Speed in music
McGowan, E.L.

Chapter 4: Polytempo Music

4.1 Introduction

As rhythm plays a principal role in my composing, performing, and teaching, I examine not only the relationships between conceived rhythmic possibilities and their musical result, but also their physical sensation. By testing rhythmic ideas through singing, tapping, and playing, an understanding emerges that combines conceptual design, sonic outcome, and performance practicality. These factors compete, collaborate, and combine to inform my compositional decisions.

Throughout this dissertation, I approach speed as something listeners and performers construct through pulse following, subdivision, density, and attention. The felt sensations of audible rhythm are therefore inseparable from the ways bodies entrain to periodicities and imagine or simulate the actions that would produce them. In practice, the relationship of tuplets and groupings to the pulse provides a primary interface where such constructions of speed are negotiated.[28] This is a topic explicitly explored in my *Rhythmic Etudes* (2014), among other works.

While the implementation of tuplets and groupings in existing practices has created a seemingly infinite variety of rhythms, the exploration of pulse itself has often been limited. Most ensemble music assumes a single pulse for all musicians, which often remains relatively constant across a piece. This monotempo condition[29] functions as a strong organizing framework because it aligns bodily entrainment with a shared predictive timeline for "when" events should occur, and it reduces the cognitive and motor costs of maintaining coordination (Huron, 2006, p. 283).

Music with multiple pulses sounding simultaneously, first termed "poly-tempo" by Cowell (1928, pp. 26 - 27) and here referred to as polytempo, occurs far less frequently. The juxtaposition of different pulses for individual players, even when the speeds differ only slightly, introduces new performative challenges. In ensembles, there usually is a strong tendency to synchronize. A performer required to play at a different speed from a neighbor must actively resist these tendencies, which means managing embodied entrainment as well as competing streams of temporal prediction (Huron, 2006, pp. 175 - 177). Polytempo therefore multiplies speed references in the room and forces a redistribution of attention and effort. This redistribution is audible, since timing nuance is grounded in bodily action and mimetic imagery even for the listener (Iyer, 2002, pp. 394 - 403).

Perhaps because of challenges such as these, there have been only a few polytempo experiments in the past several centuries, which I explore below, and the results are rich, fascinating, and expressive. The approaches can be categorized by how they treat the elemental building blocks comprising the rhythmic grid: pulse, tuplet, and meter. While some of the approaches are instinctive and effortless, others demand considerable skill and concentration. This chapter will provide an overview of those approaches before dealing with my own research into polytempo. Its successful implementation has been a central goal in a series of my musical works, and I will detail both the process and the discoveries made through these experiments.

[28] These are treated in more detail in Chapter 3: Tuplets.

[29] As defined by John Greschak in The Word "Polytempo", monotemporal music is music where "all parts are written with a common reference tempo and meter, and changes in tempo or meter occur in all parts simultaneously" (Greschak, 2007b).

Overview

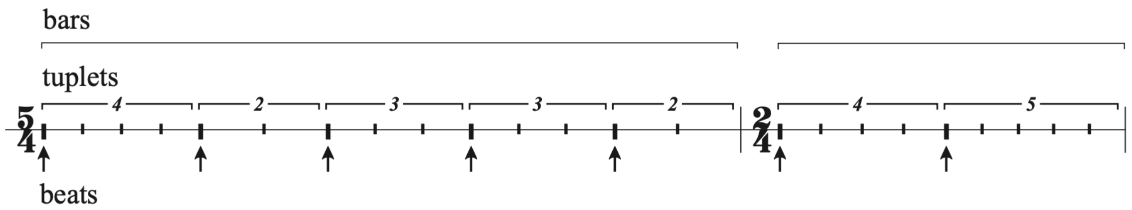
This chapter contextualizes polytempo from three perspectives and then presents the artistic and compositional research through which its design and realization are tested, showing how it offers a focused site for investigating speed as a relational phenomenon. I begin by contextualizing polytempo from three perspectives: within the identity and function of the rhythmic grid; as a theoretical permutation of the basic rhythmic elements of pulse, tuplet, and meter; and as a sonic condition encountered both in the everyday environment and in musical practice. I then turn to my artistic research through which I test these ideas, including a subsection on metronomes and on multiple sensory modalities.

Terminology

When referring to tempi in this chapter, I use both traditional Italian terms, such as *andante* (walking pace) or *vivace* (lively and fast), and numerical representations, such as 84 bpm. The terms convey the general qualitative character of a tempo (and thus the music), while the numerical values indicate exact tempi for quantitative comparison.

4.2 The Rhythmic Grid

Most Western music coordinates its various layers with a one-dimensional grid structure common to all musicians, showing the positions of the tuplets, beats,[30] and bars.[31]



Example 4.1: The Rhythmic Grid

The grid is a hierarchical structure, starting with elemental tuplet subdivisions within beats, which combine to form bars. Rhythms are lengths of sounds and silences placed within this structure. Although musicians often employ subtle rhythmic deviations for expressive purposes, this technical triumvirate plays a strong organizational role in both musical structure and performance practice. Crucially, this grid typically operates in monotemporal terms, maintaining a single tempo[32] for all beats.

