allows for the creation of completely new timbres. Lustig's *Latency Canons* demonstrates a distinct timbral experience that would have an utterly different sounding quality were the musicians to be located in the same performance space. Arriving asynchronously via the network, the layering of latent sounds gives the impression of an entirely new kind of ensemble because the "sound arrives from a distance as if starlight after the image" (Lustig, 2016).

2.1.2.4 APPROACH 4: POST-DIGITAL POLYCHROMATISM

Digital mediation creates an imperative to approach the transmission itself as a means for exploitation. Digital tools can ameliorate or exacerbate the inherent latency in networked music performance: i.e., we can rearrange the order of packets, modify the contents of packets both before and after compression, and recreate or redirect packets. There is no obligation to reproduce or attempt to reproduce reality. We can create new 'polychromatic' realities using these reduced, transmitted packets. In this sense, polychromatic means the fusion of two or more spaces, each with their physical resonant properties that are exploited and modified by importing sounds from external sources.

One element of a codec's arsenal is the reduction algorithm, where certain spectra of sound are discarded, which results in a new, reduced set of frequencies with varying degrees of fidelity to the original content. Codecs designed for network transmission may also include algorithms for managing transmission faults. Latency and congestion create packet loss, which activates codec algorithms. Most of us are probably familiar with the time-stretching effect in a video chat call when the network fails, which is the codec attempting to maintain 'speech legibility' over frequency fidelity. Such treatments can aid in the comprehension of speech; however, they are anathema to audio because they cause signals to desynchronise. I discuss the aesthetic affordances of codecs in later sections of this chapter and in detail in chapter 3. Minimising latency through compression is only one small part of a codec's arsenal that can be exploited for creative gain.

2.2 THE IMPOSSIBLE, MULTI-LOCATED, MULTI-AUTHORIAL SPACE

The conditions of latency and the loss of natural human-level exchanges of vital information means that musicians, when connected remotely over a network, cannot use tacitly known physical models of time and space. When reacting together remotely, we experience the "local present, but the networked past" (Robinson, 2013). Accordingly, performative expectations must be adjusted. The multi-located space can be exploited by articulating and reproducing spatial properties; i.e., it can be tricked and it can be widened or made smaller. The multi-located space is a reverberant, resonant space, a polychromatic space that in turn folds back into other spaces. Within that multi-located space, the distinct experience of networked audio lies in the interstitial moments between the unavoidable counterpoint of multiple authors and timelines in which there is "the vantage of being separated. In music we do find advantages like that, [that] sets up kinds of interactions that I don't think we would have with the same players in the same room" (Chafe, 2016).

The interaction between remote environments and the immediate climate surrounds us and influences a music's performance toward it becoming a multiplicity that is ever unfolding. I asked Sarah what was different about the networked music medium? Her reply was thoughtful: "the obvious things: latency, spatialisation, wideness of the experience, different aspects of hearing remote performers through the technology which is a different experience than that if they were there in person. On an artistic level, networked audio creates a *wideness* in the music, a wider experience of sound. There's also, within the distance, there's an intimacy about it. I believe that I'm hearing the remote performers through these speakers [in real time] and there's a directness that is different from, say, watching an echo of a stream or recorded video. To be able to connect live and perform together live is a different level of intimacy" (Weaver, 2016).

Sarah speaks of her intuitive level in terms of 'synchrony', which could also be thought of in terms of Csikszentmihalyi's concept of flow (Gaggioli et al., 2017). When considered in the context of ensemble performance, flow is a desirable psychological state defined as a "collective state of mind" that occurs when "members develop a feeling of mutual trust and empathy, in which individual intentions harmonise with those of the group" (Sawyer, 2003, p. 46). Flow is a state not limited to music, it may be experienced during sports or other activities; i.e., it is a state achieved through the act of performing and may similarly be achieved by a solo actor who is in complete engagement with her own creative process. In the context of networked music performance, achieving flow may be reached though the awareness and interaction with the system's effect on time or it may be achieved through fusing spaces by using harmonic and timbral resonance.

The multi-located space is an impossible space. As opposed to the singular composite space, it is fractious and heterogeneous by nature of separation. With music, we can bind what is detached and artificially bond spaces. Music can draw us in towards each other or it can separate us. Music can be exclusive or inclusive; it can create social space and generate social bonding or it can spur alienation. Nick Collins illustrated the way spaces become bonded through networked sound in his five-location network performance *Fibre Jelly*, "a networked concert where each musician performed in a different space in the ZKM building in Karlsruhe. The musicians listened to and processed each other's sound as part of their own concert. The audience could choose to wander around between the concerts or sit in the main hall and listen to a multichannel mix" (Bennett et al., 2004).

Chris observed that when he remotely engaged with another person in real-time, it "creates a very strong sensation … As soon as it becomes interactive and there is a back and forth element of trust and communication of things … we're in a dance together, and that puts us not specifically on one side or the other, it puts us in a kind of mental meld in the middle which has no physical place" (Chafe, 2016). This engagement that Chris describes relates to Csikszentmihalyi's idea of flow where "you get to where you are so absorbed in the music and the music you are making together, that the physical aspect of that just is diminished" (Chafe, 2016).

2.2.1 PARAMETERS OF CONTROL

The projection or reinforcement of mediated sound, whether that is pre-recorded, live on a stage via microphones, or transmitted remotely, inherently involves intent of spatialisation by choosing placement of playback monitors in a certain space. Spatialisation may mean choosing to reproduce a remote space's directionality, or it may involve a combination of decisions such as to merge the remote and composite spaces. Techniques in working with spatialisation and diffusion are well-documented in the literature, such as Larry Austin's *Sound Diffusion in Composition and Performance* series (Austin & Field, 2001). One of the key issues when projecting networked sound is the 'Larsen Effect'.[25] Along the resonant spectrum lies the delicate balance between reproduction fidelity and the dangers of acoustic feedback. Once monitors and microphones are switched on and a networked audio connection is made between a similarly monitored space, great attention must be paid to monitor and microphone placement and their levels. The resonant frequencies of the microphone (and a microphone's directionality), amplifiers, room acoustics, codec design, and the dynamic energy between them, e.g., the distance between speakers and microphone, *tunes* a room, setting the audible experience. This is a technical art that permits manipulation in real-time for effect. Once a room is 'well-tuned', the composer should find herself with an instrument where the careful adjustment of levels allows a distinct sonic fingerprint to sound. Participants may also choose to wear headsets for personal and remote monitoring. Using a headset creates yet another space, which is a private, utilitarian space designed for logistical purposes. However, headsets cannot help but inform the performance aesthetic because the participants become isolated from the experience as a whole.

Sound can be completely artificially generated and yet we strive to create meaning. We hear projected sound as sonic energy, as a representation of physical energy from what may be an actual acoustic event that is transmitted and reproduced in some form, or it may be constructed with no relation to an original sounding event. I present three scenarios as examples:

1. There is no obligation to transmit or reproduce reality as converted to digital form.

[25] Named after Danish electroacoustic scientist Søren Absalon Larsen who discovered the effect, referring to the "loop established in an electrophonic chain" that "constantly reinjects the signal over itself" (Augoyard & Torgue, 2014, p. 65).

2. A multi-located reality may be experienced as a singular resonant reality or as multiple, disjointed realities.
3. A local reality has no obligation to interact with a remote reality and vice versa.

Choosing where to have the audience effects how a space is transduced and amplified, and how projection and manipulation of that project can affect the treatment of the remote sound image. What is essential and intrinsic when performing together remotely is the understanding that there is no singular primary experience and therefore no single primary author. Participants each hear a different timeline experience; they are each the primary and secondary authors of their musical interaction. It is a multi-authorial experience that participants navigate by making performance choices. It is not always the case that there will be an audience on each side of the connection. Perhaps a musician or ensemble is beaming in remotely, such as the ensembles in Ray's networked performance, in which case participants may choose to exclusively focus on a fuller musical experience on the audience side. Perhaps there is no audience at all or the audience is similarly remote, such as a distributed web-based broadcast around the world to individual participants. Such decisions cannot help but affect a performance, a practical consideration I discuss in more detail in chapter 4.

2.2.2 MUSICAL IMPLICATIONS OF MULTI-LOCATED SPACE

What follows in this section is an extraction of the technical constraints of the multi-located, multi-authorial space as noted above through the perspective of the approaches I outlined in chapter 1 of post-vertical harmony, performative relationships, new timbres, and the post-digital aesthetic.

2.2.2.1 APPROACH 1: HARMONY

Sound arriving from multiple spaces opens opportunities for a harmonic blurring and deblurring, much like we can do when playing two copies of the same record and adjusting one turntable to a slower then faster speed. Harmony in networked music performance is no longer vertical, it is smeared across time, refracted, and shifted, and experienced simultaneously in multiple ways. Not only is harmony shattered by the temporal disintegration of the network as it splits itself to pieces and puts itself back together not always in the same order, it is also manipulated by spatialisation, reproduction, architectural reflections, and timbral resonance. As vibrancy occurs between sounds of relative spectral content, harmony may be reinforced and augmented. Through the exploitation of music and technique, sounds may resonate and reinforce harmonies or they may be out of phase – providing continuums for aesthetic exploration.

While strict vertical harmony may not be possible, real-time explorations of entirely new kinds of harmonic structures flourish in its place. These harmonies form in multiple ways at the same time, exposing in the extreme how sound reception is critically bound to the listener's own location. Ray observes that even in non-technical performances, "it's always the situation in music that where you stand makes a difference to what you hear" (Lustig, 2016).

2.2.2.2 APPROACH 2: THE VITAL INFORMATION OF MIXED REALITIES

Networked music is an interactive and improvisatory means of mediating presence, and the notational and technological considerations of creating and conveying vital information for the purposes of networked music performance is an important process that grounds the practical elements of this exegesis. Sarah relayed to me her experience that networked music performance is "a mixed reality experience", where there is the "immersive aspect where you are connected, but there's also the fact that you are in different locations" (Weaver, 2016). That immersive aspect occurs because music responds to our immediate own actions; it acknowledges change as it happens and we interact with it by exchanging vital information about our position within it.

Interaction presumes an order of liveness. According to Bogosian (2012, p. vii), liveness in performance is "something we make together every time it happens" and demands "temporal fluidity" (Frengel, 2014, p. 5). When experiencing liveness, we expect the circular ability to react together: "there can be no stimulus without the readiness to react and the stimulus ceases to be a stimulus with the cessation of the readiness to react" (Reybrouck, 2012, p. 396). When being together remotely, we must respond and be responded to. Sending an echo into an abyss with no reflective surface is not compelling. Being compelling while being remote demands consistency, responsiveness, imagination, and playfulness. As Weinberg (2005) explains, "the problem of interaction coherency is accentuated in Internet-based musical networks that cannot support clear real-time gestural performance cues" (p. 28). Fortunately, music has strong functional significance, i.e., music's features are "meaningful for an active perceiver" (Reybrouck, 2012, p. 394). This leads to musical responses and interactions that can reinforce remote presence without requiring visual cues and allow us to create mutually meaningful worlds by generating vital information in the form of sound. This can be achieved through specific notational approaches or through providing technical solutions to participants. In chapter 4, I discuss my approaches to providing critical vital information to facilitate musical performance.

2.2.2.3 APPROACH 3: RESONANCE & IMPOSSIBLE TIMBRES

When remote spaces are connected over the network, a new sonic world is created with the collisions and resonances of each acoustic environment, "which can be modelled [by music], something deformable and which can be altered depending on the point of view in which we have" (Bohme, 2010). These new sonic worlds are a tessellation of participatory and responsive sources. These fused, augmented sources change in timbre, pitch, and intensity according to the interpretation of the musical material.

As sounds are transmitted and echoed between locations, the networked whole is reflected on each distinct environment, which creates a multi-authorial multiplicity of experiences in "a vibratory phenomenon that impinges upon the senses" (Reybrouck, 2014, p. 3). The reflections lead to the formation of new timbres. As Truax (1999) notes, "sound interacts with actual environments in complex ways that are affected by nearly every aspect of the physical environment". Networked music performance happens in a participatory space that is performed in real-time. Participation gives a sense of being there and of having agency, which recalls Schafer's (2004) declaration of world soundscapes, "the vast musical composition which is unfolding around us ceaselessly" (p. 29). This multi-located, participatory space is a tuneable, participatory space, which is made tuneable through musical choices and made participatory through performative relationships. It is a space where performance energy fuses together in newly synergised forms but ceases to exist the moment the connection is closed.

2.2.2.4 APPROACH 4: THE POST-DIGITAL MULTIVERSE

A multi-located, multi-authorial space is embodied by the post-digital experience. As represented by sound, digital reality is deconstructed and reconstructed every few milliseconds as packets are created and disseminated. We can put these packets back together in any multitude of ways, which creates an unlimited variety of perspectives. Alvin Lucier's 1969 *I am sitting in a room* is an illustrative example of a work that would translate well to a networked context.[26] Imagine a microphone and a speaker in two locations, networked to each other; with careful attention to acoustic feedback—noting that the codec's sensitivity is now at play along with the microphone response—entirely new timbres could be experienced with each iteration. Wishart (1996) comments that our attention is not immediately drawn to the means of transmission; it is only by the degradation of the sound image that our ear hears traces of the network via the codec's response to acoustic feedback, and soon only the relationship between the network and the codec itself.

Chris recounted that the ambience of the room disappears in certain setups where the use of room microphones is avoided because they create acoustic feedback. However, the resulting sound loses the character of the originating space if a room microphone is not used. To address this problem, a technique called Virtual Microphone Control (ViMiC) is employed to generate synthetic signals.[27] "The system includes a room simulation software to construct a multichannel audio signal from a dry recording as if it had been recorded in a particular room. Both transmission sites share a location virtually, if the room parameters of the ViMiC system are set to be identical at both ends" (Chafe, 2009).

The technique of generating room tone has the effect of reconstructing the remote sound image. Digital mediation permits the creation, negation, and isolation of networked spaces by purposefully modifying or withholding remote signals, or by injecting or exploiting material or transmission artefacts. Such interferences and failures remind us that this is a live performance that is arriving to us from another space entirely, in the form of a digital signal that we did not create yet we can integrate it into our acoustic environment by any means we wish. We can reproduce the original signal as transmitted or we can reconstruct that remote signal completely. The remote reality as relayed through networked sound is completely subject to digital manipulation.

[26] Successful reproductions of Lucier's work using transmission technology exist; e.g., Patrick Liddell's (2010) 100 iterations of YouTube and the MP4 format.

[27] ViMiC was collaboratively developed by Chris Chafe, Pauline Oliveros, and Jonas Braasch (Chafe, 2016).

2.3: DIGITAL MEDIATION

Multi-located networked Internet audio is completely digital. Like digital music, it can be completely simulated (and often is during the developer's testing phase) or it can be a reconstruction of real-world activity. While audio transmission technology generally aims to mask errors, its status as a digitally mediated process allows us to both measure and manipulate the condition of the network.

Fig. 11 shows a visual representation of 10% packet loss (or "drops") in an exaggerated waveform, showing how much audio comprehension can be lost given even a small amount of data loss.

Figure 11. Visual representation of 10% packet loss in a waveform

Packet loss is the result of technical failure. Somewhere in the network, congestion has occurred due to heavy traffic, or a route has experienced machine failure due to congestion or software buffer overruns. The spectrum between reliability and failure is in full force with networked audio over the public Internet. Taking influence from the glitch and post-digital aesthetics, the composer may choose to recognise, accentuate, and exaggerate failures, or they may otherwise prefer to mask the errors using advanced codec algorithms. During the rehearsals for *Latency Canons*, Ray found that "it was really hard to stay together under these circumstances so it ended up being this very strange, very unpredictable kind of a mess" (Lustig, 2016). This shows that technical decisions cannot always be made during the composition process. Ray had earlier determined that the choice of technology would be an integral part of the outcome: i.e., "the whole ethos of the piece from the very get-go was to let all those problems shape the piece" (Lustig, 2016). In my own personal interest in digital aesthetics, I heed the renowned computer scientist Donald Knuth who "expounded on the art inherent in both programming and the program since the 1970s" (Bond, 2005, p. 120) and suggested that creative and intellectual satisfaction is found in mastering both the technology and the music that it can produce. While the remainder of this chapter focuses on the parameters that are controllable and those that are measurable, Ray's experience is a reminder that the composer can choose to embrace uncontrollable technology by allowing it to shape the result as a critical part of their decision-making.

2.3.1 PARAMETERS OF CONTROL

With the development of sophisticated telemetric tools and aides, the parameters of control in the transmission mechanisms offer a wealth of aesthetic decision-making. In this section, I elaborate on a few methods whereby the composer and musician might manipulate and exploit the noisy, error-prone public network for aesthetic means, and exploit how data transmission via packet networks adds uncertainty to the communication channel.

The latency changes each time a connection is established over a network. Furthermore, the bandwidth allowance may drop or increase, leading to lower or higher fidelity. What might be 100 ms on the previous reconnection may now be 105 ms. There may be more or fewer packet losses introduced. These changes can all occur quickly and without warning. To obtain a sufficient level of comfort for participants, where network errors and latency cannot be averted, we can put in place mechanisms to share information about the status of the network and send status and control messages about the music we play together. The tools for measurement and messaging are explored in chapter 4. By using telemetrics and simple messaging, a complex set of rules can be implemented for creative purposes.

2.3.2 MUSICAL IMPLICATIONS OF DIGITAL MEDIATION

The digitally mediated sound image presents a wide-open potential of aesthetic technique. Its reproduction and projection are subject to the same parameters and algorithms that enable its transmission. The remainder of this chapter considers the controllable parameters discussed above through the aesthetic lens of post-vertical harmony, digital relationships, timbre and envelopes, and post-digital uncertainty.

2.3.2.1 APPROACH 1: UNORDERED HARMONY

While multiple signals arrived misaligned over the network, projecting those remote signals immediately forces non-vertical harmony upon us. Because the means of transmission is already subject to digital mediation, we can put technology to play against itself. Sound arrives to us completely distinct from the original sonic energy it was created with and we can interpret and reinterpret the remote signal at will. This separation from source affords us to reconstruct the signal at will by layering, duplication, time-shifting, pitch-shifting, editing, and splicing. Signals might be analysed in real-time and delayed or reinjected into the composite space at a time when a desired harmony would occur. Any suitably sophisticated system could apply a process to redesign the remote-but-delayed reality at will for the purposes of perceived synchronicity.

2.3.2.2 APPROACH 2: DIGITALLY MEDIATED RELATIONSHIPS

Traditional ensemble performance in composite space anticipates the transmission of vital information through consistency of eye contact, human-level latency, accurate acoustic reproduction, and responsive performance environments. As Kane (2007) describes it, "what holds 'the table' together in our minds qua table is "an act of consciousness, a synthesising together of the stream of adumbrations … to posit the identity of the object, as transcendent to perception" (p. 16). Achieving the same state of experiencing heightened togetherness with multi-located performance demands either entirely new means of transferring vital information of real-time performance cues, such the visual conducting method such as practiced by Sarah,[28] or an intensive kind of listening, i.e., a conscious focus on the act of creating music together. To exacerbate the problem of maintaining togetherness between remote participants, transmission errors, incidental sounds, and other unexpected audible events may interrupt flow. Even small fluctuations can cause timing and sync uncertainties between performers. Therefore, while musicians cannot become accustomed to a fixed mode of communication, these fluctuations become part of the "way of being with each other" (Chafe, 2016). When a connection re-buffers, reconnects, or otherwise changes its status, a digital audio interface might alert the participants and allow them to make decisions based on those events.

---

[28] One of Sarah's primary interests with networked music is conducting, which requires video transmission. She has developed a "hybrid language that has grounding in traditional conducting and soundpainting, but developed my own original gestures out of that. Especially for the telematic medium because it requires certain types of gestures, both in terms of times of cuing and in terms of the artistic content" (Weaver, 2016).

The appropriate development of telemetric and messaging tools for conveying data relevant to the performance is an important area of focus for networked performance music, whether a conductor is present or not. For example, consider that the musicians may wish to change their playing if a time-signature latency has increased, or lengthen the current note or bar if there is a re-buffering or significant packet-loss event. Such decisions would be extremely difficult if there were no tools to measure and display this vital information. Disturbing the means of transmission disturbs the flow; therefore, the relationship based on interactive presence disappears as soon as we disconnect. In chapter 3, I explore several options that can facilitate participation over networked presence.

2.3.2.3 APPROACH 3: TIMBRE: EDGES AND ENVELOPES

The embodiment of networked audio as packets or grains affords an inherent granular synthesis approach, as they are transmitted in packets as small as 10 ms and may be non-sequential.[29] Mirroring Seashore's concept that "by presenting a series of slightly different still images at a rate which is just about the limit of the eye's response to changes, the impression is one of a smooth continuous movement" (Russ, 2012, p. 294). The uncertain, asynchronous transmission is illustrated by making audible the 'inter-onset time', being the "measurement of the duration between the beginnings of adjacent grains" (Opie, 1999). The instability of the network becomes the "statistical inter-onset parameter" (Opie, 1999). For example, manipulating the transmission by adjusting the packet size, increasing congestion, or dropping packets, or conversely sending multiple, redundant packets via statistical or stochastic means, creates controllable parameters for reinforcing the intrinsic network uncertainty. Mapping this uncertainty to granular synthesis parameters might allow, e.g., participants to affect the colour and texture of the remote sound image. The more uncertainty, the illustrative the example. When "grain density is high, grains overlap to create a complex spectra" (Roads, 2015, p. 178), which contrasts the arrival of many, redundant, and

---

[29] Curtis Roads (2015) notes that with sounds "less than about 50 ms, the ear no longer perceives them as separate impulses" (p. 46). Network audio packets submit to Roads' earlier observations as grains because they are a complete representation of sound as they combine "time domain information (starting time, envelope shape, duration) with frequency domain information (period of the waveform inside grain, spectrum of the waveform)" (Roads, 1996, p. 168).

overlapping packets to the disappearance or thinness of packets during period of congestion. Such processes belong to future developments as I am not aware of current technologies that yet exist to combine a granular synthesis engine with the decoding and analysis of datagrams. I discuss this possibility in chapter 5 along with other avenues for future technical developments.

2.3.2.4 APPROACH 4: UNCERTAINTY AND THE POST-DIGITAL

Digitally mediated uncertainty is a modern problem, where the transmitted presence is inherently uncertain and prone to errors: e.g., unstable bandwidth, asynchronous timing, or unreliable delivery. Through these errors, we cannot help but to arrive at an aesthetic of uncertainty/failure even if that aesthetic is to attempt to ignore errors. As Ray points out, “technology is so central to our experience of life these days that I need it to be something that is part of our expression” (Lustig, 2016).

Before packetised high-quality audio was made possible, Chris experimented with sonification of the network as “a physical modelling instrument, so you could literally pluck the network and if the tone that you heard reverberating on this resonance was stable, then you knew you had a good kind of static travel round-trip time so that meant that the network quality of service was probably behaving pretty well. If you had dropped packets you’d hear those as clicks and so on” (Chafe, 2016). Sonification is a process of using audio to convey information; thus, it is an audible representation of a system and requires access to telemetric measurement. We might look at the network as a tuneable instrument similar to the “no-input mixer”, such as Christian Carrière’s renditions of complex compositions that can emit incredibly detailed and controllable sounds, yet within a whisker of instability.[30] While these same measurements can be applied to process-based algorithms, care must be taken to not be too literal as “these data models, flung together by those irredeemably attracted to wholism, are designed to satisfy the being’s curious but credulous mind, while bearing no resemblance to how nature operates” (Nezvanova, 2000, p. 41).

[30] In 2011, Carrière (2011) was able to reproduce Pärt’s *Fratres* using a no-input mixer with careful preparation.

Embracing a technological position allows the entry of non-traditional forms; however, it also often forces an inviolable requirement for expensive or complicated technology that acts as a barrier to entry and affects the composer/performer relationship. In this case, the best technology is invisible technology or technology that is completely integral to the experience. Telemetrics, education, and transparency in technology development provides opportunities towards the creation of such an instrument.

Where uncertainty is a constant, an aleatoric approach deserves consideration. However, aleatoric music is most exciting when everything is not totally left to fate: "'while the original conception of the piece had a lot to do with letting the chips fall where they may', Lustig said, 'they can't fall too far. We do need there to be a concert'. Thankfully, Lustig managed to balance chance and control, experimentation, and execution. The music fulfilled the promise of his idea, producing a glitchy, gorgeous success" (Lowder, 2013). Although the system may play its own part: "operator interference with the composition is not disproportionately emphasised under the dubious pretence of interaction, a pretence that often betrays the slightly obfuscated silhouette of the millennia-old geocentrist viewpoint", instead giving participants the "invitation to observe and analyse data transformations, to be distracted, and ultimately to select" (Nezvanova, 2000, p. 40).

Once audio data is prepared for network transmission by being packetised, encoded, wrapped with network headers, and pushed to the socket buffer, the potential for a distinctly specific multi-located networked audio aesthetic is enormous when the transmission in all its parts is made accessible to the composer through dedicated tools. Having seen that latency and uncertainty, the multi-located and multi-authorial spaces, and digital mediation are inseparable from networked music performance, I continue to explore opportunities for creative and technical applications of the medium in the following chapters.

CHAPTER THREE: TOOL DEVELOPMENT

"The technosciences of the era exceed the ability of human reason to make sense of them and surpass the capacity of human imagination"

- Denis Smalley

Virtuosity in manipulation, control, and realisation requires a purposeful and reproducible act of structuring sound where the parameters of controlling that sound are bound to both the intrinsic mechanics that emit that sound and the external influences upon those mechanics. The negotiation of these mechanics depends on the agency a musician has in relation to the forces that cause sounds, which may be intentionally created through the development of tools or culture or they may be accidentally created as result of a technical breaking down, i.e., the by-product of other processes that produce errors and failure. Such processes reveal the "meaningful indeterminacy of interaction, where messiness and serendipity affect creativity" (Klett & Gerber, 2014, p. 280) and it is the decisions that can be made by the musician given new opportunities and how they utilise those opportunities that gives rise to an aesthetic. I fully subscribe to the notion that Georgina Born (2015) suggests, that changing aesthetic conditions also mediates the arrival of new genres.

In the case of networked music performance, we interface directly with the technology that creates the networked conditions. This technology affords new approaches, interfaces, and opportunities for virtuosity. Technology is the driving aesthetic force of networked music performance: i.e., the digitally mediated genre favours the technological perspective (Cook, 2015) because the technology itself is the subject. Unpacking the technology to much finer detail allows us to discover and use its parameters for music.

In this chapter, I consider "what would we need for an interface to support how we relate to each other" (Gill, 2015, p. 1) towards achieving a full virtuosic expression of the four aesthetic approaches outlined in chapter 2. I categorise these tools into four groups, i.e., telemetrics, transmission and projection, cueing and synchronisation, and notation and instructions, and discuss how we can musically interface with them.

