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Rhythmic Topologies and the Manifold Nature of Network Music Performance

by

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Abstract

Network music performance is no longer in its infancy. In recent years, researchers have made strides toward a more seamless approach to distributed, multi-site, realtime music performances. However, interaction over vast distances comes at the cost of latency. Today's fiber optic infrastructure transmits data close to the speed of light, but even at light speed, our acuteness to sounds in time makes synchronous planetary-scale music performance a physical impossibility.

This research proposes a method that calibrates latency to a rhythmic unit of time, which allows for novel restructuring of pulse-based network music. The technique, called toporhythm, creates a rhythmic topology between performers that can be utilized to create distributed patterns. These patterns unfold differently in each performance space, resulting in a manifold music.

This thesis presents historical context for the work, outlines the toporhythmic technique, describes the latency calibration software tool, and surveys a selection of music composed toporhythmically.

Acknowledgements

I came to the University of Calgary in search of an academic hermitage of sorts. However, it was impossible to ignore the hospitality and helpfulness of my fellow students and professors.

Firstly, I would like to thank Professor David Eagle. Prof. Eagle was utterly welcoming when I first arrived in Calgary and was instrumental to my understanding of the scope and breadth of the sonic arts. I would also like to thank my supervisor Professor Laurie Radford. His guidance in this thesis as well as his insight into concepts in new music over the past years has been invaluable. I could not begin to articulate my thankfulness for his instruction adequately, though I'm sure he could help in that regard.

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Finally, I would like to thank Alan Tyson, Scott Deal, and the IUPUI Telematic Collective, Naithan Bosse, Grant Tofani, Cole Morrison, Koltan Kreamer, and the University of Calgary New Music Ensemble for performing my compositions.

In dedication to Sharon Ann Cayko

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Introduction

How do you measure time? Perhaps a wristwatch ticks away at 60 beats per minute on your arm offering its steadfast measurement at a moment's glance. Perhaps the morning crow of a rooster, the lyrical call to prayer, or the chime of a school bell defines your daily routines. Or perhaps, more rarely in Western civilization, you measure time's passage by the slow cyclic breath of the seasons. In any case, the natural patterns that reveal themselves with the passage of time help us to organize the complex activities of our societies. We rely on repetition. We depend on duration.

It is no surprise then that pulse, rhythm, and meter are fundamental elements in musical practice, an art form that makes its home in the time domain. The primacy and pervasiveness of tracking time with periodicity and subdivision are evident in everything from bouncy nursery rhymes to head-banging death metal. The enjoyment of and engagement with time is no less important in the context of network music.

This thesis attempts to offer musicians a point of entry into the world of network music performance and its unique temporal affordances while emphasizing accessibility. To do so, I will first examine the concept of the network itself as an abstract organizational structure as well as its tangible manifestations in computer networks. Second, I will provide a historical review of network music performance as it evolved alongside information and communications technologies. That will lead us to the rhythmic idiosyncrasies of network music where I will offer my strategies for composing and performing in the medium. Finally, I will provide a survey of my own compositions for the network and the various aesthetic concerns faced in their conception.

Chapter 1: Networks

The notion of a "network" has been used for centuries as a model for understanding complex systems and interdependent relationships. As early as 1735, Leonhard Euler was developing the concept of a topology of networks in relation to the bridges connecting parts of a city.[1] Not only have networks given us a conceptual tool for understanding physical connections such as bridges, radio towers, or computers, but it can also be a useful way to understand our complex social, economic, and cultural interactions. Moreover, a modern understanding of a network inevitably grapples with the ramifications of technological mediation and information technologies (IT).

What the concept of a network can afford artists and art works is an evolving issue. On one hand, we have Marshall McLuhan's idealistic vision of the global village in 1962.[2] McLuhan poetically asserted that IT allows us to extend our physical senses across the globe, which erases distance and time, and brings with it an intensely heightened awareness and responsibility for one another. Emerging at a similar time were Roy Ascott's prescient theories and groundbreaking artworks on interactivity, participation, and feedback in cybernetics and telematic art. In 1990, he described telematics' ability to offer an "infrastructure for spiritual interchange that could lead to the harmonization and creative development of the whole planet."[3]

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[1] "Beginnings of Topology" Math Forum, accessed May 2016, http://mathforum.org/isaac/problems/bridges1.html.
[2] Marshall McLuhan. *The Gutenberg galaxy: The making of typographic man*. (Toronto: University of Toronto Press. 1962).
[3] Roy Ascott. *Telematic Embrace*. Edited by Edward A. Shanken. 1st ed. (London: University of California Press, 2003).

On the other hand, Deleuze and Guattari's book *A thousand plateaus: Capitalism and Schizophrenia*[4] sets forth a more fragmented and rhizomatic structure of networks. Deleuze and Guattari posit that complex systems consist of interconnected multiplicities or assemblages, rather than a unified whole, "it is only when the multiple is effectively treated as a substantive, 'multiplicity,' that it ceases to have any relation to the One as subject or object, natural or spiritual reality, image and world."[5] Later in 1999, Richard Coyne critiques the utopian narratives of McLuhan and others with a pragmatic survey of IT's role and the balance between a rationalist and a romantic reading of the network's implications.[6] Indeed, theorizing about what network structures can offer society is rich and compelling but it is valuable for us to now take a look at the physical infrastructure of computer networks that facilitate music performance.

1.1 Today's Network Infrastructure

Although telecommunications technologies like the telephone have allowed some degree of distant audio exchange since the 19th century, the first network of computers sending and receiving data came in the form of ARPANET in 1969. This network initially consisted of four nodes: University of California Los Angeles, Stanford Research Institute, the University of California Santa Barbara, and the University of Utah. The U.S. Department of Defense Advanced Research Projects Agency (DARPA) funded the large and expensive computers used at these institutions at the time. However, as more institutions expressed interest in the data these computers could provide, DARPA needed a way to share the information without requiring the construction of more and more

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[4] Felix Guattari and Gilles Deleuze. *A Thousand Plateaus: Capitalism and Schizophrenia* (Minneapolis, MN: University of Minnesota Press, 1988), 8.
[5] Ibid. 8.
[6] Richard Coyne. *Technoromanticism: Digital Narrative, Holism, and the Romance of the Real. Information Society* (Cambridge, MA: The MIT Press, 1999).

computers. ARPANET was the first implementation of a communications technique known as "packet switching." "In a packet switched network, messages are broken into small chunks, known as packets, which are transmitted independently between the source and the destination."[7] Using this technique, the amount and speed of data that could be sent over a network increased dramatically and thus, ARPANET and its strategies for telecommunications would develop, fracture, and expand into what we now know as the Internet.

ARPANET initially used existing telephone lines to transmit data over vast distances. Today, we still use telephones lines to transmit data but also use copper coaxial cables, power lines, fiber optic cables, and wireless methods including satellite transmission, radio, and cellular networks.

These methods each have idiosyncrasies in terms of accessibility, bandwidth, and latency that make some more viable for network music than others. Optical fiber is presently the fastest and most effective method for data transmission. Networks such as Internet2,[8] Cybera,[9] and Géant[10] provide this service for many universities and research institutions. However, these networks are expensive and geared towards business applications, not a home studio. Although there are some hopeful initiatives,[11,12] consumer internet service providers (ISPs) rarely offer fiber-to-the-home (FTTH) service. The drawback is that bandwidth-intensive and latency-sensitive network music is often exclusive to universities.

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[7] Charles J. Fraleigh "Provisioning Internet Backbone Networks to Support Latency Sensitive Applications." (PhD diss., Stanford University, 2002).
[8] "Internet2," accessed May 2016, http://www.internet2.edu/.
[9] "Cybera," accessed May2016, http://www.cybera.com/.
[10] "GÉANT," accessed May 2016, http://www.geant.org/.
[11] "Fiber to the Home Council Americas," accessed May 2016, http://ftthcouncil.org/.
[12] "Fibre to the Home Council Europe," accessed May 2016, http://www.ftthcouncil.eu/.

1.1.1 Bandwidth

Bandwidth requirements for network music can be met with even less-than-stellar network connections. Generally speaking, the transmission of CD quality audio requires 1Mbps (megabit per second) upload and download speed per channel of audio.[13] This is easily achieved with the 100+Mbps speeds offered by fiber optic cable but consumers may not be guaranteed this service. "In 2010, the Federal Communications Commission redefined 'basic' broadband service as a connection with speeds of at least 4 megabits per second (Mbps) downstream… and at least 1 Mbps upstream."[14] This means the basic coverage ISPs provide only ensures network musicians one channel of audio, which is also subject to reduction when another user, such as a neighbor, uses the network simultaneously. Fortunately, ISPs often offer higher speeds than the minimum, "For example, 94 percent of Americans in urban areas can purchase a 25 Mbps connection."[15]

1.1.2 Latency

It is difficult to find any scholarship about network music that does not address the aspect of latency, because unlike bandwidth, latency cannot be nullified even when using a high-speed research network. Here, latency can be defined as a measure of time between when a sound occurs in one location and when that sound is heard at another. As outlined by figure 1, there are numerous steps at which latency is introduced into the signal's transmission. Each of these steps can add a variable amount of latency depending on the physical distances between the source and the microphone in each space, the settings of the user's audio equipment, and reliability of the network connection. The

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[13] Ivelina Atanasova Karagyulieva, and Natalia Costas Lago. Networked Music Performance. *Technical Report CESGA-2014-003*. A Coruña, Spain, 2014.
[14] Executive Office of the President. "Community-Based Broadband Solutions: The Benefits of Competition and Choice for Community Development and Highspeed Internet Access," 2015.
[15] Ibid. 3

three main factors that contribute to latency are the propagation of sound in one physical location, the analog-to-digital conversion, and the transmission across the network. Providing specific examples in milliseconds (ms) would not be very helpful here, as each network music performance could be drastically different, though it is a reasonable assumption that latency induced along each of these stages is very difficult to keep below 25ms. The significance of this value of time will be addressed below.

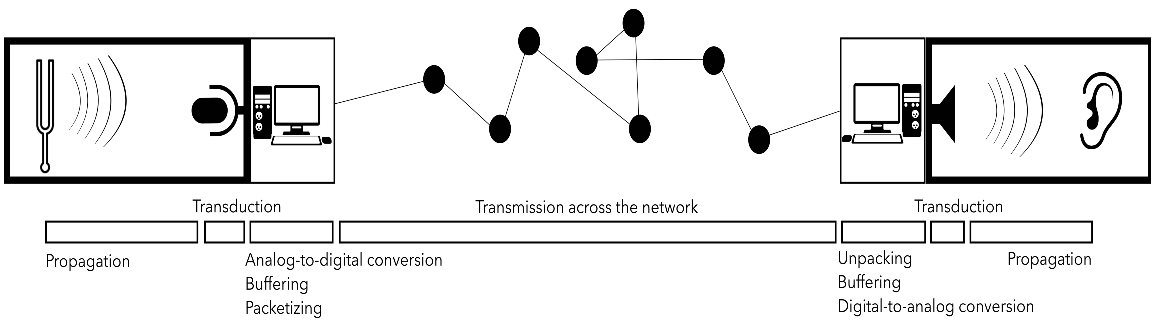

Figure 1. Factors contributing to latency

To further exacerbate the issue, when a signal is being transmitted across the network, its constituent packets can arrive out of order or at inconsistent times. This variability is known as jitter. The amount of jitter is also unpredictable unless certain QoS (Quality of Service) agreements are made with the service provider. Typically, on high-speed research networks the jitter is negligible (<5ms) and resulting audio drop-outs are rare.

Pauline Oliveros, an influential and foundational composer in network music performance says of latency:

> Latency is of course still a big issue in networked music transmissions. There are different levels of latency. There are many factors to deal with ranging from CPU power to fire walls, routers, coordination of audio and video and all manner of arcane information technology protocols and politics. I call it 'head banging', and have spent more hours than I care to count testing, checking and curbing my frustrations. So why do it? Another reason is because you can… Latency though is a part of the Internet and can be used very creatively. Another reason is because the rise of technology is inexorable. There is desire. The transmission of audio and video in both low and high quality via the Internet opens the world to otherwise impossible collaborations, a gathering of knowledge for a richer, broader musical perspective, view and exploration of the world in an expanded venue. This is the time to dream on. So we dream on![16]

The story of network music has been woven from various strands of experimental and collaborative sound-making activity that ebb and flow in tandem with IT advancements. My research lies in a particular strand of activity that follows a trajectory outlined by the researcher Benjamin Smith as, "approaching digital networks as a way to expand acoustic ensemble practice, and confronting a further philosophical divide at many turns: between artists modeling co-present musical practices…and artists looking for new musical practices in reaction to the unique potentials of the networked medium."[17] The following outlines the chronological lineage of this approach.

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[16] Pauline Oliveros. "Networked Music: Low & High Tech." *Contemporary Music Review* 28, no. 4 & 5 (2009): 433–35.

[17] Benjamin D. Smith "Telematic Composition." (PhD diss., University of Illinois at Urbana-Champaign, 2011).

Chapter 2: Background

1.1 History of Network Music Performance

Prior to the 1970s, some of the best-known collaborative musical performances that involved communication in near-realtime were the "Broadcast Works" of Max Neuhaus. Neuhaus was seeking to use telephone and radio technology to create spaces, at least sonically, in which many people could gather and that extended far beyond that of a discrete physical space. He did this with *Public Supply I* in 1966 when he realized he could, "open a large door into the radio studio with the telephone; if I installed telephone lines in the studio, anybody could sonically walk in from any telephone."[18] These telephones were amplified and sent to a speaker after being mixed by Neuhaus, this speaker was then directed into the microphone in the studio and broadcast over a large swath of New York City. Neuhaus later realized that what he had created was a community that interacted with each other through sounds; as he describes "not making a musical product to be listened to, but forming a dialogue, a dialogue without language, a sound dialogue."[19]

About a decade later, the availability and affordability of computers incited a surge in experimentation. This led to the formation of the League of Automatic Music Composers in 1976 comprised of Jim Horton, John Bischoff, and Rich Gold who was later replaced by Tim Perkis.[20] At that time, each member would create their own sound making hardware and software on early single board computers. However, the equipment

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[18] Max Neuhaus. "The Broadcast Works and Audium." *Zeitgleich: The Symposium, the Seminar, the Exhibition*, 1994, 1–19.
[19] Ibid. 7.
[20] Scot Gresham-Lancaster. "The Aesthetics and History of the Hub: The Effects of Changing Technology on Network Computer Music." *Leonardo Music Journal* 8, no. 1 (1998): 39–44.

setup and protocols for communication between the computers was inconsistent and typically the configuration of this equipment was unique to the realization of a single piece, which posed problems for repeatability. The following several years offered technological advances that remedied these problems, the most profound being the invention of the MIDI (Musical Instrument Digital Interface) protocol in 1983.

In 1985, the League performed a series of concerts entitled "Network Muse". These performances demonstrated the ability of electronics to afford networked interactions among independent agents but had yet to expand beyond a single room. Later that same year in New York the group changed its name to "The Hub" and gathered new members Mark Trayle, Phil Stone, and Scot Gresham-Lancaster. They then delved into remote collaborations, first between two locations in New York City, which, like the early ARPANET, used existing telephone lines to transmit data. At this point, precise timing was made irrelevant by the Hub's use of aleatoric methods to drive the highly conceptual musical material. Gresham-Lancaster himself critiques their 1989 performance of *HubRenga*:

> This peculiar piece illustrated the problems of a music based on a large group of 'interactors.'…With the network open to all comers and the technology simplified, we assumed it would be an egalitarian victory for art. The varying range of taste and innate talent made for a pastiche that lacked finesse and cohesion, and despite the best intentions of the contributors, the results were mixed.[21]

[21] Ibid. 42.

With the advent of the World Wide Web in 1989, access to interconnected computer networks expanded and various novel network music systems arose. These systems continued to explore the aspects of community that network music affords and resulted in a number of composition support systems and collective creation systems.[22] A common trait of these systems was that they allowed users to produce music together in an asynchronous non-realtime way by exchanging MIDI files or recorded audio that others could easily access and edit.

The next step was into the realm of unilateral telepresence systems that allowed realtime multichannel musical performances complete with video and audio to be broadcast from one site to another, expanding the concert hall to a venue that spans thousands of miles. One of the first performances of this kind was made by McGill University's Swing Band broadcasting to the Cantor Film Center of New York University in 1999. These telepresence systems naturally advanced beyond a one-way distribution of a performance and into bi-lateral collaboration wherein performers interacted with remote nodes and two separate halls were joined into one augmented performance space.

Although the technology afforded these geographically connected performance spaces, it was not advanced enough for live uncompressed audio in this format, and performers instead exchanged MIDI data or some other control data that was less bandwidth intensive. Miller Puckette describes a performance in 1999 between New York and Portland that sent MIDI data and realtime audio analyses of percussion instruments to affect video graphics and trigger sound generators at the remote node. This was done as an attempt to transcend the idea of telepresence and as Puckette describes,

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[22] Alvaro Barbosa. "Displaced Soundscapes: A Survey of Network Systems for Music and Sonic Art Creation." *Leonardo Music Journal* 13 (2003): 53–59.

> The relationships between local and remote instruments, and between sound and graphics, were constantly shifting, the perceived presence of the remote performers was enigmatic rather than didactic. Each of the two audiences got a different show; at each locale, the 'here' and 'not-here' were treated as essentially different perceptible presences.[23]

At the turn of the century, computer networks and ISPs were ubiquitous but the foundations laid by ARPANET for dedicated research networks lived on in the establishment of high-speed internet backbones such as Internet2. This sparked a wave of research spearheaded by Chris Chafe, one of the most prolific network music researchers and Director of Stanford University's Center for Computer Research in Music and Acoustics (CCRMA), and led to the creation of his group, SoundWIRE. CCRMA's work along with research efforts by Michael Gurevich at SARC (Sonic Arts Research Centre),[24] Elaine Chew,[25] and others later at Eastman School of Music and the University of Rochester,[26] produced large amounts of groundbreaking research in identifying the 25ms maximum delay, below which musicians can play in synchronization, also known as the Ensemble Performance Threshold (EPT).[27]

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[23] Miller Puckette. "Not Being There." *Contemporary Music Review* 28, no. 4 & 5 (2009): 409–12.

[24] Chris Chafe, Michael Gurevich, Grace Leslie, and Sean Tyan. "Effect of Time Delay on Ensemble Accuracy." In *International Symposium on Musical Acoustics*, 3–6. Nara, Japan, 2004.

[25] Elaine Chew, R Zimmermann, A Sawchuk, C Kyriakakis, C Papadopoulos, A R J François, G Kim, A Rizzo, and A Volk. "Musical Interaction at a Distance: Distributed Immersive Performance." In *MusicNetwork Fourth Open Workshop on Integration of Music in Multimedia Applications*, 1–10. Barcelona, 2004.

[26] Christopher Bartlette, Dave Headlam, Mark Bocko, and Gordana Velikic. "Effect of Network Latency on Interactive Musical Performance." *Music Perception: An Interdisciplinary Journal* 24, no. 1 (2014): 49–62.

[27] Alain B. Renaud, Alexander Carôt, and Pedro Rebelo. "Networked Music Performance: State Of The Art." In *AES 30th International Conference*, 1–7, 2007.

In 2007, leading researchers in the field Alain Renaud, Pedro Rebelo, and Alexander Carôt laid out the state of the art of network music including technical limitations, a classification of various networked performance systems, and a commentary on the cultural aspects of network music. In this work, they defined the categories of a Realistic Jam Approach (RJA),[28] Latency Accepting Approach (LAA), and Remote Recording Approach (RRA).[29] I place the work of this thesis squarely within the category of a LAA and will return to this in detail in the following section.