The rhythmic grid not only structures monophonic music but also allows composers to align musical layers in time, and it enables ensembles of any size to synchronize performers.

Aside from the printed score, the grid can be presented in several ways, including:

- explicit articulation in the sounding music (by its notes)
- visual indication by a conductor or performer
- aural definition by a click track or metronome
- governance by the musicians' internal sense of the grid

In most performances, combinations of these presentations occur.

The internal grid of the performer plays a significant role in live performance. This grid rests on the musician's "inner pulse," providing the temporal framework for their actions. Arising from the musician's physical and cognitive experiences, it is inherently situated in Haraway's sense: embodied, partial, and produced from a particular position.[33] However, in ensemble contexts such as swing or groove, this internal sense of time must be actively negotiated among performers, becoming intersubjective. The way the grid is conceived, performed, and engaged with, reflects not only individual embodiment but also collective synchronization, influencing how the music is articulated (Grahn & McAuley, 2009).

Cognitive psychologist Daniel Levitin, neuroscientist Jessica Grahn, and music theorist Justin London note that the elements of the rhythmic grid are represented in the body as internal oscillators - biological clocks located in the brain and in various tissues and organs.

[30] Beat: the beat is a defined marker, often referring to the notated position.
[31] Bar: a segment of time containing a specific number of beats.
[32] Tempo is the speed of the beat in music, often measured in beats per minute (bpm).
[33] See section 2.5 for more about Haraway's theory.

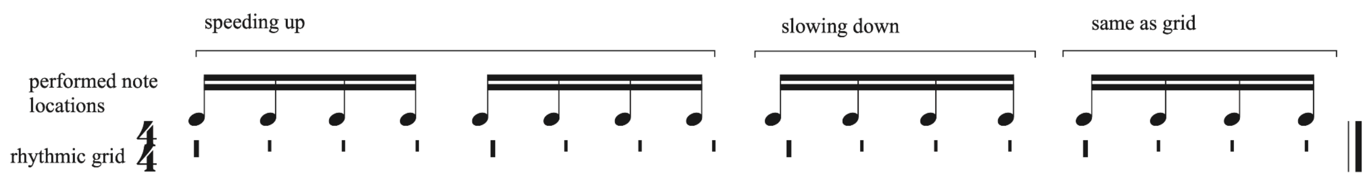
> Current models of rhythmic entrainment (Large & Kolen, 1994; Large & Palmer, 2002; Toiviainen & Snyder, 2003) posit that multiple internal oscillators phase lock to periodicities in a rhythm - most often to the beat, or tactus, but also to other levels of the metric hierarchy, such as the downbeats of successive measures. This phase locking is what allows a musician to keep track of multiple musical events simultaneously and to recover from errors while staying in time.
> (Levitin, Grahn, & London, 2018)

When two or more musicians perform together, their internal rhythmic grids must align to create a shared sense of timing. Although each musician has their own subjective grid, they must agree on a shared pulse, or underlying beat, which serves as the reference point for their collaborative performance. By paying attention to each other's playing, they can adjust these grids to match or complement their partner's timing, while still allowing for individual expressive timing.

Expression and the interaction of multiple rhythmic grids

While the rhythmic grid in Western notated music is typically expressed as whole numbers - such as the number of beats per bar and the number of subdivisions per beat, including tuplets - musicians frequently employ expressive timing,[34] introducing subtle deviations from this strict grid. These deviations include slight accelerations, decelerations or adjustments to note duration, often in the 20-100 ms range, thereby conveying excitement, calmness, phrasing emphasis, harmonic tension or other musical effects. Examples of expressive timing are notably found in swing, groove, and various non-Western musical traditions.

The following example shows a possible expressive timing, indicating the performed note positions in relation to the rhythmic grid.



Example 4.2. Expressive Timing

Music theorist Mitchell Ohriner expands upon the concept of expressive timing by identifying three types of interactions: between performer and musical object, between performer and performance tradition, and between collaborating musicians (Ohriner, 2019, p. 389). Building on my experience as a performer, I propose a further dimension to Ohriner's categories: the rhythmic grid itself constitutes a musical object with which performers dynamically interact during performance. This grid serves as the temporal frame of the music, requiring performers to maintain both cognitive and physical representations, an intellectual and embodied awareness of tuplets, beats, and bars. This practice may be common among musicians, since they are trained from early (often through counting exercises) on how the grid serves as the foundation for understanding and producing rhythm. However, certainly not every musician consciously thinks of the rhythmic grid at all times. With experience, many aspects of rhythm become intuitive. Nonetheless, during learning, practice or the performance of complex rhythms, the grid's divisions can be experienced as distinct musical events.

[34] As defined by Mitchell Ohriner, "'[e]xpressive timing' refers to variation in performed durations among notes represented in a musical score with a single rhythmic value" (Ohriner, 2019, p. 370).