3.1 TELEMETRICS

Network telemetry is a domain-specific method for reporting the network status to monitor any changes that might affect transmission and to report the analyses for decision-making in case a response is needed. Telemetrics allow us to engage remotely with accuracy and less anxiety about technical failure. Musicians are already familiar with the concept of reading a representation of data in the waveform, which is a graphical depiction of a certain time period of a sound for the purposes of monitoring or taking action on that sound. Similarly, fast Fourier transform plotting is commonly used to provide real-time frequency data so that a musician may make performance or editing decisions. Telemetrics is an equivalent measuring of a network.

Traditionally the realm of a network engineer or developer, telemetrics is a critical function of the twenty-first century. Much of our technical world relies on precise telemetrics to report even the most minute change in the delay and congestion to allow us to diagnose network error causes and severity. In commercial networks and supporting applications such as firewalls and routers, telemetric systems will push performance data such as throughput and error counters and queue statistics to stakeholders who monitor and maintain network services.

Telemetric data collection includes statistics on packet loss, latency, latency jitter, route availability, bandwidth usage, traffic types, source and destination addresses, and the investigation of the contents of any unencrypted payloads (known as 'packet sniffing'). Telemetric analysis on important metrics can be done in real-time, especially latency and packet loss. Any software designed for multi-located networked audio should provide therefore real-time programmatic access to these metrics. Programmatic access usually refers to an application programming interface (API) access where a developer can not only view the metrics, but also consume them in another software process. Access to metrics is critical to the development of intuitive interfaces that allow for a responsive performance where vital information is to be conveyed outside of the music itself.

Using these metrics, the composer may choose to program a live score, where a certain algorithm processes incoming metrics and utilises that subsequent data for effects processing or decision-making, such as time-keeping prompts and instructions or more complex tools that align the performance with the state of the network, e.g., in the audible latency traces of Cáceres' *Divertimento Ritmico*, "the asynchronicity of the wireless network is part of the compositional strategy" (Rohrhuber, 2007, p. 154). Without telemetrics, such works could not exist.

The following section provides an overview of the tools and protocols that can be used to manipulate network data for creative purposes, which I anticipate to become more accessible as the available network technology improves.

3.2 TRANSMISSION AND PROJECTION

Knowing the condition of the network tells us its current dynamic state. We can manipulate those dynamic parameters towards creating new states and conditions, thus affording new aesthetic approaches. While it may not be critical in the development of new aesthetic techniques to have access to open tools, in practice it is at least preferable to interface with tools that are dedicated to our purpose. Ray's experience with consumer software was frustrating, "it's that fight against what the software seems to want you to do … when they make free software for everybody to use, they want to make it as simple as possible so they don't want to present you with an advanced panel that might screw everything up" (Lustig, 2016). Using dedicated purpose-built technology, we can exploit and expose errors and artefacts or we can mask them with performance decisions. Without the ability to modify the parameters of the system itself, we are limited in the actions we can take.

Considering the importance of tool development, I believe that networked music performance remains an experimental field precisely because open, comprehensive, resilient and accessible tools do not currently exist that allow the Internet to be used for collaborative, real-time, high-quality musical purposes. What usually happens is that the composer or engineer hacks together a variety of tools using partially compatible protocols for a one-time use scenario in a performance or installation. Real-time Internet audio protocols and tools have been available for over 20 years; however, high-quality, low-latency software designed for specifically for making music together is a developing field at the time of this writing and no singular service or application is available that is either sufficiently sophisticated, affordable, or interoperable to provide wide-spread compatibility for easy collaboration between musicians. There is no universal networked sound protocol. Therefore, composers must implement their own systems and protocols or deploy network practitioners to implement systems on their behalf. It is my expectation that network tools will be developed by the musical community to support both experimental and highly functional networked music performances where transmission and telemetric technologies integrate seamlessly with existing music software and protocols. Network telemetrics will remain esoteric to musicians until the adoption of protocols that expose the underlying processes of the transmitted sound and allow easy manipulation of that transmission by tools that are already in use such as Max/MSP[31] and SuperCollider.[32] Networked music performance should not demand heavy technical knowledge. As tools become commonplace, any musician who is already comfortable with software tools and protocols will have the opportunity to become "latency-native" without needing to also become a network engineer.

The following section provides an overview of actionable parameters for transmission and projection technology and examples of tools and implementations that allows us to interface and manipulate them.

3.2.1 TRANSMISSION PROTOCOLS

The choice of technology directly determines how a composer can interface with the transmission. Off-the-shelf Voice over Internet Protocol (VoIP) software permits the transmission of high-quality audio; however, as most applications are designed for voice transmission, they will prioritise speech intelligibility over sound fidelity, which means that undesirable artefacts may occur at the expense of musical timing. Alternatively, the WebRTC project[33] allows for finer control of parameters but requires at least some programming knowledge. As the requirements become more refined, e.g., to avoid time-stretching or codec artefacts, deeper knowledge of how to program and manipulate the system is required.

---

[31] Max is a visual programming language for music and multimedia. The Max Signal Processing (MSP) add-on allows for the manipulation of digital audio signals in real-time. https://cycling74.com/products/max

[32] SuperCollider is an Open Source platform for audio synthesis and algorithmic composition. https://supercollider.github.io

[33] Web Real-Time Communication (WebRTC) is a free, open-source project that provides applications with real-time communication. https://webrtc.org

3.2.2 NETWORK TOPOLOGIES AND QUALITIES

The means of transmission can be further manipulated by how we approach connecting a network of peers. Alexandraki and Akoumianakis (2010) proposed three methods for peer connections: a mesh network, which connects each individual peer to every other peer; a star network, which uses a centralised hub to route and process signals; or a combination of these two models. The type of network depends on the protocol and application used, and the technical sophistication available at each peer.

Once a sound signal is transmitted to the Internet, it has parameters subject to constraints beyond our control, but which can also be adjusted: i.e., latency and packet loss. The signals arrive individually over a mesh network; therefore, the composer can manipulate latency and traffic shaping to each individual peer using network operations, which allow her to adjust the musicians' response time and manipulate the timbre of a sound through exploiting a codec's response to acoustic feedback.

3.2.3 CODEC MANIPULATION

Audio is encoded or compressed so that it can be reduced for transmission in smaller pieces over the Internet. Through a corresponding process, audio is reproduced by decoding or decompressing the received data. A codec's fidelity can be measured by how much the decoded sound represents the original.

Consumer codec design is primarily concerned with achieving fidelity in the speech range for legible perception of voice communication. Ray discovered that the software he used for *Latency Canons* was not ideal for music content because it used a codec designed "very intelligently for speech. And it's suppressing incoming speech, adding echo detection, feedback prevention and all this … complicated stuff that works great for speech but it's really posing problems" (Lustig, 2016).

While a codec's trade-off for fidelity and size is often seen as transparent and inaccessible, it is nonetheless a parameter that can be manipulated where interfaces expose the internal settings to the end user, e.g., with the WebRTC project. The WebRTC project permits modifying the codec, including operations such as selecting or disabling error correction modes. When a codec encounters missing audio due to lost packets, it must implement some kind of error-correction scheme. Packet loss may be intermittent and only a few milliseconds long, or it may last a few seconds, with successive loss or any random combination of data packets interspersed with drops. As there is no way to predetermine which type of packet loss might occur, the composer must determine how she will manage errors prior to a musical event. Solutions to error correction include:

- **Time-stretch existing audio data available in an earlier buffer**. This method affects the playback timeline between remote participants, which means that the notes that the composer intends to line up may be wildly out of sync by any number of seconds.
- **Synthesise missing audio data**. This method does not affect the playback timeline, which may be crucial for certain types of rhythmic, tightly synchronised music. The downside is that the synthesis is not particularly advanced and may sound robotic or thin. It currently works better for voice material by using word-prediction analysis. New machine-learning advances show immense promise for musical prediction.[34]
- **Permit silence** or intersperse with new material.

Going beyond adjusting a codec's settings, we may adjust the sensitivity of input filters, buffer lengths, input and output sources, and noise-cancellation behaviours. Writing an entirely new codec or creatively repurposing an existing open-source codec[35] is another potential method of defining new aesthetic territory, where manipulations include editing look-up tables and filter coefficients designed for conventional, stable psychoacoustic encoding to make them unconventional and unstable,[36] modifying APIs for access to low-

[34] Google's new synth engine *WaveNet* shows promise in this field. Especially once a real-time implementation is available, it could provide a variety of aesthetic opportunities in musical prediction for live performance situations (van den Oord et al., 2016).

[35] Several codecs transmit high-quality audio and are open source; therefore, they are available for modification and redistribution: e.g., MPEG Layer II, OPUS, and FLAC.

[36] A multi-media example of this is the reprogramming of the Wolfenstein 3D video game by net-art duo Jodi (Corby, 2013). By removing all content except abstract symbols, the player was left with a disconcerting experience that exposed a reliance on learned game-play expectations.

level parameters for real-time manipulation of the codec's operation, and adding alternative forms of error correction.

When using consumer software, codec-level manipulation is not permitted and by default usually involves a combination of time-stretching and synthesis. Consumer software also introduces additional unwanted artefacts such as 'comfort noise', which is a low-level noise in the place of silence designed for voice calls so that the receiver knows that the sender is not disconnected. See Appendix II for an overview of the available WebRTC telemetric parameters.

3.2.4 PROJECTION AND ACOUSTIC FEEDBACK

Any musician who has worked with microphones and speaker monitors knows that there is a delicate line between input levels and monitor output power. At a certain threshold, an open microphone will resonate with its initial signal that is amplified by the monitors; this causes a circular feedback loop, which results in a loud noise. Acoustic feedback, known as the Larsen effect after the Danish scientist Soren Larsen for his ground-breaking work on electroacoustic feedback, can quickly damage both equipment and ears. With open microphones in multiple locations, the opportunity for acoustic feedback amplifies. The sound engineer now must tune additional remote sources to the local space. However, with careful tuning and processes, acoustic feedback can be used as a purposeful effect: e.g., the delay between sources along with the gradual decay in acoustic power as the volume is lowered can be manipulated for the tell-tale quality of networked feedback.

There are two main methods to avoid acoustic feedback entirely: noise cancellation and echo reduction or amplification design. All codecs that are designed for communications include a noise and echo cancellation algorithm, which works by algorithmically reducing problematic frequencies that cause feedback. While this means there is a certain level of safety, it causes musical signals to be dulled or blurry because its purpose is for the intelligibility of speech frequencies only within the range of 2–5 kHz. Avoiding acoustic feedback through amplification design requires that microphones and speakers are not sufficiently close by in relation to their power to cause signal reinforcement. This is usually achieved by placing microphones very close to the instruments, but far away from the speaker monitors. Musicians will prefer to wear headphones and receive a live feed of the remote signals, as well as their own instrument, if loudness levels require it. This closed-microphone situation does mean losing the acoustic resonance of the room: Chris found a solution to compensate for the lack in sonic ambience through “room simulation software to construct a multichannel audio signal from a dry recording as if it had been recorded in a particular room” (the ViMiC mentioned in chapter 1) (Chafe, 2009, p. 25).

Acoustic feedback is not necessarily a technical hurdle to be overcome. It can also be a utilitarian source of creative investigation. Steve Reich’s 1968 *Pendulum Music* and Stochausen’s 1964 *Mikrophonie I* demonstrate music that uses amplification technology actively as an instrument. The recursive effects of the ‘No-Input Mixer’ cross-coupled oscillators, digital delay line circular buffers, and analogue video feedback systems could be reproduced by encoding and decoding signals ad infinitum in combination with acoustic feedback. Several opportunities exist for exploiting the distinct latent, codec-mediated qualities of networked sound via acoustic feedback (Holopainen, 2012).

3.3 SYNCHRONISATION

Networked audio creates a tense environment for musicians when audio-visual cues are detached, e.g., the nod of a lead instrumentalist to begin a section together can no longer be relied on—even where video is available. Sarah noted that development still falls short from being what “we really need to fully manifest this medium” (Weaver, 2016).

Multi-located networked audio presents new notation challenges and opportunities. Unstable latency means that musicians cannot rehearse and expect that rehearsal to be under consistent conditions. Network latencies change from one connection to the next and the lack of a referential visual connection between participants means that “keeping your place” is difficult (Lustig, 2016). Successfully performing together remotely demands that we accept that time between participants is manifold and multiplexed: i.e., “in a system in which there are only behaviours in response to messages, the structure of inclusion and control become inherently relative” (Rohrhuber, 2007, p. 144) and participants must rehearse a process instead of a series of notes intended to arrive simultaneously and predictably.

3.3.1 CUE MESSAGES AND SHARED CLOCKS

During the rehearsals for *Latency Canons*, Ray realised very quickly that a shared cue with each ensemble was required for starting, stopping, and locating cues. Achieving synchronicity without a perceptually shared cue caused his multi-located ensembles to be unsure of their place in the score—or be unsure when and where to start at all. As he recounted to me in conversation, “it gets really complicated and it’s glitchy and signals are chopping out and the conductor is freezing for a moment and then starts to move again but then you’re human so you can’t exactly figure where that conductor is in the music when the conductor starts moving again” (Lustig, 2016). Ultimately, this inability to synchronize created the distinctive sound of wavering echoes heard in the recording of *Latency Canons*. Ray explains that “you might be getting a mixed signal with music you are hearing on your headset from the other side … it’s very hard to keep your place so sometimes … [they] were actually coming in early … there was this little ‘pre’ echo, because they were a little off from where we were” (Lustig, 2016).

Decisions on when to start and stop are more difficult to agree on when the group cannot rely on a shared fixed-tempo or clock. Ray found an element of frustration during rehearsals where “that dissonance, that cognitive dissonance for them, to have it not line up, they would just stop playing all together so or they would completely lose their place. It’s not easy to stay together and that’s a part of the whole nature of the system that’s sort of this beautiful manifestation of it” (Lustig, 2016).

While Rohrhuber (2007) notes that “a common time was maybe the last notion of unified observation that persisted in science after having adopted an essentially relational view” (p. 154), musicians have traditionally held the expectation that they will perform in a shared composite space where human-level synchronisation is the perceptual norm. Networked music performance disrupts this expectation and causes difficulty for musicians to synchronise, leading to difficulties when performing music that is written to be played with a tightly synchronised clock.

Using network technology, we can construct shared clocks. While these shared clocks are intrinsically unsynchronised due to network latency, they can be centralised by using a dedicated system that broadcasts events, or they may be decentralised and multi-authorial: asynchronously generated and intercepted by one or more participants. A centralised clock might broadcast a metronome as audible beats or instructional cues directly to the headsets or screens of participating musicians. These cues may become a critical part of the decision-making process, such as in Anne La Berge and Robert Heumen’s *Shackle*, which incorporates a “self-designed, cutting-edge digital cueing system which operates as a sometimes visible third member” (La Berge and Heumen, 2006). Virtual conductors might distribute cues that are preprogrammed and triggered by events or timing, or cues output by sophisticated random number generators, or a combination of both. With developments in machine learning, I imagine a future cueing system that contributes by analysing and exposing musical structures as they occur, and perhaps integrated with haptic technology that extends and shares participants' musical causality by introducing and manipulating artificial vibrotactile feedback (Hayes & Michalakos, 2012).

A simple cueing example could be achieved remotely with a networked system that linked each location and distributed cue messages, whether those cues are interactive, gestural musical instructions such as those transmitted in *Shackle*, or simple procedural synchronization signals to either a human participant or machine. Table 1 shows how a series of cue messages might look, where the cue is a shared central "computer" and Alice and Bob are distant from each other and communicating via a network. Alice and Bob wish to start performing their instruments at perceptually the same time so they set up the central cue system to request acknowledgement from both Alice and Bob that they are both ready to begin, which then begins a countdown. Alice and Bob might take a few seconds to accept and acknowledge the request with, e.g., by using a mouse click or interface switch. When the cue receives both acknowledgements, it sends the Begin command. Alice and Bob receive this message via their interface and start playing their music together. This simple machine interface relieves Alice and Bob of the extra complication of deciding who acts as conductor by delegating these tasks to the machine.

Table 1. Cue example of messages sent from the cue, Alice, and Bob

ACTOR	TIMESTAMP	MESSAGE	RESULT
SYSTEM	11:00:01	Acknowledge request	ALICE OR BOB INITIATES THE CLOCK
ALICE	11:00:06	Acknowledge	Alice selects "READY"
BOB	11:00:09	Acknowledge	Bobs selects "READY"
SYSTEM	11:00:10	Countdown: 5 seconds	System notification
SYSTEM	11:00:11	Countdown: 4 seconds	System notification
SYSTEM	11:00:12	Countdown: 3 seconds	System notification
SYSTEM	11:00:13	Countdown: 2 seconds	System notification

SYSTEM	11:00:14	Countdown: 1 second	System notification
SYSTEM	11:00:15	Begin	Alice and Bob's clock starts counting

The advantages of a programmed, shared cue, or "digital conductor", include minimising opportunities for human error in cueing, minimising frustrations in miscommunication, allowing for real-time score changes and "live coding", shared telemetrics and analytics, and the potential to distribute DSP effects and control mechanisms.

Where video cameras are used, a multi-space ensemble might employ a conductor to synchronise rhythmic flows. Ray ultimately achieved a shared cue by placing a person with each remote ensemble to act as local conductor, using a dedicated communication channel between them and the lead conductor. Sarah has extensive experience in conducting over video using fields and gestures. Remote conducting "requires certain types of gestures; it's very different conducting a local and remote ensemble at the same time" (Weaver, 2016). She suggests that the composer may indicate certain field positions in the score for musical changes or use them as section indicators.

Creating a shared clock experience is a technical matter. Once a system is in place, participants can quickly learn how to interact with it. Consumer software does not currently exist for such purposes, but it is a fairly simple process for a technically knowledgeable person to execute their project on a per-need basis using tools such as Max/MSP or web development knowledge. The actual method of sharing cues is less important than the participants' perception that they are interacting with each other. Achieving a sense of shared time is an important factor in creating intimacy between remote participants if the composer has prioritised this as a goal (Nevejan, 2012).

3.3.2 ERROR INSTRUCTIONS

Errors when using technology in live performance situations are common, even more so when using unreliable packet networks as the mode of transmission, which affirms Herndon's (2015) statement that digital real-time composition warrant reactions rather than anticipation. Furthermore, other technical constraints and points of failure such as firewalls, bandwidth constraints, time zone misunderstandings, and equipment failure can lead to a non-start concert. If nothing else, participants should agree on what happens if, during a performance, the network fails and audio is lost from one or all sides, and what to do if that audio is not re-established in a certain period of time.[37]

For example, the composer might instruct participants to stop performing in the case of network issues and restart the performance once the network refreshes. Alternatively, the musicians might be instructed to continue the performance as rehearsed or otherwise revise the performance accordingly. A more common error would be the network re-buffering and interrupting the rhythmic flow due to increased latency. A composition response could present the new latency to the musicians who then adjust their performance accordingly.

Exploiting endemic and inevitable network errors is a fertile area of aesthetic exploration, where the development of performance-based error instructions can lead to a distinct and engaging musical experience.

3.3.4 CULTURAL STRUCTURES

Control structures can be tools developed purposefully, through misuse, or through the extension of natural and social structures. Control structures can also be developed over time through cultural expectation. If enacting cultural norms through shared musical experience reinforces social relationships, it could be said conversely that through enacting resonant performative relationships, we can create new cultural structures. We can look to the example of Gaelic psalm singing, which is a "form of collective vocal improvisation" (Meek, 2016). The precentor leads a congregation with phrases, which may be repeated in any alternative way as desired by the individuals. Waves of shimmering antiphony sweeps across the hall, the music pulsating as melodies move in and out of unison, harmonies in and out of phase. Described as "a sense of history in the music … the music of a people who have survived the ages in a harsh climate and under the rule of others, but still hold proudly to a form of music unlike any other" (Meek, 2016), psalm singing reinforces their shared cultural experience. A similar experience might occur when bringing several choirs together over a network to perform using, e.g., a combination of a suitably engaging score and certain instructions to

[37] The Internet is not completely unstable. Technical solutions can be found to mitigate failure, including bonded network connections and backup networks.

deviate and improvise on that score. Both a new means of resonant shared cultural experience and new forms of musical exchange could arise.

3.4 SCORING

Two characteristics of networked music are latency and the disruption of traditional forms of communication between musicians, particularly when reading a fixed-time score. While latency effects an ensemble's reaction time and disrupts the possibility of reproducing precise harmonic structures, it extends musical opportunities with another dimension: i.e., response time. While subject to latent and unstable transmission, networked music performance cannot rely on a stable response time. Unlike in composite space, we cannot reliably repeat a musical performance when connected over a network. The musical score for remote participants must therefore be considered a guide to be followed, not a concrete predetermined object that can be linearly reproduced. It is "best regarded not as an encoded representation of sound, but as a stimulus or provocation for the performer to react to and against" (Croft, 2007, p. 59).

A networked music composition is a polymorphic structure. The interpretation depends on the responses of the receiver according to the system of transmission where "not only processes based on transmission of sound energy are of interest, but also those of vital information, such as numbers or signs" (Rohrhuber, 2007, p. 142). We are reminded that when transferring a message between multi-located spaces, "the receiver's context differs from the sender's context in some respect" (Rohrhuber, 2007, p. 142). Using responsive computer-aided tools, this vital information can be made transparent to participants so it can be folded back into the music itself or used as a performance guide to minimise anxiety.

Chris recounted a performance that, as an example, may have benefited from additional vital information messages. This work was "fully notated in kind of fast rhythm with predictive latencies baked into the score. One of the difficulties was that we found it really hard to play the piece without having done piece by piece building it up from sections, and again missing the ability to rehearse at a level that this thing needed and warranted. It's difficult, it's really difficult" (Chafe, 2016). Complicated scores, such as those described by Chris, may benefit from a scoring system integrated into the means of transmission. An integrated score will transmit vital information of the system itself as interaction occurs, enabling the development of complex performative relationships while not increasing anxiety. Musical complexity when combined with unconventional processes can result in undesirable experiences, which suggests that musicians need consistency and familiarity with a new system.

While it is exciting to consider the many opportunities afforded by an integrated scoring method within the networked music performance system, its musical instruction methods must be as varied and distinctive as any composer and participant needs. Freeman and Colella comment that the "composer must negotiate a complex web of software development environments and languages, networking infrastructures and protocols, hardware and display devices, and budgetary and logistical requirements, all while factoring in design considerations such as time synchronisation, notation styles and refresh rates", which suggests that "there is no single system that can support every need" (Freeman & Colella, 2010, p. 102). The remainder of this section outlines a few scoring and notation methods that transmit instructions to participants in networked music performance, whether for human participants or computational methods and processes for machine interaction.

3.4.1 STATIC NOTATION

The predetermined static score, whether printed on paper or distributed via digital screens, conventionally assumes that musicians are in composite space and not subject to differences in time. A static score may describe notes and articulation in the same way as any traditional score; however, the composer, who is now subject to the uncertain harmonic result caused by post-vertical harmony, will find a need to add additional instructions, particularly for time-keeping and synchronisation. While there are no formally recognised asynchronous notation techniques, "developments in terms of notational detail have been paralleled by the exploration of graphic and other forms of indeterminate scores" (Pace, 2009, p. 150) in the twentieth century. I discuss some graphical and textual solutions in chapter 4 that I developed to introduce multi-located time-keeping instructions in the context of traditional static notation.

3.4.2 RESPONSIVE SCORES

A responsive score is a musical instructional system that responds to changes in state and provides vital information about that state to participants using computer-aided techniques. Responsive scores are particularly useful for creating scores that adapt to conditions, such as changes in latency and bandwidth as they occur.

Hajdu and Didkovsky (2009) assert that a scoring system needs to "be free of compositional biases and capable of representing a large spectrum of styles and performance practices ranging from guided improvisation to composition" (p. 397). Problematically, such systems—while being constantly in development—are under constant degeneration given the ever-accelerating rate of technological change. Within years, a computing tool developed for a particular purpose is deprecated due to its incompatibility with newer communication protocols or made redundant through new advances, such as operating systems that demand upgrades and security verifications. Because of the rapid rate of redundancy in the software world, any list I might give here of available software will soon be outdated.[38] However, several open-source protocols are still in place after some decades. They not only withstood commercial development whims,[39] but in their steadfastness, they have also cemented themselves as viable methods for compositions given their entrenchment within the music community. In Table 2, I list a few common human-readable scoring and notation protocols that have a strong history and expectation of continued development support for some time to come, so that composers and musicians may commit to becoming intimately familiar with these protocols.

Table 2. Programmable notation protocols

PROTOCOL	SOFTWARE SUPPORT
MusicXML	Sibelius
JMSL	Max/MSP
Lilypond	Max/MSP
Manuscript	Sibelius
MaxScore	Max/MSP

[38] See Hajdu and Didkovsky (2009) and Freeman and Colella (2010) for a comprehensive overview of network music and real-time notation and scoring software made at the time, where many of the tools are no longer available or up to date.

[39] Recent examples include Apple's requirement that applications are encrypted using a paid certificate, limiting the ability to easily distribute free software.

Canning’s 2013 work *nodescore* is an aleatoric hypertextual musical framework (Canning, 2012) that allows reuse and development by other composers. Similarly, Quintet.net is a freely modifiable instructional notation framework built on the Max/MSP and MaxScore protocol that “provides shared access to a musical score for collaborative composition” (Collins & d’Escrivan, 2017, p. 150). Responsive scores can be improvisatory and real-time, suggesting an aesthetic approach where programs that are written as improvisation to generate the artistic outcome (Sorensen & Brown, 2009) to allow the musician to “keep a sense of challenge and improvisation about electronic music-making” (Collins et al., 2003, p. 322).

We may eschew the human-readable requirement completely and use technology to generate music, which extends performance beyond the range of human physicality. Nancarrow used his piano player works to seek liberation from the constraints of human performance and found an “excessive, hyperactive virtuosity [that] is paralleled on the experiential level in the manifold perceptual difficulties” (Drott, 2004, p. 534). With this aspiration reflected in today’s practice of live coding, where computer languages are the primary interfaces of artistic expression, integration with digital networks is a natural development. Computer code is easily transmitted and highly collaborative, where any algorithm can be applied at any time during the process, such as injecting environmental variables or transforming instructions into the supported data formats for available machines at any location.