The late 2000s was the point when network music began crystallizing as an art form that exhibited some measure of "standard practice", so testing and theorizing gave way to performing and practicing. Research institutions held large-scale performances such as the Pacific Rim of Wire concert between Stanford and Beijing,[30] the TeleJazz performances between Banff and Toronto,[31] and *Auqsalaq* a multi-site telematic opera.[32]

However, as the infrastructural technologies continue to change and grow, these network performances give rise to new questions about presence and interaction over vast distances. Because of this ever-evolving groundwork that facilitates the practice, researchers must continually reevaluate and restructure, or draw new lines of flight[33] for the approaches to music in this medium. Young composer/performer/researchers like

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[28] "This approach is considered when real-time live music interactions are crucial and when the goal is to get as close as having geographically displaced musicians feel like they are playing in the same space." (ibid. 2)

[29] "This approach involves producing music by using the internet as a medium for remote recording sessions. In this case the audio signal sent to is 'time stamped' which makes it possible to ignore latency issues as there is no real human-to-human interactions." (ibid. 7)

[30] Juan-Pablo Cáceres, Robert Hamilton, Deepak Iyer, Chris Chafe, and Ge Wang. "To the Edge with China: Explorations in Network Performance." In *ARTECH 2008, 4th International Conference on Digital Arts*, 7–8. Porto, Portugal, 2008.

[31] Chris Chafe. "Living with Net Lag." In *AES 43rd Internatonal Conference*, 1–6. Pohang, South Korea, 2011.

[32] Scott Deal and Matthew Burtner. "Auksalaq, A Telematic Opera." In *International Computer Music Conference*, 511–14. Huddersfield, UK, 2011.

[33] Guattari et al. *A Thousand Plateaus,* 9.

Jason Freeman, Benjamin Smith, Pedro Rebelo, and Franziska Schroeder are just a few that exemplify an engagement with the technology, aesthetics, theory, and practice of network music.

Outside of academia, network music practices continue to garner interest. The success of commercial applications such as MusicianLink[34] and eJAMMING AUDiiO[35] as well as the recent emergence of free online jamming communities like Sofasession[36] and Jammr,[37] show that this relatively new technology offers not only a novel musical practice but also a potential in the marketplace.

1.2 Previous Latency Accepting Approaches

Nicolas Bouillot,[38,39] Juan-Pablo Cáceres, and Alain Renaud[40] provide some of the seminal research in LAAs. As mentioned before, Renaud et al. define a variety of approaches to network music of this sort and define a LAA as follows:

> This approach considers the internet as a decentralized and space independent medium and thus connecting globally, network delays of more than 200ms are common and perfectly acceptable. Accepting these delays beyond the EPT and finding new ways of delayed musical interaction is an alternative approach to the realistic jam approach.

[34] "MusicianLink," accessed May 2016, https://www.musicianlink.com/.
[35] "eJAMMING AUDiiO – The Collaborative Network for Musicians Creating Together Online in Real Time," accessed May 2016, http://ejamming.com/.
[36] "Sofasession," accessed May 2016, http://www.sofasession.com/.
[37] "Jam Together Online | Jammr," accessed May 2016, https://jammr.net.
[38] Nicolas Bouillot. "The Auditory Consistency in Distributed Music Performance : A Conductor Based Synchronization." *Information Sciences for Decision Making*, no. 13 (2004): 129–37.
[39] Nicolas Bouillot. "nJam User Experiments: Enabling Remote Musical Interaction from Milliseconds to Seconds." In *New Interfaces for Musical Expression*, 142–47. New York, 2007.
[40] Juan-Pablo Cáceres and Alain B Renaud. "Playing the Network : The Use of Time Delays as Musical Devices." In *International Computer Music Conference*, 24–29, 2008.

Providing a *new way of delayed musical interaction* is precisely where my interest lies and is the core of this research. "Temporal separation refers to the time it takes for the actions of one person to reach another while acting together."[41] When this temporal separation stretches beyond tolerable asynchrony, it can eventually fold back into a displaced rhythmic synchrony. The following two examples are precedents to this strategy.

1.2.1 nJam

The nJam system developed by Nicolas Bouillot provided one of the first latency accepting approaches (LAA) that allowed users to control their signal's latency by a musical unit of time. The users heard not only the sound that they produced in their respective locations but also their delayed signal, which was sent back to them along with the remote user's signal in the form of a global mix. In addition, the system provided users with a global metronome that aided in synchronizing their playing. They conducted experiments by testing performers' experiences of the system over a range of tempi and lengths of adaptive delay.

In these experiments, the researchers found that the greatest comfort and accuracy among users was attained when the delay matched that of some structure present in the musical material. That is, if the musical phrase was twelve quarter notes long, a delay of twelve quarter notes resulted in the greatest ease because performers could play in unison with their past selves and the remote musician. Whereas a delay of four quarter notes resulted in odd rhythmic phasing with their delayed sound over a twelve note cycle.

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[41] Chafe et al., "Effect of temporal separation on synchronization in rhythmic performance" 1.

The results of nJam's experiments point toward the idea that music in this medium changes our structuring of musical time; as one user comments, "It is possible to create a new kind of playing with this latency parameter. This would be a new improvisation concept. For example, musical questions and answers would take place on two different temporalities: the present and the past!"[42]

1.2.2 Ninjam

Another latency accepting approach to network music is the Novel Intervallic Jamming Architecture (Ninjam) developed by Cockos Inc. This is open source software integrated in the digital audio workstation Reaper as a plug-in (ReaNINJAM). Ninjam accounts for latency employing a similar method to that of nJam in that a user defines a specific tempo. Instead of a rhythmic unit however, Ninjam delays the audio stream by a matter of at least one measure or bar. The creators describe it as follows:

> The NINJAM client records and streams synchronized intervals of music between participants. Just as the interval finishes recording, it begins playing on everyone else's client. So when you play through an interval, you're playing along with the previous interval of everybody else, and they're playing along with your previous interval. If this sounds pretty bizarre, it sort of is, until you get used to it, then it becomes pretty natural. In many ways, it can be more forgiving than a normal jam, because mistakes propagate differently.[43]

[42] Nicolas Bouillot. "nJam User Experiments: Enabling Remote Musical Interaction from Milliseconds to Seconds." 146.
[43] "NINJAM," Cockos Incorporated, accessed May 2016, http://www.cockos.com/ninjam/.

As their names imply the two aforementioned latency accepting approaches lend themselves to jamming and improvised music. This style of music making seems to have become the *modus operandi* for many network music performances. This could be due to recent shifts in the roles of composers and performers, though it could also be due to the fact that network music is still somewhat technically complex and often involves lengthy setups, troubleshooting, and an understanding of basic audio technology, potentially leaving practitioners with much less time to rehearse.

The present research offers an alternative to jamming environments by proposing strategies for a music oriented toward acoustic musicians that is focused on the rhythmic affordances of latency in the networked medium. It also proposes a strategy for composing temporally displaced music.

Chapter 3: Rhythmic Topologies

3.1 Manifold Music

Rhythm, "the language of time",[44] is undoubtedly a central feature of all musical practices. The study of rhythm has, in recent years, expanded beyond the field of music and into mathematics,[45] psychology,[46] and neuroscience.[47] Fred Lerdahl and Ray Jackendoff's book *A Generative Theory of Tonal Music*[48] in 1983 proposed a novel approach to grouping and meter that led to many subsequent studies on rhythm. Though Lerdahl and Jackendoff's linguistics-based approach to musical structure has its shortcomings, what this approach and others emphasize is the distinction between rhythm and meter. Justin London defines it as follows.

> Rhythm involves patterns of duration that are phenomenally present in the music, and these patterns often are referred to as *rhythmic groups*. It is important to note that these "patterns of duration" are not based on the actual duration of each musical event—as a rhythmic pattern can be played legato or staccato, for example—but on the *interonset interval* ("IOI") between the attack points of successive events. By contrast, meter involves our initial perception as well as

[44] A.C. Lewis. *Rhythm: What it is and how to improve your sense of it*. (San Francisco, CA: RhythmSource Press. 2007)
[45] Francisco Gómez-Martín, Perouz Taslakian, and Godfried Toussaint. "Interlocking and Euclidean Rhythms." *Journal of Mathematics and Music* 3, no. January 2010 (2009): 15–30.
[46] Peter Vuust and Maria a. G. Witek. "Rhythmic Complexity and Predictive Coding: A Novel Approach to Modeling Rhythm and Meter Perception in Music." *Frontiers in Psychology* 5, (2014): 1–14.
[47] Catalin V. Buhusi and Warren H. Meck. "Relativity Theory and Time Perception: Single or Multiple Clocks?" *PLoS ONE* 4, no. 7 (2009).
[48] Fred Lerdahl and Ray Jackendoff. *A Generative Theory of Tonal Music*. (Cambridge, MA: MIT Press, 1983.)

subsequent anticipation of a series of beats that we abstract from the rhythmic surface of the music as it unfolds in time.[49]

In the context of network music performance, this understanding of rhythm and meter must include a new dimension, that of relativity. In a network music performance, performers can be separated by thousands of miles and the sounds produced in one location are transduced into messages of light and transmitted across that distance. As described above, the amount of time this process takes is called latency. When this latency is a constant, we can use it creatively to make what Cáceres and Renaud call "distributed rhythmic patterns."[50] That is, the patterns played at each node arrive at the remote nodes at various times. This results in a *manifold music*.[51]

I will discuss below how manifold music changes our approach to composing rhythms and our anticipatory schema of meter, but I would like to point out that the concept of manifold music is not limited to temporal sequencing. Due to the fact that network music of this sort takes place in a number of disparate locations, the situatedness of both performer(s) and listener(s) in their respective environments complete with its local context results in one piece of music that can be heard/experienced in phenomenally different ways simultaneously.

Returning now to rhythmic constructs, a simple example of the manifold nature of this music can be seen in Figure 2. Here, suppose two performers are separated by a one-way delay of 250ms, that amount of time can be expressed as an eighth note at 120bpm.

[49] Justin London. *Hearing in Time: Psychological Aspects of Musical Meter*. (New York: Oxford University Press, 2004)
[50] Renaud et al., "Playing the Network."
[51] Similar to the concept of a manifold in topology, manifold music is locally heard in one form but in a different location the same music is heard in another form.

As highlighted by the red and green arrows, the first beat played by Node 1 (N1) is heard an eighth note later at Node 2 (N2). When this eighth note offset is symmetrical between the two nodes, a unison attack at N2 with N1 results in the round trip time (RTT) of a quarter note offset back at N1. The relationship of an eighth note each direction defines this example's simple *rhythmic topology*.

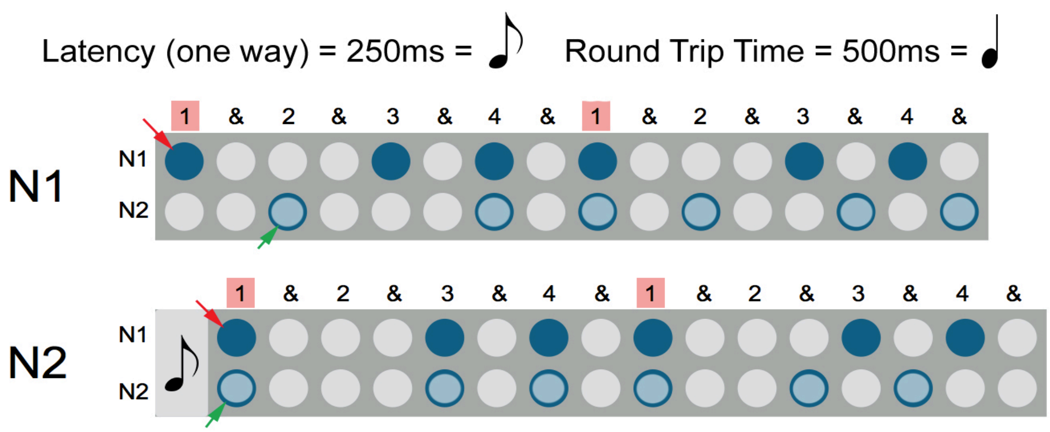

Figure 2. Bi-located distributed rhythmic pattern

3.1.1 Initiate Node

Once the rhythmic topology is known we can begin constructing patterns with knowledge of how they will unfold at the remote node. One of the main concerns is that of designing simultaneous musical events. Indeed, no event can occur at the same time at all nodes. However, the node that begins the first pattern or phrase sets the reference, or downbeat, for all other nodes thereafter. This node is called the *initiate node* (IN).

The establishment of an IN among any number of connected nodes provides a composer with a reference upon which further rhythmic relationships can be constructed. This becomes very useful as we will see below when more than just two nodes are involved. Furthermore, it is possible to design rhythmic groups that imply, or entrain, different meters depending on which node one is listening from.

3.2 Exercising the Network

In my research, developing an understanding of bi-directional distributed patterns started with creating a series of exercises that resembled that of a warm-up routine for a drumline. They focused on simple rhythmic patterns that were repeated in an effort to tightly synchronize attacks and internalize the pulse. Drawing heavily from concepts posed by Cáceres and Renaud, the exercises helped performers familiarize themselves with feedback locking and understanding that the rhythms heard in one location are unlike those simultaneously occurring at the other location. Additionally, each exercise began with an audible "count-off" by the IN, which addressed the issue of starting together when performers could not rely on visual cues.

Audible cues and performer-as-conductor have precedence in many musical traditions including West African drumming, Gamelan, American marching bands, as well as the music of Steve Reich. These predecessors in particular offer a number of other useful strategies and approaches to music that rely on rhythmic accuracy within a metrically ambiguous framework. These will be discussed in relation to my compositions below.

3.3 Stylistic Considerations

The aspects of network music that I've been describing thus far suggest a certain stylistic approach to music in a latency-accepting context. Primarily, it suggests pulse-based or groove-based music. Previous studies on ensemble accuracy in network music tended to use either musicians trained in European classical music[52] or that "were not selected for any particular musical ability."[53] European classical music, as I will describe below, is far more malleable in terms of temporal resolution, both because of the instruments used, and the style of expression. Also, the importance of training, skill, and specialization in groove-based or pulse-based music was overlooked in these studies. Would members of a Drum Corp International (DCI) drumline identify and navigate time delays in the same way as a violinist and violist playing Mozart?

In the cases I have described thus far, the delay between two nodes determines the tempo and remains relatively static unless jitter occurs; therefore deviation from the tempo results in too much temporal separation and subsequent desynchronization rather than expressiveness, but slight timing deviations, if still "in time", can be very expressive. As Vijay Iyer points out:

> In groove-based music, this steady pulse is the chief structural element, and it may be articulated in a complex, indirect fashion. In groove contexts, musicians display a heightened, seemingly microscopic sensitivity to musical timing (on the order of a few milliseconds). They are able to evoke different kinds of rhythmic qualities, such as apparent accents or emotional mood, by playing notes slightly late or early relative to their theoretical metric location.[54]

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[52] Bartlette et al. "Effect of Network Latency on Interactive Musical Performance"
[53] Chafe et al. "Effect of temporal separation on synchronization in rhythmic"
[54] Vijay Iyer. "Microstructures of Feel, Macrostructures of Sound: Embodied Cognition in West African and African-American Musics." (PhD diss., University of California, Berkley, 1998). 58.

Iyer's study on microtiming provides invaluable insight into the expressivity of rhythmic feel in groove-based music. His findings also lead to new questions in the network music medium. As previously mentioned, a constant latency of 25ms is enough to desynchronize performers over time. This is because the performers are both reacting to each other's sound as if the remote performer is consistently dragging 25ms behind the beat. The consistency of this delay is of vital importance here because small variances in note onsets are common in non-network music performances.

In Rudolf Rasch's study on ensemble synchronization,[55] he found that among professional string and wind trios performing typical repertoire, synchronous attacks tended to vary by 27 to 37ms among the winds and 37 to 49ms among strings, while the tempo remained constant. The style of music addressed in Rasch's study is much more forgiving in terms of temporal resolution and the collective push and pull of tempo. This looseness of temporal precision is simply not a salient feature in many other musical practices such as hip-hop, funk, and metal, not to mention the hyper-precise style of DCI drumlines.

> Groove has no correlate in European concert music, and is therefore indescribable by models derived from it. Groove-based musics do not often feature the phrase-final lengthening, *ritardandi*, *accelerandi, rubati*, or other expressive tempo modulations of European classical music; rather, they involve miniscule, subtle microtiming deviations from rigid regularity, while maintaining overall pulse

[55] Rudolf A. Rasch, "Timing and synchronization in ensemble performance," in *Generative Processes in Music: The Psychology of Performance, Improvisation, and Composition* ed. John A. Sloboda et al. (Berkley: University of California Press, 1988), 79.

isochrony. This mode of rhythmic expression has a whole tacit grammar unto itself, with its own set of esthetics, techniques, and methods of development.[56]

In a network music performance where musicians are separated by a rhythmic value of time, an isochronous pulse holds them together. If the musicians are trained to maintain that pulse even when there are slight variations, rather than blend to fit an expressive temporal shift, the tempo will remain constant. Furthermore, if network jitter induces subtle microtiming deviations outside of the performer's control, perhaps it could contribute to a "network feel."

3.4 Software Implementation

Up to this point, the strategies addressed can be achieved with the native network-induced delay between two nodes. Meaning, the amount of latency is fixed and therefore determines the tempo and rhythmic unit possible for two performers. In the example above, a round trip time of 500ms relegates performers to distributed patterns at either 120bpm or 60bpm in a duple meter or 80bpm or 160bpm in a triple meter. To extend this strategy to more than two nodes however brings a host of new considerations. As Ken Fields points out, "trans-chronotopic metricity" can prove quite difficult and the network rarely provides convenient temporal ratios between connected nodes.[57]

Therefore, my research has sought to offer a sort of temporal calibrator. Built in the programming environment Max/MSP,[58] this tool (often called a "patch") can be used to align the audio stream traveling to and from a remote node to a user-defined rhythmic

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[56] Iyer. "Microstructures of Feel, Macrostructures of Sound: Embodied Cognition in West African and African-American Musics," 16.
[57] Kenneth Fields. "Syneme: Live." *Organised Sound* 17, no. 01 (February 14, 2012): 86–95.
[58] "Cycling '74," accessed May 2016, https://cycling74.com

value of time (quarter note, eighth note, etc.), given that the value is not *less* than the inherent network latency.

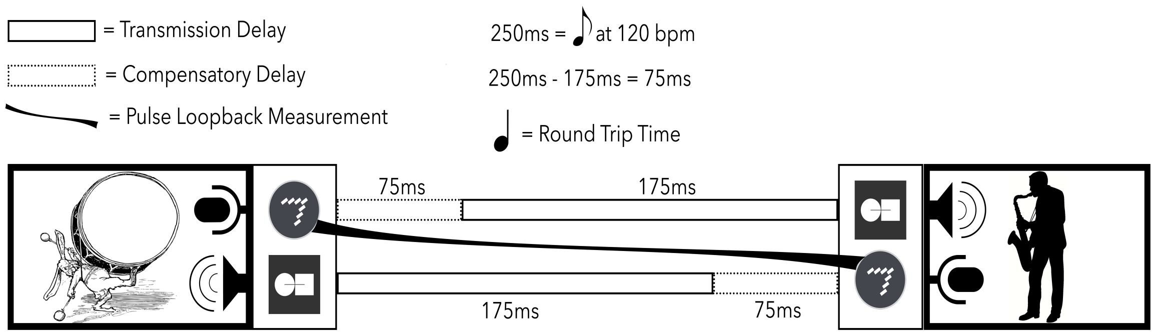

Figure 3. Core functionality of the software

3.4.1 Latency Measurements

The patch first determines the amount of latency in the network with the Pulse Loopback Measurement (PLM). This is achieved by sending a click through a dedicated channel of audio to the remote node, which is routed directly back. The amount of time elapsed between when the click is sent to when it is received tells us the signal's round-trip time. That number is then divided in half to establish a one-way time (assuming symmetrical signal paths). The time found by the PLM gives us the total Transmission Delay. With this number in place we can then add a Compensatory Delay that aligns the signal to the desired rhythmic value at any desired tempo.