Interaction with the grid becomes particularly dynamic during expressive timing, which is characterized by temporary deviations. In practice, I may adjust my internal grid to accommodate expressive timing, creating momentary expansions or contractions, or maintain the original grid positions, allowing expressive deviations to remain distinct. Expressive timing may also involve intentional tempo alterations of the grid itself, amplifying musical expressivity.

Expressive timing may thus be conceived as generating its own additional rhythmic grid. Performers therefore engage simultaneously with a *fundamental grid*, presenting the basic rhythmic structure, and an *expressive grid*, presenting interpretative deviations. These two grids may be merged into a single cohesive structure or kept distinct, resulting in multiple concurrent grids that one performer negotiates simultaneously.

In ensemble settings, this multiplicity of grids expands further. In a duo, for example, each performer's grids interact with those of their partner. When temporary rhythmic deviations occur, ensemble musicians have several interpretative options. Two musicians may have fundamentally synchronized grids but differ in their expressive deviations. At times, I might perceive my partner's acceleration as intentional and expressive. At other times, I may interpret it as unintentional rushing, just as they may perceive my steadiness as deliberate slowing down. The second musician can choose to align with these deviations, introduce independent expressive timings, or maintain a consistent grid. These dynamic interactions reveal communication, interpretative nuance, and musical choice.

Levitin, Grahn and London describe the management of these multiple grids through a hierarchy of internal oscillators:

> The hierarchical oscillators are even more important for musicians who want to play rubato or before or behind the beat - they need to know exactly when various levels of beat are being experienced (by themselves, by listeners, and by other ensemble players) in order to expressively alter their own timing. Musicians often use these techniques. Frank Sinatra famously sang behind the beat (giving the performance a cool quality), and Kendrick Lamar tends to sing ahead of the beat (giving the performance urgency). (Levitin, Grahn, and London, 2018, pp. 51-75)

This hierarchical model underscores the nuanced cognitive demands of expressive timing, emphasizing awareness not just of one's own internal grids but also of ensemble members' and listeners' rhythmic perceptions. In performance, similar techniques appear when soloists subtly rush ahead of the ensemble for expressive effect, highlighting virtuosity and excitement.

Recent research into sensorimotor alpha oscillations in the brain further clarifies how musicians interact with internal rhythmic grids, highlighting distinct cognitive strategies according to musical roles, such as playing in unison, canon or polyphonic textures (Christensen, Slavik, Nicol, & Loehr, 2023). As Christensen et al. explain, "leaders show greater reliance on internal models of action timing and increased activity in brain areas associated with internally driven motor processes such as action planning, initiation, and monitoring" (Christensen, Slavik, Nicol, & Loehr, 2023, p. 306). This observation echoes the discussion of interacting rhythmic grids, as it suggests that leadership in ensemble contexts draws heavily on an internally maintained temporal framework, one that must remain stable even while adapting to the real-time dynamics of other performers. It reinforces the idea that effective ensemble timing is not purely reactive but anchored in proactive, embodied control of the temporal structure. Later in this chapter, I explore how polytempo performance strategies leverage these cognitive processes according to the composition's structural characteristics.

Ultimately, the expressive potential of rhythmic timing in ensembles emerges from the interplay between multiple rhythmic grids. The manner in which these grids interact, synchronize, or intentionally diverge reveals performers' nuanced temporal sensitivities, creating diverse expressive possibilities aligned with the music's stylistic context.

As ensemble size grows, so does the complexity of rhythmic grid interactions, necessitating sophisticated coordination strategies. A professional string quartet musician, for example, continuously negotiates rhythmic relationships with the grids of their three colleagues. In larger ensembles, rhythmic coordination typically relies either on a central figure, such as a conductor, or on a network of mutual cueing among musicians. Such intricate interactions produce powerful expressive synchronizations, exemplified by symphony orchestras, and depend on the synchronization of both sight and hearing as well as the development of a common inner pulse (Lidar, 2016, pp. 5–8). The exploration and refinement of these modalities has been central to my approach to implementing polytempo music, as discussed later in this chapter.

4.3 Combinations of Rhythmic Elements For Possible Musics

Returning to the three parameters related to the rhythmic grid mentioned above, an examination of the implementation of pulse, tuplet, and meter offers a useful perspective for developing a typology of approaches to pulse-based music. Within these classifications, both existing (historical) examples of polytempo can be located, and possible avenues for further exploration identified.

Each parameter involves several variations, based on comparisons between layers in the music, for example between bass and treble parts, left and right hands on the piano, or two or more of any parts or players in the music.

- Pulses and tuplets can be the *same* or *different* between layers.
- Meters can be the *same*, *different* or *nonexistent*.

Pulse and tuplet are always relevant for this typology. Without pulse, there can be no polytempo. Moreover, when there is pulse, there is always some kind of tuplet, however many subdivisions it contains; even a beat without subdivision can be described as a tuplet of 1.