3.4.3 MACHINE INSTRUCTIONS AND PROTOCOLS

A machine protocol is a prescribed system of rules for direct communication between entities to transmit both data and information about data variation. Any digital technology that provides access to the protocol level can be exploited for use over the network, which allows “the network of human relations to include the algorithmic network of the program” (Rohrhuber, 2007, p. 146). Music protocols are formalised rule systems that afford the exchange of musical data between systems to be transformed or reproduced. This might be data that represent descriptions of sound, as in the case of the Sound Description Interchange Format (SDIF), a “general-purpose sound description format framework” (Wright et al., 1999, p. 175), which is the “standard for the representation of analysis results” (Wright et al., 1999, p. 174), or it may be gestural and articulation data, such as the Musical Instrument

Digital Interface (MIDI)[40] control protocol, or a lower-level protocol, such as Open Sound Control (OSC)[41] designed to transport general data between music platforms. A composer can make use of these protocols to implement a complex, real-time musical instruction system that is fully responsive with the digital network and its telemetric vital information, sending information from one machine to another to respond to changes in state. On a notational level, such information could be predefined as instructions, e.g., the composer could lay out a set of rules for participants to follow in response to change, or it could be improvised as a computing process by applying an algorithmic process when certain conditions are satisfied. In chapter 4, I discuss some technical solutions that I have put into practice to provide cueing and telemetric information to participants to complement the static scores, alongside data analysis, transformation, and integration with machine protocols to generate and initiate musical content.

3.4.4 GESTURAL NOTATION AND TRANSLATION

Gestures can be transmitted visually using video transmission or they can be abstracted into streams of machine data for translation into other forms. Electronic instruments such as electric keyboards and string instruments that convert gestures to MIDI are common; we can convert devices such as gaming controllers and motion-capture systems into MIDI or OSC data, or we may create purpose-built instruments with sensors and motion-detection systems, such as Waisvisz's *The Hands* (Torre et al., 2016), Sonami's *Lady Glove* (Sonami, 2006), or we may use computer analysis on images and sounds to extract movement data. Once data is collected, it is simply a matter or relaying that data to a remote machine, which allows the development of real-time interactive music. Video transmission allows remote conducting using formal gestural notations, such as the body and sign languages of Walter Thompson's *Soundpainting* (Eisenberg & Thompson, 2003) and Lawrence "Butch" Morris' *Conduction* (Morris, 2006), respectively. These methods make use of video transmission where latency is

---

[40] MIDI is an industry standard music technology protocol designed for making digital sound generators interoperable and inter-controllable. https://www.midi.org

[41] OSC is a protocol for communication among computers, sound synthesizers, and other multimedia devices that is optimized for modern networking technology. http://opensoundcontrol.org

somewhat higher so it must be compensated for during performances. Sarah, who is also a soundpainting practitioner, tells me that when she uses video for conducting, "I slow down my cues, because when it's coming over the video and given the latency, I joke that it's like the German downbeat, where you give the cue and sound comes a second or two later. I find that if I make gestures that are a little slower, like medium tempo, we can kind of bridge that again with that wider concept of time" (Weaver, 2016).

3.5.5 PROCESSING AND SYNTHESIS

When a composer puts a note to the stave, it is an instruction to reproduce a certain kind of sound. When that sound producer is human, she will specify detail via graphic symbols or textual instructions. When the sound producer is a machine, the instructions will be in the form of a stream of numbers and digital representations of symbols. Those instructions might be predetermined, algorithmic, or a combination of both. The machine might be programmed to emit synthesised sounds based on these instructions, which generates a given set of frequencies and envelopes using spectral data or modelling, or the machine may contain pre- or live-recorded samples on which the machine applies a DSP algorithm. This kind of interactive machine activity interplays well with the streams of data provided by the network: i.e., whether than data is decoded audio, gestural streams, or telemetric information, it can be fed into a machine, manipulated, and merged with live audio from all remote directions to allow the composer a rich palette of sonic possibilities.

Chris expects future computing technology will result in "'performance-guided synthesis' in which a very convincing model takes its cues in real time from a performer" (Chafe, 2009), effectively eliminating the effect of latency where a process can predict events and make decisions ahead of the arrival of actual networked audio streams (Chafe, 2016).

In the creatively expansive area of computer-assisted notation, scoring, synthesis, and DSP, there is a wealth of potential for the development of complex and meaningful network-enabled works. One inspiration is Jacob Sello's 2008 *Slices*, which makes use of a real-time computer-generated MaxScore linked with gesture translation. By engaging with gesture, the "score, interpretation and visuals are inseparably linked" (Sello, 2008) and differ in each performance. By engaging with the computer not only as a means of transmission, but also as score and sound generator, we can translate and interpret telemetric and gestural data derived from the network, which makes our interactions with each other and with the machines audibly responsive and promoting processes where the “main goal is to connect these processes meaningfully to each other” (Sello, 2008).

CHAPTER FOUR: MUSIC DEVELOPMENT

> *"Music articulates the absent space"*
>
> - Daniel Schorno

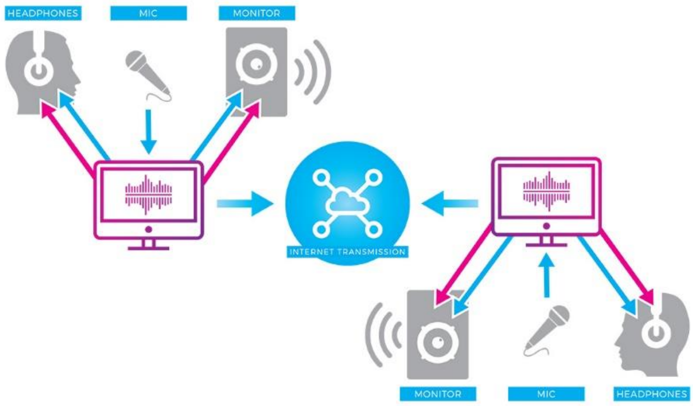
In the following chapter, I detail the creation and performance of musical works that exploit the characteristics of networked performance music described in chapter 2: i.e., latency and uncertainty, multi-located and multi-authorial space, and digital mediation. I explain in detail how, using workshop-led discovery and the development of custom tools, I apply the ideas developed in the first chapters to the musical composition of ensemble music. My primary aim in this portfolio is to develop musical strategies that are sufficiently intriguing to encourage musicians to perform together remotely without having access to dedicated low-latency networks or highly technical environments. With the aim of expressing the ideas gleaned in my research, I focus on writing music that accepts and embraces uncertainty, acoustic feedback, and an unstable configuration of bandwidth and technology. The music in this portfolio explicitly demands a multi-located network performance for its full realisation.

I completed three original compositions for chamber instruments and electronics based on the ideas generated from the collaborative experiments and workshops outlined in the next section. Each musical work subsequently informed the next as I gained a deeper understanding and sophistication of the potential aesthetic opportunities, arriving at a composing method that simulates real-time performance with actual network latency using sampled instruments, multiple computers, and custom software. Constant experimentation with how sounds reacted together an actual networked environment allowed me to explore resonant effects of harmony and timbre during the musical development process.

4.1 DISCOVERY AND WORKSHOPS

Writing music for networked music performance requires imagining the possibilities of new dimensions of music: i.e., latent interaction between participants, resonant opportunities of the connected performance spaces, and the technical considerations available to the performers at the time. Through practical workshop exercises with musicians over a network, I arrived at the composition and technical solutions that were put into practice for approaching harmonic and melodic development in my music portfolio.

Figure 12. Technical setup for workshop and experiments



4.1.1 WORKSHOP: DANIEL SCHORNO

As a cellist, composer, and electronics expert, Daniel Schorno's participation in my first workshop was a joyful experience, not the least because we had worked together at STEIM some years ago and it was a delight to find a new common performance space together over the Internet (he was in Amsterdam and I was in Wellington), but because Daniel and I had performed together in the past and had a compatible aesthetic, which allowed improvisation to take place. In the workshop, I was also playing the cello and while I did not provide any music for Daniel and I to play together, I communicated verbally a set of ideas I had previously written down to discuss and run through. Both of us were in a bright reverberant room with wooden floors and good microphones, which was excellent for cello performance and experimenting with resonance and melodic and rhythmic feedback. While no recording of the workshops exists, extensive notes were taken during our interaction. We began by improvising on a short theme that was invented in the moment and performed a few trials to explore the sonic space that was created between us. Our focus quickly landed on repeating phrases with variations, a technique which served well to explore latency and resonant effects as a means to articulate latency and harmonic progression, while maintaining a sense of rhythmic stability from the perspective of the performer. Repeating a phrase, with or without variation, enables the performer to pay attention to musical elements such as changes in time signature and dynamics without needing to be concerned with exact synchronisation of notes with their remote performers.

When we paused and deliberated on the music that was evolving as a course of the separated nature of our communication, Daniel commented that “without the body we experience disorientation, the musical organisation orients us”. He noted that performing music over a network was a “profoundly disorienting experience” where “both realities are alternative” and the music appeared from “neither this room nor that room”.

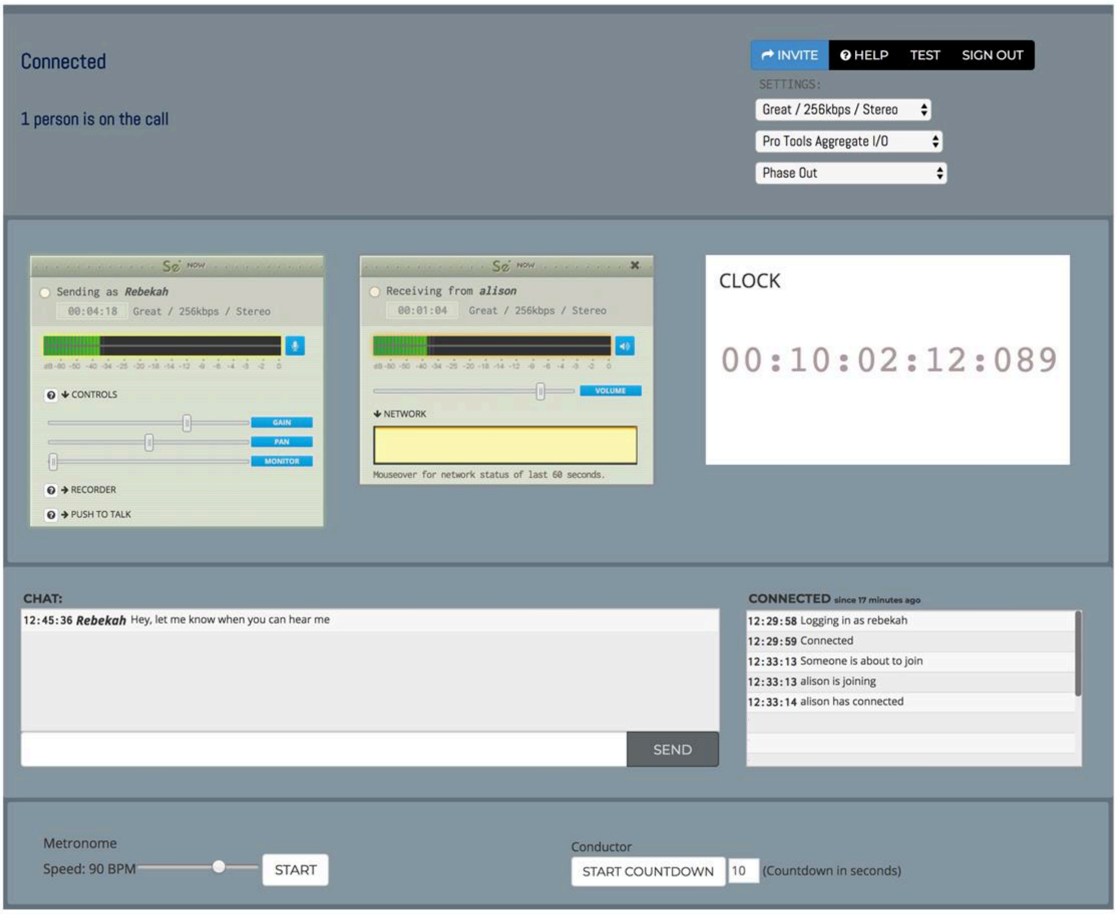
Daniel’s insight that “distance-mediation highlights the articulation of space, the new kind of space created” and “perceiving the other acoustic entity is an imagination of the space, highlighting the emotional aspect” was valuable to me.

4.1.2 WORKSHOP: ALISON ISADORA

My improvisatory workshop with Daniel led me to develop many musical fragments and concepts to explore with Alison Isadora, who at the time was Composer in Residence at the School of Music and living in an adjacent suburb in Wellington. A composer and violinist, Alison has significant experience in ensemble improvisation and I was interested to get her thoughts on the networked performance experience. Our geographical proximity to each other helped me to fully realise that even a smaller latency isn’t much better at encouraging synchronisation. When comparing the musical discovery with Daniel, who was connected with me over a more latent connection, Alison and I were easily finding ourselves out of sync. This led me to understand that any latency, when above the threshold for natural synchronisation, has an inevitably disorientating effect.

Given that I had previously experienced sync disorientation with Daniel, I had prepared a software tool that was integrated into the WebRTC interface, where a shared cuing clock could be activated by either side and would begin the countdown to a start indicator and optional metronome. Fig. 13 shows a screenshot of the interface.

Figure *13*. Central clock and metronome



With the aid of a digital cue to indicate synchronisation events, the workshop with Alison was more focused on the temporal experience of musical time. Alison quickly observed that the network makes it easier for asynchronous complexity. Our playing confirmed my proof of concept that as rhythms became complex, various timbral interplays occurred, particularly when dynamics and articulations seemed to create rhythmic elements using the natural asynchronicity of musical alignment between us, e.g., when the notation specified playing a series of crotchets and increasing the speed until both instruments were playing tremolo. This tremolo created the effect of notes asynchronously chasing each other between spaces, which gradually came to a kind of synchronicity as the note speed became too fast to follow any individual instrument. The timbral effects inspired me to seek further interplay of articulations, such as microdynamics, note placement, and pitch alignment, where phase beating, digital transmission artefacts, and glitches interact with the room's acoustic feedback.

Performance-wise, we both felt a strong natural tendency to seek alignment with what we were hearing from each other. At one point we were playing from the same score and became completely out of sync. I was expecting this to happen; however, Alison stopped and stated that we were no longer at the same bar. We replayed the music with more precise attention to the shared digital timer, which shows that traditional notation can work as long as markers are in place for musicians to refer to. This attention to timing allowed us to perform more advanced material with tightly specified musical elements such as glissando effects that I hoped would overlay and create an effect of pitch-shifting across multiple locations. This worked spectacularly and I continued to explore this idea in the music composition *Phase Not Phase*.

Alison and I ended our workshop with a discussion of aleatoric notation. She reminded me that many decades of contemporary music notation have been developed and iterated to convey and transmit rhythmic and harmonic information between musicians where the element or parameter may not be absent but can specify a layer of freedom not usually associated with that parameter; e.g., a score that has no time signature or bar dividers, and specifies a set of notes or melodies to be reiterated at the musician's will until a certain event occurs. Aleatoric systems are ideal for networked music because they increase the degree of autonomy, which allows participants to create their own vital information instead of seeking it from a remote source. Such systems engender performance resilience by decreasing the concern of participants losing sync with each other. I put this concept into practice to some extent in each composition in my music portfolio, which I discuss further in chapter 4.

Alison and I communicated over an ad-hoc WebRTC interface that I had implemented, which presented a large yellow 'talkback' button, such as that found on radio transmission devices, so we could ensure a closed voice loop while the instrument microphones were live to avoid the codec's sensitivity to the speech frequencies creating feedback. For this reason, I advised that we did not speak until each musical experiment was complete and only then enable the talkback feature while speaking. A core benefit of the talkback system is that the interface provided visual feedback when Alison's talkback was opened. This meant that I could take care to open my voice microphone only when hers is closed. Such systems are important to allow for natural conversation given the technical limitations of networked communication.

4.1.3 "OFFLINE" EXPERIMENTS

The pair workshops were a practical and successful corroboration of the multi-authorial concept of there being no singular musical experience in a multi-located performance. The interactions confirmed for me that creating music together over a network allows for new musical strategies. I continued experimenting with the ideas generated from these workshops by connecting two, and sometimes three, computers in different networks and acoustic environments, outputting a variety of musical phrases I had created with sampled instrument libraries.

In addition to feeding back the network signals to and from active monitors, which gave rise to musical content and effects that suit my personal aesthetic, I experimented with various methods of affecting the network itself, e.g., by forcing bandwidth constraints, modifying codec parameters, and triggering events to external effect generators.

4.1.4 FINDINGS AND SUMMARY

By reworking the most successful experiments from the pair workshops in combination with technical exploration of manipulating the means of transmission directly, I developed a series of musical ideas to compose with, such as rapid tremolos that create shifting timbral effects as they interact with the codec and room acoustics, and the spectrally rich collisions of noisy artificial string harmonics. In consideration of the technical factors that affect realistic expectations of performance conditions, I give specific attention to the limitations and affordances of network latency, the multi-located experience, acoustic feedback, and the associated technical support required to manage feedback and event synchronisation.

Latency is the primary characteristic of networked music; a full expression of networked music performance demands that latency is embraced as a core factor in both harmony and notation. Furthermore, while network latency can be reliable during a performance, the undetermined delay factor that occurs in every setup—be that due to a performance in a new concert hall or a new combination of locations—removes the reliance of writing music based on the assumption of constant synchronicity. Even if the latency is stable and known before starting a performance, the multi-located space itself may be ephemeral. Perhaps it is a new set of venues with a long or short latency, or perhaps new equipment has affected the latency and network stability. Through technical experimentation, I was able determine what kinds of sounds and musical passages work when they arrive asynchronously to each other, with a simple method of realigning musical passages with a variety of offsets in a digital audio workstation (DAW) program. My offline experiments were instrumental in my compositional development, leading to my development of software tools that manipulated the audio signals as they were sent and received. Manipulating the signal separately to the participants' output formed my approach to digital mediation, i.e., there is no obligation to faithfully transmit the signal because the machine may also create vital information.

The audio information created by the microphone and reproduced by the monitor is also heavily subject to non-intentional interference in networked music: i.e., acoustic feedback. While we generally seek to avoid the shriek of feedback, it is a constant force. In the pair workshops, I was able to mitigate this by requesting that Daniel and Alison take care with their voices and control their audio levels. Performance-wise, I sought to expose the qualities of the multi-located performance space through resonant feedback by having open microphones and carefully constructed musical phrases. Thus, I learnt that feedback can be used as a strategic musical tool to create resonance and harmony and does not have to be avoided completely.

In other situations, there may be less control by participants. Solutions must be flexible given that each environment creates a distinct set of technical circumstances that directly informs the networked music performance experience, technical support and equipment, participant unfamiliarity, and new notation, particularly in regards to the network and audio equipment and technical support available for participants.

4.2 NETWORKED ENVIRONMENT SETUPS

The development of a functional composing framework that simulates the network during the composition process has been the most useful tool in the development of my compositional strategies. Derived from the impetuses of the practical workshops with Daniel and Alison, I constructed a functional method for discovering and experimenting with real-time networked audio between multiple sources, which allowed me to measure and manipulate latency, acoustic feedback, and resonance under various conditions.

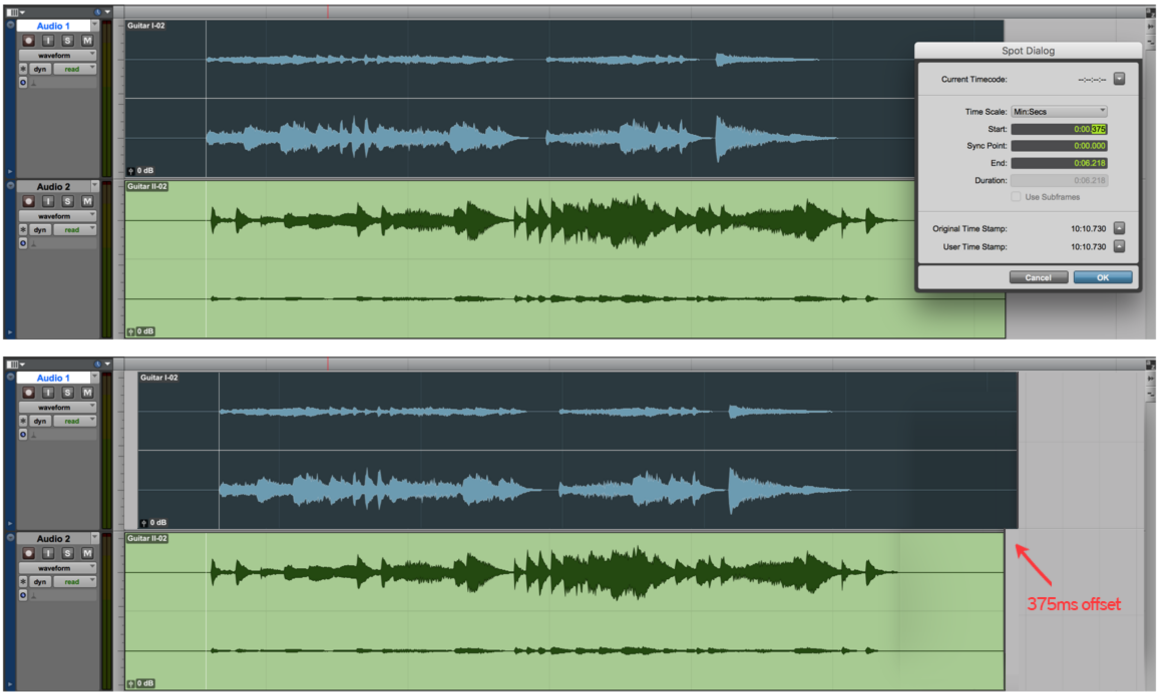
4.2.1 SIMULATING A NETWORKED PERFORMANCE ENVIRONMENT

When writing music, composers rely on a personal collection of tools, which may include internal listening experience. More recently, due to new technologies, we can now simulate orchestration in real-time: e.g., a MIDI stream of notes played through a hardware sampler or a full orchestral simulation using computer sampling and synthesis linked directly to notation software. When writing for a single location, the composer can rely on their traditional knowledge. However, in the case of working with multi-located spaces and, especially, when working with non-fixed latencies that cannot be predetermined, I found that the available software was lacking the networked experience of latency between musicians. To fully grasp the implications of writing for networked music, the composer must listen to her music under multiple conditions.

Understanding that I needed to create a composing environment where I could write and test my ideas, I arrived at two methods to simulate a networked musical performance: offline and online methods. The non-real-time offline method requires no custom software and will successfully generate the experience of a network performance with little effort. The real-time online method is technically complex to setup, yet once done so, it allows for sophisticated options in experimentation and playback.

The first composition method is offline simulation. The offline method requires nothing more than two audio tracks and a multi-track DAW, where the tracks can be shifted earlier or later in time to simulate the network latency effect. In Fig. 14, I show this how this action is applied in a DAW. Room effects and reverb can also be applied here to simulate a performance environment. I primarily used the offline method for developing the first portfolio work, *Unison Not Unison*.

Figure 14. Offline method



The second composition method is online simulation. The online method involves real-time monitoring of how a networked performance may sound. Establishing a real-time playback monitor involved routing the audio signals from the notation software directly to network audio software running over WebRTC, which broadcasts the signals over the Internet. Real-time network playback not only allowed me to experience the effect of the network, codec, and room acoustics as I wrote the music, but also allowed me to interject processes such as bandwidth and latency manipulation due to the open-source nature of the software providing access to statistics and telemetric data.[42] Simulating an environment that provided network data feedback led me to consider the effects of changing latencies and bandwidths that can occur over a public Internet connection and how I can approach and embrace these changes in the musical score.

I also used the online method to experiment with feeding back network statistical data to processes such as filters and synthesis triggers via Max/MSP and SuperCollider, using both OSC and my own custom websocket protocols over JavaScript from the Chrome

[42] See Appendix II for the data exposed via WebRTC.

browser which was running the WebRTC instances. For a full description of the online method, see Appendix III.

4.2.2 PERFORMANCE CONSIDERATIONS

In a performance setup, the configuration would be similar to the workshop configuration detailed in Fig. 12. In a concert room, there would additionally be the expectation of a sound engineer being present to manage acoustic feedback and levels. A sound engineer permits the interaction between microphone and monitor to be subtler; thus, the participants do not have to be concerned that acoustic feedback might interrupt their performance.

4.3 MUSIC PORTFOLIO

Drawing on ideas inspired through conversations, workshops, and experiments led me to the development of the music portfolio works described in this chapter. I focused on the following areas of interest, where a specific technical aspect demands a reconsidered musical approach:

- **Latency and its effect on harmony**: how the uncertain, indeterminate arrival of musical content over a network insists on a non-vertical approach to harmony.
- **Acoustic and codec feedback and its effect on resonanc**e: how the reinforcement of certain frequencies calls for a consideration of the acoustic and digital effects inherent in the networked music system.
- **Multi-located participation and its effect on event synchronisation**: how performance synchronisation and participation anxiety can be approached through computer-controlled cueing and notational cues in the score.
- **Digital mediation and its effect on sound reproduction**: how we can approach the means of transmission as a source of manipulatable material in itself.

These approaches were applied musically in my portfolio works and for each of these, I developed new software tools and notational elements.

- *Unison Not Unison*: this work explores the dovetailing of a continuously evolving melodic line with a "who starts first" cueing method as indicated in the score, along with experimenting with the acoustic feedback of amplified instruments.

- *Phase Not Phase*: taking the shimmering tremolos that appeared (to my unexpected delight) from the performance of *Unison Not Unison*, this work reinforces the idea of resonance between acoustic instruments through rhythmic and harmonic motion, and applies the concept of manipulating the transmitted signal to create new extended techniques.
- *Echo Not Echo*: embracing the acoustic resonance in *Phase Not Phase*, this work develops more complex musical passages through rhythmic and harmonic phasing and exploiting the natural resonance between the instruments.

Each composition is accompanied by performance notes, which outline the technical requirements and score interpretation suggestions. In considering notational precision, I assume a 'positivistic' view of the role of notation. By positivistic, I mean the notion that the score acts as a set of instructions that informs the participant "in essence what to do" (Pace, 2009, p. 152), around which she can elaborate. For example, she may add musical expression using note articulations and tempo modifications, such as rubato and microdynamics, "depending upon the degree of notational exactitude" (Pace, 2009, p. 152).

4.3.1 *UNISON NOT UNISON*

Unison Not Unison is a work for two electric classical guitars. Composed for two audiences, the intent is that there are in effect two versions of the work performed simultaneously, each being equally valid interpretations and demonstrating a multi-authorial approach. The primary technical concepts I wanted to explore in this work were the implications of network latency and acoustic feedback, and how they guided my discovery into functional notation for networked music performance. The title *Unison Not Unison* refers to the melodic motifs that overlay each other and weave in and out of unison in response to the latency and notation. The title is also a direct reference to Nevejan's YUTPA framework, which I consistently use as a reference model as I explore strategic applications of the networked system, in particular considering the multi-authorial aspect of networked performance. The music is carefully and explicitly written so that the participants' experience is a valid and complete expression of the music. The multi-authorial perspective is illustrated by Ray's comment that "if the delay is central to the musical experience, then the delay has to be kind of shared equally in all of the different locations" (Lustig, 2016).