Additionally, if the signal paths are not symmetrical across the network, or if there are any other unforeseen factors introducing latency, the option of "temporally tuning" the signal is available. This is done like other forms of tuning, by listening. I have found the most accurate way to tune is with eighth notes at a moderate tempo. The user pulses at the chosen tempo (with a metronome), that sound emerges in the remote location and is fed directly back. The user then adjusts the amount of delay until the local sound and the fed back sound are tightly synchronized. Performing this act also has a way of helping the performer focus on micro-timing variances in their own playing.

3.4.2 Additional Functionality

In addition to acting as a temporal calibrator, the patch utilizes the User Datagram Protocol (UDP) to exchange control messages. Firstly, this allows one node to set the tempo for all other nodes reducing the possibility for accidental miscalculations, but it also opens up another line of message-based communication that can be used for a variety of other functions.

3.4.3 Artsmesh and Jacktrip

One of the pioneering pieces of software that facilitated network music performance was Jacktrip[59] and the JACK audio server.[60] Developed in 2008 by Chris Chafe and Juan-Pablo Cáceres at CCRMA, Jacktrip has come to be the "industry standard" for exchanging high quality, uncompressed audio over the internet with as little latency as possible. Routing audio channels and setting preferences for Jacktrip can be done with a number of different Graphical User Interfaces (GUIs) such as JackPilot[61] and qjackctl.[62] However, even with the aid of these GUIs in routing audio, the connection between two computers must still be done with commands in a terminal window, as seen in figure 3.3.

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[59] Juan-Pablo Cáceres and Chris Chafe. "JackTrip: Under the Hood of an Engine for Network Audio." *Journal of New Music Research* 39 (2010): 183–87.
[60] "JACK Audio Connection Kit," accessed May 2016, http://jackaudio.org
[61] "Jacktrip for OS X," accessed May 2016, https://ccrma.stanford.edu/software/jacktrip/osx/index.html
[62] ibid.

```
Ethan-Caykos-Macbook-Pro-2:~ Ethan$ jacktrip -c 136.159.206.255 --clientname Node2 -n2 -b16
SETTING ALL PORTS
Setting JACK Process Callback...
SUCCESS
---------------------------------------------------------
The Sampling Rate is: 44100
---------------------------------------------------------
The Audio Buffer Size is: 128 samples
                      or: 512 bytes
---------------------------------------------------------
The Number of Channels is: 2
---------------------------------------------------------
Using UDP Protocol
---------------------------------------------------------
Peer Address set to: 136.159.206.255
---------------------------------------------------------
UDP Socket Receiving in Port: 4464
---------------------------------------------------------
Waiting for Peer...
```

Figure 4. Jacktrip connection in a terminal window

Until very recent efforts by Dr. Lawrence Fyfe, a teaching assistant with Chris Chafe and Stanford University's Online Jamming and Concert Technology Kadenze course,[63] the installation process for Jacktrip was very involved and dissuading for musicians who may not be familiar with shell commands in terminal. Furthermore, as operating systems continue to update so must Jacktrip and JACK, making the use of these programs a moving target. This is the nature of computing and should not be seen as a drawback or a barrier to entrance into the field. Rather, the efforts of educators like Fyfe and Chafe in rendering the technology transparent are made all the more valuable.

Another step toward accessibility of network music performance is in the Digital Presence Workstation (DPW) Artsmesh.[64] In development by Ken Fields at the Central Conservatory of Music (CCOM) in Beijing, Artsmesh seeks to reduce the complexity of network music performance and bring all the aspects of audio and video transmission into one piece of software. In addition to facilitating the routing of audio and video signals

[63] "Online Jamming and Concert Technology," accessed May 2016, https://www.kadenze.com/courses/online-jamming-and-concert-technology-iii/info
[64] "Artsmesh: Live Network Music Performance," accessed May 2016, http://artsmesh.com/index.html

among numerous nodes in a performance, Artsmesh offers a host of other features including a digital score follower, clock synchronization, OSC functionality, and its own social network environment that allows practitioners to find each other easily, promoting collaboration. Over the past two years, I have actively tested and practiced network music using this software and although the development process is a fairly slow one, its implications are exciting to say the least.

Chapter 4: Survey of Compositions

4.1 Toward a Toporhythmic Technique

When composers write a musical phrase they have an idea of what that phrase sounds like, either by hearing it in their mind's ear, by performing it on an instrument, or by playing it on a computer. That phrase may involve multiple lines or contours consisting of multiple instruments or timbres, but it is one thing, it is in one order; it may be multiple but it is not yet a multiplicity. In network music, we compose multiplicities.

A single musical phrase has as many forms as there are nodes involved in the performance of it, therefore composing music of this sort requires a special methodology. Similar to the way we understand four-dimensional shapes by their three-dimensional shadow, a composer of network music can only empirically hear one stream of events at a time, but is aware of how those events relate to each other and subsequently unfold in all performance spaces.

The argument could be made that all music is a multiplicity because every brain that processes the sounds entering a listener's ears, hears them differently. A listener's location in the performance space, their training in listening, their level of hearing deterioration, attention, or even their level of gastrointestinal distress at the time of listening all contribute to the way an individual is going to perceive the performance of a piece of music.

However, many of these factors are out of the composer's control, regardless of intent. The instant a sound is made, its ownership is relinquished to the listener. This is no different in network music and in fact, the situatedness of the listener contributing to their multiple receptions of sounds is again, multiplied by the number of physical locations involved in the performance. So, how does one go about creating music that functions in several forms simultaneously? This research addresses that question by proposing a *toporhythmic* technique.

Derived from the Greek *tópos* meaning "place", toporhythm offers a useful and concise term for constructing patterns that vary depending on location. I emphasize that toporhythm is more of a technique rather than a phenomenal occurrence like that of a polyrhythm. A listener cannot *hear* a toporhythm; they simply hear the music that is unfolding in their local listening space. Rather, the composer or performer constructs music toporhythmically by considering all the possible outcomes of a specific pattern in relation to the other patterns at the remote nodes.

This does not require any drastic changes to current notational techniques. The only difference is that each location has its own *score* not just its own *part*. This way, within a single location a performer need not change their practice in reading music. They simply read their part and hear the other parts as notated on the page as the composer has already compensated for the rhythmic displacement. In the following sections I will describe my notational methods in regard to this manifold music.

4.2 *Topologies*

In conceptualizing the toporhythmic technique, I composed a piece of process music called *Topologies.* In instrumentation (human hands) and form (rhythmic phase shifting), it pays homage to Steve Reich's *Clapping Music,* but the process does not function in exactly the same way. The piece was made out of a desire to adequately demonstrate how complex rhythmic interactions naturally reveal themselves in manifold music, even when the sonic material is as stark as possible. To describe the piece's process I will first return to the role of the initiate node (IN) now in a tri-located performance.

As previously discussed, the IN sets the downbeat for all other nodes, effectively establishing the metric anticipatory scheme. In figure 2 there were only two nodes involved. This meant that their rhythmic topology was made up of only two variable rhythmic units, which happened to be an eighth note in both directions (quarter note RTT). In *Topologies,* there are three performance spaces, each related by a different rhythmic value. This increases the possible amount of rhythmic relationships to six variable rhythmic units because each node's relationship to every other is a composite of their one-way latencies.

In fact, as more nodes are added to any toporhythmic network music performance, the relationships in the rhythmic topology can be found with elementary combinatorics. To determine the possible amount of rhythmic variables from a total of n nodes we use $n!/(n-2)!$ which simplifies to $n(n - 1)$. This tells us that a four node rhythmic topology has twelve possible rhythmic variables, five nodes has twenty, and so on. The system allows for asymmetrical relationships within the rhythmic topology (ie. an eighth note from Node 1 to Node 2 but a quarter note from Node 2 back to Node 1). However, *Topologies* maintains a symmetrical rhythmic topology for the sake of clarity.

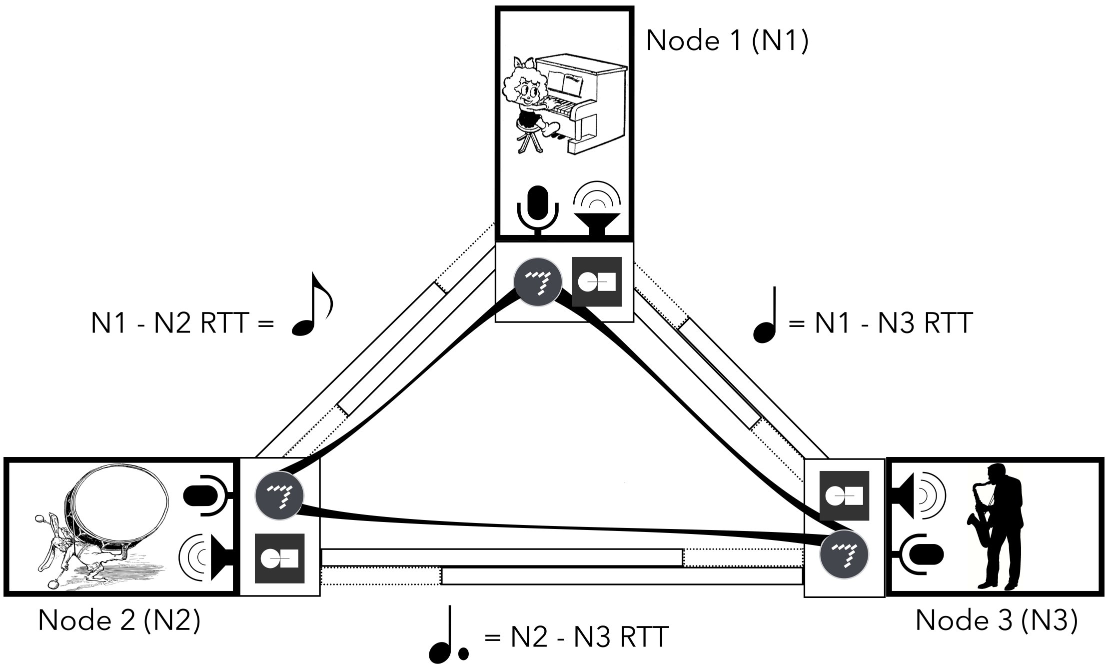

Figure 5. Rhythmic topology among nodes in *Topologies*

Within a fixed rhythmic topology the role of the IN can switch between performers. *Topologies'* main underlying process explores the rhythmic and metric results of this shift in role. The piece begins with Node 1 (N1) as the IN. N1 simply begins clapping an eighth note pulse at the desired tempo. When the other two nodes have begun clapping in unison, N1 starts the seven beat pattern. As each of the other nodes joins in with N1, their returning pattern is displaced by their respective RTT rhythmic values. In turn, the performers shift their pattern within the seven beat meter to result in one *tutti* measure for each node. Once this has completed, the performers return to an eighth note pulse and a new node assumes the role of IN. Thus, the rhythmic configuration in relation to the IN is rearranged and a new metric starting point is established.

In order to keep track of each node's role as they shift, I felt the additional terms penultimate node (PN) and terminal node (TN) were beneficial. Figure 6 illustrates measure 16 of *Topologies* in a binary notation that allows a view of all three nodes at once. At this point in the piece, Node 3 (N3) is the IN, N1 is the PN, and N2 is the TN. An examination of the figure shows us that in order for the TN to hear all parts in unison the other nodes need to place their pattern on a different part of the seven beat meter. Also, bear in mind that the rhythmic topology is still the same among nodes. For instance, the downbeat at N3 takes three sixteenth notes to reach N2 and another three for N2's unison attack to get back, resulting in the dotted quarter RTT.

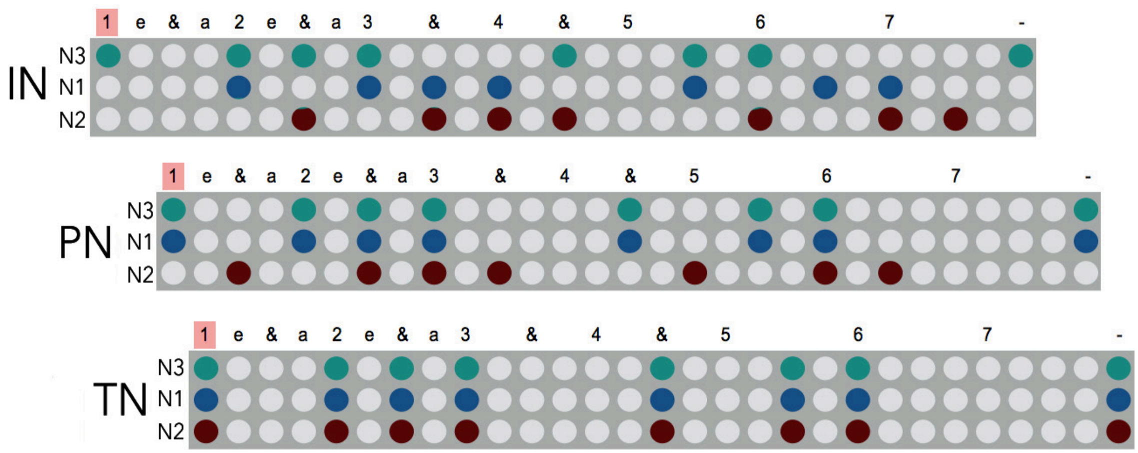

Figure 6. Rehearsal mark G, *tutti* at the terminal node

After composing and performing the piece, I found many surprising and delighting formal rules that make this type of music making a potential playground for serialist procedures and organization. A complete analysis of the piece is not necessary in this document but may be of interest in the future. The set of three scores can be found in Appendix A.

4.3 *Blind Men and the Elephant*

> Things happen for reasons. You can't quite catch what they are, because they're not linear or obvious. But listen: The same elements keep coming back, and while it's not important that you figure out when and why, it's enough to sense, deep down, that nature has its processes. – Kyle Gann[65]

The manifold nature of network music can afford more than just rhythmic complexity. Because network music exists in the decentralized space of the internet, it allows for new forms of participation, different approaches to listening, and new dramaturgical models that artistically consider the multiplicity of distributed performances. Perhaps with a foolish youthful ambition, *Blind Men and the Elephant* aims to integrate all of these affordances while also demonstrating the toporhythmic technique in a tri-located performance.

First and foremost, I wanted to create a piece of music that gave the listeners agency and an ability to shape their listening experience in realtime. Audience participation can come in many forms, some more active and more direct than others. In *Blind Men and the Elephant* I did not want to require participation, only offer it. Also, as accessibility has maintained a constant presence in my research, I sought to use a form of electronic participation that required little premeditation on the part of the listener. This was achieved through the use of Twitter.[66]

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[65] Kyle Gann. The World in Little Bits, *Village Voice,* May 17, 2005, http://www.villagevoice.com/music/the-world-in-little-bits-6403631
[66] "Twitter," accessed May 2016, https://twitter.com

The score for *Blind Men and the Elephant* comes in the form of a series of repeating modules that are each one measure in length and are read on a computer screen in front of the performer. The instrumentation is variable but requires two polyphonic instruments and one monophonic instrument in a low register. In some modules, performers are given a set of pitches and a corresponding rhythm, but the pitches can be played in any order. In others, pitches are given in a certain order but the rhythm can be improvised. While in others, the modules are through-composed. The time signature of each module is different and there are several forms in which each module can be presented. A compilation of the score's elements can be found in Appendix B.

The piece is broken into four sections with a number of modules for each section. Performers progress through the modules at will, but each section lasts a fixed amount of time. Between each section the performers return to a "pivot" module which acts in a similar way to the pulsed eighth notes in *Topologies* by allowing performers time to settle into the pulse before entering the next section. To cue each new section, a second performer in each space emerges in time with the pulse by either clapping or playing a small percussive instrument, and over about 15 seconds the cue diminuendos to silence and the performers move on.

Within each section, the module a performer is currently reading from can change due to an audience member's participation. For each module, there is a legato version, a staccato version, a version with an accent pattern, and a version that changes dynamic. An audience member simply needs to send a tweet that includes one of the terms, "legato", "staccato", "accent", or "dynamic", and includes the username "@telephantmusic". At numerous unknown points in time, the software built for the piece will search Twitter for these specific tweets and when they are found, the software changes the performers' score to reflect the audience members' suggestions.

Due to the fact that the score can change dynamically, it is necessary that the score is digital. In addition, the material needs to be composed in a way that allows performers to make the required adjustments while maintaining continuity. The use of repeating modules not only addresses this issue, but also suggests a different mode of performance and listening. Iyer comments on this by saying:

> I have experienced one of the most interesting musical revelations of my life, gradually over the last several years, in studying West African dance-drumming and in playing jazz, hip-hop and funk. The revelation was that the simplest repetitive musical patterns could be imbued with a universe of expression.[67]

The longest of the four sections of the piece lasts 392 seconds. In that time, performers progress through only six different repeated modules. This makes for long spans of time where performers are repeating the same phrase over and over. While in the midst of this act the performer must remain actively engaged, not only because of the obvious reason that they are performing music, but also because each performer is playing in a meter unlike the one a remote performer is playing. Therefore, one cannot mindlessly "check out" and catch up in the next measure. Each performer maintains their local cycle of time, which becomes engrained in their bodily movements, as much as it does in their aural and intellectual understanding of the musical phrase. When a change

[67] Iyer. "Microstructures of Feel, Macrostructures of Sound: Embodied Cognition in West African and African-American Musics," 58.

occurs in the performers part, the subtle, or not so subtle, shift in articulation or accent pattern elicits this "universe of expression" Iyer mentions.

It is my hope that the listener also remains active in the midst of the polymetric repeating modules. Once an understanding of each phrase is entrained, the listener can mentally "step back" and identify larger structures emerging in the sonic texture, be they upper harmonics, or hyper-metrical arrival points. Moreover, the listener can decide at any point that they would like some sort of change in sonic color or shape. In that moment they can act on that decision with a computer or mobile device using the network, and their desire will be met.

4.3.1 New Music Ensemble Performance

On March 28th 2016, *Blind Men and the Elephant* was performed by members of the University of Calgary's New Music Ensemble. In the two months leading to the performance, quality rehearsal of the music was limited as the technical setup absorbed most of the allotted rehearsal time. This, along with performer error on the day of the concert, made for a regretfully rough performance. However, the performance highlighted a number of interesting considerations in network music of this kind.

Franziska Schroeder and Pedro Rebelo[68] have discussed at length the usefulness of dramaturgy in, "addressing design strategies and performative relationships in networked environments."[69] In *Blind Men and the Elephant,* I wanted to address every possible aspect of the networked environments, from the arrangement of the performance spaces to the visual aesthetic of the software interface and web presence. The title of the piece

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[68] Pedro Rebelo. "Dramaturgy in the Network." *Contemporary Music Review* 28, no. 4–5 (2009): 387–93.
[69] Franziska Schroeder. "Dramaturgy as a Model for Geographically Displaced Collaborations: Views from Within and Views from Without." *Contemporary Music Review* 28, no. 4–5 (2009): 377–85.

reflects the ideas conveyed in the process of network music by being derived from an ancient parable about individual perspective. I wanted a dramaturgical model for every step in the piece's conception and realization. I became very aware however, that the network provided them for me, rather than me applying them to the networked context.