These options permutate into 12 possible combinations:

- 1.	same pulse	same tuplet	same meter
- 2.	same pulse	same tuplet	different meter
- 3.	same pulse	same tuplet	no meter
- 4.	same pulse	different tuplet	same meter
- 5.	same pulse	different tuplet	different meter
- 6.	same pulse	different tuplet	no meter
- 7.	different pulse	same tuplet	same meter
- 8.	different pulse	same tuplet	different meter
- 9.	different pulse	same tuplet	no meter
- 10.	different pulse	different tuplet	same meter
- 11.	different pulse	different tuplet	different meter
- 12.	different pulse	different tuplet	no meter

Only the latter six categories (those with a different pulse) qualify as polytempo. As will be shown in the examples below, monotempo approaches can still yield considerable rhythmic richness; however, this categorization helps illuminate explored and unexplored pathways, and provides context for the works presented here.

Below are one or more musical examples of each class, as utilized in at least one section of a work.

Category 1: same pulse - same tuplet - same meter

Igor Stravinsky, *Septet* (1953)

Most written music follows this combination. Quarter, eighth, and sixteenth notes all line up neatly within each beat and bar.

Example 4.3. Stravinsky, *Septet*, score excerpt. [Video](#).

Category 2: same pulse - same tuplet - different meter

a. Antonin Reicha, *Fugue No. 30* (1803)

In the upper staff we see an 8/4 meter, with a 3/4 meter below beginning halfway through the first bar. This could be notated entirely in 8/4 (or cut time) with accents to mark the beginnings of each 3/4 bar. Single accented notes, however, do not capture the subtle hierarchies of stress and non-stress throughout whole bars.

Example 4.4. Reicha, *Fugue No. 30*, score excerpt. [Video](#).

b. Johann Nepomuk Hummel, *Clarinet Quartet* (1808)

Here there are four simultaneous meters: 2/4, 12/8, 3/4, and 6/8. While the polymetric approach is clear, also in the musical phrasing, several aspects are less so, such as the reason for leaving out most barlines in the lowest line and the fact that the idiomatic writing in 3/4 could also have been represented in 9/8.

Example 4.5. Hummel, *Clarinet Quartet*, score excerpt. Video.

Category 3: same pulse - same tuplet - no meter

a. György Ligeti, *Etudes for piano: Étude 1, "Désordre"* (1985)

No meter is given. While all the eighth notes of both layers are in sync, the accents enable juxtaposed irregular groupings, which phase in relation to each other as the bottom-layer groupings periodically shift an eighth note.

Example 4.6. Ligeti, *"Désordre"*, score excerpt. Video.

b. Charles Ives, *Concord Sonata* (1840-60)

As in *Désordre* above, no meter is given and a common pulse unifies both layers. The barlines in this example function solely as structural markers for phrasing.

Example 4.7. Ives, *Concord Sonata*, score excerpt. Video.

Category 4: same pulse - different tuplet - same meter

Frédéric Chopin, *Trois Nouvelles Études* (1839)

An explicit example of triplets in the right hand against eighth notes in the left hand. From bar 9 each layer continues at its own speed.

Example 4.8. Chopin, *Trois Nouvelles Études*, score excerpt. Video.

Category 5: same pulse - different tuplet - different meter

A. Johannes Ciconia, *Le Ray au Soleyl* (est. 1390s)

A prolation canon[35] based on the ratios of speed 4:3:1. Here it is notated in the same meter for convenience, although the metrical identity of each layer would manifest in the length of each proportion.

Example 4.9. Ciconia, *Le Ray au Soleyl*, score excerpt. Video.

b. Giovanni Battista Vitali , *Balletto* (1689)

With the first violin in common time, the second violin in 12/8, and the violone in 3/4, this is a notational example of aligned beats with misaligned barlines.

Example 4.10. Battista Vitali, *Balletto*, score excerpt. Video.

[35]A prolation canon has the main melody accompanied by one or more imitations of that same melody in other voices, and at different speeds.

c. Wolfgang Amadeus Mozart, *Oboe Quartet* (1781)

Beginning in the sixth bar on the first line, the oboe switches to common time over continuing 6/8 in the strings. This is written as a meter change, although the result is a 4:3 relationship throughout the section, at various speeds: 2:3, 4:3, and 8:3.

Example 4.11. Mozart, *Oboe Quartet*, score excerpt. Video.

Category 6: same pulse - different tuplet - no meter

Kaikhosru Sorabji, *Transcendental Study no. 71* (1940-44)

Much of Sorabji's music is without meter, using dotted lines to indicate phrasing, similar to the phrasing barlines in Ives's *Concord Sonata*. The changing tuplets in both hands suggest an approach to notating rubato.

Example 4.12. Sorabji, *Transcendental Study no. 71*, score excerpt. Video.

Category 7: different pulse - same tuplet - same meter

a. Charles Ives, *The Unanswered Question* (1908, revised 1930-35)

Throughout this piece the flutes have recurring interjections that increase in speed with each iteration. According to the score, they need not be played at the exact notated position but "somewhat impromptu," following one of the flute players. The notation of different speeds defies the traditional convention of vertical alignment.