Unison Not Unison centres around a continuously evolving melodic line, which is dovetailed between the two musicians according to an alternating series of cues as to who begins the phrase, and who responds once they hear notes arriving over the network. The dovetailing effect exposes the network's relative time by exploiting its latency and notation and creates a chasing effect through the repetition and variation of melody, harmony, and texture. In this sense, *Unison Not Unison* uses network latency as an aleatoric element: i.e., each performance and iteration of the phrase will be different.

Unison Not Unison also introduces two musical ideas, which became major themes in my subsequent work: the use of tremolo to expose and explore post-vertical harmony, and the acoustic feedback of resonant frequencies created through the open monitors.

Aesthetically and thematically, I found inspiration in the Monteverdi echo effects heard in his works, such as *L'Orfeo* and the 1610 *Vespers* (Chua, 2005), where a solo vocalist on the main stage of a large reverberant venue sings phrases that are repeated by a second vocalist of the same register in a distant part of the performance space such as a balcony or recessed gallery to use the natural latency and reverberation of the architecture for dramatic effect. Reverberant spaces create additional echoes, which extend the singular phrase into multiple reflections. With *Unison Not Unison*, I wanted to recreate that same experience of reflective space and arrived at two motifs, which reappear throughout the composition: i.e., the rapid dovetailing of phrases that highlights the latency and multi-located nature of the performance, and the repetitive and rapid tremolos that blur the listener's perception of what location the sounds arrive from.

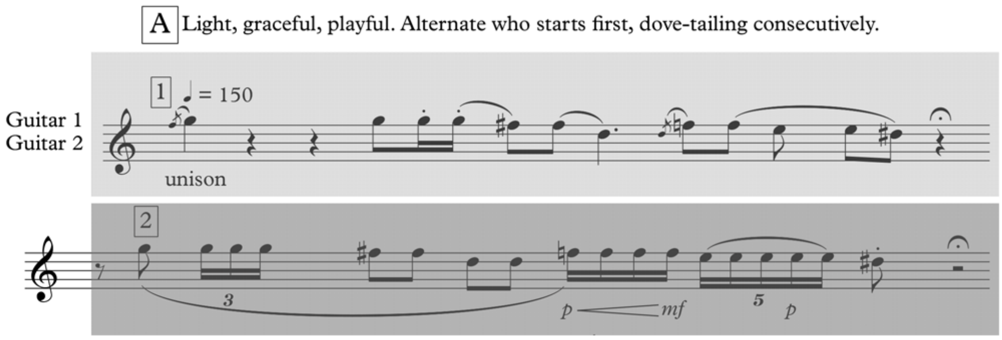
In addition to being inspired by highly structured seventeenth century music, I embrace and encourage the unexpected qualities that occur when indeterminacy creates surprising resonances, e.g., when electronic noise reverberates with acoustic space. A network codec's reaction when compressing wide-frequency sounds such as acoustic feedback is an interesting aesthetic effect and a central section of *Unison Not Unison* uses the EBow to exploit such effects.

Unison Not Unison was developed using the offline method (described in section 4.2) on the environment setup by recording musical passages and manually adjusting the start time of the tracks to experience the dovetailed phrases given various latencies. *Unison Not Unison* moves through several sections, which elaborate on the musical theme of unison through vertical alignment caused by coincidence in contrast to polyphony through misalignment caused by latency. The material is based on melodic variations derived from the opening motif (Fig. 15).

Figure 15. Unison Not Unison motif

The first section (A) is presented in the score as a series of phrases to be played equally by the two musicians (Fig. 16). In fact, network latency creates a dovetailing effect and highlights the asynchronous character of networked performance: i.e., each phrase is heard out of sync while expressive rubato allows for the parts to weave in and out of unison and the score indicates that the musicians alternate in leading the phrase delivery.

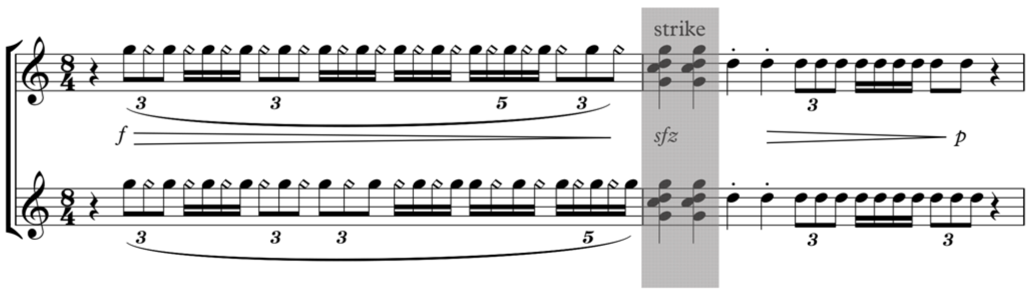
Figure 16. Variations on the motif with alternating phrase leading



The purpose of alternating phrase leading is to reinforce the equal importance of both musicians on each side of the connection, given that the audience's experience will be to give more weight to the present musician. In Fig. 16, the score instructions specify that Guitar 1 or Guitar 2 should alternate in leading, while the other instrument should begin playing once they hear playback of that phrase. The first line will be initiated by Guitar 1, while the second line will be initiated by Guitar 2, and so on. By not relying on precise vertical harmonic alignments, the music removes the need for a network-distributed clock and simplifies performance concerns. Traditionally, musicians will inhabit a shared visual space where a conductor or designated musician will indicate the start of the phrase or section with a physical non-musical movement, e.g., a nod of the head, downbeat gesture with the hand, or a networked clock device. As demonstrated in *Unison Not Unison*, musicians can use and transfer the vital information embedded in the music as a replacement for visual cues.

Section B introduces the tremolo motif, which creates a quite different listening experience where the performance instructions are to elongate notes as needed to achieve a perceptual synchronisation. Without the score indicators of which participant is leading, the music has more asynchronicity. This asynchronicity succeeds musically because where there are no distinct melodic phrases to articulate the latency between participants, the latency itself becomes unimportant and the music focuses more on the timbral experience rather than the melodic experience. Sections D and E combine the unison and tremolo motif by repeating the main theme as a falling series, with each phrase culminating in a long-held note that is finally heard in unison as both parts ‘catch up’ with each other. In section E, a series of struck attacks occurs (Fig. 17) with the intention that the coinciding of notes would depend on the approach. Thus, the speed and latency create an aleatoric indeterminacy where the musicians arrive synchronously or asynchronously on the struck notes in relation to each other, with further variation with each repeated phrase.

Figure 17. Strike notes that may or may not sound in unison



By designing for uncertainty, the score makes allowances for both the connection latency and responsorial latency. In *Unison Not Unison*, this is achieved through the performance instruction of applying liberal rubato and supplying opening rests and closing fermatas so the musicians can explore shared rhythm.[43] By asking that the musicians approach phrase

[43] As Alison and I discovered in our workshop when improvising, the natural response when performing alongside another musician is to try and rhythmically synchronise together. We were naturally drawn to finding a shared rhythm which meant slowing down or speeding up independently from the other to negotiate the network latency.

delivery through listening to the remote participant instead of adhering to a metronome count was beneficial in two core ways: the first being that I could be confident of an expressive performance where the musicians could focus on phrase delivery rather than keeping in time with each other, and the second being that it appealed to my sense of intrigue when uncertainty comes into play.

Section F enters with a new rhythmic pace and stronger sense of latency. Sustained quarter- and half-measure notes mean that a strong sense of post-vertical harmony develops, where the uncertainty of note arrival causes harmonic indeterminacy. Harmonic indeterminacy (Fig. 18) occurs when harmonic events cannot be predetermined due to unstable latencies because the phrases indeterminately move out of sync depending on latency.

Figure 18. Passage designed for effects of harmonic indeterminacy

The written notes interplay with the actual vertical position of the notes as sounded (Fig. 19).

Figure 19. Post-vertical harmonic experience changes depending on note arrival

The latter part of section F falls into a series of tremolos, which further blurs the experience of harmonic progression through the tighter overlapping of change. When Guitar 1 changes from one chord to another during a tremolo, Guitar 2's current chord tremolo overlaps this transition. The faster transitions diminish the post-vertical harmony effect where instead of hearing chord changes that suggest harmonic progression, we hear a harmonic blurring that is less distinct and more timbral.

Section G further highlights the means of transmission by creating acoustic collisions. With each guitarist using an EBow driver, beating notes and electroacoustic pops are created as the audio codec responds the acoustic material. The EBow and codec interplay feeds back to the monitors and recursively back to the codec and network, which acts as a circular resonator. Interspersed with the sustained EBow notes are grace notes, trills, and other incidental effects that are designed to articulate the codec's response to the EBow.

Unison Not Unison was performed and recorded twice, the first being a concert performance and the second at a small private house concert. The first concert was performed on June 1st, 2017 by Wiek Hijmans and Sjors van der Mark. Wiek was in a concert hall with an audience in Amsterdam while Sjors was at his home in Tilburg, some 100 km south. The performance was successful, which showed that Wiek and Sjors were able to make interpretive decisions towards a cohesive, virtuosic performance. It was their first performance using a network setup and I was pleased to find that the score fared well given that the network and acoustic feedback conditions had not been verified before the day of performance.

As a work, *Unison Not Unison* embodies the parameters I outlined for exploitation in this exegesis: i.e., latency and uncertainty, the implications of the multi-located and multi-authorial space, and digital mediation of the transmitted signals. Rhythmically, *Unison Not Unison* does not make any tightly synchronised demands because the aleatoric method of presenting phrases to be performed 'at will' by participants means that no specific note is intended to align with another. By removing the requirement to focus on composer-specified note alignment, negotiating the latency and uncertainty, and making their own rhythmic alignment decisions were the key focuses for Wiek and Sjors during their rehearsals. Knowing that the audience would be with Wiek in Amsterdam, they arrived at the idea of aligning certain percussive strike notes so the audience would experience the percussive effects in full effect. This shows that participants can manipulate the limitations of the disruption of unison in multi-located performance with musical strategies. These performance delays create a virtuosic expectation, which requires focused rhythmic practice and a musical understanding of network latency to achieve precise event articulation. The uncertainty of possibly missing the intended alignment elevates Wiek and Sjors' performance satisfaction when they achieve their goals. The possibility of misaligning synchronous events heightens the excitement of performing in a live setting.

A secondary effect of unexpected artefacts was caused by the technical equipment used for the performance, such as when the metallic plucking of the strings created by the tremolo effects seemed to appear in the middle of the room due to how those particular frequencies interacted with the codec and monitors. Sjors was using a Lenovo laptop with a built-in microphone. Such laptops tend to have built-in acoustic feedback algorithms that cannot be easily disabled, which dampen and modify the outgoing signal. This resulted in a less-resonant performance than I planned for. Happily, the algorithm offered something wonderful in return: i.e., the laptop microphone processor had an unanticipated reaction to acoustic feedback that gave way of echoing bursts of resonant noise when certain sounds resonated, particularly when the EBow was in use.

A networked performance is ultimately subject to equipment behaviour, transducer and codec properties, and network delays; therefore, artefacts are an inevitable by-product of the system. I was fortunate to be able to arrange a second workshop for the purposes of obtaining an excellent recording with Wiek and using a DAW to simulate the duet performance. Using this method, we recorded one guitar voice and played it back over the system while playing the second guitar voice over the network software to obtain a recorded experience of the codec response and acoustic feedback. It demonstrates how network latency causes post-vertical harmonic events and timbral artefacts. Wiek commented that “the latency is far more exciting when it’s cancelled out at certain points. then the rest of the latency becomes far more effective” (Hijmans, 2017).

4.3.2 *PHASE NOT PHASE*

Phase Not Phase is a work for alto voice, two pianos, and electronics, where each participant performs from a separate location, thus requiring three distinct spaces. Like *Unison Not Unison*, the work is designed so that each location experiences a valid representation of the work. The concepts explored in *Phase Not Phase* are exploiting acoustic feedback to create sonic textures, exploiting the opportunities afforded by digital mediation by manipulating the transmitted signals, and using a centralised clock for participant cueing. The title *Phase Not Phase* refers to the phase effect created by piano tremolos.

After the *Unison Not Unison* performance, I was drawn to section F, which arises in the middle of the piece, where both instruments are playing shifting chord tremolos and the amplified guitar sounds seem to create an acoustic 'in-between' space. The emanating sound is a cohesive result of the combination of rapidly repeated notes, the timbral qualities of the guitar feedback with the amplification system, and the spectral collisions of the codec and transmission equipment. Murail (2005) states that sounds are not stable identities, but are essentially fields of forces; thus, latency allows new opportunities to manipulate the forces of harmony, rhythm, and timbre to reveal a wealth of strategies for musical expression. The cohesive tremolo effect inspired my focus on harmonic blurring as a strategy to explore how remote spaces creates continuous resonant sounds, which that are perceived as being in between those spaces. These new sounds could not occur in composite space.

Resonant spaces are not specific to networked music performance. Resonance can be artificially recreated in composite space with digital-processing technologies, such as reverb and acoustic feedback, and latency effects can be reproduced through specific notational instructions. In considering what elements are distinct to networked music performance, I considered approaching the transmitted signal as a manipulatable entity itself. In *Phase Not Phase*, I apply a pitch bend effect on the received signals, which disrupts the original even further from its compressed and transmitted state. This disruption responds to the notion that when we digitise communication, the signal no longer directly references the original input because it becomes a signal ready for manipulation. Such manipulations may be as subtle as using the highest-possible means of reproduction through good quality encoding and reproduction, or we may completely deconstruct and destroy the digitally mediated signal.

In *Unison Not Unison*, the notated method for synchronising phrases was very successful; however, in *Phase Not Phase*, the added complexity of three multi-located musicians, and the longer phrase structure means that without a conductor, there is a greater likelihood of synchronisation drift such as was experienced in my workshop with Alison. Fortunately, technology provides a solvable solution. For *Phase Not Phase*, I developed an interface for the alto to interact with that not only sends time-keeping and cuing events, but also manages the pitch bend effect. The interface allows the pianists to focus on their performance while the alto, being 'hands free', could be used to operate and trigger software.

Programmatically, the work was prompted by the poems of the Spanish poet María Cegarra Salcedo, which were introduced to me by the Israeli vocalist Ayelet Harpaz, to whom *Phase Not Phase* is written and dedicated. The Spanish poet María Cegarra Salcedo was trained as a chemist and her crisp, elegant poetry appeals to my aesthetic. I have used the original Spanish version of María Cegarra Salcedo's 1986 *Ausencia Total* (Cegarra Salcedo, 1999). The poem's leitmotif of falling, trembling, and palpitation suggested an ideal text for my interest in exploring tremolo and trills.

As a continued exploration of the textures that arose in *Unison Not Unison* through gradual modal chord progression via the messy, noisy tremolos of the guitar and network collisions, in *Phase Not Phase*, I consider how three sonic worlds might combine to create multiple yet mutually influential spaces that expand and contract through their changing rhythms and densities.

Phase Not Phase was developed through the online method of transmitting musical passages over a network connection to multiple computers and listening to the acoustic effects of the results. To enable the pitch bend effect, I implemented a method where each signal could be routed and controlled remotely over the network by the vocalist. This system included a method for displaying and triggering event cues using a networked shared clock (Fig. 13).

Section A of the work opens with a solo alto line introducing sustained, ornamented notes. When the pianos enter, they play a simple unison accompaniment that is made rhythmic through latency, finally breaking into trills and ornaments that reflect the vocal line. In section B, the piano trills become the tremolos that establish the core content of the work. The tremolos exhibit an extended morphing of harmonic shapes over long sustained notes that shift between consonance and dissonance, with the compound intervals widening and compressing around the central keyboard. Two types of tremolo are used: chord tremolo (vertical) and alternating tremolo (horizontal). Oscillating between tremolo speeds and types, network latency adds additional musical complexity to the material that results in delicate asynchronous rhythms and beating notes that phase between sources.

Bar 29 introduces an electronic glissando of the piano, which responds to the natural glissando of the voice. The glissando is effectively a pitch bend effect that is triggered using the notational instruction seen in Fig. 20.

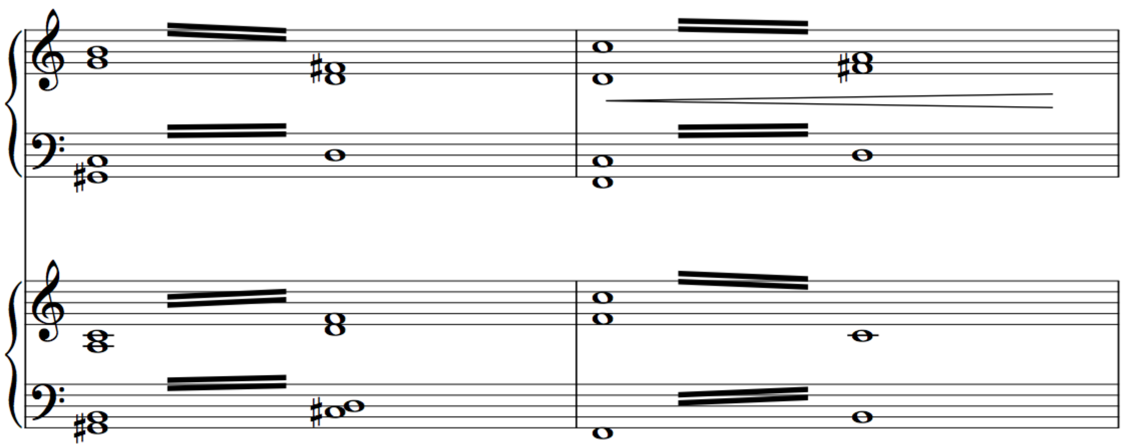
Figure 20. Electronic glissando instruction

The glissando effect on the pianos is particularly successful because as listeners, we cognitively know that a piano cannot pitch bend, which leads to the perception that the received signal is not a faithful representation of the instrument. The electronic glissando grounds the work as digitally mediated and networked. In composite space, the signal cannot be separated from its source: i.e., a piano’s struck notes must be sounded in the space they are created, while sounds can be altered before being reproduced over the network. Electronic signal manipulation exposes the digital mediation of the system; i.e., even a faithful reproduction is just a reproduction. The effect illustrates the potential of digital mediation in networked music performance to create new instruments and timbres, where the degree of manipulation determines the relationship of the sound generator with the sounded experience.

Section D opens with a succession of notes played as quickly as possible as the tremolos increase in intervallic width, loudness, periodic repetition, and speed. The repetition and loudness create resonances between the two piano sources as the more chaotic signals reflect against each other in acoustic space. Through periodic manipulation using tremolo speed, the sync window is modified, which causes phasing effects between harmonic consonance and dissonance, depending on the latency that affects note alignment.

From the recording session, I learnt that if a section demands synchronicity in a rhythmic phrase and a conductor is an unavailable resource, the composer must supply vital information by creating musical content that clearly conveys sounds that participants can use as markers for timekeeping and rhythmic alignment. *Phase Not Phase* is largely based on tremolo and trill materials, where each piano plays chords that, aside from a few exceptions, change modally at the start of each bar and last for the duration of that bar or an even part thereof. The consistency of note durations along with the rapid but constant repetition of the tremolo allow the musicians to rely on their internal counting. The musicians know when they have successfully synchronised with the other at the beginning of each bar because the tremolo chords will have landed at a new harmony together. This audible cue is the essential signal to each musician that they are rhythmically in phase together. This exploits the post-vertical harmonic-blurring approach by using harmony as the vital information for timekeeping and synchronisation. Each chord lasts much longer than the latency sync window and uses tremolo repetitions to create a sustained effect.

Figure 21. Tremolo section in Phase Not Phase*, bars 69 and 70*



With the sustained harmony created by the tremolos, each piano harmonically blurs with the other at the moment of the chord change (Fig. 21). The notated tremolos are heard as multiple iterations of the chord shown in Fig. 22: i.e., an overlapping of the chord change occurs depending on the network latency.

Figure 22. Illustration showing how the tremolo is heard with network latency

In correlation with the discussion on post-vertical harmony in chapter 2, this shows that harmonic blurring is not disruptive to musical performance in practice. Once the chord change has occurred in both parts, the musicians experience a harmonic alignment while the tremolo continues that chord. This new harmonic stasis signals that the moment of change has ended, synchronisation has occurred successfully, and the musicians know that they are at the same place in the score.

Section J was highly problematic during the initial performance attempts. Unlike the previous tremolo sections, the pianists did not have harmonically static content or long note durations to synchronise with. The two piano parts were workshopped by Dante Boon and Reinier van Houdt, each in a separate location within the city of Amsterdam. After Dante and Reinier ran through the work and found some issues in synchronising together, I made it clear that note synchronisation wasn't important, and to consider the phrase only because each phrase lasts for a varying duration but always ends on a high trill note followed by a pause. By specifying that aiming for the trills to sound together after each rising motif was the aim of that section and not attempting to achieve note-for-note synchronisation in the instructions, this was much more successful. After several rehearsals, we recorded an excellent version of this section. During our discussion, Dante and Reinier agreed that given more time for rehearsal, more complex rhythms could be possible when shared rhythmic markers were provided liberally. This workshop encouraged me to consider aleatoric notation for future work because a traditional score can only suggest vertical rhythmic alignment, while a latent network environment can never realise this.

Timbrally, the work resonated with the multi-located room environment as hoped. Given the matched timbral quality of two pianos, the harmonies blended perfectly between both spaces, which led to special moments, such as at bar 142, where the rapid tremolos slowed suddenly to a beating effect. The two piano sources playing the same note with alternating speeds created the sensation of a single oscillating piano hovering somewhere in-between in the network, which perfectly illustrates the title *Phase Not Phase*.

4.3.3 *ECHO NOT ECHO*

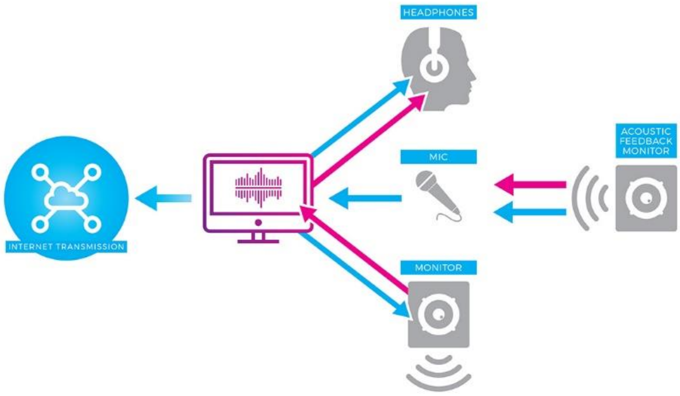
Echo Not Echo explores the idea of creating spectral fusion through seeking resonances between natural instrumental timbres in combination with the additional layers created by acoustic feedback of the performance space. The work is for two equally matched quartets of flute, marimba, piano, and violoncello, with an electronics component. It is designed to be performed in two locations, each with an audience. Inspiration was taken from *Phase Not*

Phase, where resonating timbral effects are achieved by alternating between trills and types of tremolo, whether it is the rapid repetition of notes on the same pitch, or rapid alternation of notes at different pitches, and the acoustic feedback that occurs using open microphones. In *Echo Not Echo*, I extend this idea further by directly manipulating the amount of acoustic feedback to reinforce or dampen the resonances of multi-located space. Two flutes—which in the same location would be perceived as sounding the same note—alternate between being heard as distinct instruments that echo each other, and as a single composite instrument that resonates between the multi-located, digitally mediated spaces. In addition to the traditional composition choices of instrument selection and performance instructions, the timbral experience in networked music is affected by the technical factors of network latency and transmission codecs, microphone setup and speaker diffusion, and acoustic feedback levels. All these choices interplay to create distinct location-specific musical experiences that embrace network music's characteristics as a source of material.

I found inspiration in Ray Lustig's *Latency Canons*, where phrases performed by multiple remote ensembles arrive into a single performance space with a blurred, ringing echoing. This work has been instrumental to me in considering how to approach the intrusion of one space into another and how those spaces fold back into each other. The resonant decays of *Latency Canons* remind me of the echoes heard after many voices have sung a loud chord in a reverberant space.

With this inspiration in mind, I first developed *Echo Not Echo* as a reduction for two pianos to structure the phrasing of the work as a whole before adding timbral effects. By listening to the piano simulation via the online method, I could fully experience the network and acoustic response to the chords and phrasing. For *Echo Not Echo*, I was also interested to explore the effects of acoustic feedback and latency manipulation. Having a simplified score let me quickly test effects and make rapid changes to the score. A simple method to do this is to route each track from the score program individually to a network audio system, such as WebRTC, and mute the actual Sibelius output so the audio is only heard over the network. E effects can be applied once the tracks are separated and transmitted to simulate a multi-located experience. In this case, I routed the transmitted audio into Max/MSP to manipulate acoustic feedback and latency. Feedback is controlled by having two monitor systems on each side, with each monitor positioned at the optimum place in each space to avoid acoustic feedback. A second monitor is placed near the microphone and carefully used to generate feedback effects on demand with both local and remote signals (Fig. 23).

Figure 23. Performance feedback setup with acoustic feedback monitor



With this acoustic feedback process, I became interested in the way sources blurred to cause a disorientation of multi-located space. As notes echoed and repeated from the score, the music seemed to roll in motion between the locations. Applying additional latency further disrupted synchronisation, which led to a push-and-pull sense of which of the transmitted sources was the original source and which was echoing.

Structurally, *Echo Not Echo* explores a vertical to horizontal theme, where notes are initially placed vertically and are broken by rhythm to become horizontal motifs. This material reflects how the synchronisation of playing vertical chords over the network is disrupted by transmission latency. Section A opens with a constant striking of held notes where the intention is to experience this chord disruption, which breaks briefly to a horizontal theme in section C, and then returns to the chord repetition.

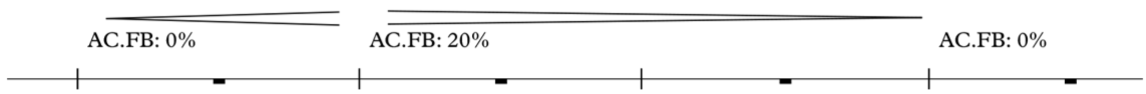
Sections E through F explore combinations of repetition and arrhythmic chord placement to suggest a wide rolling motion between the acoustic spaces, while trills and tremolo interplay with dynamics to create more complex micro motions and oscillations. Through section E, a subtle latency effect is applied to the received transmitted source, which is indicated in the score as a DELAY instruction to the electronics system (Fig. 24).