As the performance was about to begin, I took my place in one of the three performance spaces on the university's campus. The main performance space was in the basement of the school of music. I was one floor up in another performance space, and the third performer was in a studio in an adjoining building. Half of the audience was directed to the performance space in which I was located, and the other half would remain in the main performance space, while the third space contained only the performers and a technician.

After my local audience arrived, I asked the performer in the main space, via the microphone, if we could begin. He remarked that we should wait a while longer to allow more audience members to arrive. As I waited, I began explaining the process of the piece to my local audience. Upon receiving no signal from the main performance space to begin the piece, I continued talking about the piece for some time. Little did I know that back at the main performance space, the audience had all arrived, the door had been shut, and they were anxiously waiting for me to stop rambling and get on with the show.

This set up a rather tense and nervous atmosphere in the main performance space exacerbated by the fact that I was not speaking directly into the microphone, so my voice in the main performance space was difficult to hear. However, in my space the audience was excited, enthusiastic, and now well informed. After the performance I talked to several audience members, some from the main performance space, and some from mine; their impression of the piece could not have been more different.

In conclusion, the process of the piece's composition and performance was an enriching, educational, and completely unfamiliar experience. This is in part because of the manifold nature of the music, but also because I explored serialist procedures for the first time. A detailed analysis of the procedures used is beyond the scope of this document, but in general I chose to derive the piece's various meters, tempo, and overall structure from the first nine triangular numbers.[70] The numbers provided the framework in which I was able to develop and reveal interesting musical correlates. The use of serialist procedures was done for a number of reasons, but was primarily due to a curiosity for the way complex organisms move within fixed systems. I abhor strict rules and absolutes, so I imposed them on my compositional process and challenged myself to navigate them. Also, given the framework of a constant pulse, I wondered how performers would navigate the range of repeated overlapping polymetrical modules while retaining some improvisational freedoms.

Looking back, I felt that the process of composition as well as the performance of the piece resembled the manner in which a vine grows along lattice. It clings to the lattice's rigid lines, even relies on them, but does not trace them directly. As three sonic vines in time, our performance of *Blind Men and the Elephant* may have had a number of bugs, but was healthy.

[70] 1, 3, 6, 10, 15, 21, 28, 36, 45. (excluding 0)

4.4 *BeijCalgIndi*

Another recent performance that exemplified the network's ability to connect vast distances was that of *BeijCalgIndi*. Unlike the previously mentioned works, *BeijCalgIndi* was a structured improvisation rather than a through-composed piece. The impetus for the performance was IUPUI's[71] Telematic Collective concert. The performance took place on the evening of April 25th in Indianapolis and Calgary, and the morning of April 26th in Beijing. Due to the improvisatory nature of the piece, less effort was directed toward complex rhythmic structures. Instead, a sort of distributed rhythmic backing track was used to help maintain a temporal cohesion.

The backing track was meant to function as a rhythmic analog to the tanpura[72] by providing a foundational sonic element over which other elements could be improvised. Like a tanpura, it supplied a tonal center, although it also provided an underlying pulse and subtle rhythmic activity, as well as structural changes within the piece, all while remaining in the background, allowing the improvising instrumentalists the sonic foreground.

My patch was used to align our latencies to a rhythmic unit, although the style in which the musicians improvised did not necessarily require strict rhythmic alignment, and the backing track provided a temporal stability. The instrumentation was electric bass in Beijing, electric guitar in Calgary, and alto saxophone and drums in Indianapolis. The rhythmic backing track was played from Beijing, which effectively made that node the IN. However, the effect of the rhythmic displacement was navigated by ear in the moment, rather than by notes on the page.

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[71] Indiana University Purdue University of Indianapolis
[72] A large chordophone used as a drone accompaniment

There were numerous notable moments in rehearsal and during the performance. At times, I felt as if I were playing *outside of myself* in that I was aware my sounds were arriving at a different point in time at the remote nodes, so I would actively play where I would usually leave negative space and vice versa. I found myself closing my eyes more often and drawing inwardly to examine the sound alone. I thought less of my physical actions themselves, and more of the sounds that resulted from them. Franziska Schroeder speaks of performance in this context as follows:

> The absence of communal breathing, the impossibility of glancing at the other, reinforces the performative body as one that is present while noticing itself being present in the presence of absent others. It is this lack of being able to rely on the physicality of the other performative bodies that urges a particular fine-tuned listening, asking the performer to abstain from some of her learned expectations or experiences.[73]

Admittedly, our performance was not free from learned expectations and experiences. The performers' backgrounds in music training were diverse and each one brought their own strategy and technique to improvisation in this medium. Also, as with *Blind Men and the Elephant,* rehearsal time was limited. Due to unforeseen issues with time zones on the day of the performance, we had less than 20 minutes to set up a tri-located trans-pacific network music performance, but we pulled it off.

[73] Franziska Schroeder. "Network[ed] Listening—Towards a De-Centering of Beings." *Contemporary Music Review* 32, no. 2–03 (2013): 215–29.

Chapter 5: Conclusion

5.1 Contributions and Future Work

The overarching objective of this research is in providing a trajectory that narrows the gap between musicians and music technology, particularly in the field of network music performance. The recent decades have seen major strides toward a seamless and transparent use of technology in the creative arts. However, it is evident that in most universities there is still a disparity between those who populate the practice room versus the studio, how those spaces are used, and the standard narratives that reinforce this distinction, whether purposefully or not. Subsequently, this disparity is perceptible in the works being performed in concert halls and in venues downtown. It is also evident in the estranged looks on many performers' faces when a microphone and computer are placed on stage with them, and the similar apprehensiveness of many music technology students asked to perform a jury.

However, as I am writing, the climate is changing (in more ways that one and for better or worse). Musicians in, out, and between academic circles are embracing technology in their practices. The studio, which was once exclusive to funded institutions, is now available to a much broader scope of musicians. A computer, audio interface, a microphone, some speakers, and a few cables are enough to reveal a world of creative potential. This research seeks to address and insert one more element in to that studio dynamic, that of a stable network connection. Even for those who are familiar with sound making technologies, communications technologies require an expanded vocabulary and an understanding of the current infrastructural climate of ISPs.

5.1.1 A Tool, a Technique, and a Series of Works

The more palpable contributions this research makes are in a basic software tool that facilitates rhythmic network music, a strategy for composing and performing manifold music, and a series of works that demonstrate this technique.

Max/MSP provided a simple language for creating my software. The tool needed to be as simple as possible to use, efficient in function, and attractive in form. Max/MSP was the optimal environment for reaching this goal. Going forward, I believe there are multiple ways to improve upon the tool.

Presently, the PLM (pulse loopback measurement) has no way of integrating the analog-to-digital and digital-to-analog conversion into the calculation. Including this factor would result in a more accurate compensatory delay and thus less temporal tuning would be required. Additionally, as DPWs like Artsmesh become more established, perhaps a "plug-in" functionality would be ideal for this type of tool, rather than operating in a third-party software application.

An understanding of rhythmic topologies and the toporhythmic technique has the potential to provide new perspectives and exciting challenges for composers and performers alike. It is my hope that other musicians find this affordance of the network as compelling as I do, and bring aspects of this research into their own practices. It has become evident to me that much of what the toporhythmic technique elicits sonically, bears a remarkable resemblance to the fields of Topology and Graph Theory. I use the terms *manifold* and *topology* because of their striking descriptive accuracy not because of any literal similarities to their meaning in mathematics, although some may exist. It could prove useful in future years to study the organizational principles of toporhythm purely through the lens of mathematics in order to reveal formal rules. Alternatively, perhaps the music can inform mathematicians' understanding of Topology.

Prior to creating the compositions described above, I wrote and performed a bi-located piece for percussion entitled *Network Gyre*. This piece was my first foray into the toporhythmic technique and was performed several times. The score can be found in Appendix C. Also, the exercises mentioned earlier were similarly bi-located, which makes the process of audio connection and rhythmic alignment drastically simpler. That simplicity is precisely the reason why all of the works described in this research were tri-located. However, due to the manner in which my technique makes connections and the style of performance, I found that adding large numbers of nodes would not be advantageous.

Firstly, this is because each additional node in a network, where all nodes are connected to every other node (known as a mesh network topology), increases the number of connections quadratically.[74] When using stereo audio, this means that with four nodes, each node must route twelve audio channels (six incoming, six outgoing). One can imagine that a network orchestra dynamic could quickly turn into a technical goat rodeo.[75] A solution to this problem could be in a different connection strategy, such as a star topology where each node connects to a central server that acts as a hub, receiving and distributing all the audio signals accordingly.

Finally, we have yet to scratch the surface of what can be done with two or three nodes. In my experience, the small chamber group, jazz trio, or small rock band dynamics

[74] "Network Topology" Wikipedia. accessed May 2016, https://en.wikipedia.org/wiki/Network_topology#Mesh
[75] "Goat Rodeo: A chaotic situation, often one that involves several people, each with a different agenda/vision/perception of what's going on" Urban Dictionary. accessed June 2016, http://www.urbandictionary.com/define.php?term=Goat%20Rodeo

are the most engaging forms of ensembles. They afford individuality while requiring interdependency. Tri-located or bi-located network music effectively renders each of the "members" in a trio into a multiplicity in and of itself that can potentially be populated by a number of performers each. My compositions offer only a sample of what can be done in this dynamic and further collaboration with composers and performers would be desirable. Recordings and videos of all the aforementioned compositions can be found online.[76]

5.2 Concluding Remarks

Network music performance is no longer in its infancy. It has learned to walk and is now learning to dance. Acknowledging the primacy of meter and pulse in musical practice, my research promotes a more rhythmically informed approach to the music created for networked performance.

The notion of a network has pervaded modern society as a prevailing organizational structure. In many countries, transportation of physical bodies as well as information has become much faster and more accessible than in the past. This has resulted in a sort of diffusion; more pluralistic and multicultural societies where communities overlap, intersect, and intertwine. As time passes, entropy increases, and this process viewed in society is one of conformation, resistance, diasporization, assemblage, and continual negotiation between the nodes themselves, and the system connecting the nodes. These are aspects of the flux in our societies throughout history, but could just as well describe an improvisation or composition of a piece of network music.

[76] "Thesis Material" Ethan Cayko. accessed June 2016, http://ethancayko.com/thesis-material/

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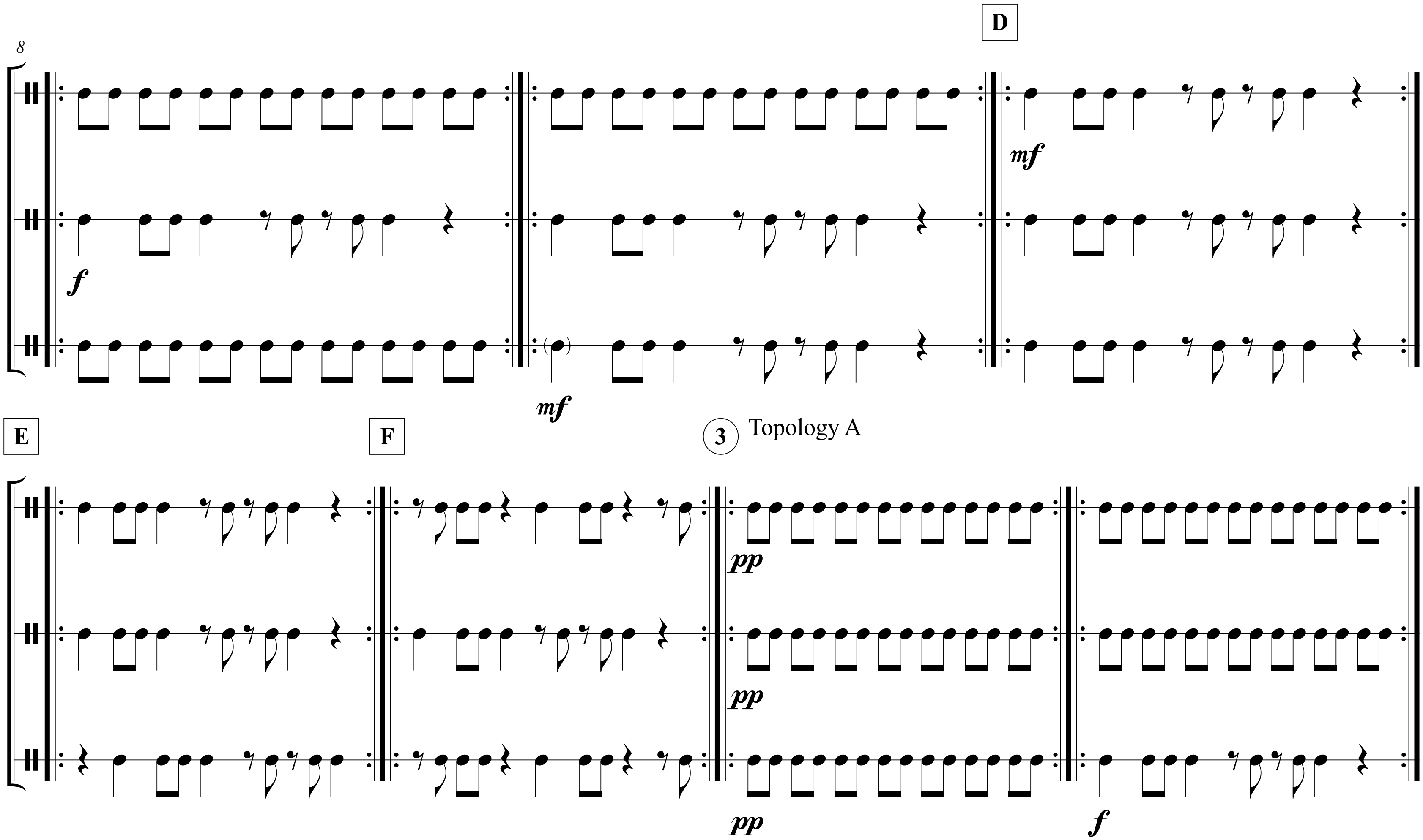
Appendix A: *Topologies* Scores