Example 4.13. Ives, *The Unanswered Question*, score excerpt. Video.

b. Witold Lutosławski, Symphony No. 2 (1965-67)

In this section the three flutes have the same metrical and melodic structure, in three different tempi and transpositions.

Example 4.14. Lutosławski, *Symphony No. 2*, score excerpt.

Category 8: different pulse - same tuplet - different meter

a. Charles Ives, *Central Park in the Dark* (1906, revised 1936)

One of the earliest polytempo compositions, if not the earliest. Polytempo is achieved by specifying one layer to change meter and speed up while the other remains at Tempo I. How this is achieved, for example with two conductors or with individual leaders for each of the two separate layers, is not specified.

Example 4.15. Ives, *Central Park in the Dark*, score excerpt. Video.

b. Carl Nielsen, *5th Symphony* (1920-2)

In this other early polytempo example, Nielsen uses a metronome to give the snare drum its own tempo, without barlines to avoid alignment with the rest of the orchestra.

Example 4.16. Nielsen, *5th Symphony*, score excerpt. Video.

Category 9: different pulse - same tuplet - no meter

Building Music (McGowan, 2013)

Each musician has their own tempo of repeated notes and non-metric texture. Explored in more depth below, the notated barlines function not in the traditional sense of meter, but to delineate harmonic changes.

Example 4.17. *Building Music*, score excerpt. Video.

Category 10: different pulse - different tuplet - same meter

Charles Ives, *The Unanswered Question* (1930-35)

In another section of this work (also used in Category 7), the range of speed is broadened not only by shifts in tempo but also by variations in tuplets, which here introduce the distinctive character of triplets.

Example 4.18. Ives, *The Unanswered Question*, score excerpt. Video.

Category 11: different pulse - different tuplet - different meter

Elliott Carter, *String Quartet No. 3* (1973)

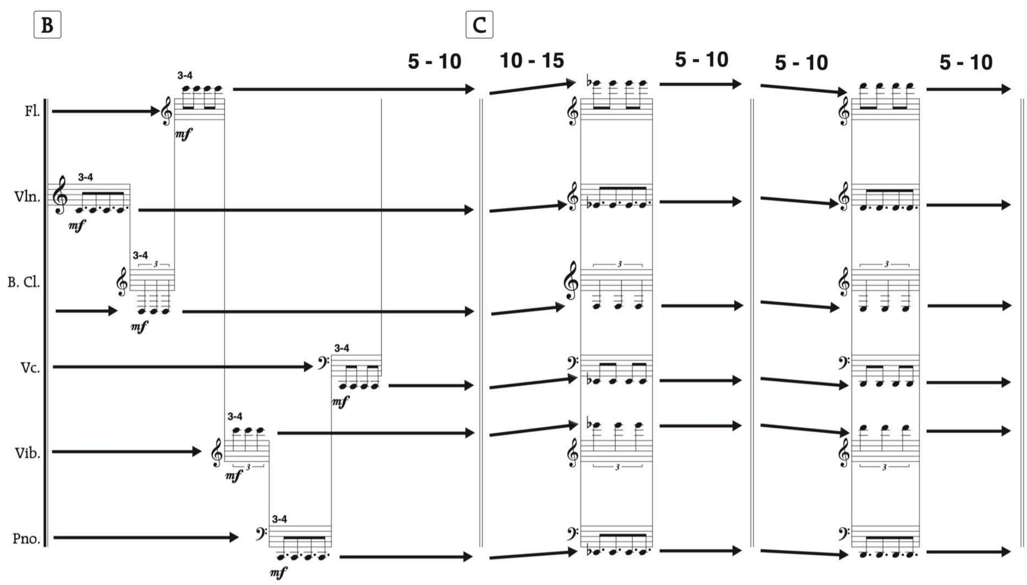
The four players are divided into two duos, each with its own tempo and meter. Within each duo the materials often employ different tuplets. The tempi are related so that the beginnings of each bar coincide.

Example 4.19. Carter, *String Quartet No. 3*, score excerpt. Video.

Category 12: different pulse - different tuplet - no meter

Sydney Polypulse (McGowan, 2019)

Explored in more depth below, the speed of each player's repeated notes is determined by the combination of their own tempo and tuplet. As in *Building Music* above, repeated notes erase metrical identity.



Example 4.20. *Sydney Polypulse*, score excerpt. Video.

Reflections

This categorization has proven fruitful for understanding how the building blocks of the rhythmic system create pathways for mixing speeds in music.

In the first six categories, the pulse plays a consistent role. On this foundation, the differences and boundaries between tuplet and meter are explored. The difference between the two appears primarily one of scale: the ways in which tuplets are juxtaposed (as in Chopin and Mozart) are similar to the ways in which meters are juxtaposed (as in Reicha). Tuplet duration is related to single beats, whereas meters relate to multiple beats. This mirrors the different scales of speed in the Beethoven examples: when tuplets are slowed down, they become meters, allowing other details to emerge.