Figure 24. Signal delay score instructions for electronics engineers

The system has captured the amount of network latency by monitoring latency over the network. A delay process can be applied on the signal to increase the distance between the locations, which in effect creates a rallentando effect without the need to convey a change in timing to musicians and adding performance complexity.

Sections F through I maintain network latency (which may or may not be static depending on the network conditions) and develop the natural resonance of timbres while introducing a vertical triplet motif that undulates between instruments and spaces. Section J extends the material and instrument timbres by introducing the electronic manipulation of acoustic feedback through the secondary monitor system. The feedback level is notated in the score (Fig. 25) as being between level 0 and 10. The levels must be calibrated before the performance.

Figure 25. Acoustic feedback score instructions for electronics engineers



Acoustic feedback has the effect of changing the timbre of the ensemble by causing condition-dependent resonances that are particularly responsive to architecture, and microphone and monitor setups. Used as a subtle effect, the acoustic feedback adds a digital aesthetic to an otherwise acoustic sound world. For example, in bar 160, what is otherwise a very quiet, undulating passage of triplets becomes a wash of reverberations. The acoustic feedback is quickly lowered before section L brings in louder material, where faster iterating notes offer a crisp counterpoint to the previous blurred sections. Sections L through O use the same harmonic material as in the previous sections, extending the vertical chords into passages of horizontal runs and arpeggios. By exploiting network latency, these rapid horizontal runs sound more complex and polyphonic than the score suggests. Section P resumes the acoustic feedback effect by highlighting the acoustics of the spaces through slower note articulation. The arpeggios in section Q are extended timbrally using the acoustic feedback effect, which is timed to align with the feedback envelopes as the arpeggios reverberate and peak at the end of the section with 30% feedback, with the intention that the opening bars of section R are experienced as resonant feedback decay.

Echo Not Echo embraces *participant autonomy* on a rhythmic level. Participant autonomy means taking an aleatoric approach. In *Echo Not Echo*, this means that note alignment is determined by the participant's response to the technical conditions imposed by the network. The aleatoric approach to rhythm in networked music creates a meaningful interaction with the latent and uncertain characteristics of the system. Note motifs and phrases are presented as rhythmic elements to be woven in and out of synchronisation. How motifs align depends on the performance conditions and the electronic manipulations of the signal. Concrete phrase-level structures can be moulded more easily by providing audible vital information as anchor points. This is illustrated in section Q (Fig. 26), where notes overlap and interweave to arrive at piano arpeggios that signify the end of each phrase.

Figure 26. Phrase-level sync is achieved using anchor events while finer-level articulation can be asynchronous

By making use of the arpeggio anchors, the material exploits phrase articulation as a musical instruction to encourage asynchronicity and create rhythmic density. Layered gestures result in a jumbled pile of notes, which are heard with upward directionality as created by the rising pitch and decreasing note durations. This motif continues through to section T, where the rhythms become increasingly dense and harmonically isolated. The intensifying rhythmic syncopation heightens the perception of each instrument operating independently, an effect that is exploited with the sudden return to timbral and modal unity in section U. Extended note lengths permit a kind of breathing space where participants can rely on the expectation of sounding together.

CHAPTER FIVE: NEW AESTHETIC CHALLENGES

"I, the machine, show you a world the way only I can see it"

- Dziga Vertov

Networked music performance is a complex system based on the interaction of protocols which are often overlooked as having manipulatable parameters. In this exegesis, I have examined the fundamental elements of the medium and the implications of manipulating the network's characteristics for composing music and fostering new aesthetic strategies. Tying together my theoretical research and music portfolio, this chapter reconsiders the fundamental constraints and implications of networked music performance and how I have practically and aesthetically approached these constraints in the accompanying music composition portfolio. Through conversations and workshops with experts and subsequent analysis of the constraints, and the analysis of the musical material created for my composition portfolio, I strengthened two understandings. Firstly, that using musical content and technology, we can transmit vital information that addresses the limitations of networked music performance that are particularly detrimental to performative relationships and the ability to synchronise across the network, which leads to more-sophisticated approaches to harmony and rhythm. Secondly, that I am interested in continuing the exploration of the new timbral experiences made possible by multi-located networked music and the post-digital aesthetic. My hope is that I have expressed these approaches in practice through my compositional output.

During the research undertaken for this exegesis, I defined the primary characteristics that expose networked music performance as latent and uncertain, multi-located and multi-authorial, and digitally mediated. These qualities are distinct to and inseparable from networked music performance. Flowing from the discovery and analysis of the causes of these primary characteristics was the development of four aesthetic approaches: post-vertical harmony, the effects of the network on performative distance relationships, new resonant timbres through the collision of multiple spaces with transmission technology, and the post-digital aesthetic. I outline the relationships between these approaches with their primary characteristics in Table 3.

Table 3. Musical relationships between primary characteristics and aesthetic approaches

	LATENCY & UNCERTAINTY	MULTI-LOCATED & MULTI-AUTHORIAL	DIGITAL MEDIATION
POST-VERTICAL HARMONY	Blurred, unstable harmony	Multiple harmonic possibilities, all equally valid	Mediated transmission permits modification of musical properties that affect harmony (pitch, note alignment)
PERFORMATIVE RELATIONSHIPS	Disruption of human-level rhythms	Disruption of access to vital information and visual cues	Manipulates what events are given primary focus
RESONANCE & FUSED TIMBRES	Unexpected timbral experiences though uncertain delays	Timbral fusions and collisions of spaces and their echoes. Dialogue of remote and local acoustic energy	Codec and acoustic feedback interference
POST-DIGITAL APPROACH	Latency is the audible mark of the networked medium	Input from uncontrolled sources. New 'impossible' spaces	Complete ability to manipulate remote sound image means no obligation to reproduce reality: i.e., what we experience are the audible traces of the system

These approaches have deeply informed my compositional output, the practical applications of which I summarise in the remainder of this chapter.

5.1 POST-VERTICAL HARMONY

When two or more participants are connected over a network, the same number of musical experiences come into play. If an audience could experience each multi-located performance, they would hear a distinct difference between each performance because sounds arrive in a different order according to the location. This multi-authorial situation directly informs harmony in networked music performances as being perceptually blurred across note boundaries. What I term *post-vertical harmony* is where the alignment of notes arriving over the network cannot be guaranteed to be vertically positioned in relation to any other note, thus disrupting harmonic phrasing. Given the practical knowledge that harmonic indeterminacy is unavoidable, the composer must make decisions how to approach harmonic progression in her music.

In *Unison Not Unison*, I explored how harmony accidentally occurs through polyphony as a natural result of latency. The procedure, where latency disrupts unison passages to become dove-tailed phrases, becomes a canon tapestry of notes that uses reoccurring modal relationships to relate to each other harmonically. I applied this process throughout all three compositions. The passages largely maintained modal chord relationships by focusing on rhythmic and articulation changes rather than complex harmonic progression. Modal chords allowed the music to remain harmonically grounded, even when manipulating the arrival of notes in *Echo Not Echo* through latency manipulation.

When precise harmonic progression is desired, the composer may achieve harmonic vertical alignment through considering the sync window and extending note length (or note repetition, as demonstrated in the tremolo motif that reoccurs in my music portfolio). While accidental harmonic artefacts will occur on the edges of the sync window, harmonic alignment occurs when notes sound together within the duration of the window. The tendency for harmonic indeterminacy across the sync window edges is an unavoidable limitation of networked music performance and is considered as an aesthetic by-product of the system that the composer may choose to embrace as a compositional element or leave to chance.

When dissonance is sought, inharmonic passages are easily achieved by exploiting the sync window and playing harmonically unrelated notes that are smaller in duration. In section S of *Echo Not Echo*, fast passages of notes and accidentals fly past each other, which exploits the natural complexity created by latency, resulting in an asynchronous *harmonic turbulence*. Such turbulence would require more effort to notate for—and perform—in composite space. By embracing an aleatoric approach to musical elements, harmony and rhythmic complexity accidentally occur through the polyphony created by latency. The score sets up a set of possibilities and note relationships, where the latency and participant responses determine how the notes align in performance.

5.2 PERFORMATIVE RELATIONSHIPS AND VITAL INFORMATION

The disruption of performative norms over a latent, multi-located networked connection affects how participants consider the construction, rehearsal, and listening of music. Thus, achieving a sense of shared-time is an important factor when creating intimacy between the remote participants is the goal (Nevejan, 2012). To address these concerns practically, the composer creates vital information that is both embedded in the sound content and transmitted over the network as messages. This vital information creates the event markers that act as anchors for participants to synchronise with each other and it also encourages a musical environment in which participants are given the autonomy to meaningfully interact with the limitations of the network.

To create vital information within the musical material itself, the composer makes use of note articulation, phrasing, dynamics, and other audibly detectable events that participants can use to audibly synchronise. With *Unison Not Unison*, time-keeping was managed by providing passages to both guitar parts that only needed to begin (relatively) with each other, and annotating each passage with a symbol to communicate which guitarist began the phrase. With this method, the musicians found it easy and even enjoyable to play tag, where their goal was to present to the audience the alignment of certain events by listening and rehearsing their timing together. *Phase Not Phase* uses the vocal line as a grounding anchor for synchronisation; thus, the pianists have word-based cues to follow. When there is no vocal line or the sung line is based on repetition as in section C, the piano phrasing is more nebulous. If the musicians lose sync with each other, they can catch up by listening to the changes in dynamics and articulation. The music is specifically designed that even where a bar or two might be out of synchronisation for a short time, the overall structure remains cohesive. *Echo Not Echo* continues to explore the creation of meaningful musical performative relationships over the network by providing phrases that are intended for asynchronous collision. Purposeful asynchronicity through aleatoric scoring approaches removes the need for participants to maintain strict time on a small scale, which allows them to instead focus on the larger phrase and to enjoy the echoes that occur as sounds bounce back and forth between the locations.

To perform ensemble works such as *Echo Not Echo* in composite space, participants would usually expect a conductor. I anticipate that tools could be developed that transmit vital timing and event information, aiding in the development of more complex structures. A networked application can act as a virtual conductor, where specific score notation in combination with latency monitoring permits a flexible timing system. Alternatively, a human conductor could be used over video transmission, such as described by Sarah Weaver (2016).

When considering performative relationships, I also question what musicianship and virtuosity mean in a networked context. Wiek commented to me after performing *Unison Not Unison* that performer training means gaining an "understanding of physics at work and technology limitations" (Hijmans, 2017). Providing the musician with vital information in the music and with technology is an important aid towards encouraging more participants to experiment with networked music, with the aim to create a new generation of musicians for whom latency and the multi-located experience is second-nature.

5.3 TIMBRAL COLLISIONS

Taking inspiration from Seashore's concept of timbral sonance, I am satisfied with how my music portfolio expresses the exploitation of multi-located spaces to create the perception of a fused sonic space through the rapid iteration of sound. The intent of creating a fused instrument from many reflects the acousmatic experience where "we forget about what agent, object, or action made the sound or what the sound signifies; we focus only on the musical properties of the sound – its internal rhythms, its timbres and textures" (Andean, 2013, p. 1). I first noticed the effect in *Unison Not Unison* where the tremolos of the guitars created a shimmering effect that made it difficult to determine which side of the connection was creating which sound, resulting in the perception of a single instrument that hovered somewhere in between. I continued this idea in *Phase Not Phase* by alternating tremolos, trills, and glissandos, which serve to make new instruments, which mirrors Murail's (2005) concept of "sounds that are neither harmonic complexes nor timbres but something between the two" (p. 124) and one space becomes the other with a shared resonant timbre. As Braasch (2009) states, "audible colourations and echoes are a common side effect in two-way transmission systems" (p. 4) and while it is possible to avoid these colourations with the appropriate technology, *Echo Not Echo* pursues those colourations and spectral echoes further by exploiting additional dimensions of resonance: i.e., those of multiple instruments and their natural resonant qualities, e.g., a flute tremolo and marimba tremolo create a particularly vibrant sound together and how those resonances react to the manipulation of acoustic feedback at the electronic level. Location considerations determine the amount of control over acoustic feedback and careful calibration must be made. In my musical experiments, however, I show that it can provoke exquisite effects.

5.4 THE POST-DIGITAL AESTHETIC

Even with off-the-shelf software, elaborate music can arise such as shown by Ray Lustig's orchestra-ensemble hybrid in *Latency Canons*. Comprised of musicians who have never met, performing in spaces that are separated by great distances, the resulting work bristles with radiant energy that arrives with each multi-located signal. This listening experience illustrates the new day-to-day reality of our networked lives. One of the interesting opportunities for me in working with networked music performance is exploring the influence of the technology I use daily on music. My musical interests have long been towards exploiting instrumental resonances through software manipulations, and the additional resources that networked music makes available are of great potential.

The familiar network drop-outs that we experience on a public video chat call pixelates our faces and distorts our voices also lead to an expectation of failure. Under these conditions, "we have no choice but to interact with slightly incoherent shared objects" (Rohrhuber, 2007, p. 154). Manipulating distantly arriving sounds through acoustic feedback, transmission modification, and other forms of signal processing is how we explore and come to terms with our tacit and learned responses to digitally mediated presence.

5.5 FUTURE WORK

The music philosopher Lydia Goehr sees music not just as an auditory phenomenon, but sees music as in the making, as being produced. Goehr (2003) asks, what we are doing when we engage in a musical way? By focusing on the institutions and systems within which we produce music, we expose the technology, the mechanics of that technology, and conventions of behaviour, i.e., the expectations that are formed, when we use that technology. If we are to embrace the technology that permeates our lives, we are to embrace a musical exploration of the properties of that technology, which are properties of a system born from the technological inventions and compromises driven by the human need to address our innate social need for communication. It is through the exploitation of technology's properties that the composer can articulate the tangled relationship of unstable, latent transmission, with the appeal to participants to experience presence through networked mediation. While we gloss over the disengagement that the technology we use to transmit digital presence tends to create in participants in the production of the work as a whole, revealing the finer grains of the network technology integrates the music better with the notes on a page for a more meaningful experience.

The relationship between the cause and effect of our experience when composing music during the nascent stages of creativity, when a new aesthetic is being explored, is an embodiment of musical creativity as a cognitive and performative causality (Nagy, 2016). Stylistically, the scope for aesthetic expression is gigantic here although Meyer (1989) notes that "most changes in Western music have involved the devising of new strategies for the realisation of existing rules, rather than the invention of new rules" (p. 20). It stands to reason that early interpretations of networked music performance will be reinterpretations of existing musical structures, pending technological developments that address the need for tools that aid in realising complex remote relationships. While early forms of sophistication in new musical forms are derived from existing skill-sets, Norman, Waizvisz, and Ryan (1998) appeal to the musician-technologist that she must seek to capture the "skill and imagination and expressiveness of a performer" by creating an instrument that can be approached with virtuosity. On a technical level, this can mean developing new systems such as multi-located tuning guides, predictive latency synthesis engines, and designing new integrations with dynamic scores and time-keeping systems that respond to network and participant conditions. We can use technology to generate live manuscripts that match note durations to real-time latency, which allows predetermined harmonic progressions by embedding critical vital information for performance precision. As we improve our understanding of the spectral neurological effects of latency or the effect on pitch responses due to variations of frequency and spectral envelopes, and device communication, we can write more-sophisticated scores and build more-sophisticated machines that can interact with us.

The approaches and strategies discussed in this text are not necessarily limited to networked music as a genre because creative minds readily remap novel technologies and creative approaches to other forms of expression. For example, we might consider latency and instability as technical devices and envision interfaces where such properties can be manipulated beyond their physical constraints, or even embody those constraints as core, purposeful characteristics.

Virtuosity of expression in networked music means exploring how participants respond to each other and to other spaces. It means exploring how a score can be musically expressive while transmitting the vital information needed for synchronisation and phrase alignment. It means accepting that there is no singular experience because the network shatters any notion of synchronisation as being anything but an illusion, as “time itself has meanwhile turned out to be a multiplicity” (Rohrhuber, 2007, p. 154). How can the composer best make transparent the fact that simultaneous events are occurring and different experiences are being formed? What happens when the technology we use interrupts with reproduction fidelity or fails completely? This means designing for uncertainty, developing musical content “that lives at that timescale” (Chafe, 2016), and conceiving of music that illuminates the distance between us, music that draws us together.

BIBLIOGRAPHY

Alexandraki, C., & Akoumianakis, D. (2010). Exploring new perspectives in network music performance: The DIAMOUSES framework. *Computer Music Journal*, *34*(2), 66–83.

Andean, J. (2013, June). Sound and narrative: Acousmatic composition as artistic research. Paper presented at the First International European Sound Studies Association Conference. *Journal of Sonic Studies*, 7. Paper retrieved from https://www.researchcatalogue.net/view/86118/86119.

Augoyard, J., & Torgue, H. (2014). *Sonic experience: A guide to everyday sounds*. Montreal: McGill-Queen's University Press.

Auslander, P. (2012). Digital liveness: A historico-philosophical perspective. *PAJ: A Journal of Performance and Art*, *34*(3), 3–11.

Austin, A., & Field, A. (2001). Sound diffusion in composition and performance practice II: An interview with Ambrose Field. *Computer Music Journal*, *25*(4), 21–30.

Bauer, A., & Kerékfy, M. (2017). *György Ligeti's cultural identities*. New York, NY: Routledge.

Beiguelman, G. (2006). For an aesthetics of transmission. *First Monday*, 0. doi:10.5210/fm.v0i0.1553

Bennett, J., Collins, N., Matthews, K., Scanner, Wellmer, A., & Zeitblom. (2004). Fiber jelly. On *Surround Music* (Edition ZKM – 8). Mainz: Wergo.

Bogosian, E. (2012). *Pounding nails in the floor with my forehead*. New York, NY: Theatre Communications Group.

Bohme, G. (2010, March). The meaning of a sound place. G. Bohme, the aesthetics of the atmosphere. *Digicult: Digital Art, Design and Culture*. Retrieved from http://www.digicult.it/digimag/issue-052/the-meaning-of-a-sound-place-g-bohme-the-aesthetics-of-the-atmosphere/

Bond, G. W. (2005). Software as art. *Communications of the ACM*, *48*(8), 118–124.

Born, G. (2015). Making time: Temporality, history, and the cultural object. *New Literary History*, *46*(3), 361–386.

Bourriaud, N. (2002). *Relational aesthetics*. Dijon: Les Presses du réel.

Braasch, J. (2009). The telematic apparatus – Seen from an instrument builder perspective. In Oliveros, P., Weaver, S., Dresser, M., Pitcher, J., Braasch, J., & Chafe, C. (2009). Telematic music: Six perspectives. *Leonardo Music Journal*, *19*(1), 95–96.

Cáceres, J.-P., & Renaud, A. (2008). Playing the network: The use of time delays as musical devices. Paper presented at ICMC, Belfast, Ireland (pp. 244–250).

Canning, R. (2012). Real-time web technologies in the networked performance environment. Paper presented at ICMA2012 Non-Cochlear Sound, Ljubljana, Slovenia (pp. 315–319).

Carrière, C. (2011, December). *Fratres*. Montreal, QC: OBORO. Retrieved from http://www.christiancarriere.com/works/fratres-oboro/

Cascone, K. (2000). The aesthetics of failure: “Post-digital” tendencies in contemporary computer music. *Computer Music Journal*, *24*(4), 12–18.

Chafe, C. (2009). Audio setup and the future of the telematic medium. In Oliveros, P., Weaver, S., Dresser, M., Pitcher, J., Braasch, J., & Chafe, C. (2009). Telematic music: Six perspectives. *Leonardo Music Journal*, *19*(1), 95–96.

Chafe, C. (2016, October 12). (R. Wilson, Interviewer).

Chafe, C., & Cáceres, J.-P. (2009, July 21). JackTrip: JackTrip Documentation. *CCRMA*. Retrieved from https://ccrma.stanford.edu/groups/soundwire/software/jacktrip/

Chua, D. K. (2005). Untimely reflections on operatic echoes: How sound travels in Monteverdi’s *L’Orfeo* and Beethoven’s *Fidelio with a Short Instrumental Interlude*. *The Opera Quarterly*, *21*(4), 573–596.

Collins, C. (2015, March). Contribution of women musicians to symphony orchestras. *CMUSE*. Retrieved from https://www.cmuse.org/contribution-of-women-musicians-to-symphony-orchestras/

Collins, N. (2002). *Impossible music*. Warwick: NoiseGate.

Collins, N., & d’Escrivan, J. (2017). *The Cambridge companion to electronic music*. Cambridge: Cambridge University Press.

Collins, N., McLean, A., Rohrhuber, J., & Ward, A. (2003). Live coding in laptop performance. *Organised Sound*, *8*(3), 321–330.

Cook, M. (2015). *Telematic music: History and development of the medium and current technologies related to performance* (Doctoral dissertation). Retrieved from https://search-proquest-com.helicon.vuw.ac.nz/docview/1748614440?accountid=14782.

Corby, T. (2013). *Network art: Practices and positions*. New York, NY: Routledge.

Croft, J. (2007). Theses on liveness. *Organised Sound*, *12*(1), 59–66.

Drott, E. (2004). Conlon Nancarrow and the technological sublime. *American Music*, *22*(4), 533–563.

Demers, J. (2010). *Listening through the noise: The aesthetics of experimental electronic music*. Oxford: Oxford University Press.

Eisenberg, J., & Thompson, W. F. (2003). A matter of taste: Evaluating improvised music. *Creativity Research Journal*, *15*(2–3), 287–296.

Emmerson, S. (2017). *Living electronic music*. New York, NY: Routledge.

Freeman, J., & Colella, A. (2010). Tools for real-time music notation. *Contemporary Music Review*, *29*(1), 101–113.

Frengel, M. (2014). Interactivity and liveness in electroacoustic concert music. In Collins, K., Kapralos, B. & Tessler, H. (Eds.), *The Oxford handbook of interactive audio*. Oxford: Oxford University Press.

Gabrielli, L., & Squartini, S. (2016). *Wireless networked music performance*. Singapore: Springer.

Gaggioli, A., Chirico, A., Mazzoni, E., Milani, L., & Riva, G. (2017). Networked flow in musical bands. *Psychology of Music*, *45*(2), 283–297.

Gann, K. (2010). *No such thing as silence: John Cage's* 4′33″. New Haven, CT: Yale University Press.

Gibson, J. J. (1986). *The ecological approach to visual perception*. London: Psychology Press.

Gill, S. (2012). Rhythmic synchrony and mediated interaction: Towards a framework of rhythm in embodied interaction. *AI & Society*, *27*(1), 111–127.

Gill, S. (2015). *Tacit engagement: Betwixt and inbetween*. New York, NY: Springer International Publishing.

Goehr, L. (2003, November). Imaginary museum of musical works: An essay in the philosophy of music. *Oxford Scholarship Online*. Retrieved from http://www.oxfordscholarship.com/view/10.1093/0198235410.001.0001/acprof-9780198235415

Hayes, L., & Michalakos, C. (2012). Imposing a networked vibrotactile communication system for improvisational suggestion. *Organised Sound*, *17*(1), 36–44.

Hajdu, G., & Didkovsky, N. (2009). On the evolution of music notation in network music environments. *Contemporary Music Review*, *28*(4–5), 395–407.

Helmholtz, H. L. (2009). *On the sensations of tone as a physiological basis for the theory of music*. Cambridge: Cambridge University Press.

Herndon, J. (2015). *Composing music in the silent body* (Doctoral dissertation). Oakland, CA: Mills College.

Hijmans, W. (2017, August 30). (R. Wilson, Interviewer).

Holopainen, R. (2012). *Self-organised sound with autonomous instruments: Aesthetics and experiments* (Doctoral dissertation). University of Oslo: Oslo.

Houtsma, A. J. M., Rossing, T. D., & Wagenaars, W. M. (1990) *Auditory demonstrations* (Philips Compact Disc 1126-061). New York, NY: Philips.

Kane, B. (2007). *L'Objet Sonore Maintenant*: Pierre Schaeffer, sound objects and the phenomenological reduction. *Organised Sound*, *12*(1), 15–24.

Klett, J., & Gerber, A. (2014). The meaning of indeterminacy: Noise music as performance. *Cultural Sociology*, *8*(3), 275–290.

La Berge, A. & Heumen, H. (2012). About Shackle. *Shackle*. Retrieved from http://shackle.eu/about-shackle

Lazzaro, J., & Wawrzynek, J. (2001). A case for network musical performance. *Proceedings of the 11th International Workshop on Network and Operating Systems Support for Digital Audio and Video* (pp. 157–166). ACM. Port Jefferson, NY.

Liddell, P. (2010). Video room 1000. *YouTube*. Retrieved from https://www.youtube.com/watch?v=icruGcSsPp0

Lowder, J. B. (2013, April). Glitchy Google Hangouts make beautiful music. *Slate*. Retrieved from http://www.slate.com/blogs/browbeat/2013/04/10/google_hangout_music_ray_lustig_composes_canon_using_glitchy_conferencing.html

Lustig, R. (2016, July 12). (R. Wilson, Interviewer).

McKinnon, D. (2007). *The acousmatic and the language of the technological sublime*. Leicester: Electroacoustic Music Studies Network.

Meek, N. (2016, November). Noel Meek explores the sights and sounds of Gaelic psalm singing. *The Wire*, 393. Retrieved from https://www.thewire.co.uk/in-writing/the-portal/noel-meek-explores-the-sights-and-sounds-of-gaelic-psalm-singing

Meyer, L. B. (1989). *Style and music: Theory, history, and ideology*. Chicago, IL: University of Chicago Press.

Moles, A. A. (1984). *Kunst und computer*. Ostfildern: DuMont Verlag.

Morris, L. D. (2006). Conduction® is. *Contemporary Music Review*, *25*(5–6), 533–535.

Murail, T. (2005). The revolution of complex sounds. *Contemporary Music Review*, *24*(2–3), 121–135.

Nagy, Z. (2016). *Embodiment of musical creativity: The cognitive and performative causality of musical composition*. London: Taylor & Francis.

Nattiez, J. J. (1990). *Music and discourse: Toward a semiology of music.* Princeton, NJ: Princeton University Press.

Nevejan, C. (2007). *Presence and the design of trust*. Amsterdam: University of Amsterdam.

Nevejan, C. (2012). In time: Between emergence and design. In van Mensvoort, K., & Grievink, H. J. (Eds.), *Next nature* (pp. 214–221). New York, NY: Actar.

Nezvanova, N. (2000). The Internet, a musical instrument in perpetual flux. *Computer Music Journal*, *24*(3), 38–41.

Norman, S.-J., Waizvisz, M., & Ryan, J. (1998). Touchstone. *STEIM.* Retrieved from http://steim.org/archive/steim/texts.php?id=2

Oliveros, P. (2009). From telephone to high speed Internet: A brief history of my tele-musical performances. In Oliveros, P., Weaver, S., Dresser, M., Pitcher, J., Braasch, J., &

Chafe, C. (2009). Telematic music: Six perspectives. *Leonardo Music Journal*, *19*(1), 95–96.