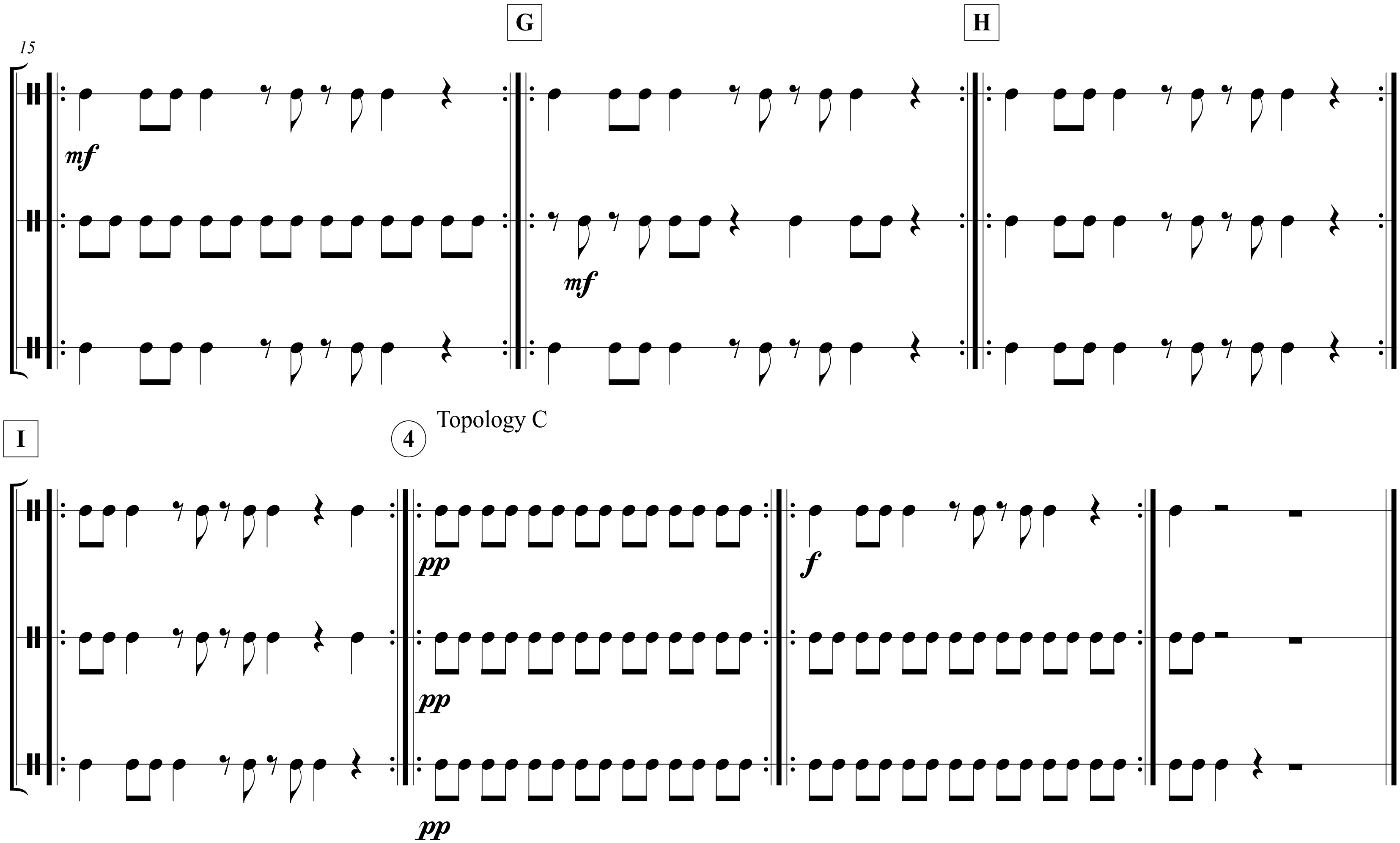
Topologies

for tri-located percussion

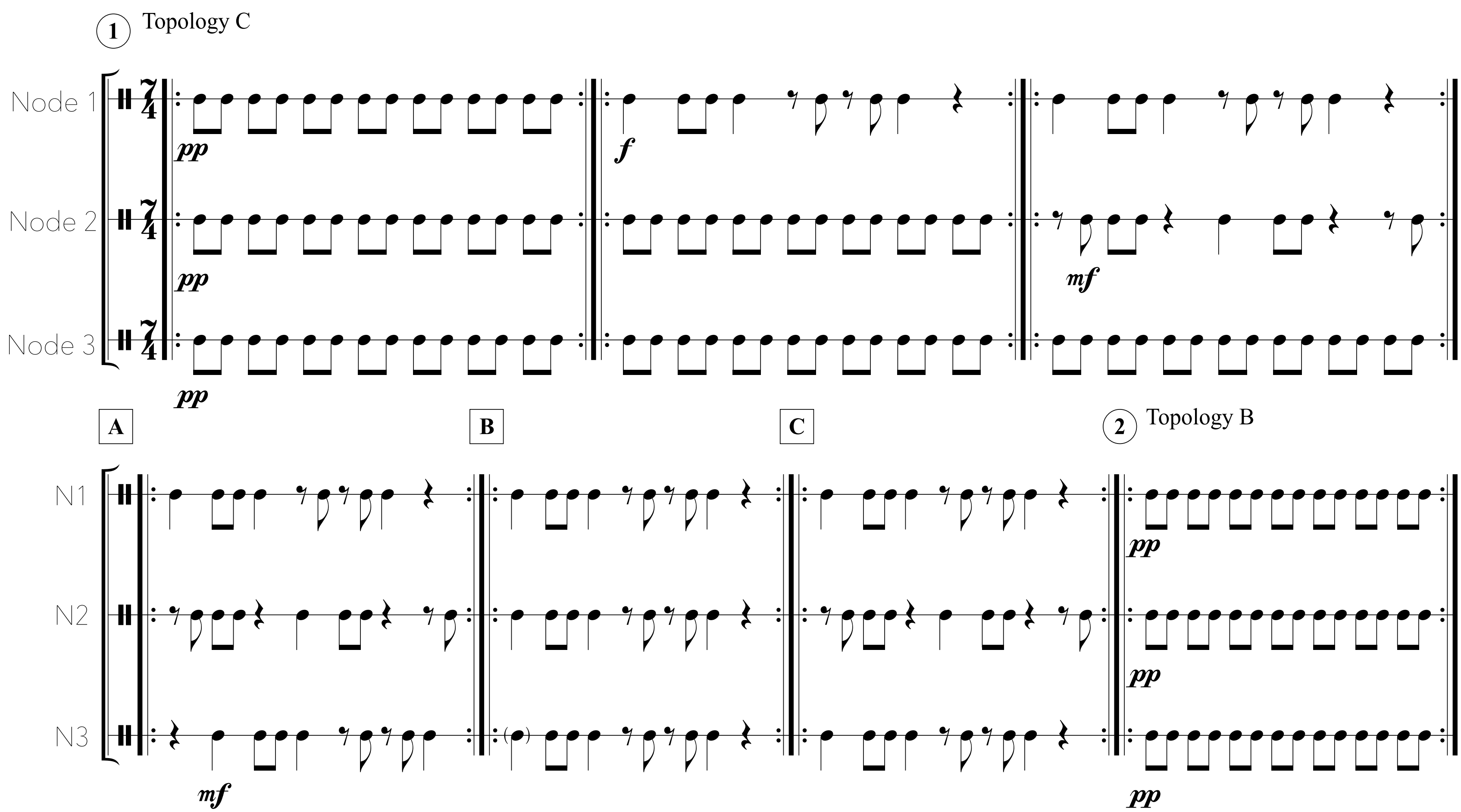
Node 1

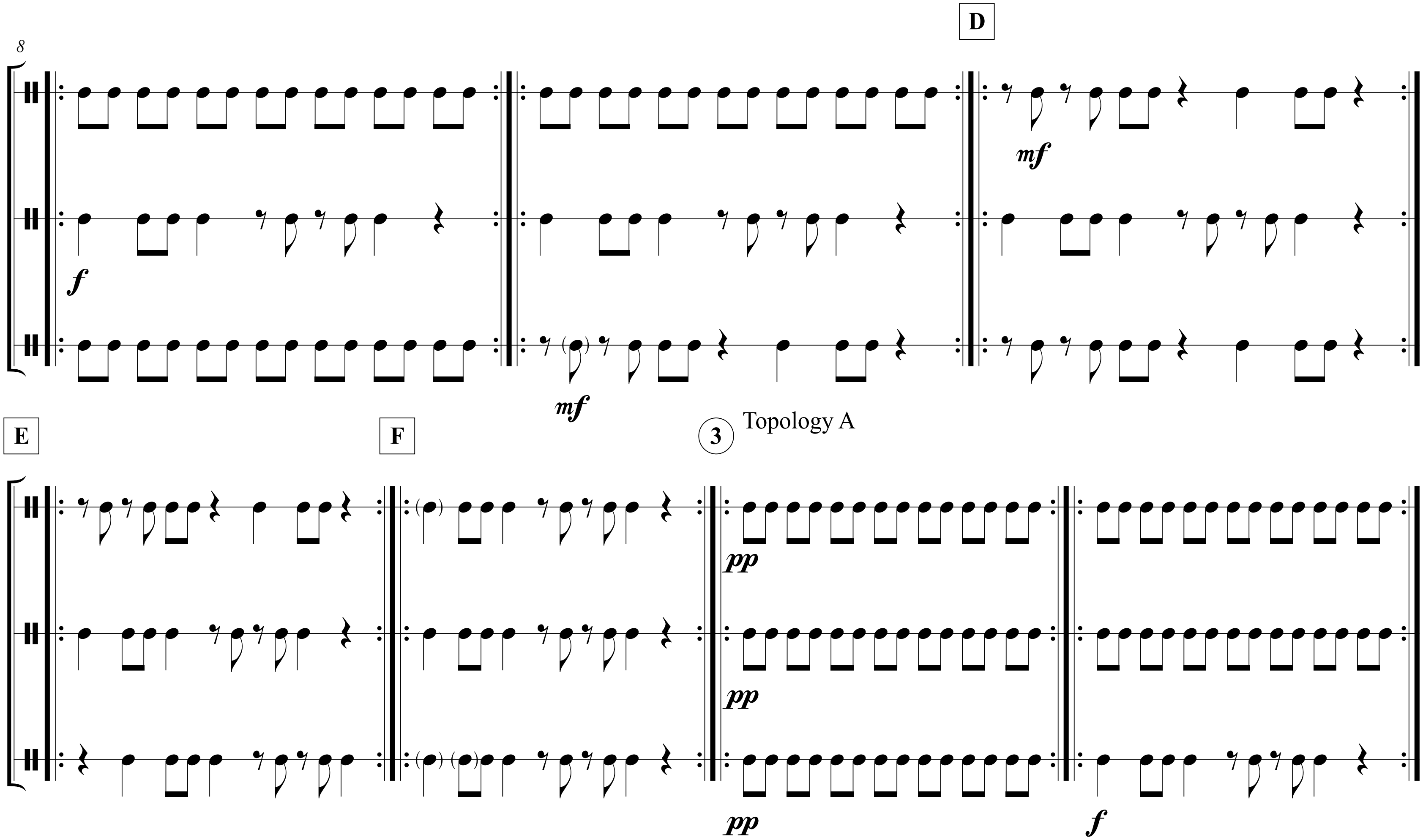

1
Topology C
Node 1
Node 2
Node 3
pp
pp
pp
f
mf
A
B
C
2
Topology B
N1
N2
N3
pp
pp

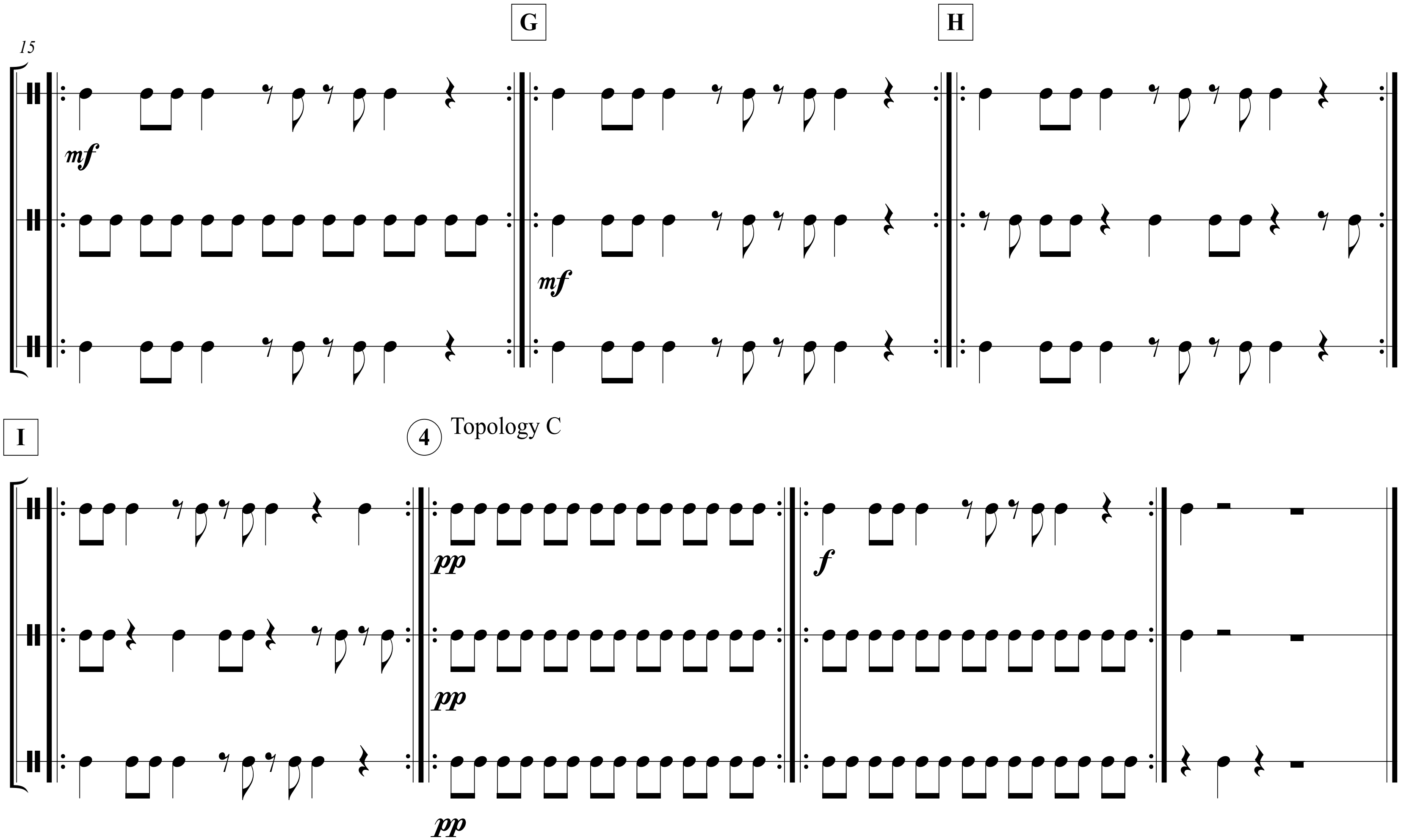

8
D
f
mf
mf
E
F
3
Topology A
pp
pp
pp
f


15
G
H
mf
mf
I
4
Topology C
pp
pp
pp
f

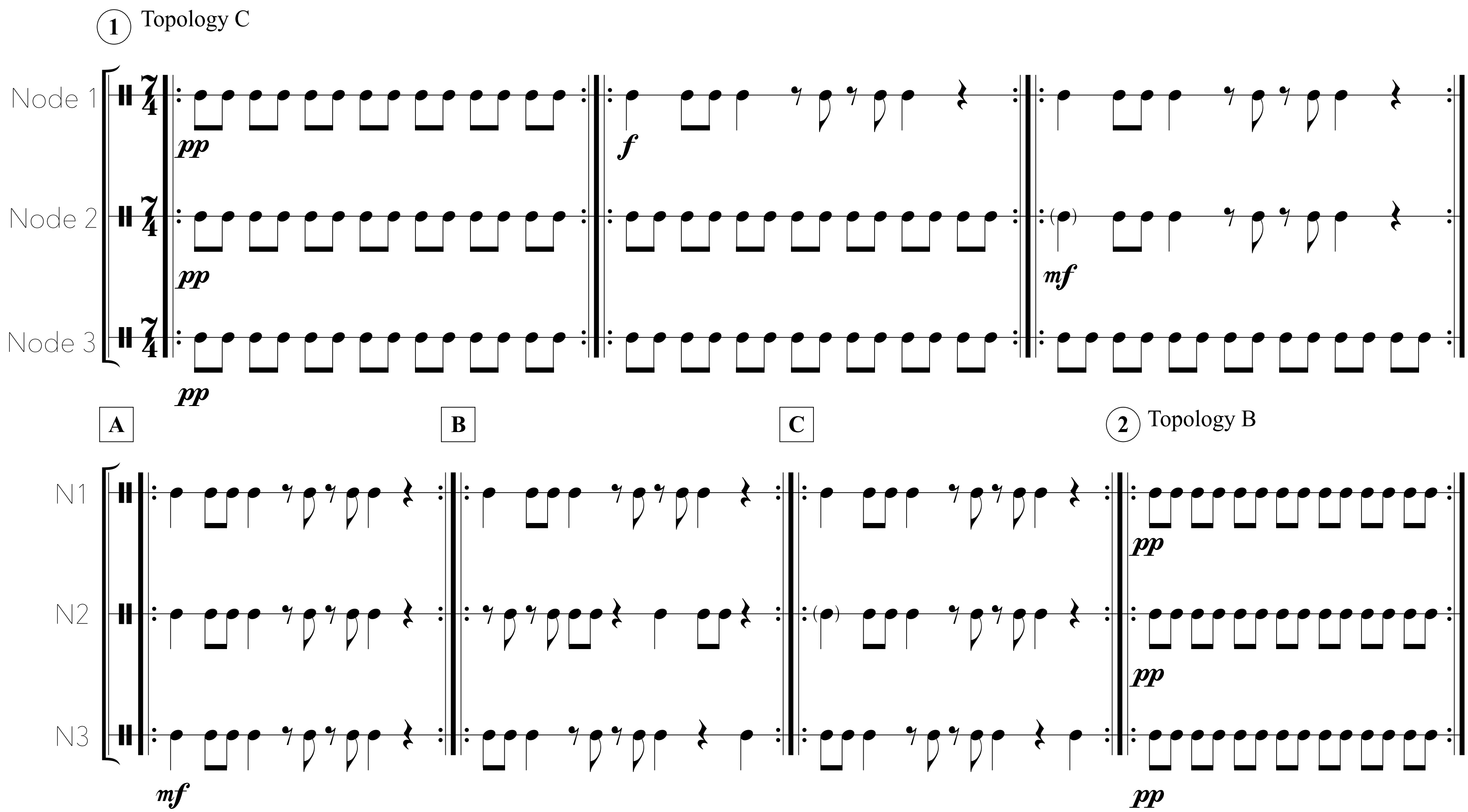
Node 2

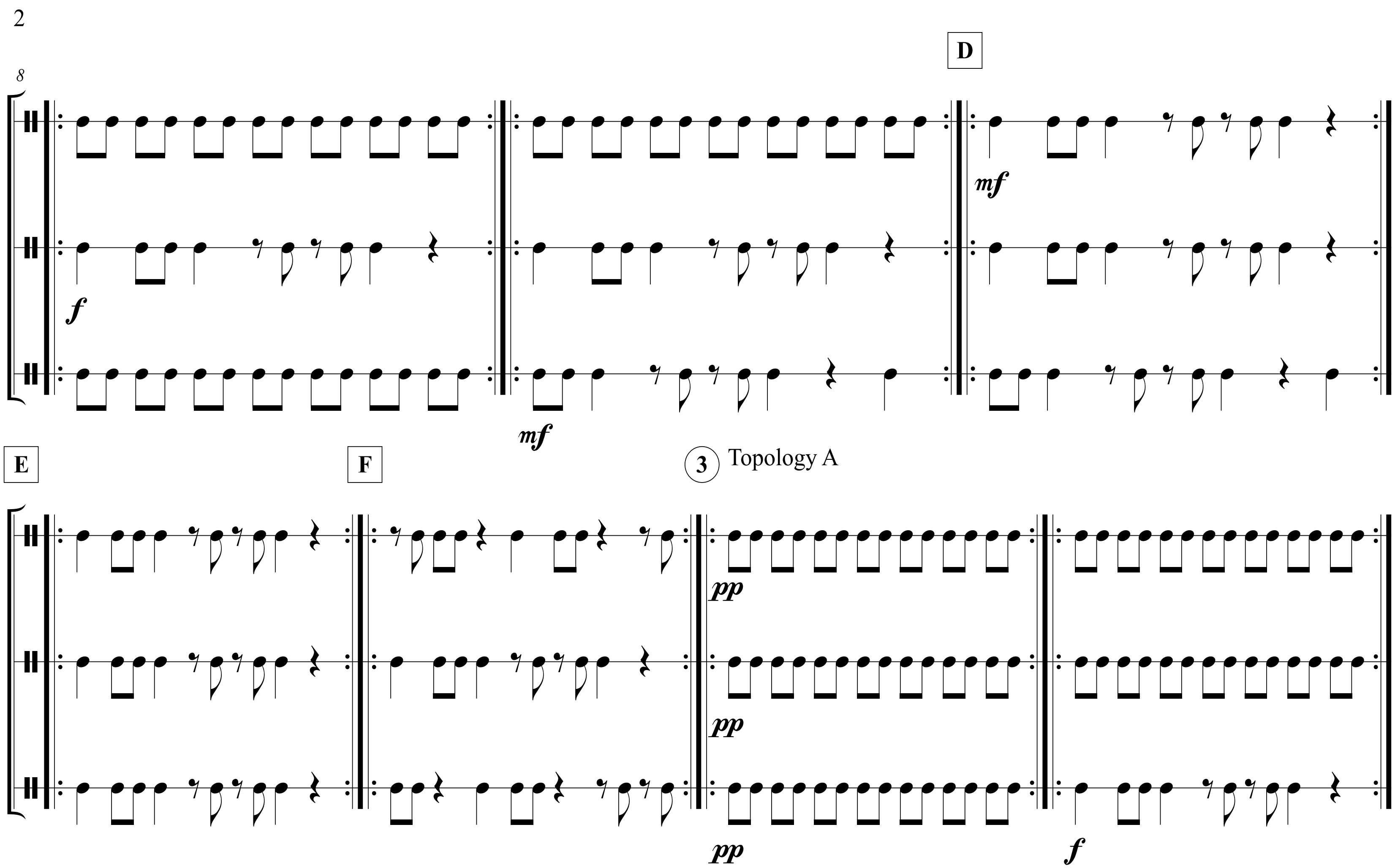


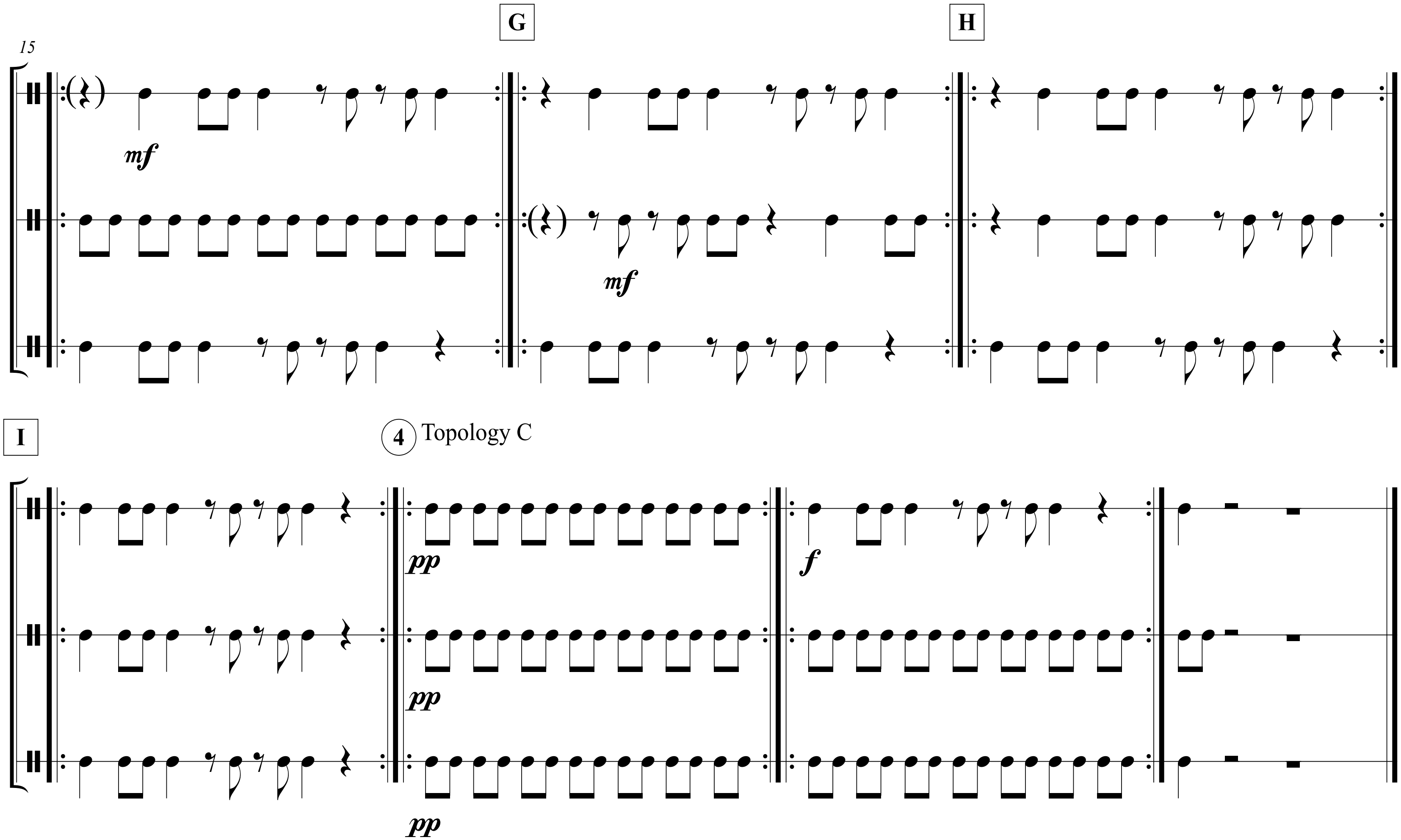

8
D
mf
f
mf
E
F
3
Topology A
pp
pp
pp
f


G
H
15
mf
mf
I
4
Topology C
pp
pp
pp
f

Node 3


1
Topology C
Node 1
Node 2
Node 3
7/4
pp
f
mf
A
B
C
2
Topology B
N1
N2
N3

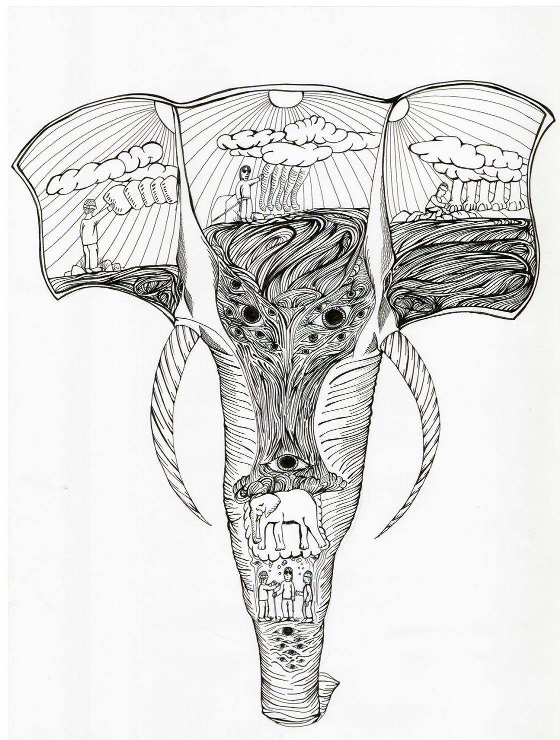

2
8
D
mf
f
mf
E
F
3 Topology A
pp
pp
pp
f


15
G
H
mf
mf
I
4
Topology C
pp
pp
pp
f

Appendix B: *Blind Men and the Elephant* Rehearsal Scores

Blind Men and the Elephant

for tri-located ensemble

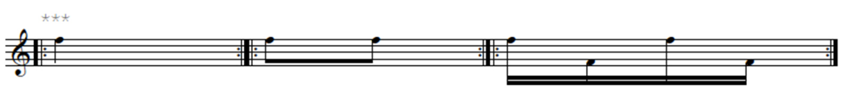


Notes about the score

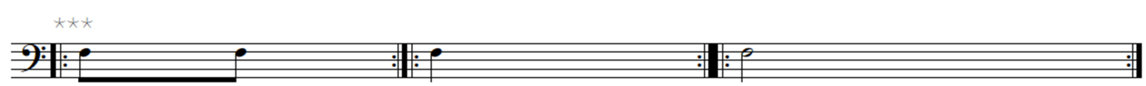
The following is a representation of the digital score used in performance and is intended for rehearsal and practice purposes.

The instrumentation for Blind Men and the Elephant is variable but Nodes 1 and 2 must be polyphonic and Node 3 must be able to reach G2. Also, the repetitive nature of the piece would prove difficult for instruments that require the performer to breathe often, such as woodwinds or brass. Nodes 1, 2, and 3 are solo performers but each is accompanied by a Cue performer. The Cues should be performed with either a small percussive instrument such as claves or by clapping.

There are four sections in the piece (A, B, C, and D) and each section lasts a certain amount of seconds. Modules within each section should be played left to right, top to bottom, but can be repeated as many times as the performer likes. The variants of each section (shown in a solid-line box) can arise at any time due to audience participation. When this occurs, performers continue playing their current module but change to fit the new variation. Each section concludes with performers returning to the "Pivot" module (shown in a dotted-line box). The "Cue" modules (shown in a dashed-line box) signify the ending of each "Pivot" and trigger the advancement into the next section.