The polytempo works of the latter six categories can be divided into two main approaches. The first comprises works that create distinctly different temporalities through layering, as in Ives and Nielsen. These layers possess their own musical identities, characterized by elements such as melody, harmony, rhythm, and timbre, and are further differentiated by speed. The second approach encompasses works in which a direct juxtaposition of different speeds fosters a new, singular, composite sound, as in Carter's quartet and my own compositions. While these works also aggregate individual parts to form a cohesive whole, the parts are more uniform in material content and more closely synchronized in phrasing and points of intersection. Much of the musical content emerges from the explicit interactions between the layers.

4.4 Polytempo Music

Before outlining various approaches to polytempo music, it is useful to consider some familiar examples from everyday life.

Unsynchronized sound in nature

Unsynchronized sound is common in our daily environment. A walk through a city, for example, presents a constantly shifting mix of uncoordinated sounds from vehicles, machinery, weather, birds, and human activity. Such experiences can inspire musical ideas, offering examples of layered rhythms and tempi found outside composed contexts. These may combine regular, irregular, and singularly occurring sounds.

- Animal sounds

    Example 4.21. *Cacophony of animal sounds in our yard*, video.

- City sounds

    Example 4.22. *Vehicle Noise in Dhaka Street*, video.

- Hospital machine sounds

    Example 4.23. *HP Viridia 24 ECG/Resp, SpO2 Alarms*, video.

Composed polytempo music

Music in which two or more different tempi occur simultaneously can be roughly divided into two categories (Greschak, 2007a):

- *Static polytemporality*: two or more simultaneous tempi that remain constant.

- *Dynamic polytemporality*: at least one of the simultaneous tempi changes over time (Mikolajczyk, 2019, p. 16).

Here are some examples of each category to give an idea.

Static polytemporality:

- Conlon Nancarrow, *Study No. 9* (1951 - 1960), for player piano

    The groundbreaking *Studies for Player Piano* explored a wide range of approaches to multiple simultaneous speeds. In *Study No. 9* the three layers are in tempi to the proportions of 3, 4 and 5, and at 1'30" the music demonstrates the polytemporal quality where each layer inhabits its own rhythmic grid of speed. According to composer-scholar Kyle Gann:

    > It is almost as though Nancarrow is imagining three continuously running stereo type tape loops that he can bring in one track at a time via a mixer, with the additional luxury of being able to change speeds. (Gann, 1985, p. 82)

    Example 4.24. Nancarrow, *Study No. 9*, video.

- *Hydraulic Principles* (McGowan, 2012), for player piano
  To give a reference to Nancarrow's approach to polytemporality, *Hydraulic Principles* is a work, also for player piano, that is monotemporal; all of the layers during the climax (5:00) relate to the same underlying pulse.

  Example 4.25. *Hydraulic Principles*, video.

- György Ligeti, *Poème Symphonique* (1962), for 100 metronomes
  The metronomes, all set to different tempi, start at the same time and are left to wind down at their own speed. At first the resulting sound is a blizzard of clicks, but as metronomes fall out, individual voices begin to emerge, revealing interesting phasing patterns.

  Example 4.26. Ligeti, *Poème Symphonique*, video.

- Michael Gordon, *Trance* (1995), for large ensemble
  The sound of "Part 1" of *Trance* reveals three clear independent musical lines, each with its own strong pulse, yet notated to a single rhythmic grid.

  Example 4.27. Gordon, *Trance*, audio.

- Marc Sinan, *AM ANFANG* (2020), for Djiguiya Orchestra Bamako, the Marc Sinan Company, the Neue Vocalsolisten Stuttgart, choreographer Kettly Noël and video
  In order to create independence and separation between the five groups, each is given its own tempo via click tracks, synchronized by a single computer.

  Example 4.28. Sinan, *AM ANFANG*, video.

- Christina Kubisch, *Identikit* (1974), for five pianists, cassettes and headphones
  This work utilizes polytemporality in a similar manner to Ligeti's *Poeme Symphonique*, with strings of notes in a constant speed from each player on the piano.

  Example 4.29. Kubisch, *Identikit*, audio.

Dynamic polytemporality:

- Conlon Nancarrow, *Study No. 21, "Canon X"* (1961), for player piano
  Each of the two layers in the music, one fast, one slow, perform a continuous speed change to transform into the other.

  Example 4.30. Nancarrow, *Study No. 21*, video.

- Yannis Kyriakides, *Wavespace* (2011), for mixed octet, live electronics and live video
  (excerpt beginning at 06:23) The passage from the excerpt combines layers of different temporalities: a regular pulse, one speeding up, one slowing down, and several others which are irregular.

  Example 4.31. Kyriakides, *Wavespace*, audio.

- Florent Ghys, *Il va pleuvoir en fin d'après-midi* (2018), for ensemble

  The basic syntax is similar to *Building Music* with the use of layers of repeated notes at different speeds. Similar to *Wavespace*, this piece uses click tracks to cue individual musicians to gradually speed up and slow down throughout the work, increasing or slowing down the phasing duration.