Opie, T. (1999, November). Synchronicity of granular synthesis. In *Sound in a nutshell: Granular synthesis*. Retrieved from https://www.granularsynthesis.com/hthesis/sync.html

Pace, I. (2009). Notation, time and the performer's relationship to the score in contemporary music. In M. Delaere (Ed.), *Unfolding time: Studies in temporality in twentieth century music* (pp. 149–192). Leuven: Leuven University Press.

Pignato, J. M., & Begany, G. M. (2015). Deterritorialized, multilocated and distributed: Musical space, poietic domains and cognition in distance collaboration. *Journal of Music, Technology and Education*, *8*(2), 111–128.

Poole, D. (2011). *Digital transitions and the impact of new technology on the arts*. Ottawa, ON: Canadian Public Arts Funders.

Reybrouck, M. (2012). Musical sense-making and the concept of affordance: An ecosemiotic and experiential approach. *Biosemiotics*, *5*(3), 391–409.

Reybrouck, M. (2014). Music as environment: An ecological and biosemiotic approach. *Behavioral Sciences*, *5*(1), 1–26.

Ritter, S., Dosch, H. G., Specht, H.-J., Schneider, P., & Rupp, A. (2007). Latency effect of the pitch response due to variations of frequency and spectral envelope. *Clinical Neurophysiology*, *118*(10), 2276–2281.

Roads, C. (1996). *The computer music tutorial*. Cambridge, MA: MIT Press.

Roads, C. (2015). *Composing electronic music: A new aesthetic*. Oxford: Oxford University Press.

Robinson, J. (2013, December 17). Improvising through wires – making telematic music. *YouTube*. Retrieved from https://www.youtube.com/watch?v=Nm8hVHBFm78

Rohrhuber, J. (2007). Network music. In Collins, N., d'Escrivan, J. (Eds.), *The Cambridge companion to electronic music* (pp. 140–155). Cambridge: Cambridge University Press.

Roig-Francolí, M. A. (1995). Harmonic and formal processes in Ligeti's net-structure compositions. *Music Theory Spectrum*, *17*(2), 242–267.

Russ, M. (2012). *Sound synthesis and sampling*. London: Taylor & Francis.

Sawyer, R. K. (2003). *Group creativity: Music, theater, collaboration*. London: Taylor & Francis.

Schaeffer, P. (1977). *Traité des objets musicaux: Essai interdisciplines*. Paris: Éditions du Seuil.

Schafer, R. (2004). The music of the environment. In C. Cox, & D. Warner (Eds.), *Audio culture, revised edition: Readings in modern music* (Ch. 6). New York, NY: Bloomsbury Publishing USA.

Seashore, C. E. (1936). The psychology of music. IV. The quality of tone: (2) Sonance. *Music Educators Journal*, *23*(2), 20–22.

Sello, J. (2008). Score, interpretation and visuals are inseparably linked. *Jacob Sello, Intermedia Art*. Retrieved from https://jacobsello.de/slices/

Shannon, C. E., & Weaver, W. (1948). *The mathematical theory of communication*. Chicago, IL: University of Illinois Press.

Sonami, L. (2006). On my work. *Contemporary Music Review*, *25*(5–6), 613–614.

Sorensen, A., & Brown, A. R. (2009). Interacting with generative music through live coding. *Contemporary Music Review*, *28*(1), 17–29.

Swafford, J. (2014). *Beethoven: Anguish and triumph*. Boston, MA: Houghton Mifflin Harcourt.

Taylor, P., & Harris, J. (2007). *Critical theories of mass media: Then and now*. New York, NY: McGraw-Hill Education.

Tenney, J. (1988). *A history of consonance and dissonance*. New York, NY: Excelsior Music Publishing Company.

Thon, L. E. (2003). 50 years of signal processing at ISSCC. In: 2003 IEEE International Solid-State Circuits Conference, Digest of Technical Papers, ISSCC (pp. 27–28).

Torre, G., Andersen, K., & Baldé, F. (2016). The hands: The making of a digital musical instrument. *Computer Music Journal*, *40*(2), 22–34.

Truax, B. (1999). *Handbook of acoustic ecology, 2nd edition*. (CD-ROM version). Cambridge, MA: Cambridge Street Publishing.

van den Oord, A., Dieleman, S., Zen, H., Simonyan, K., Vinyals, O., Graves, A., Kalchbrenner, N., Senior, A., & Kavukcuoglu, K. (2016). WaveNet: A generative model for raw audio. *9th ISCA Speech Synthesis Workshop*. Sunnyvale, CA.

von Helmholtz, H. (1912). *On the sensations of tone as a physiological basis for the theory of music*. London: Longmans, Green.

Walker, J. A. (1987). Art works as commodity. *Circa*, *32*, 26–30.

Weaver, S. (2016, December 14). (W. Rebekah, Interviewer).

Weinberg, G. (2005). Interconnected musical networks: Toward a theoretical framework. *Computer Music Journal*, *29*(2), 23–39.

Wishart, T. (1996). *On sonic art*. London: Psychology Press.

Wright, M., Beauchamp, J., Fitz, K., Rodet, X., Röbel, A., Serra, X., & Wakefield, G. (1999). Analysis/synthesis comparison. *Organised Sound*, *5*(3), 173–189.

APPENDIX I: EXPERT PRACTITIONERS

Chris Chafe

Chris is currently director of Stanford University's Center for Computer Research in Music and Acoustics. His important contribution in developing the well-regarded software JackTrip and supporting numerous telematic installations and performances began as an interest in using Internet latency uncertainties for physical modelling of virtual sonic instruments, where you could "listen to the quality of service of the network by using your ears" (Chafe, 2016). Much of his musical work is created specifically for networked performance. As an engineer, he provides in-depth insights from his intimate knowledge of technical possibilities and limitations.

Chris gave me an hour of his valuable time, in which we discussed network technology and the music that lives there. Our mutual life-long passion for audio transmission led me to ask many questions, including Chris's thoughts on where future technology will take us and the meaning of "being together while being remote".

Ray Lustig

Ray is a New York-based composer whose large-scale orchestral work *Latency Canons* is a valuable case study in the aesthetic successes made possible by networked audio technology, and the equal frustrations and sublimeness of the technology's potential. Ray's experience with a large-scale multi-located and multi-ensemble performance under public Internet conditions and using off-the-shelf software provided me with an engaging account of both the composer- and participant-level experience outside of institutional low-latency configurations, and inspired a realisation in me of how much more there is left to explore aesthetically in this medium.

Speaking with Ray was important to my realisation that when you connect disparate spaces, notated pitched music is affected in all directions, not only temporally. This led to my investigation in timbral resonance and asynchronous harmonies between remote sources and directed my attention towards the four aesthetic approaches that are the spine of this exegesis.

Sarah Weaver

During Sarah's career as experimental composer, conductor, and ensemble manager, she has seen and taken advantage of many new technical possibilities for networked audio. Her artistic motivation is strongly focused towards the expression of synchrony between remote participants and she has a wide breadth of knowledge derived from her personal experience in conducting and performing multi-spaced networked audio.

Sarah's complete comprehension of forming networked music performance works of all sizes offered me important insight into the considerations of participants outside just the technical constraints, and the importance of flow in performative relationships. Sarah observed that "there's a directness that is different from say watching an echo of a stream or recorded video and to be able to connect live and perform together live is a different level of intimacy" (Weaver, 2016).

Daniel Schorno and Alison Isadora

Daniel and Alison generously gave their time to validate a variety of trials before I started writing my composition portfolio. Daniel was in Amsterdam, Alison was in Thorndon, Wellington, and I was in central Wellington at the time. By connecting remotely, we were able to validate that my concepts would be technically feasible and confirm that the ideas I had in mind were musically engaging. I am indebted to their input at an early crucial stage.

Wiek Hijmans and Sjors Van der Mark

Wiek and Sjors commissioned *Unison Not Unison* for a performance in June 2017 in Amsterdam. Wiek and Sjors were largely able to develop the performance based on my score instructions, which validates and reinforces my commitment to exploring how vital information can be embedded and transmitted as musical signals and as forms of notation. I had an additional opportunity to work with Wiek and conduct a studio recording of *Unison Not Unison* for the purposes of experimenting with simulated latencies and acoustic feedback effects. Both the live and studio recording are presented.

Dante Boon and Reinier van Houdt

Dante and Reinier recorded the piano parts of *Phase Not Phase* in February 2018 from two separate locations during a private workshop setting. The recording is an accurate structural and harmonic representation of the composition, and was to my delight easily recorded without significant rehearsal time. We hope to find an opportunity to present the work in full in 2018 with Ayelet Harpaz singing.

APPENDIX II: WEBRTC TELEMETRIC PARAMETERS

Web real-time communication (WebRTC) was initiated by Google in 2011. WebRTC has become the de facto standard for open-source video and audio communications over the Internet. Accordingly, many open-source libraries and implementation methods now exist for a composer or technologist to build her own custom software, requiring no more than web browser technology knowledge. Most interfaces and frameworks are concerned only with best effort transmission, which means to transmit information for voice and video communication where the remote participants can understand what is being said and visually communicated. With music applications, the composer will wish to extend the basic WebRTC features and access real-time telemetric data for performance purposes.

The available WebRTC statistics can be found in the RFC for the WebRTC stats project: https://www.w3.org/TR/webrtc-stats

The WebRTC project also offers sample JavaScript demos and corresponding code: https://webrtc.github.io/samples/src/content/peerconnection/constraints

While there is a significant amount of telemetric data that can be extracted I consider the following two statistics most useful:

Round trip time

Round trip time (RTT) is a critical statistic when creating tightly synchronised compositions or developing real-time scores. RTT specifies the time it takes for a packet to be sent to the remote connection and returned. To obtain the one-way latency, we take the RTT and divide by 2. This is the time it takes for the remote connection to hear the audio we are playing. While latency generally hovers around a single value once a connection is established, this parameter can change at any time depending on the quality of the network connection. Increased latency occurs when the network is unable to maintain throughput and can intensify in severity leading to a complete loss of connectivity. Network issues are manifested as packet loss and can be caused by many reasons, the most common being network congestion due to insufficient bandwidth, and low Wi-Fi signal strength due to interference or distance from the transmitter. Once congestion levels have returned to normal, RTT will decrease.

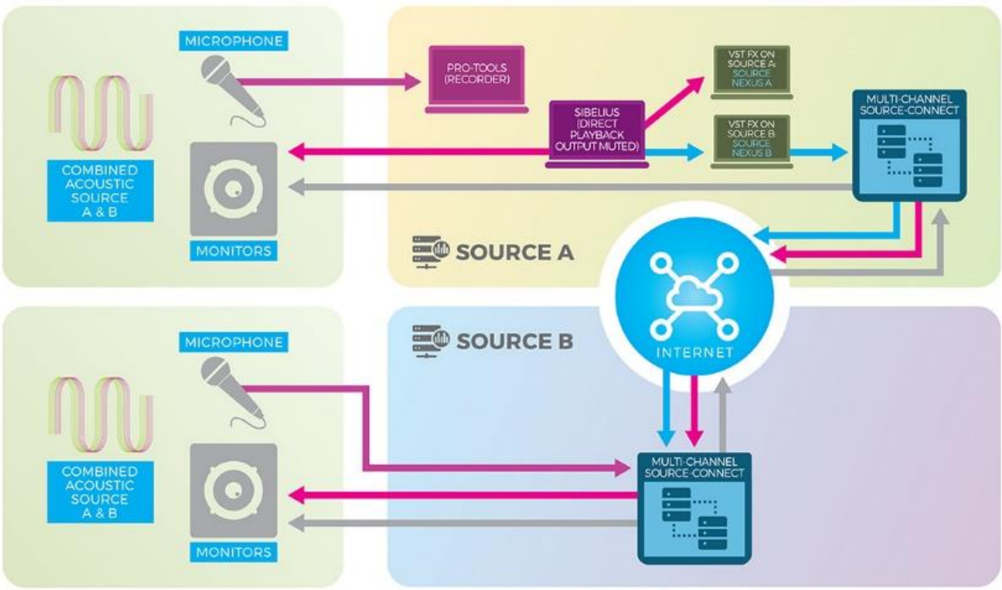
Packets lost

The percentage of packet loss is caused by network issues. Low levels of packet loss (under 10%) or sporadic spikes are generally managed by the error correction algorithms embedded in audio codecs and transmission protocols. Higher levels of packet loss affect transmission fidelity, leading to audibly discernible interference heard as pops, clicks, and time-stretching. Monitoring packet loss is important when connecting over the public Internet and audio artefacts wish to be avoided. Alternatively, these lost packets could be used for expressing the state of the network and folding back into the composition. Regardless, it is helpful for real-time situations to know if there are network interruptions and monitoring packet loss is an excellent indicator of whether outages are expected to continue and be catastrophic, or be intermittent and largely ignored.

APPENDIX III: METHOD OF SIMULATING A NETWORKED PERFORMANCE DURING THE COMPOSITION PROCESS

One of the difficulties in composing networked music is imagining the result. How might sounds collide in acoustic space given various latencies? To answer this question and to fully understand the performance environment, I employed a composition method that simulates a networked music performance in real-time that can be experienced directly from the notation software during playback. The process I describe in this Appendix could be adapted for other sound-generating software and transmission applications: i.e., the means of sound creation and transmission is unimportant to the process if they satisfy the performance requirements. That is, we must experience both the remote transmission signal and the acoustic feedback created by the microphone and monitors in both spaces simultaneously.

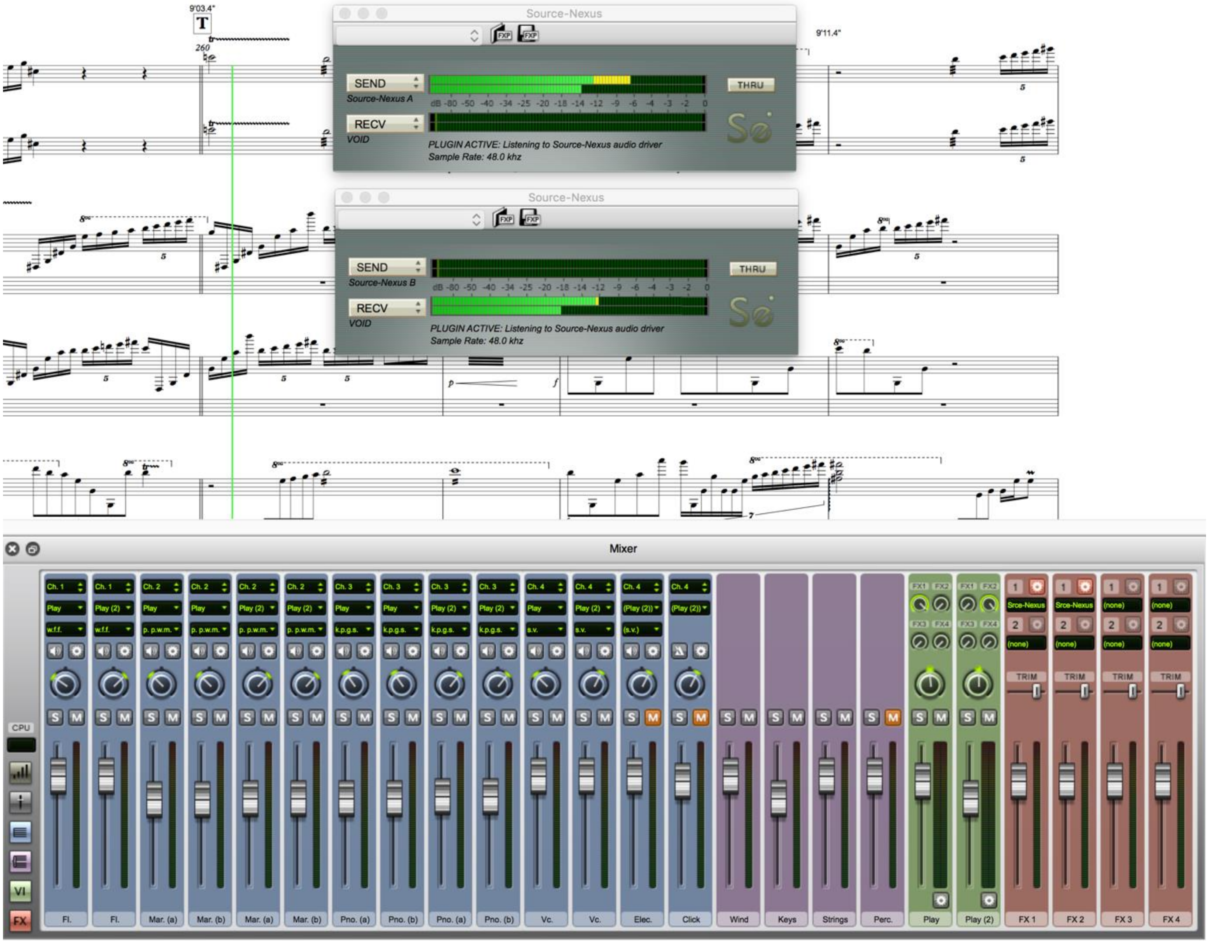
Figure A3-1. Diagram showing the audio routing between sources A and B



In the above figure, source A is the sound generator and also the space we will monitor and record from. Source B is the remote space that simulates an acoustic secondary source.

The method starts with a sound generator in Source A, in this case *Sibelius* (version 8.7). Under the playback settings, add two Source-Nexus VST inserts to the channels. On the Sibelius mixer, we can set each instrument to go to a player instance. In the case of *Echo Not Echo*, I set up two players and routed each pair between them using the Play FX1 and FX2 pots.

Figure A3-2. Sibelius 8 sending separated instruments to the VST audio routers



With each quartet now distinctly separated for playback, I can route the signals to different sources.

To get the full sounding experience, both sides need to return an acoustic room mix. To do this, I send the first quartet (the red arrows in Fig. A3-1) down channels 1 and 2, and the second quartet (the blue arrows) over channels 3 and 4 over Source-Connect Pro X. Source B, which is in an audibly separate room, receives the separated signals in a multichannel format. Source B must now route channels 3 and 4 back to source A because it was the original material source. In addition, source B sends a mix of both signals to its monitors, and returns the acoustic signal via a microphone setup back to source A (the black arrows).

Source A now has a complete circle of audio, as if it were originally generated by real instruments by source B. It sends this signal to the monitors along with the original first quartet. The blend of these signals bouncing back to each other through the merging of their acoustic spaces creates a reverberant delay effect. The depth of this effect is dependent on the latency of the network connection. The result is an accurate sonic experience of real-time networked music performance. The recording of *Echo Not Echo* found on the accompanying audio CD was conducted using the above method in combination with the additional acoustic feedback method described in chapter 4.

Tools used:

Sibelius (avid.com)

Pro Tools (avid.com)

Source-Nexus Pro (source-elements.com)

Source-Connect Pro X (source-elements.com)

APPENDIX IV: MUSIC COMPOSITIONS

In this Appendix, three composition scores and performance notes can be found, in addition to the CD track listing for the supporting audio recordings.

Unison Not Unison

For two electric guitars

2017

Program notes

Unison Not Unison asks two electric guitarists to consider the musical consequences of network latency. With each musician presented with similar material to perform, network latency is exploited as a musical parameter to create canon effects and unexpected harmonies. What is viewed on the page as horizontal and synchronous becomes polyphonic and asynchronous in realisation as guitar timbres merge and rebound across the network.

Duration: c. 12:30 minutes

Performance notes

Sections A and J anticipate one performer to begin the phrase while the other listens for the sound and begins the phrase. Each performer thus alternates who starts first with each successive phrase. The work in full will be a balanced audience experience on both sides of the connection. All other sections specify that performers try and start together. While this is not technically possible, it allows for decision-making during rehearsal and performance. Synchronisation is not expected by design; therefore, performances may differ on each iteration.

Technical requirements

Each performer must be in a different location with no audible way of hearing each other, e.g., in different cities or buildings, or completely different rooms of any performance space.

An Internet connection and a high-quality audio connection connects each performer. Performers should connect using any high-definition (HD) network audio software, such as Source-Connect, that uses OPUS, AAC, or a similar codec. *Consumer-level software programs such as Google Hangouts or Skype are not suitable.*

Where possible use a high-quality microphone and monitors. Acoustic noise reduction in software and hardware should be disabled to allow for some feedback. Take care to place monitors well away from microphones to avoid excessive feedback and carefully balance all audio signals while ensuring the equal level of both guitars in the room. Performers may wish to use headphones for closer monitoring.

An EBow is required for section G.

UNISON NOT UNISON

REBEKAH WILSON


8
rit.
mf
A tempo
pp
9
mp
f
p
10
tr
ppp
p
mf
11
ppp
12
13
14
15


B
1
♩ = 90
Listen to each other for when it is time to start each phrase.
Elongate and shorten notes as needed so you can stay in sync.
ppp
mf
pp
5
2
vibr.
3
4
mp
p
ppp
5
6


6
6
6
6
6
6
7
5
mf
pp
vibr.
mf
pp
8
5
ppp
ppp
9
C
3
3
p
ppp
ppp
5
accel.
5
7
7


D
1
♩ = 180
Time the phrases so the glissandi arrive at a similar time. Alternate who starts.
gliss.
2
3
4
5


6
mp
mp
7
mp
pp
mp
pp
8
mp
mp
9
mp
mp
10
mp
mp


11
mp
mp
12
13
mp
mp
14
tr
15
mp
mp


16
17
mp
18
tr
E
1
♩ = 150 Quickly, lightly. Alternate who starts first.
② ③ ② sim.
strike
f
sfz
p
2


3
4
5
6
7
sfz
p
f
5
4


F
1
♩ = 90
Speed up and slow down, to find the right speed where sync might occur.
p
notated harmonics can be played as normal notes with different timbre
p
tr
pp
2
mf
tr
pp
mf
tr
pp
tr
pp
3
tr
mf
pp
tr
mf
tr
mf
pp
mf
tr
pp
4
f
pp
pp
5
f
pp
5


mf
pp
5
mf
pp
5
f
p
mf
p
f
p
mf
p
accel.
mf
p
mf
p
mf
p
mf
p
mf
p
mf
p
G
1
♩ = 40 with EBow, sustain or other method for elongating the note
3
ppp
ppp
ppp
2
sfz
ppp
ppp
ppp
gliss.


ppp
3
sfz
mp
mf
tr
p
4
pp
5


H
= 150 Try to align the struck chords.
strike


4
5
6
7
sfz
p
f


8
9
J
1
A tempo ♩ = 150
Dovetail on each other's phrases
2
3

Phase Not Phase

For two pianos and alto voice

2017

Program notes

Phase Not Phase resolves to intertwine timbres of two pianos and alto voice, arriving as distinct signals from disparate spaces. Rapid iterations of piano trills and tremolos resonantly merge and oscillate with the precise Spanish words of María Cegarra Salcedo (*Ausencia Total* 1986, in *Poemas para un silencio* published by Academia Alfonso X el Sabio, 1999). The music is driven forward in a wash of acoustic feedback from multiple sources where each location, separated by distance and disrupted by network latency, experiences a distinct, unique version.

Duration: c. 11 minutes

María Cegarra Salcedo

María Cegarra Salcedo (1903–1993) was the first woman chemist to gain professional status in Spain as well as being a great poet. Her poems demonstrate her fascination with the twentieth century's rapid exposure of the underlying physics of nature, combined with an awe for life's scientific and passionate forces.

Performance notes

Timekeeping is set by the alto performer. The piano parts listen for her cue and keep to her count. An electronic glissando effect on each remote signal is controlled by the alto or any third-party. This effect is not heard by the local performer and can be ignored as a performance instruction.

The pianos may phase in and out of sync with each other. The exact alignment of notes is neither expected nor guaranteed. Where the alto is not singing, the pianos keep in sync by counting and listening to the remote signal. Due to latency, it is anticipated that in these sections there is no necessity to stay completely in sync because the music allows for significant drift of a bar or more. In section J, the pianists should focus on the phrase, expecting to land on the trill more or less together when possible. By design, synchronisation is not expected, and performances may differ in each iteration.

Technical requirements

Each performer must be in a different location with no audible way of hearing each other, e.g., in different cities or buildings, or completely different rooms of any performance space.

An Internet connection and a high-quality audio connection connects each performer. Performers should connect using any HD network audio software, such as Source-Connect, that uses OPUS, AAC, or a similar codec. *Consumer-level software programs such as Google Hangouts or Skype are not suitable.*

Where possible use the high-quality microphone and monitors. Acoustic noise reduction in software and hardware should be disabled to allow for some feedback. Take care to place monitors well away from microphones to avoid excessive feedback and carefully balance all audio signals while ensuring the equal level of both pianos in the room. Both piano signals should be transmitted at a sufficiently low level to blend well with the alto voice. Performers may wish to use headphones for closer monitoring.

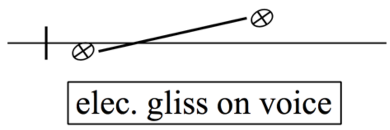
Explanation of electronics

The alto voice or third-party engineer controls an electronic a glissando effect across all network participants. This effect is applied to each remote signal only: no local performer would have the effect applied to their own signal. For example, this means that each pianist will hear a glissando on the other remote piano, and the alto voice in section *J*. The alto will hear the glissando effect on both pianos, but not herself. Software that implements this method may be provided by the composer or can be implemented using any digital glissando tuning effect that rises or falls by 100 cents over a duration of 5 s. After the glissando has completed the effect is cancelled out and returns to the original tuning. Any artefacts heard are anticipated and welcomed.