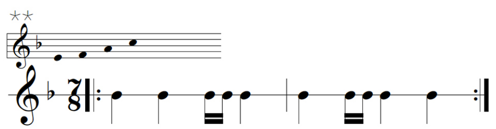


***
At the beginning, Node 1 initiates the piece by pulsing on a quarter note, Node 2 then joins in unison, followed by Node 3. When all nodes have arrived at a quarter note, Node 1 progresses to eighth notes, followed by Node 2, then Node 3. When all nodes have arrived at eighth notes, Node 1 progresses to sixteenth notes and the other nodes join as before. At this point, the clock is started in the software, and performers move into Section A.

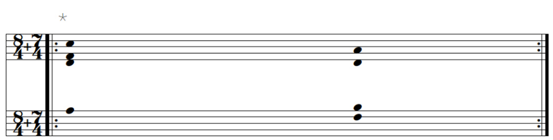


The conclusion of the piece functions the same way as the beginning, but in reverse. After the final cue, Node 1 moves to a quarter note pulse, followed by Node 2, then Node 3. When all nodes have arrived at a quarter note Node 1 stops, followed by Node 2, and finally Node 3 concludes the piece with half notes.

Notes about the Score



**
Modules with this indication are given a notated rhythm, and a series of pitches. The pitches can be played in any order, simultaneously as chords, or repeated as many times as the performer chooses but should always follow the notated rhythm.



*
Modules with this indication are given a series of pitches or chords with no particular rhythm. These should be played in the sequence given, which repeats after the length of the time signature. The rhythm can be improvised within the given meter and notes can be repeated before continuing to the next note in the sequence.

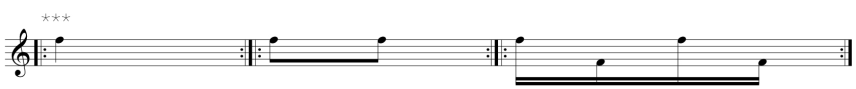
Transitions between modules should be smooth and seamless. Performers should focus on a continuity of sound and through the repetition become aware of tiny variances in each note. It is advised to memorize each module and become comfortable with the movements they require on one's instrument. Although performers should maintain consistency of sound, occasional small embellishments are encouraged, the score is a guide, not an absolute.