  Example 4.32. Ghys, *Il va pleuvoir en fin d'après-midi*, video.

- Ned McGowan, *Telescopic Ladder* (2003) (from *Tools)*, for mixed quartet

  This passage represents an early exploration of the polytempo effect, realised through structured improvisation. The classification is somewhere in between static and dynamic polytemporality, as static speeds are switching constantly in the various parts, plus an additional accelerando at the end.

  Example 4.33. *Telescopic Ladder,* video.

4.5 My Polytempo Works

4.5.1 General aesthetic and technical setup of my polytempo music

The approach to the polytempo technique I used in the works below employs static polytemporality, where each instrumental part consists of repeated notes, each at its own speed.

- *Building Music* (2013)
  for solo voice, large wind ensemble of 24 instrumentalists (flute, oboe, clarinet, bassoon, soprano, alto, tenor, baritone and bass saxophones, 2 piccolo trumpets, 2 trumpets, cornet, 4 trombones, bass trombone, tuba, guitar, bass, and 2 percussion) and video

- *For Bob* (2015)
  for large ensemble and solo voice
  composed for the posthumous birthday of musicologist Bob Gilmore
  In what follows four different performances of *For Bob* are considered.

  version 1: mixed instruments
  2 flutes, 2 violins, 2 violas, piano 4 hands and 2 vocalists, myself conducting
  version 2: flutes
  7 flutes, alto flute, bass flute and contrabass flute
  version 3: Jerboah
  2 recorders, Paetzold bass recorder, contrabass flute, guitar, glockenspiel and voice (ensemble Jerboah)
  version 4: Fokker Organ
  flute/contrabass flute and Fokker Organ (with parts triggered via MIDI and parts played live)

- *Sydney Polypulse (2018)*
  for flute, clarinet, violin, cello, piano and vibraphone

In these pieces, all voices are intended to have equal prominence, creating a "cloud" of simultaneous speeds. This equality contrasts with the typical hierarchical approach that places some layers in the foreground and others in the background. The similarity of material across the repeated note texture unifies the sound, while each player remains distinct through their unique speed, timbre, and often pitch. Each voice functions as both a soloist and part of the whole. Within this equality of prominence, the individuality of each voice still enables connections between any two speeds, ranging from close to far apart. Phase effects emerge as repeated notes align, drift, and realign. In this setup, each line of repeated notes at a fixed speed is straightforward to execute, while the richness comes from the interplay between speeds. Layers of simplicity combine into a multifaceted web of fixed tempo relationships, producing a structured and resonant sound. That said, maintaining one's tempo remains a challenge for performers, a subject explored later in this chapter.

4.5.2 Entrainment and polytempo performance difficulties

As mentioned above, musicians readily coordinate when playing notated music by articulating from a shared, monotemporal rhythmic grid. Within entrainment theory, this kind of coordination is described as the interaction of two or more autonomous rhythmic processes that adjust and eventually "lock in" to a common phase or period (Clayton, Sager & Will, 2005, pp. 1–3). In ensemble performance this synchronization depends on a complex interplay of perceptual, cognitive, and motor processes that underlie what is often called sensorimotor synchronization, the rhythmic coupling of movement to an external sequence (Repp & Su, 2013, p. 403). One influential account of ensemble synchronization emphasizes that such coordination presupposes shared performance goals and relies on skills such as anticipatory auditory imagery, prioritized integrative attention, and adaptive timing, all of which link internal timing mechanisms to real-time motor control (Keller, 2007). Empirical studies of duet performances further show that auditory feedback, visual cues, rehearsal, familiarity with co-performers, and shared stylistic understanding all contribute measurably to the precision with which musicians stay together in time (Goebl & Palmer, 2009, pp. 427-428).

The tendency to synchronize rhythm is not only a learned musical skill but also a general feature of human interaction. Entrainment research frames it as a widespread property of biological and social systems in which rhythmic processes tend to adjust to one another, from the synchronised flashing observed in some firefly populations, through the temporal coordination of conversational speech, to coordinated bodily movement such as walking, clapping, or dance (Clayton et al., 2005, pp. 2–3). In cognitive terms, this involves automatic alignment processes and predictive timing abilities that support the joint action of adaptive error-correction and anticipatory internal models in sensorimotor synchronization (van der Steen & Keller, 2013, p. 2). Laboratory work on tapping tasks indicates that phase-correction mechanisms operate largely automatically, while slower period-correction processes require conscious attention (Repp, 2005; Keller, 2007), and that in-phase coordination is much more stable than antiphase or syncopated coordination (Keller & Repp, 2005). Musicians therefore not only anticipate upcoming events once entrained but also experience a strong attractor towards synchrony, a "gravitational pull" that makes it cognitively and motorically difficult to remain deliberately out of time. As I will argue below, this attractor becomes particularly resistant in polytempo contexts, where the maintenance of distinct tempo layers requires performers to counteract precisely the mechanisms that normally make ensemble playing feel intuitive.