The rise or fall is indicated in the score as follows:

Glissando rise on received piano signal(s), from 0 to 100 cents

Glissando fall on incoming piano signal(s), from 100 to 0 cents



Glissando rise on received vocal signal(s), from 0 to 100 cents

PHASE NOT PHASE

REBEKAH WILSON

Text by María Cegarra Salcedo (from the poem "Ausencia Total")


7
e - lla ha - ci - a el cie - lo de los nom - bres
pp
pp
A
10
pp
p
ca - llar a - ho - ra es mi - des - ti - no


13
p
mp
p
no pue-do no-m-brar - la no
me
16
pp
p
res - po - - n - de
su nom - bre


18
B
= 180
na - ve - ga - a
23


29
mp ppp
mp ppp
33
mf
ppp
mf
ppp


38
p
ppp
p
ppp
42
p
ppp
p
ppp

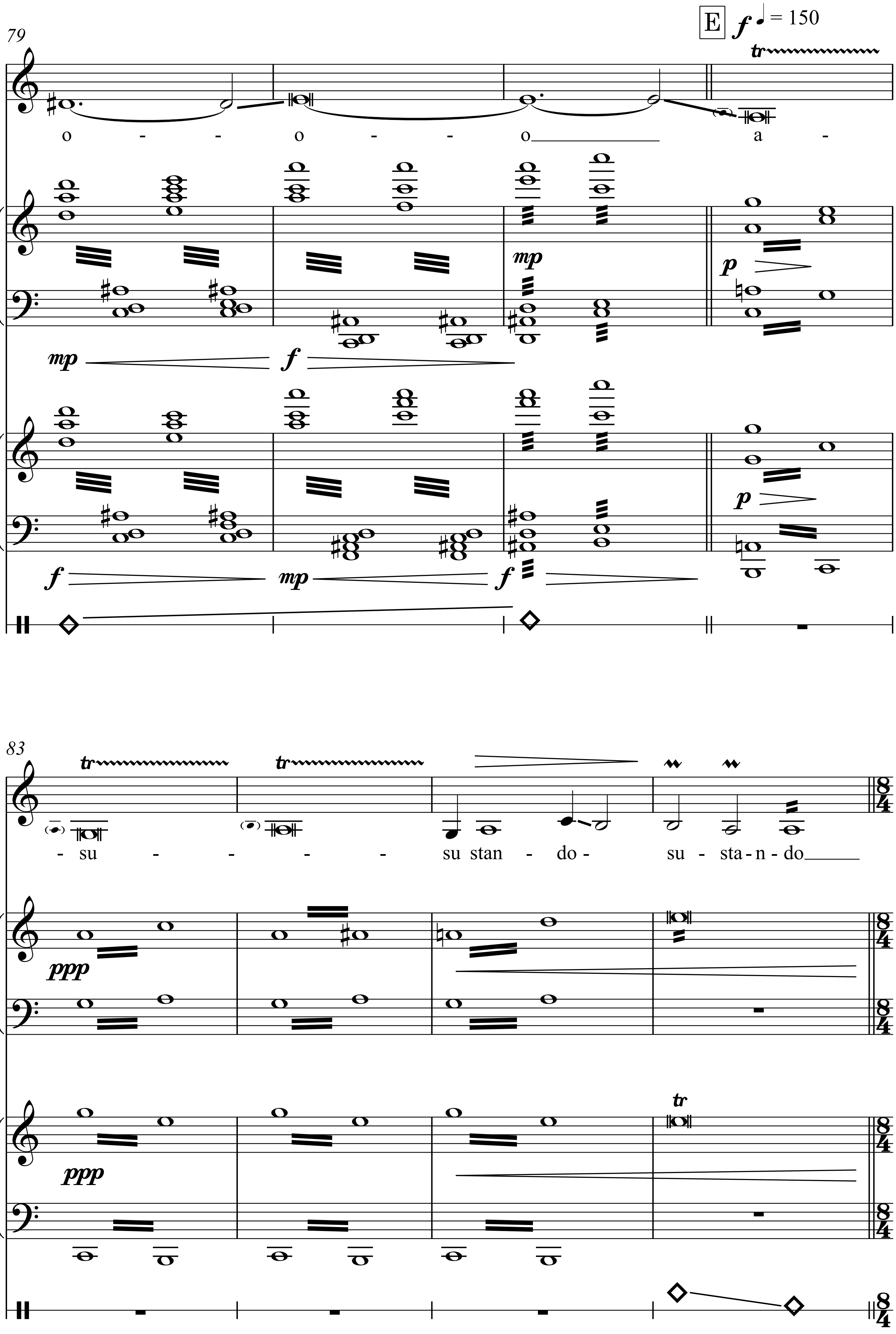

45
ff
ff
49
rit.
8va
mf
f
8va
mf
f


54
C
♩ = 150
p
mp
sin ech-o ni son-ri-sa pal - pi - tan-
(8)
pppp
ppp
59
3
-do pal - pi - tan - pal - pi - tan - pal - pi-tan-
pp

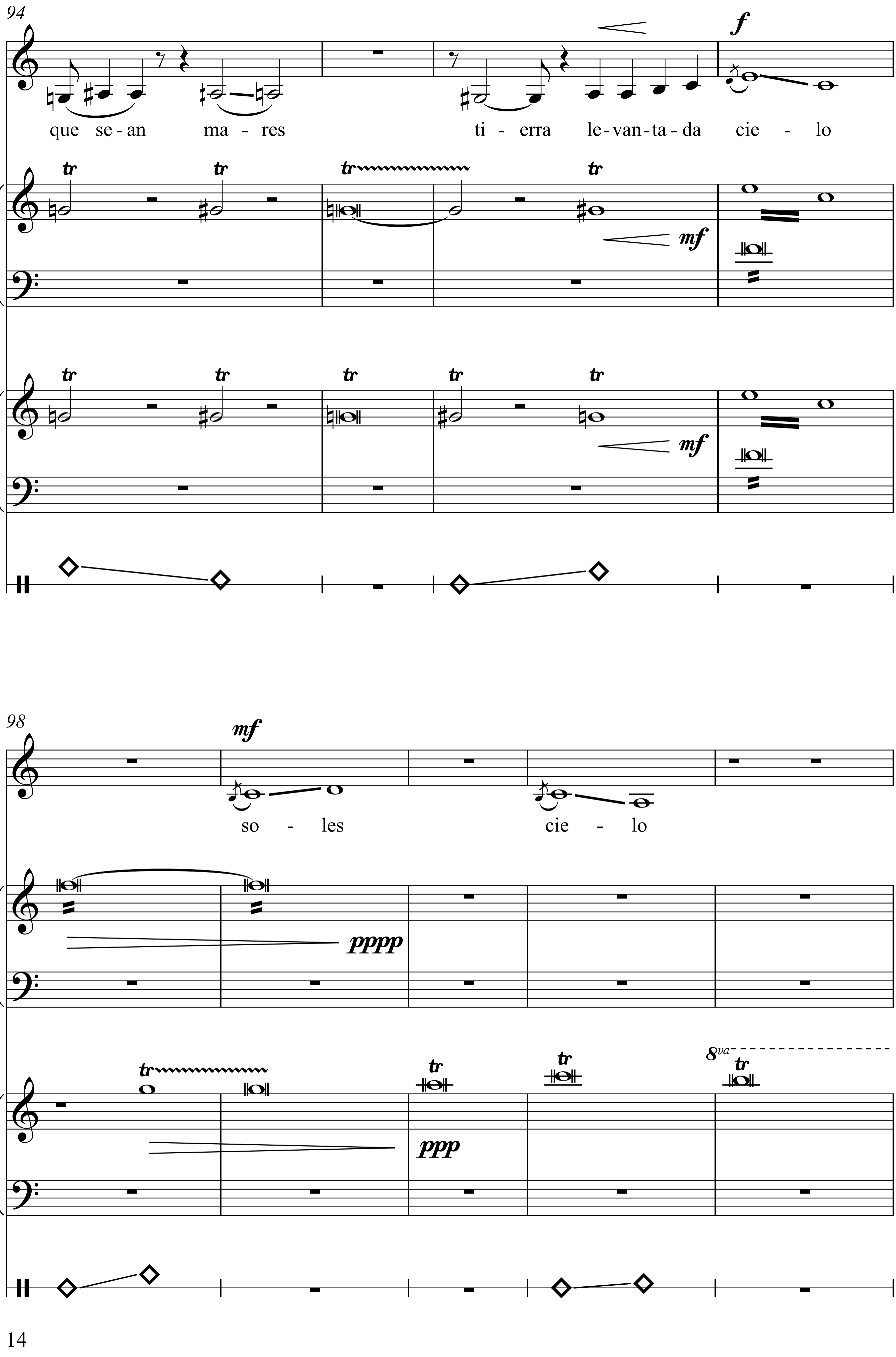

61
3
3
3
do a-su-stan-do- a - su - stan - do - pal-pi-tan - do pal -
63
mf
tr
tr
tr
-pi - tan-do a - su - - - stan
mp
mp
pp


67
mf
3
a - su - stan - do pal - - - - pi - tan -
pp
69
3
3
- do do - pal - pi - tan - do a - su - stan - do

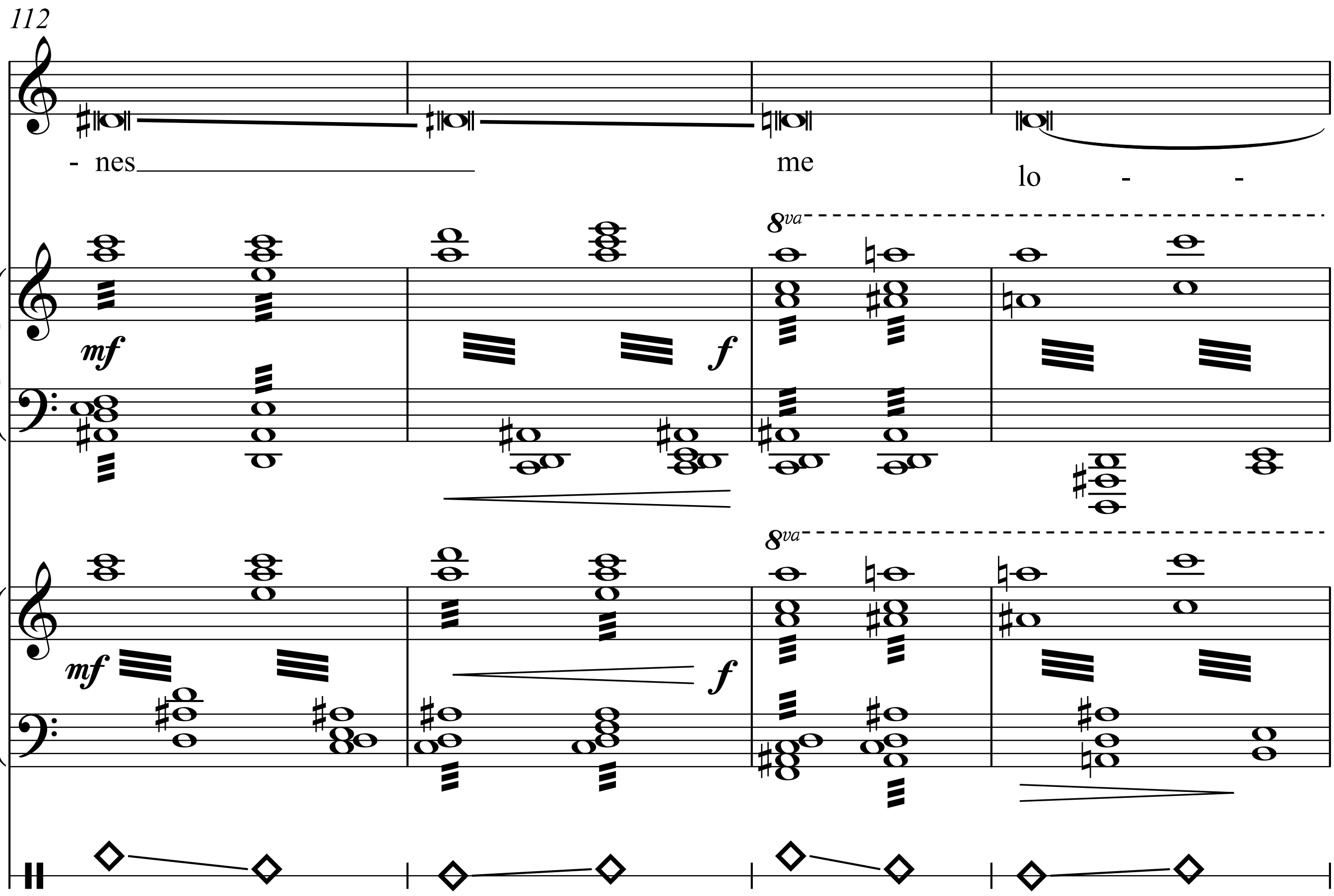
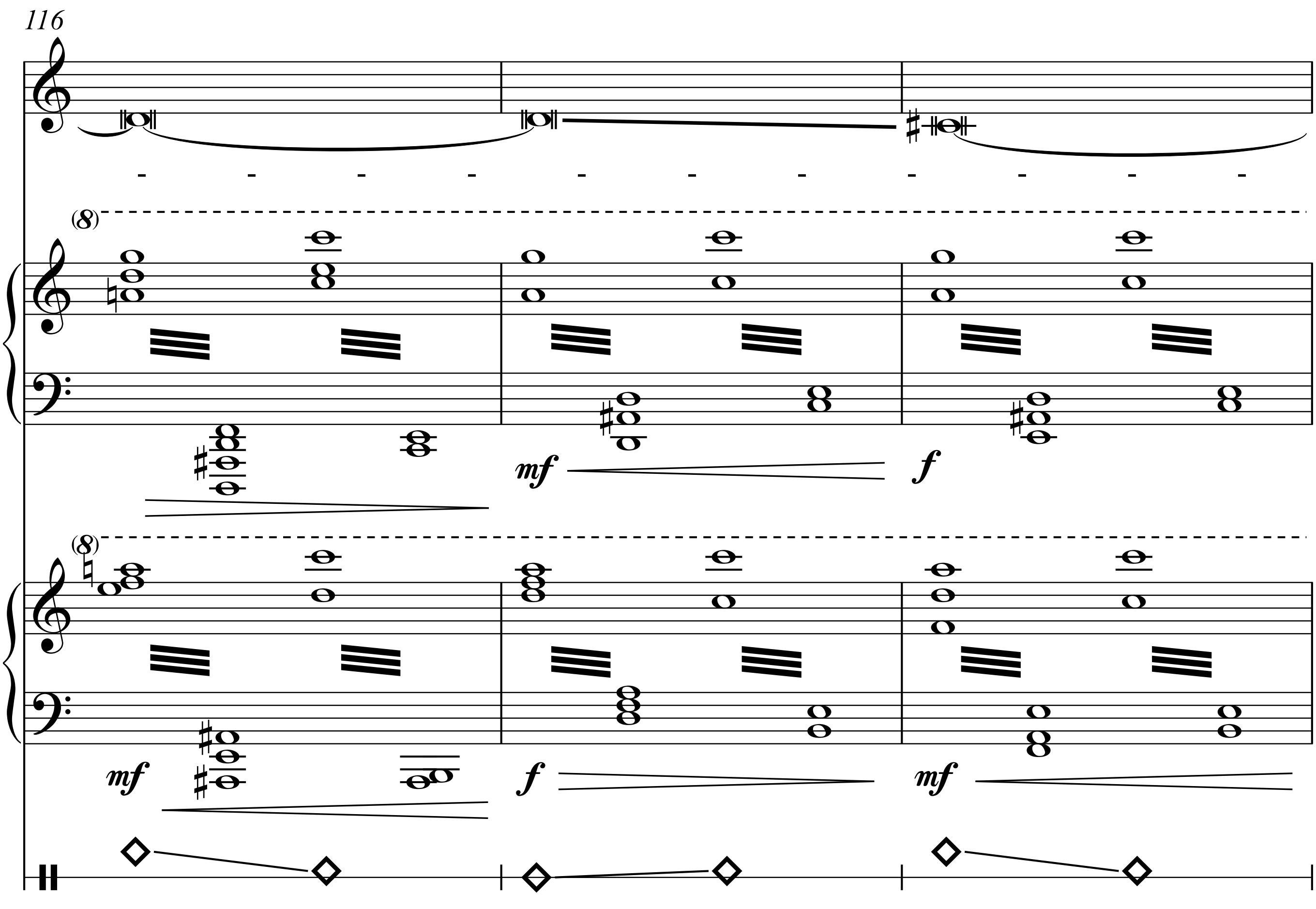

71
tr
a - - su - - - - su stan - do -
mp
75
D
♩= 90
f
- o - o - - o - - o - -
mp
f

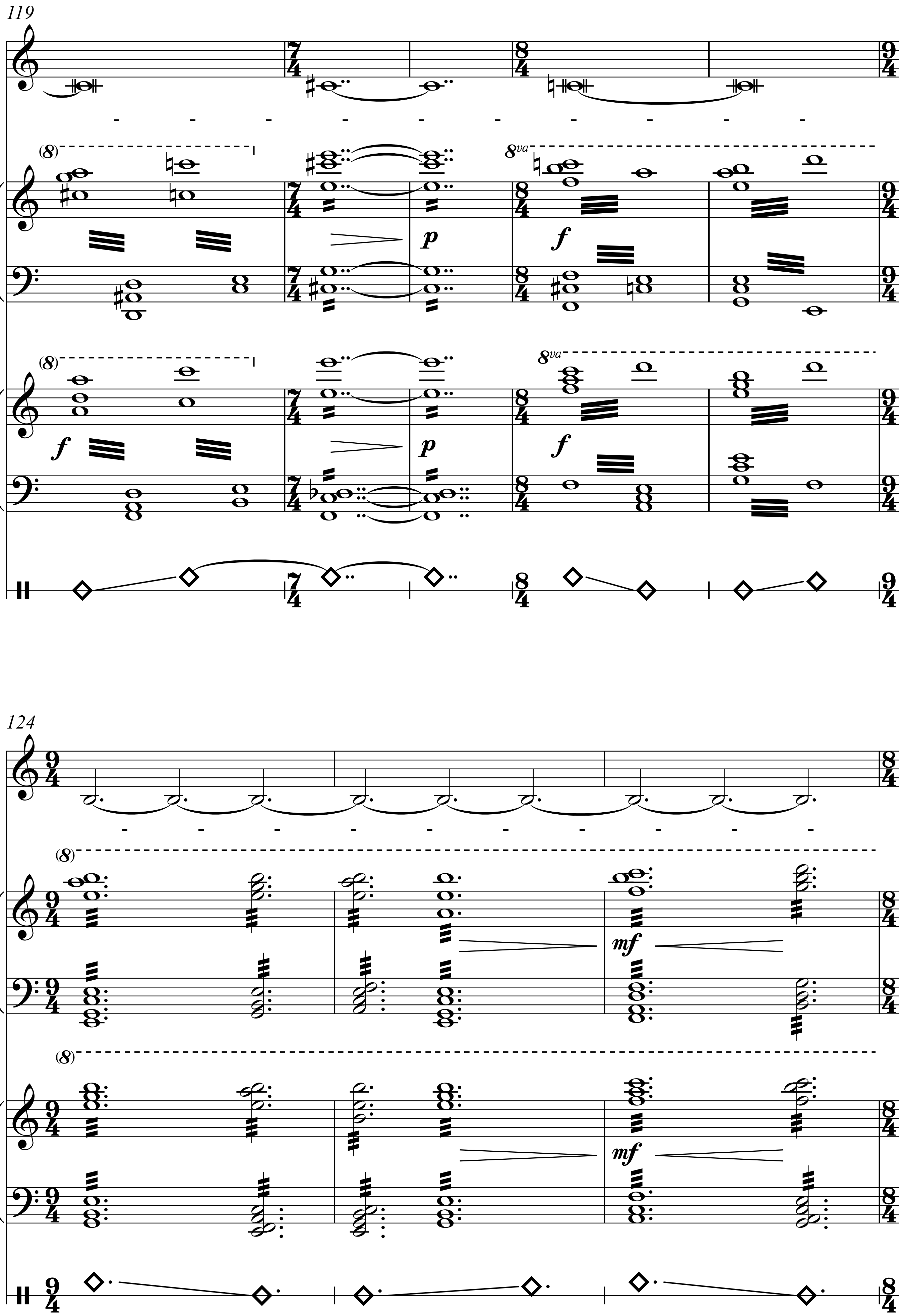

79
E
f ♩ = 150
tr
o - - o - - o a -
mp
f
mp
f
mp
f
p
p
83
tr
tr
- su - - - - su stan - do - su - sta - n - do
ppp
ppp
tr
8
4


87
F
♩ = 180
f
f
91
G
♩ = 150
mp
quie - ro
tr
pppp
pp
tr
tr
pppp
pp
tr


94
f
que se - an ma - res ti - erra le-van-ta-da cie - lo
tr
mf
98
mf
so - les cie - lo
pppp
ppp
8va


103
p
so - les
cie - lo
(8)
tr
pppp
108
p
H
♩ = 90
f
so - les
qui - - - - - - -
f
f


112
- nes
me
lo - -
8va
mf
f
8va
mf
f

116
- - - - - - - - - - - -
(8)
mf
f
(8)
mf
f
mf


119
(8)
8va
f
p
124
mf


127
(8)
f
p
(8)
p
f
130
p
ppp
mf
ppp
mf


135
mf
ff
ff
139
pp
pp
mf
pp
pp
mf

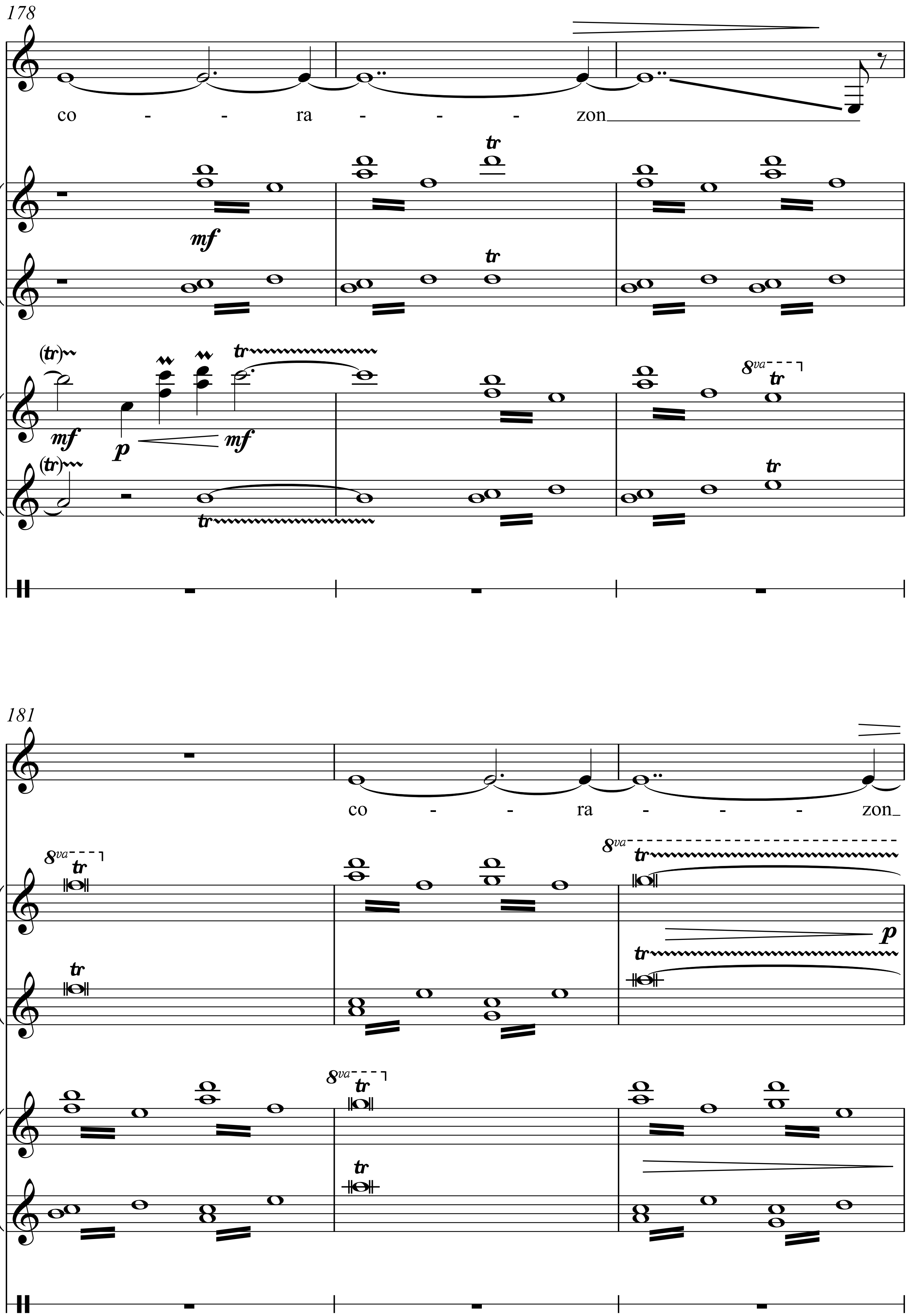

145
rit.
I
= 150
pp
de - vuel - van
Quie - ro quie - ro
tr
p
ppp
150
que se - a Di - o - os
que se -

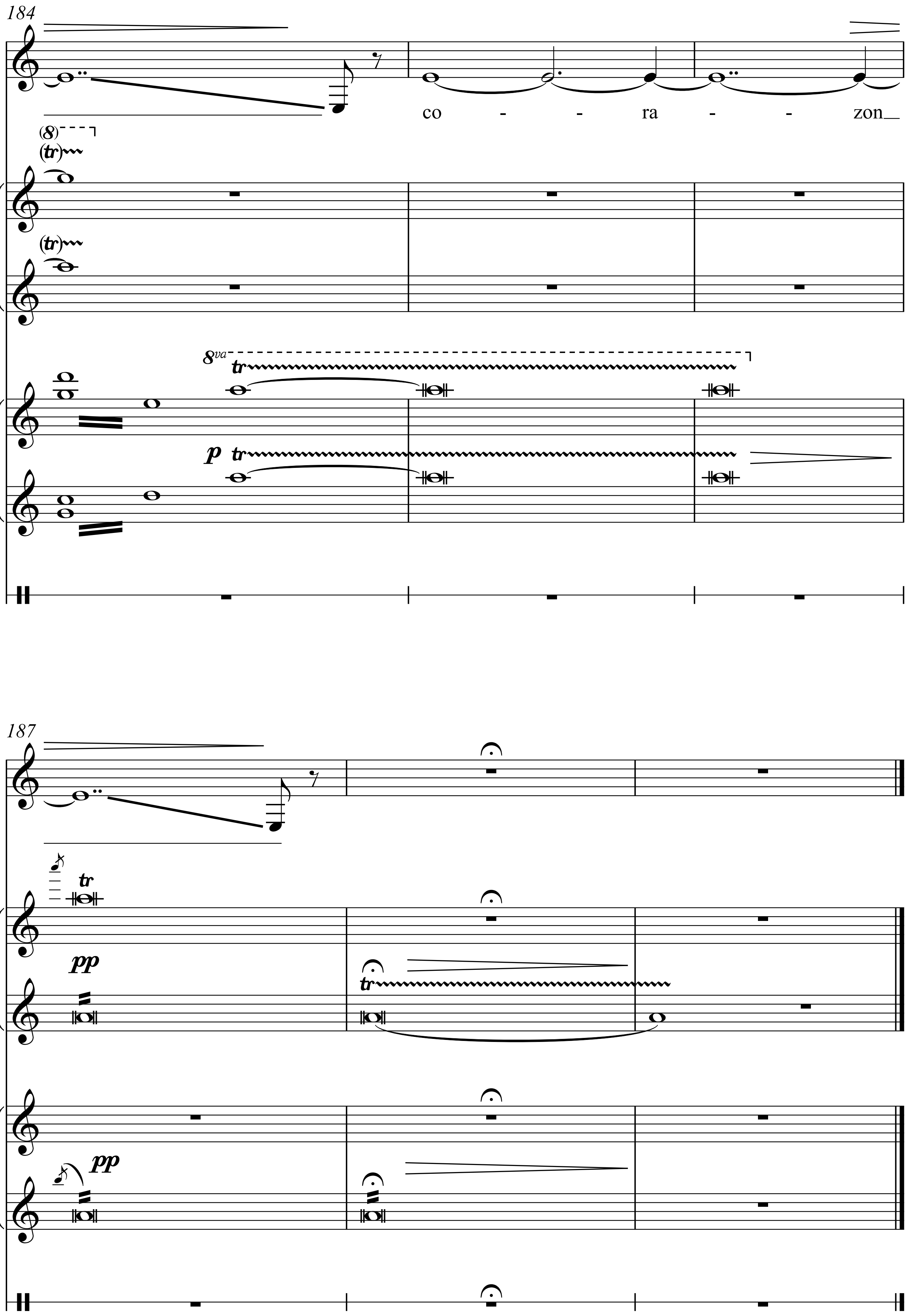

153
3
-a Di - o - os quien ab - ra el ciel - lo
tr
pp
tr
pp
156
de los nom - bres de - jan - do - lo ca - er sob - bre
p
p


159
J
♩ = 180
f
me de - so - la - do
co -
8va
tr
ppp
mf
f
163
- ra - - - zon
co -
8va
tr
mf
elec. gliss on voice


166
ra - - - zon co - -
8va
tr
mf
elec. gliss on voice
169
-ra - - - zon co - -
p
elec. gliss on voice


172
-ra - - - zon co - -
8va
tr
p
mf
elec. gliss on voice
175
-ra - - - zon


178
co - - ra - - - - zon
tr
mf
(tr)
p
8va
181
co - - ra - - - zon


184
co - - ra - - zon
(8)
(tr)
(tr)
8va
tr
p
tr
187
tr
pp
tr
pp

Echo Not Echo

For two quartets of flute, marimba, piano, and violoncello

2017

Program notes

Echo Not Echo is an exploration of how complex timbral and rhythmic effects can be created over a network. Through the repetition of tremolos and trills made asynchronous by latency and augmented by the reflective interferences of multiple acoustic spaces, new timbres arise as resonant sounds collide and intersect. Sonorous timbres give way to volatile rhythmic gestures, shifting in and out of synchronicity as sonic energy oscillates in the space between: the quartets become one, then separate, then become one again.