Blind Men and the Elephant

Node 1 rehearsal score

Beginning

Node 1



A

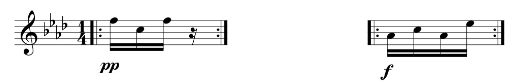
Node 1

A
Node 1

Staccato

A
Node 1

Dynamic



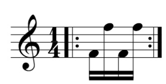
A
Node 1

Accent

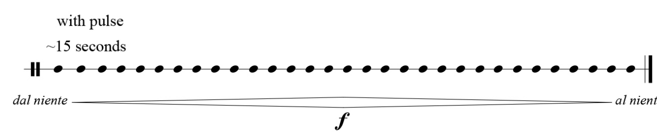
A
Node 1

Legato

Pivot
Node 1

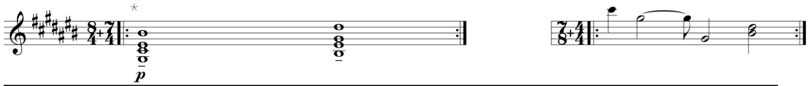


Cue



B

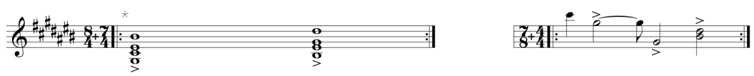
Node 1



B

Node 1

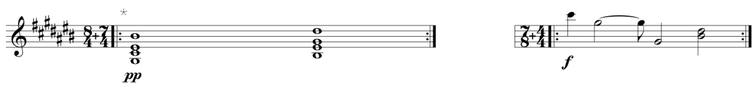
Accent



B

Node 1

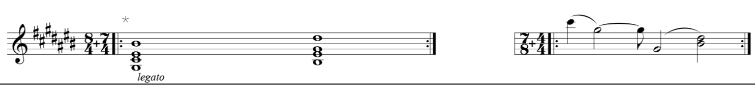
Dynamic



B

Node 1

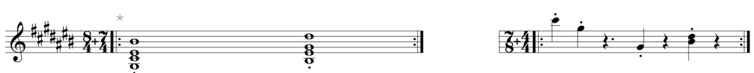
Legato



B

Node 1

Staccato



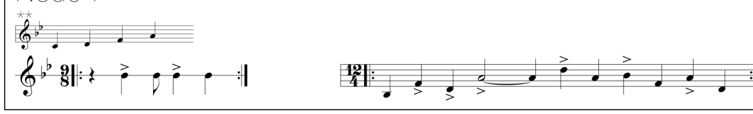
C

Node 1

C

Node 1

Accent



C

Node 1

Dynamic

C

Node 1

Legato

C

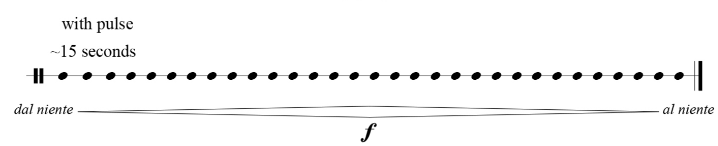
Node 1

Staccato

Pivot

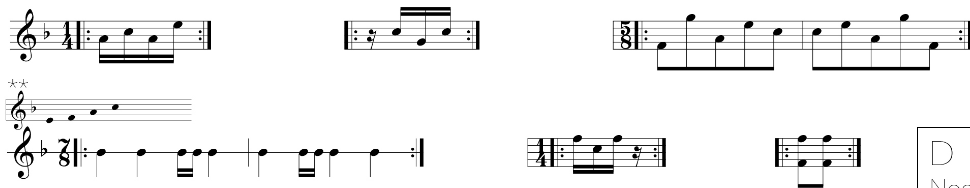
Node 1

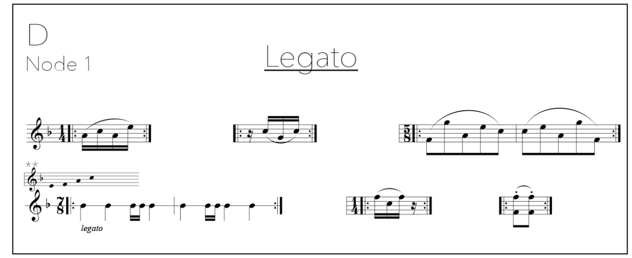
Cue

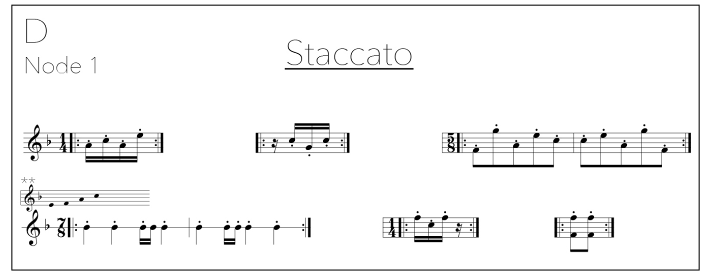


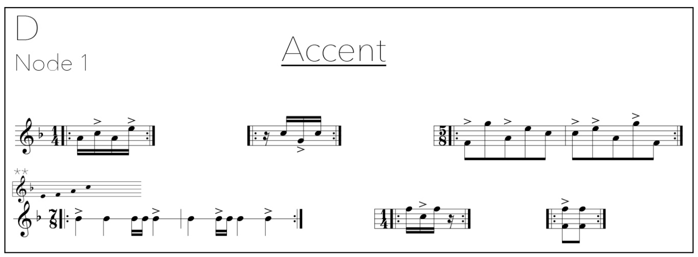
D

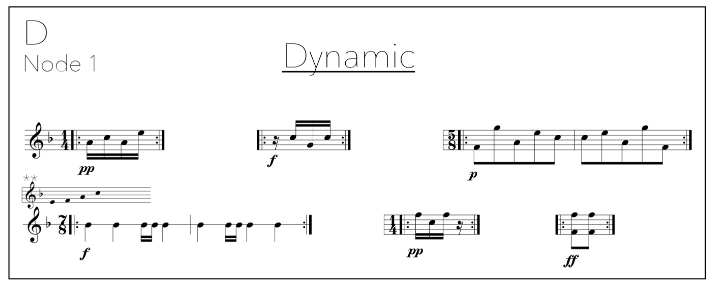
Node 1

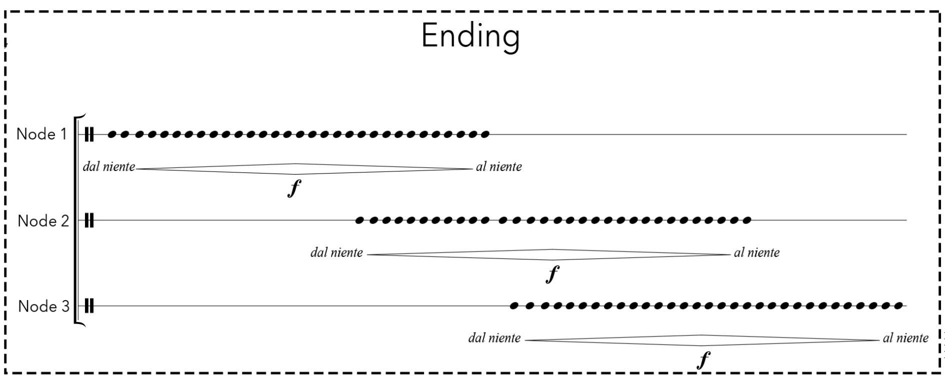






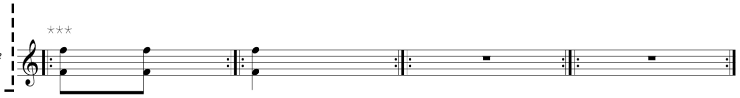






Ending

Node 1

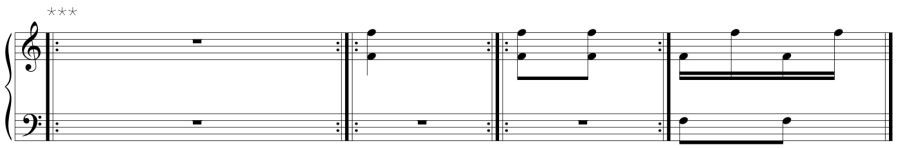


Blind Men and the Elephant

Node 2 rehearsal score

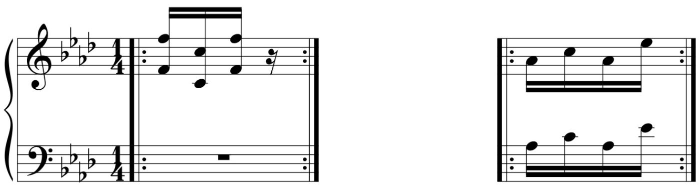
Beginning

Node 2



A

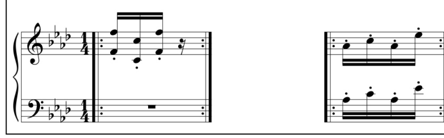
Node 2



A

Node 2

Staccato



A

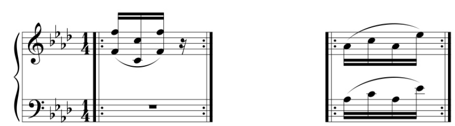
Node 2

Dynamic

A

Node 2

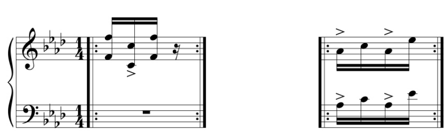
Legato



A

Node 2

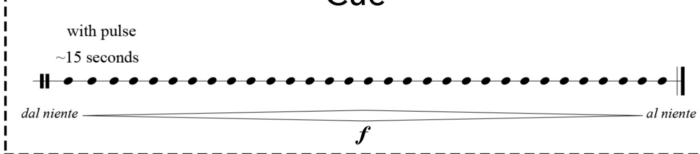
Accent



Pivot

Node 2

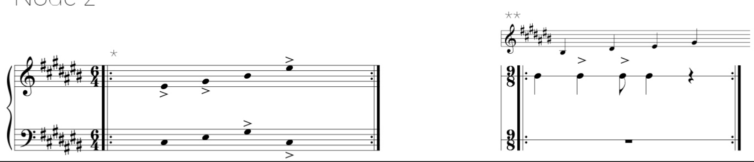
Cue



B
Node 2

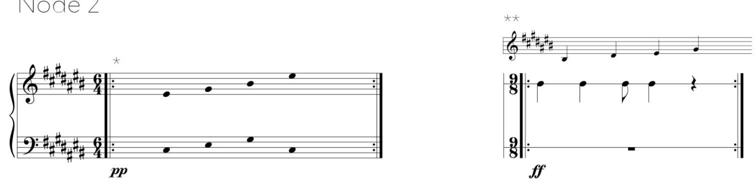
B
Node 2

Accent



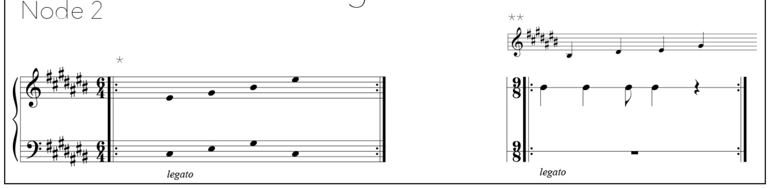
B
Node 2

Dynamic



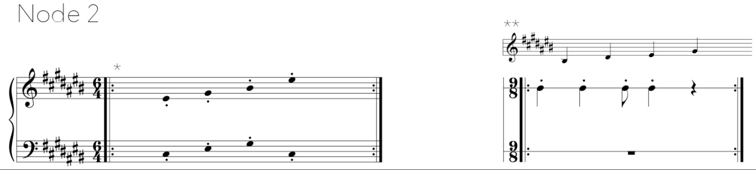
B
Node 2

Legato

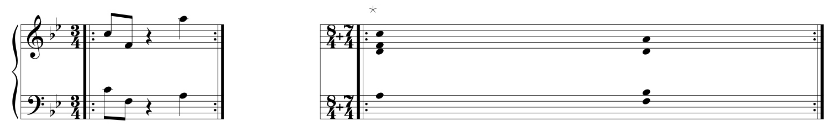


B
Node 2

Staccato



C
Node 2

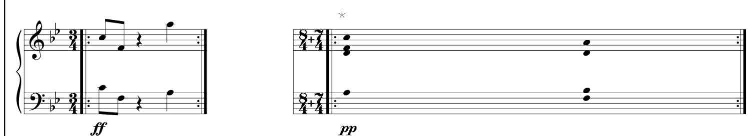


C
Node 2

Accent

C
Node 2

Dynamic

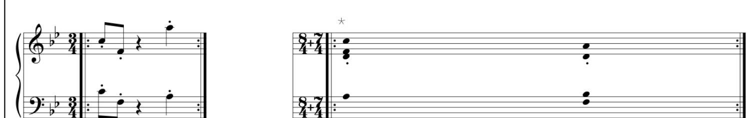


C
Node 2

Legato

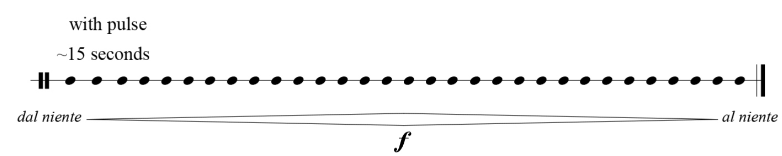
C
Node 2

Staccato



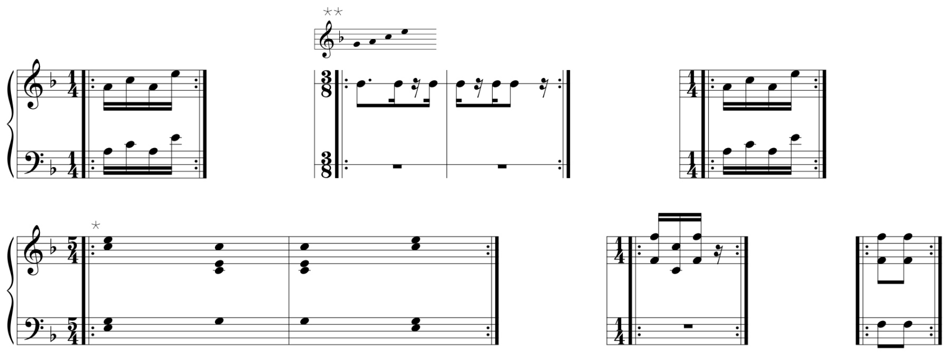
Pivot
Node 2

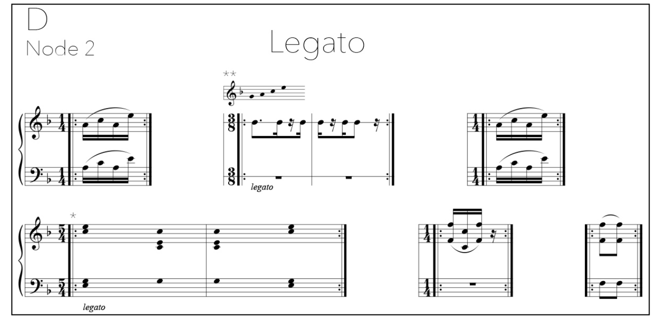
Cue

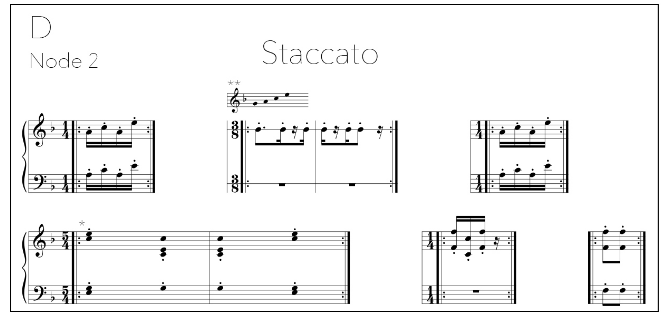


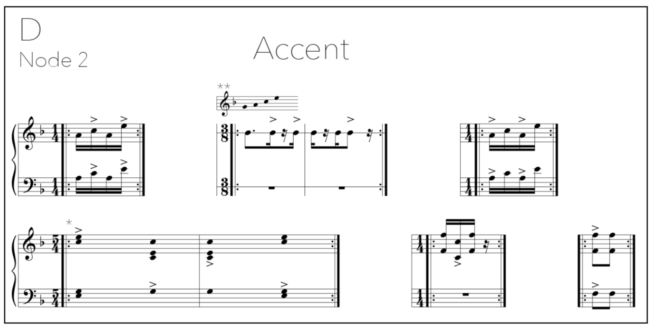
D

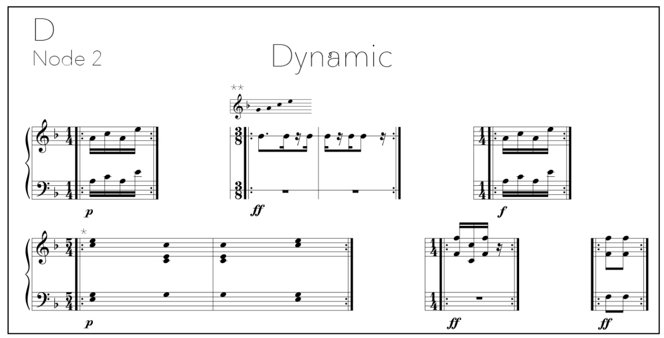
Node 2

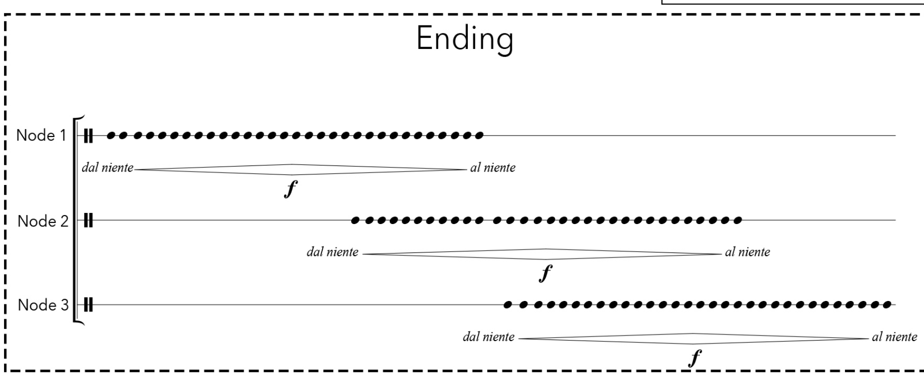






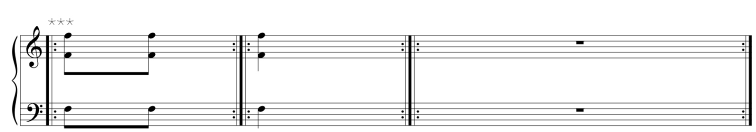






Node 2

Ending



Blind Men and the Elephant

Node 3 rehearsal score

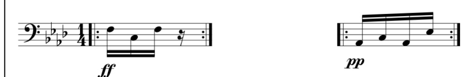
Beginning

Node 3

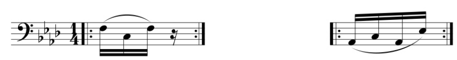
A
Node 3 *Staccato*

A
Node 3

A
Node 3 *Dynamic*



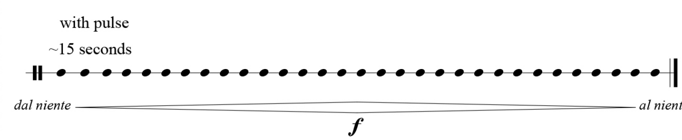
A
Node 3 *Legato*



A
Node 3 *Accent*

Pivot
Node 3

Cue



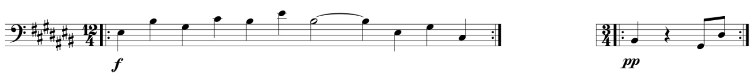
B
Node 3

B
Node 3

Accent

B
Node 3

Dynamic



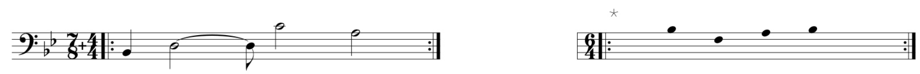
B
Node 3

Legato

B
Node 3

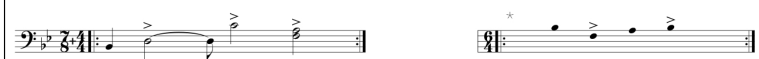
Staccato

C
Node 3



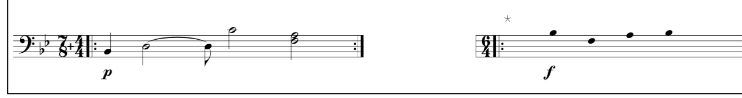
C
Node 3

Accent



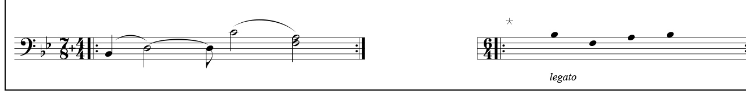
C
Node 3

Dynamic



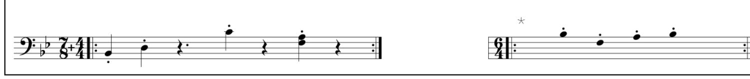
C
Node 3

Legato



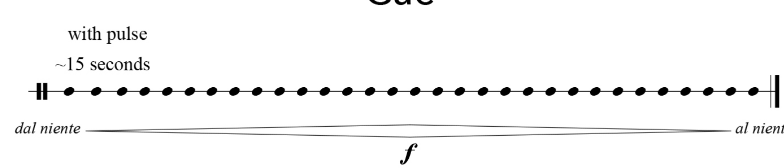
C
Node 3

Staccato



Pivot
Node 3

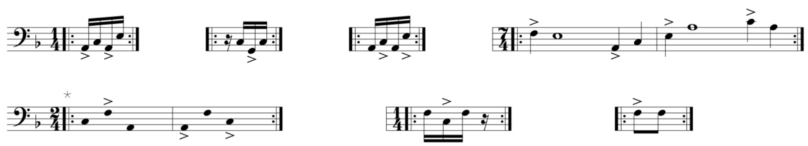
Cue



D
Node 3

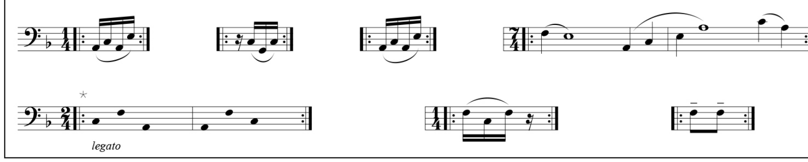
D
Node 3

Accents



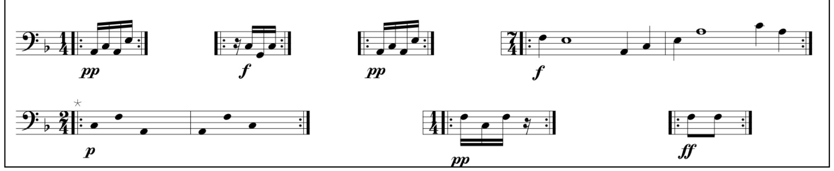
D
Node 3

Legato



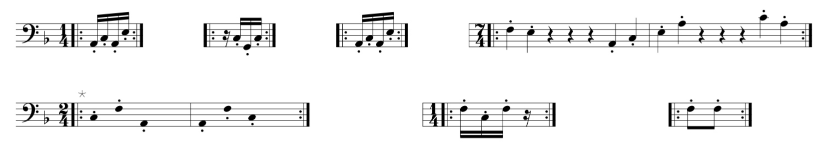
D
Node 3

Dynamic

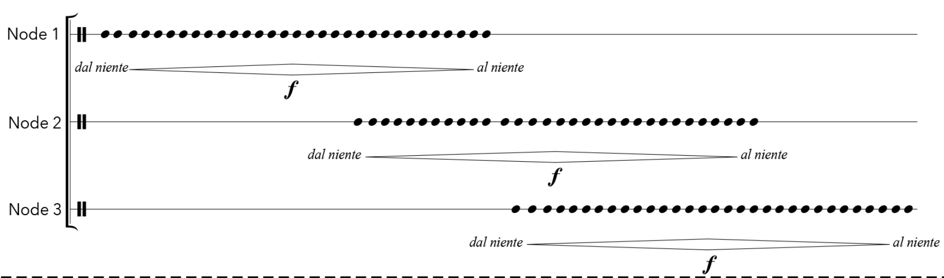


D
Node 3

Staccato



Ending



Ending

Node 3

Appendix C: *Network Gyre* Scores

Network Gyre

For bi-located percussion

Network Gyre

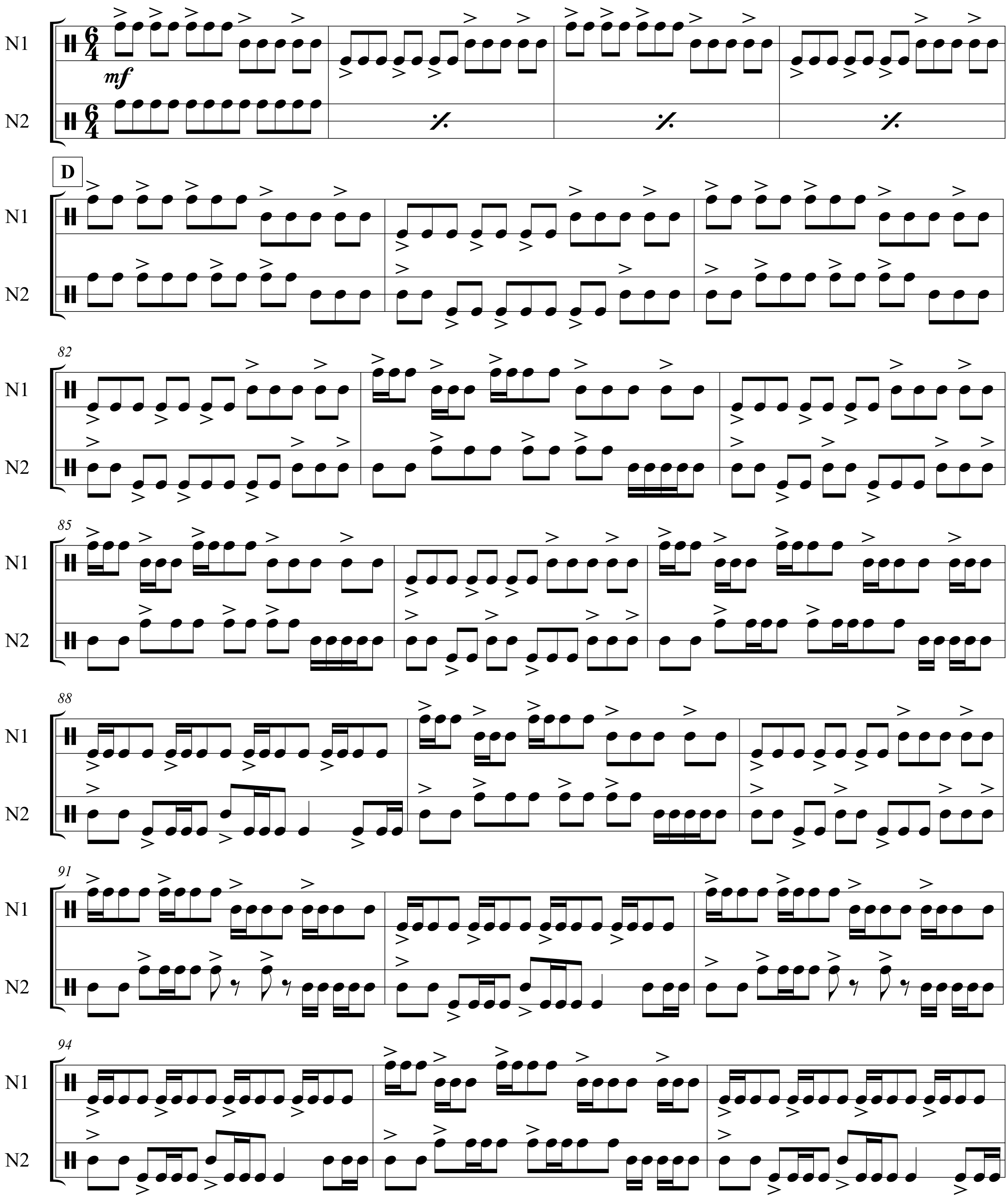
For bi-located percussion

Node 1 Score


20
N1
N2
23
26
30
B
niente
mp
34
38
C
f
mf
3


5
46
N1
N2
mf
f
51
54
58
subito p
subito p
62
65
R R L R R L R R L R R L
R L R R L R R L R R L R
sim.
both players continue pulses with one hand
fade in and out the above repeated patterns one player at a time in any order
take ~8 sec for each, players should overlap slightly