Duration: c. 11 minutes

Performance notes

Throughout the work, each performer should aim to match the remote audio as closely as possible in timbre and volume. The intention is that in sections A–I and U–V, the sound of both quartets should merge, creating the effect of a single sounding body. In the other sections, the phrasing and dynamics of rhythmic gestures is more important than timbral considerations.

For timekeeping, a networked digital clock is to be programmed to sync remotely and display bar counts, time signature changes, and tempi markings. For this reason, no rallentando or accelerando is recommended. Performers should endeavour to synchronise when notes start within the latency duration. In section P, the asynchronicity (caused by latency) will be most audible, as the notes ring clearly without tremolos to blur the attacks. For sections M through O, attention to phrase-level timing is suggested. The rhythmic gestures are not intended to align on a fine-grained level. Performers should interpret the timing of these phrases with the intent to be in synchronisation on a longer phrase level. For example, in bar 181, network latency will cause the falling flute motifs to be heard asynchronously. The intention here is that the falling phrases are experienced as shifting in and out of sync.

Gesture where note alignment is not as important as phrase-level synchronisation

A similar effect is anticipated in section R starting on bar 235:

This gesture between instruments which may or may not sound as written

How synchronously this gesture is heard is dependent on the network conditions and the response time of performers. Each gesture is expected to be slightly different in terms of synchronisation.

In general, during these sections, performers should be concerned with phrase-level synchronisation. Where the music is more static in the opening of section U and all of section V, bar-level synchronisation should be the goal.

Technical requirements

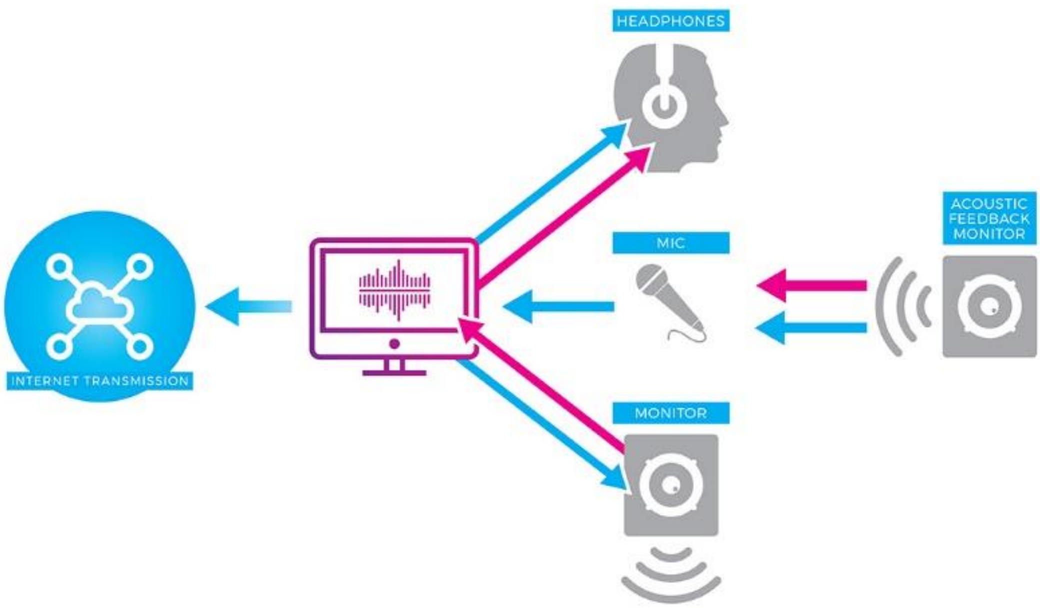
Each performer quartet must be in a different location with no audible way of hearing each other, e.g., in different cities or buildings, or completely different rooms of any performance space.

A networked synchronisation clock is needed to count each bar location. The composer can provide this or any digital programmable networked music performance tool will suffice. A conductor may be present for each quartet or the bar count can be displayed on a highly visible screen.

An Internet connection and a high-quality audio connection connects each performer. Performers should connect using any HD network audio software, such as Source-Connect, that uses OPUS, AAC, or a similar codec. *Consumer-level software programs such as Google Hangouts or Skype are not suitable.*

Where possible use a high-quality microphone and monitors. Acoustic noise reduction in software and hardware should be disabled to allow for feedback. Take care to carefully balance all audio signals while ensuring equal level of both quartets in the room. Performers may wish to use headphones for closer monitoring.

Echo Not Echo has special requirements for monitoring. The following diagram explains that an acoustic feedback monitor returns the remote signal back to itself, and accordingly should be placed near the microphone. This monitor is set to -inf dB by default, and the volume is increased according to the acoustic feedback electronic instructions in the score.



Explanation of electronics

An audio engineer on both sides of the connection engineer will need to control the electronic effects.

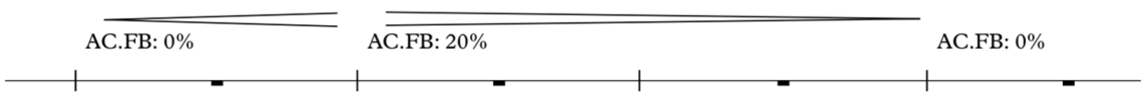
Delay

The delay effect is achieved by artificially incrementing and decrementing the latency of the incoming remote signal before it is broadcast to the monitors. This can be done manually using delay software or hardware, or the composer can provide control software. The delay effect is indicated as below, where 100% means the total network latency.

To determine the network latency, open a Terminal or Command application and type in 'ping IP_ADDRESS' where the IP_ADDRESS is the remote connection's public IP address. If the ping tool determines the latency as 100 ms, then DELAY 10% is a 10 ms delay.

Acoustic feedback

To further excite timbral resonance, the acoustic feedback effect is used carefully to create additional audio effects. An engineer can manually adjust the feedback level by increasing and decreasing the volume of the acoustic feedback monitor, or the composer can provide control software. The acoustic feedback effect is indicated as below. The engineer should determine beforehand the optimal levels for what decibel level will reference 100% because this will change according to the performance conditions.



ECHO NOT ECHO

REBEKAH WILSON


14
B
C
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.


27
D
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
p
mp
pp
mf
tr


40
E
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
DELAY: 0%
DELAY: 10%


54
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
mp
p
pp
mf
3
DELAY: 0%
DELAY: 15%
DELAY: 0%
DELAY: 20%
DELAY: 0%


67
F
♩ = 180
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
p
mf
pp
ppp
f
5
3


80
G
♩= 130
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
gliss.
p
mf
ppp
mp
pp


94
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.

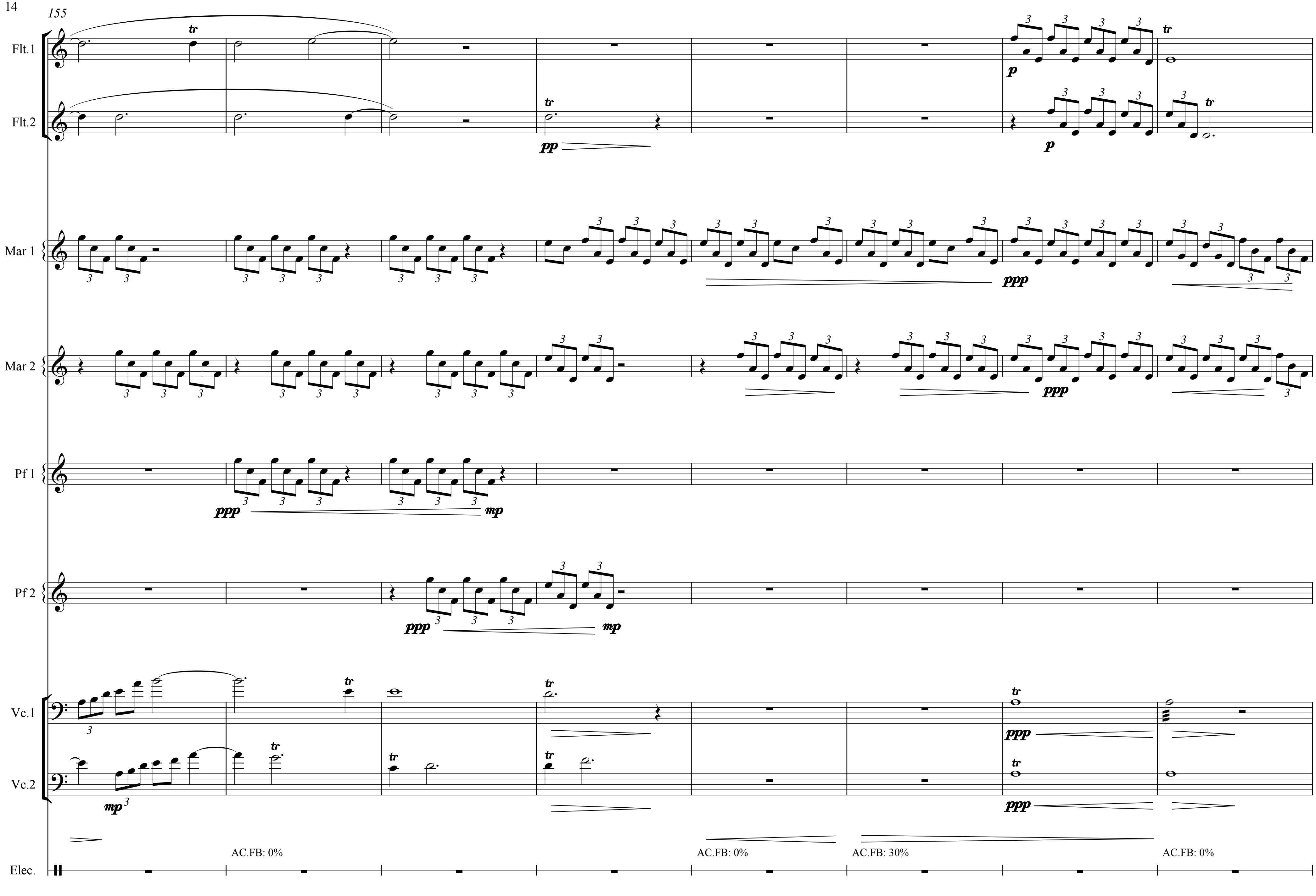

108
H
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.

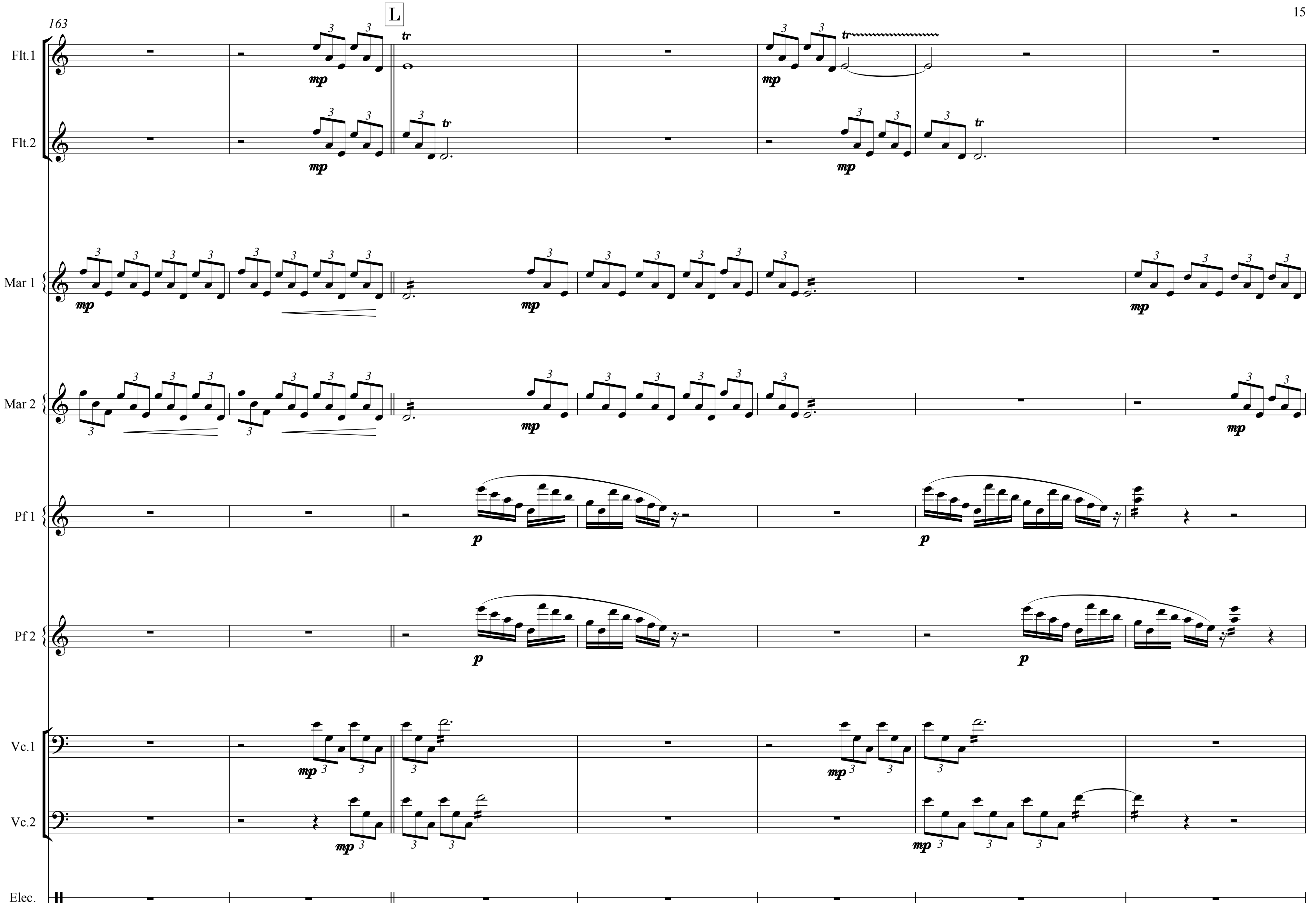

120
I
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
p
mp
f
pp


J
130
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
f
f
mp
mp
f
f
pp
pp
tr
tr
p espress.
p espress.
AC.FB: 0%


139
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
mp espress.
mp espress.
AC.FB: 0%
AC.FB: 10%
AC.FB: 0%


147
K
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
espress.
mp
ppp
f
p
pp
tr
AC.FB: 20%
AC.FB: 0%
AC.FB: 10%
AC.FB: 0%
AC.FB: 0%
AC.FB: 20%


155
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 0%
AC.FB: 0%
AC.FB: 30%
AC.FB: 0%

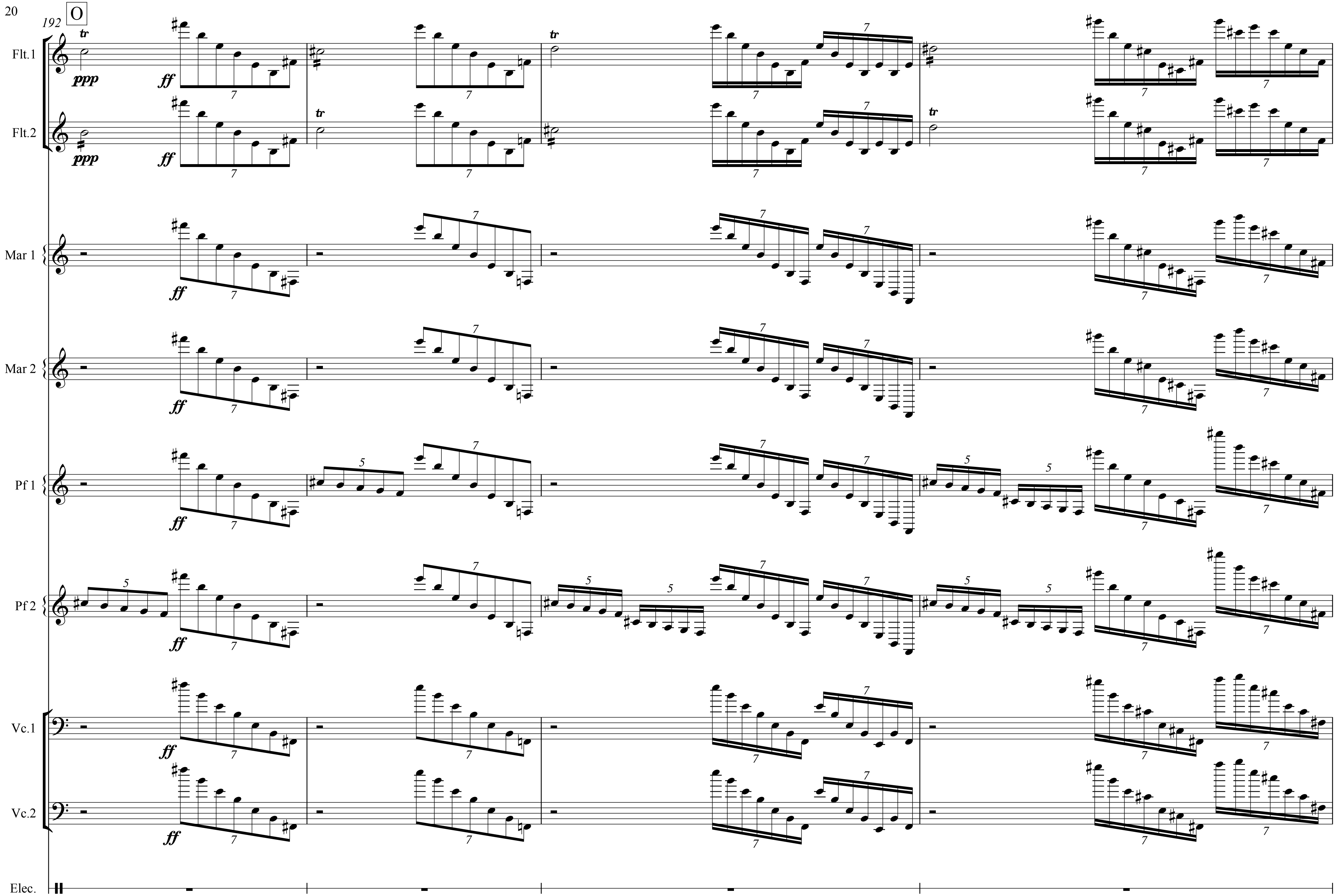

163
L
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
mp
p


170
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
p
mp
tr
pp


177
M
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.


183
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.


N
188
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
f
ff


192
O
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
ppp
ff


P
♩ = 100
196
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 0%
AC.FB: 20%


204
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
ppp
tr
pp
3
AC.FB: 0%
AC.FB: 0%
AC.FB: 30%
AC.FB: 0%
AC.FB: 20%
AC.FB: 0%


212
Q
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 10%
AC.FB: 0%
AC.FB: 10%
AC.FB: 0%
AC.FB: 15%
AC.FB: 0%
AC.FB: 20%
AC.FB: 0%
AC.FB: 25%
AC.FB: 0%


219
R
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
mf
p
pp
wide vibr.
AC.FB: 30%
AC.FB: 0%


227
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
p
mf
tr
Ped.


235
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
mf
p
tr
Ped.

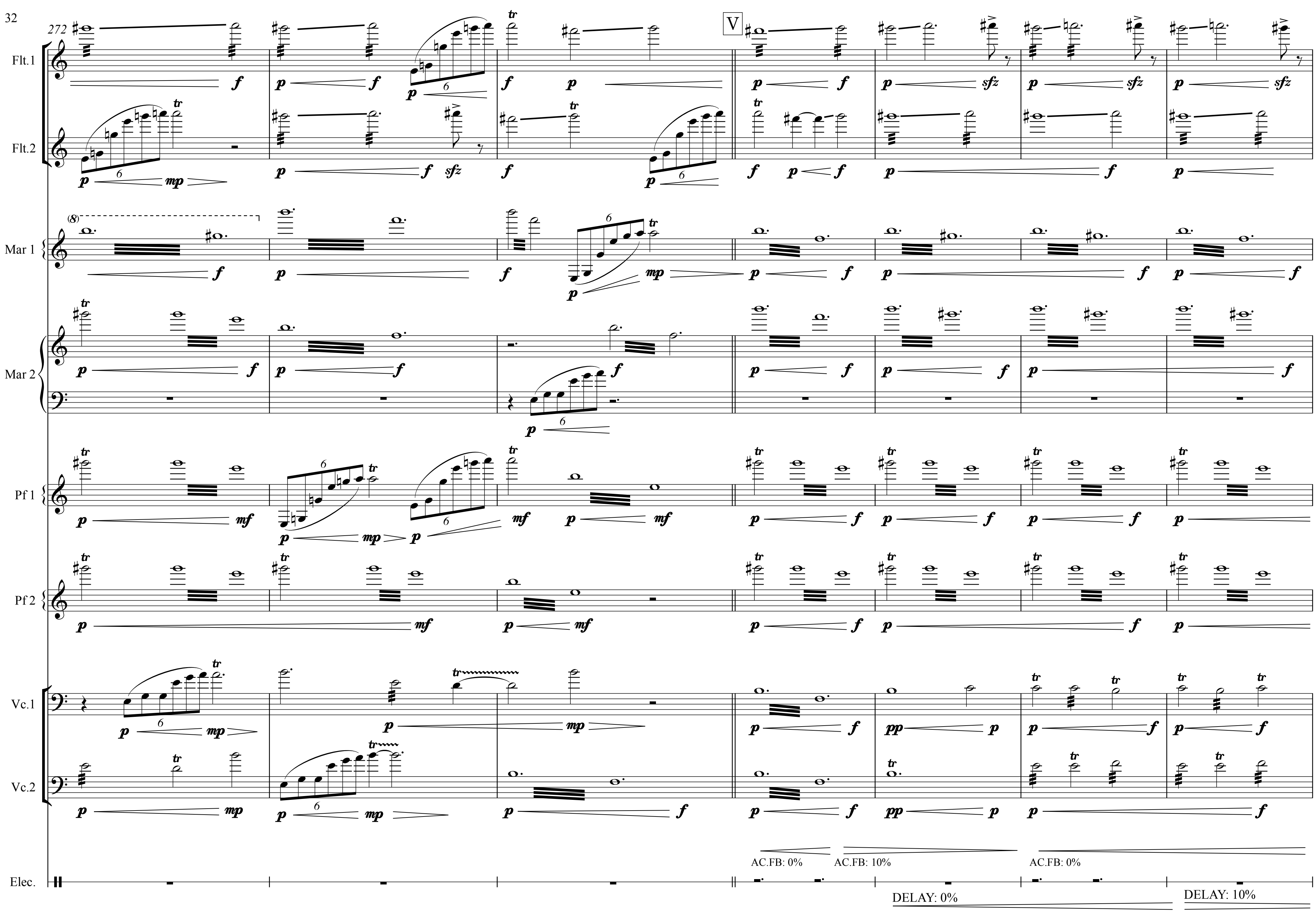

243
S
♩= 90
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
mf
p
tr
Ped.


250
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
tr
6
7
8va
Ped.


256
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.


260
T
tr
port.
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
8va
p
f
5
6
7


265
U
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.



272
V
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 0%
AC.FB: 10%
AC.FB: 0%
DELAY: 0%
DELAY: 10%


279
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 20%
AC.FB: 0%
AC.FB: 20%
AC.FB: 0%
DELAY: 0%
DELAY: 20%
DELAY: 0%
DELAY: 20%
DELAY: 0%


286
Flt.1
Flt.2
Mar 1
Mar 2
Pf 1
Pf 2
Vc.1
Vc.2
Elec.
AC.FB: 20%
AC.FB: 0%
AC.FB: 20%
DELAY: 20%

Audio CD track listing

Track #1: *Unison Not Unison*

Live recording with Wiek Hijmans and Sjors van der Mark

Maze festival June 2017, Amsterdam …………………………………………………. 12:45

Track #2: *Unison Not Unison*

Workshop recording with Wiek Hijmans

February 2018, Amsterdam ……………………………………………………………. 16:07

Track #3: *Phase Not Phase*

Live recording with Dante Boon and Reinier van Houdt (starts at section B)

February 2018, Amsterdam ……………………………………………………………. 10:40

Track #4: *Echo Not Echo*

Studio constructed recording …………………………………………………………... 11:20

The audio tracks along with the video recording of the live performance of track #1 and a video score of track #4 can be found online at masters.loopcontrol.io