6



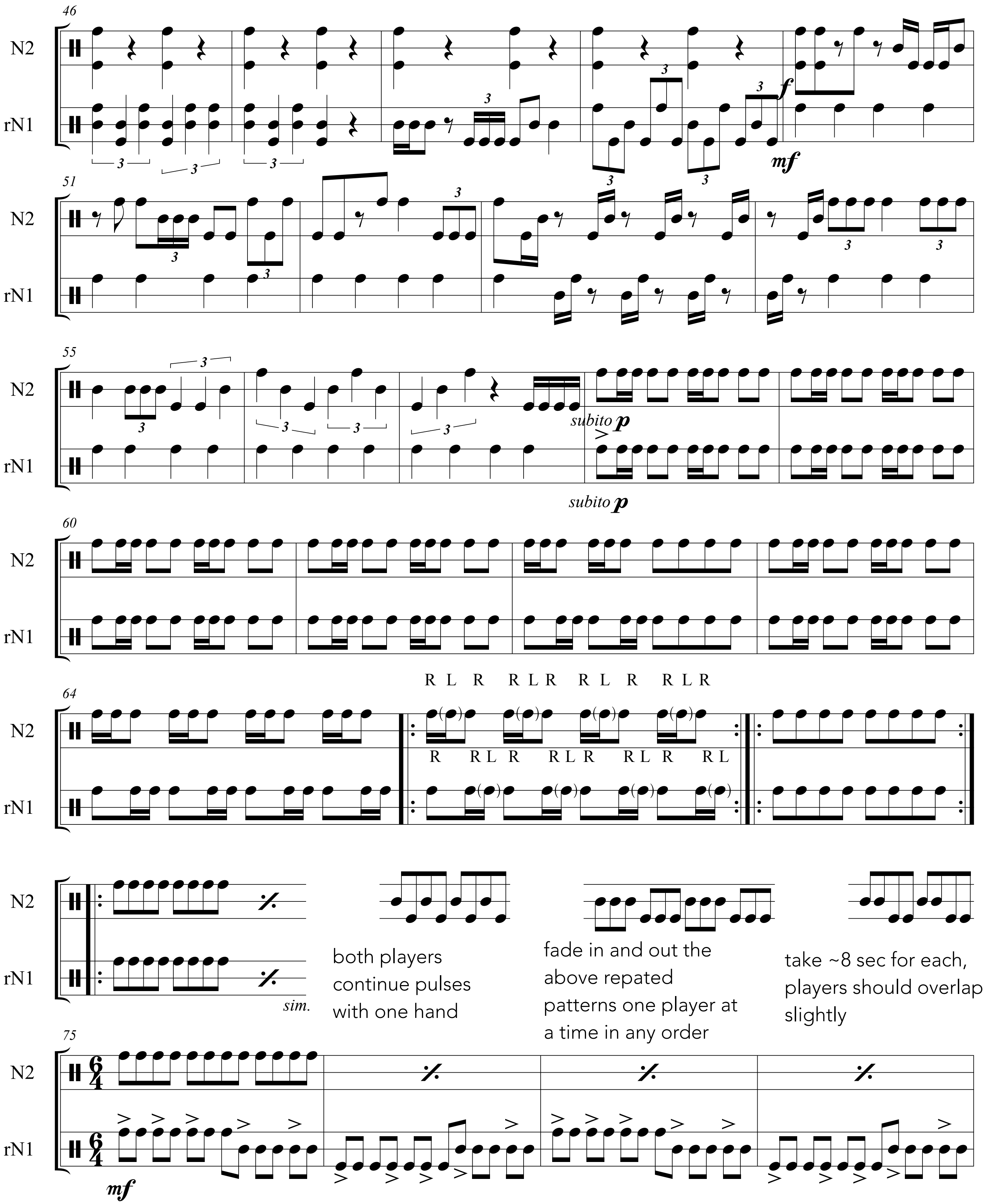
7

Network Gyre

Node 2 Score

For bi-located percussion


20
N2
rN1
23
26
30
B
niente
mp
34
38
C
mf
f
3



N2
rN1
subito p
subito p
mf
R L R R L R R L R R L R
R R L R R L R R L R R L
sim.
both players continue pulses with one hand
fade in and out the above repated patterns one player at a time in any order
take ~8 sec for each, players should overlap slightly
mf


D
N2
rN1
82
85
88
91
94
97


100
N2
rN1
103
107
111
115

Appendix D: Software Tutorial

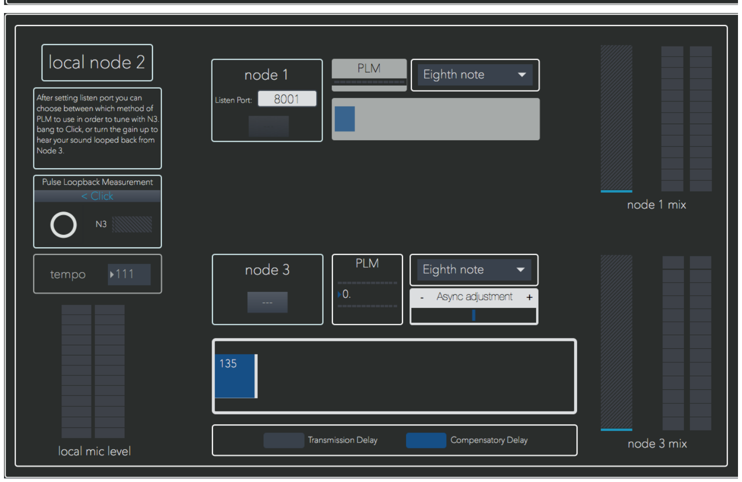
Software Tutorial

for implementing the toporhythmic technique

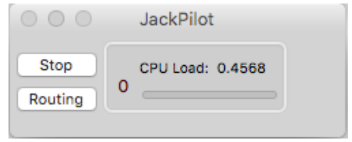
Introduction

This tutorial is meant to aid in using the Max/MSP patch built in conjunction with this research. Audio routing and connecting to a remote computer are done in separate software (such as Artsmesh, qjackctl, or JackPilot) and will not be described here. However, instructions for routing audio in and out of Max/MSP will be provided.

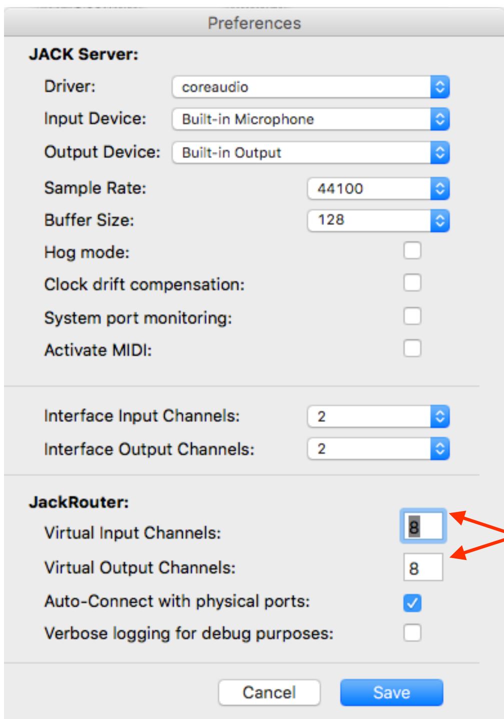
The basic function of this software is in calibrating the latency between each node in a network music performance, to a rhythmic unit of time. To do this, each node must delay their local signal by a certain amount of time before it is sent over the network. Therefore, each node needs their own version of the patch, though not all nodes need to control every variable. Node 1 has the most controls and we will mainly focus on Node 1's functions. But first, an overview of the audio routing is necessary.

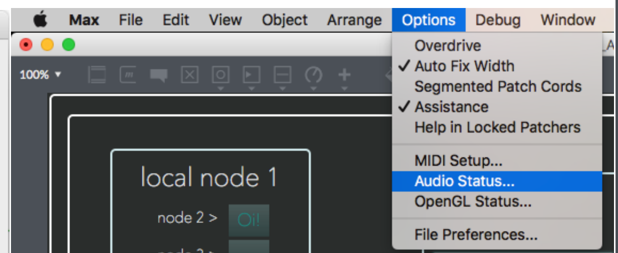


First things first…



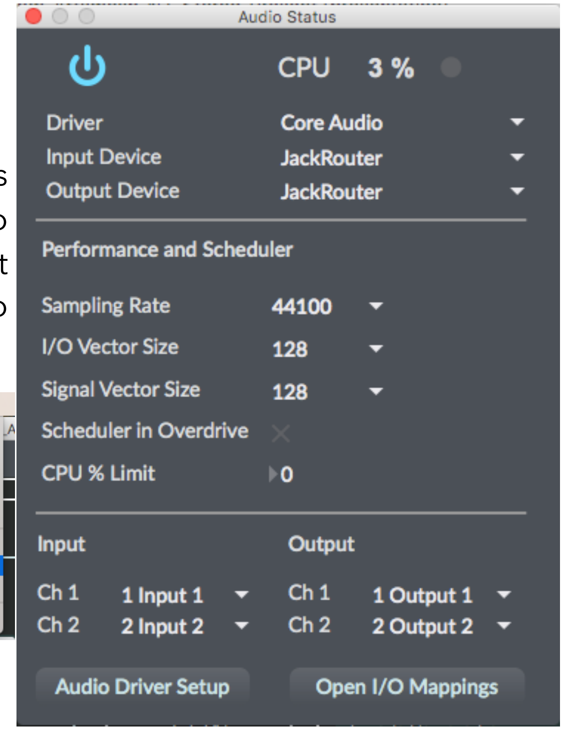
Again, this tutorial will not be addressing how to make audio connections in software such as qjackctl or Artsmesh, but will be using JACK audio server (JackRouter) to route audio to and from Max/MSP. Therefore, it should be addressed that the JACK server needs to be running prior to opening Max/MSP. This is demonstrated using JackPilot.





Once the JACK Server is running, open the Max patch, navigate to the "Options" tab, and select "Audio Status…"

make sure you have 8 virtual input and output channels, you'll need these later.



The above window will appear. Here, you set JackRouter as your Input and Output device. Then, choose all of the desired preferences, such as Sampling Rate and Vector Sizes, and make sure that they match those set in the JACK preferences. Then, turn on the audio in the top left.

Routing Instructions

Below are the routing instructions for stereo audio to and from every node in a tri-located network music performance using this patch. It includes the PLM (Pulse Loopback Measurement) channels, which will be addressed later in the manual. This routing can be done in Artsmesh, qjackctl, or JackPilot.

Node 1	Node 2	Node 3
Routing (done in Artsmesh):	Routing (done in Artsmesh):	Routing (done in Artsmesh):
Max Recieves (adc)	Max Recieves (adc)	Max Recieves (adc)
1 - system send 1	1 - system send 1	1 - system send 1
2 - system send 2	2 - system send 2	2 - system send 2
3 - node 2's send 1	3 - node 1's send 1	3 - node 1's send 1
4 - node 2's send 2	4 - node 1's send 2	4 - node 1's send 2
5 - node 3's send 1	5 - node 3's send 1	5 - node 2's send 1
6 - node 3's send 2	6 - node 3's send 2	6 - node 2's send 2
7 - node 2's send 3*	7 - node 1's send 3*	7 - node 1's send 3*
8 - node 3's send 3*	8 - node 3's send 3*	8 - node 2's send 3*
Max Sends (dac)	Max Sends (dac)	Max Sends (dac)
1 - system recieve 1	1 - system recieve 1	1 - system recieve 1
2 - system recieve 2	2 - system recieve 2	2 - system recieve 2
3 - node 2's recieve 1	3 - node 1's recieve 1	3 - node 1's recieve 1
4 - node 2's recieve 2	4 - node 1's recieve 2	4 - node 1's recieve 2
5 - node 3's recieve 1	5 - node 3's recieve 1	5 - node 2's recieve 1
6 - node 3's recieve 2	6 - node 3's recieve 2	6 - node 2's recieve 2
7 - node 2's recieve 3*	7 - node 1's recieve 3*	7 - node 1's recieve 3*
8 - node 3's recieve 3*	8 - node 3's recieve 3*	8 - node 2's recieve 3*
(*=PLM channels)	(*=PLM channels)	(*=PLM channels)

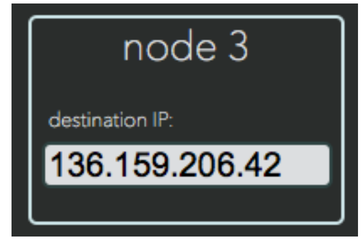
- Latency Calibration

- UDP functionality

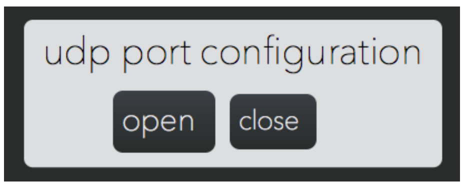
Two main components of the patch are its use of UDP for sending and receiving controls and calculating the compensatory delay

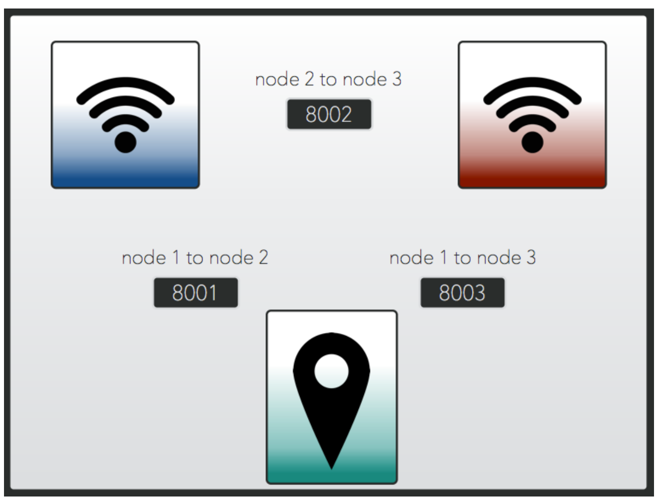
UDP Functionality

In network music, communication can be difficult. In most cases, an external tool (such as Skype) is used to roughly communicate prior to connecting audio. This is done in order to ensure that everyone's settings are the same and there won't be any conflicts with sampling rate or vector sizes. Aligning the latency using this software presents another potential conflict, if each location controlled their tempo and compensatory delay independently, there could easily be a miscalculation, resulting in unwanted temporal relationships. Therefore, a sort of hierarchy is built into the system that allows Node 1 to control the tempo for all nodes, and to set the compensatory delay for two of the three connections. The remote nodes need only to set their proper udp listen port.

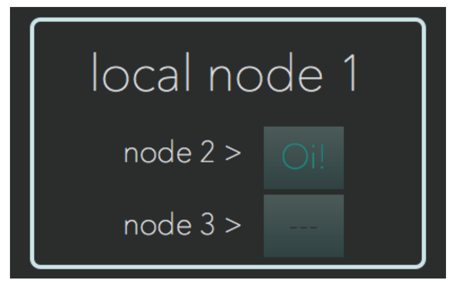


1) Node 1 enters the IP addresses of the remote nodes.

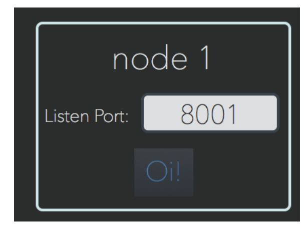




2) Node 1 opens the "udp port configuration" window and sets all the udp ports between each node.



3) Node 1 can check the connection with the remote nodes by digitally yelling, "Oi!"

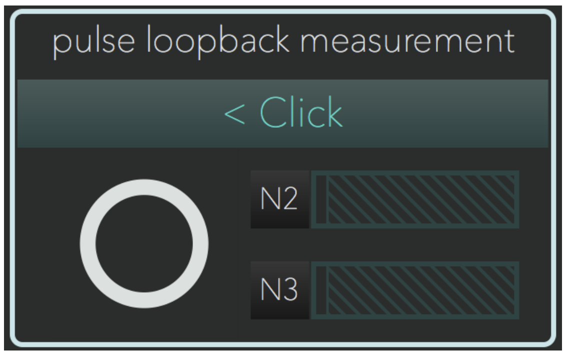


* If the remote node hears it, we've got a connection

** If not, there may have been a number entered out of order somewhere and digitally pounding your fist on the table can help.

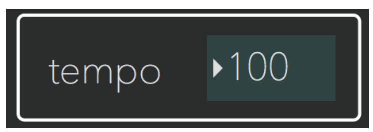
Latency Calibration

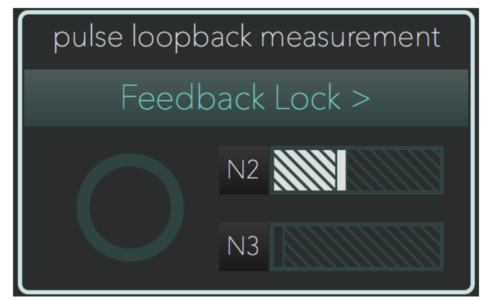
There are two ways to calibrate the latency to a rhythmic value using the PLM (Pulse Loopback Measurement), the Click and the Feedback Lock. I find it works best to use a combination of both methods in order to get the tightest sync.



If the routing has been done correctly, hitting the button in the pulse loopback measurement section while in Click mode, should send a click to all nodes, which is route it directly back. The time elapsed during the click's journey is gives us the PLM.

Once we have a PLM number in place, choose a desired rhythmic value and a tempo and the patch will run the calculation. However, this calculation does not consider the latency added through A-to-D and D-to-A conversion by your audio interface and speakers. This is where Feedback Locking comes in handy.





In Feedback Lock mode, your audio now travels the same route that the Click travelled before, coming right back upon arriving at the remote node. However, it is now delayed locally according to the calculation made using your chosen rhythmic value and tempo.

Latency Calibration
continued

Using Feedback Lock mode is a good way to aurally confirm everything is working. Change the rhythmic value while making a sound and you will hear the patch make the timing adjustment. There is still one problem though, at this point we are only considering one A-to-D and D-to-A conversion. In order to integrate all levels of latency into the compensation we need to "temporally tune" with the remote node. To do this we make small adjustments with the Async adjustment.

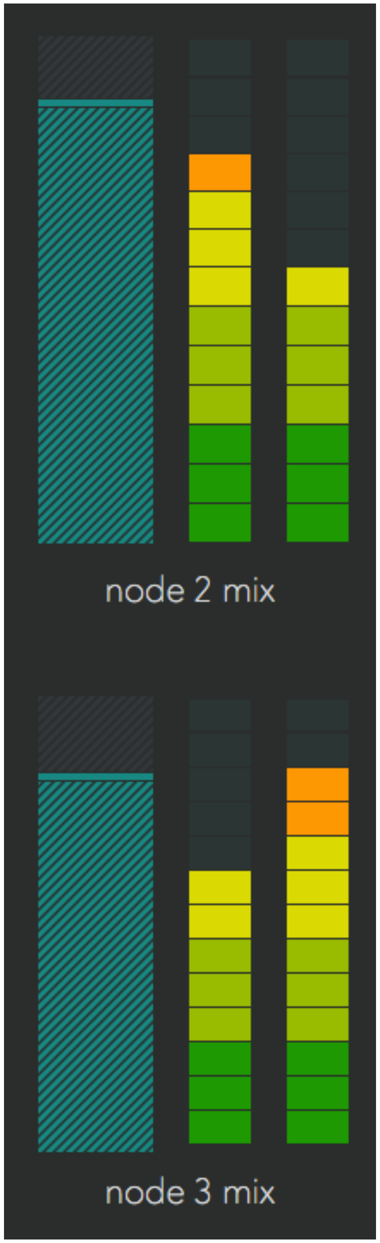
I find the most effective way to "temporally tune" is with the aid of a metronome. Have the remote node point their microphone toward their speaker and bring their gain up for Node 1. At Node 1 set your metronome to the rhythmic value and tempo you've chosen, and play it into your mic. Turn up the gain to the remote node and if your unit is set to a quarter note, you should hear the metronome click coming back a quarter note later. The local click from the metronome should fall exactly in time with the sound returning through the speakers. If it is slightly ahead or slightly behind, use the Async adjustment to bring it into tune.

* This should be done with one node at a time as the extra feedback echoes from a third node can cause confusion.

Play music…toporhythmically

The software is designed so that Node 1 can take care of most of the tuning adjustments and other parameters. However, Node 2 must follow the same procedure to tune with Node 3. Also, it is each node's responsibility to choose a desired rhythmic value. This means asymmetrical rhythmic relationships are possible (eighth note from Node 1 to Node 2, but a quarter note from Node 2 back to Node 1). However, these should be chosen after having tuned using a symmetrical rhythmic relationship.

Once all nodes are in temporal tune, the only step left is to set levels and play. The software allows you to set a level for each remote node's incoming signal and it is advised to consider your gain-staging along the way. Gain levels for your microphone should be robust, leaving plenty of headroom in the Max patch.



Useful Terms

Listed below are some common terms found in the practice of network music performance

Audio

Sampling Rate:

44.1kHz is CD-quality, but 48kHz is also common

Bit Depth:

16 bit is CD-quality, but 24 bit is also common

Vector Size (Buffer Size):

a larger vector size (2048) means more latency but less CPU usage, a smaller vector size (64) may cause some interfaces to click but results in very low latency

Network

IP address:

Internet Protocol address used for computers to find each other over a network. IPv4 example: 127.255.255.255
IPv6 example: 2001:0DB8:AC10:FE01::4

Bandwidth:

The more the merrier, but stereo audio at 44.1kHz needs at very least 2Mbps upload and download speed