The strength of this pull often goes unnoticed until one deliberately tries not to synchronize. Even a small difference in tempo, such as 124 and 120 bpm occurring simultaneously, demands considerable effort to maintain: the ratio of 31:30 is so close that performers are continually drawn into alignment. By contrast, combinations such as 120 with 60 or 40 bpm, whose ratios are much simpler and more widely separated, are relatively easy to sustain as distinct layers. In the polytempo music described here, these finely graded tempo relationships are not incidental details but central to the music's identity.

Example 4.34. 124 and 120 bpm, audio.

For this reason, all of my polytempo works require each musician to use a metronome set to their own tempo. In theory, this provides a personal rhythmic grid that stabilizes each player's tempo and allows the ensemble's layered tempi to emerge clearly. In practice, however, resisting the surrounding players' timing remains challenging. Even with precise metronomic guidance, musicians must consciously focus on their own grid and suppress the natural urge to align with nearby sounds. This skill develops through targeted practice, and in the following section I outline strategies for cultivating it.

4.5.3 Polytempo research in my works

From here, the chapter examines five practice-centered problems that recur in my polytempo work: selecting tempi, implementing note values, using metronomes, coordinating musicians, and developing performance practice. Rather than presenting the three works separately, the chapter uses *Building Music* (2013), *For Bob* (2015), and *Sydney Polypulse*(2018) as recurring case studies within each problem-oriented section. This organisation foregrounds process and iteration: work titles function as local labels for the example at hand, not as a return to a work-by-work narrative.

4.5.4 Choosing the tempi: ratios and ranges

In static polytempo ensemble music where each musician maintains an independent tempo, a primary compositional consideration is the choice of tempi. Unlike in monotemporal works, tempo must be decided for each independent tempo layer, which may be assigned to a single musician or shared by several, making the selection process inherently more complex. Determining these tempi, and understanding their interrelationships, can thus constitute a distinct and often timeintensive phase of the compositional process.

This section first outlines tempo-selection approaches found in representative polytempo works by other composers, and then presents a detailed account of my own research, decisions, and outcomes. Dynamic polytempo works, which employ techniques such as acceleration, deceleration, tempo curves, and technology assisted modulation, are excluded here because their continuous tempo modulation and frequent reliance on technological mediation raise different compositional and performative questions than the globally static tempo layers examined in this chapter. As composer Marc Kenneth Yeats argues in his thesis, "Control, Flexibility, Flux and Complexity: A Timecode-Supported Approach to Polytemporal Orchestral Composition"(2021, pp. 33–72), many dynamic or large scale polytempo works presuppose a substantial technical infrastructure, for example computer controlled click tracks, systems with multiple or video conductors, networked video scores on iPads, mobile phone timecode and stopwatch frameworks, or headphone and app based guides. This creates a very different performance ecology from the one I address. By contrast, the works discussed in this chapter rely on ubiquitous electronic or digital metronomes that provide a single tempo for the entire piece, and explore strategies of notation that generate internal dynamism while remaining within a globally static polytempo field.

Tempi in ratios

Two primary approaches to tempo selection parallel two common approaches to pitch relationships: one uses simple ratio-based systems, akin to scales formed from whole-number ratios as in just intonation, and the other employs systems where a chosen range is divided into equal intervals, akin to the 12-tone equal-tempered scale. Both approaches appear in the *tempo-scale* theories devised by Henry Cowell and Karlheinz Stockhausen.

A tempo scale lists tempi that correspond to the degrees of a musical scale. Each "note" of the scale has a corresponding tempo, and interrelationships between tempi correspond to those between pitches. Both Cowell and Stockhausen illustrate this concept with chromatic scales, assigning the lowest pitch a tempo of 60 bpm and the octave above 120 bpm. The underlying assumption is that the doubling of pitch frequency over an octave corresponds to a doubling of tempo, as both relationships form a 2:1 ratio.

In *New Musical Resources*, Cowell applies simple ratios derived from just intonation to both pitch and tempo, proposing that relationships among tempi can be treated analogously to relationships among pitches (Cowell, 1930, p. 107). Elliott Carter takes up this idea in his use of metric modulation, which is described more precisely here as speed modulation, and he treats it as a counterpart to harmonic modulation for articulating musical form (Bernard, 1988, p. 199). The *Double Concerto* (1961) brings this line of thinking to a particularly systematic point, since simultaneous speeds become a normative condition of the piece. Carter draws on a unified set of ratios, from 5 to 10 and their reciprocals, to derive ten distinct tempi, including a 49:50 relation between 24.5 and 25 bpm. Each tempo is paired with a specific interval, so that rhythmic and pitch relations are coordinated as one structural dimension (Bernard, 1988, pp. 188–189).

Stockhausen, in his article "...how time passes…" , applied the 12-tone principle of equality to the same octave distance as Cowell, creating the equivalent of an equal tempered chromatic scale by dividing the octave into twelve equal steps (each related by the ratio $\sqrt[12]{2}$ to 1) (Stockhausen, 1957/1959, p. 21). In *Gruppen*, his polytempo work for three orchestras, the ensembles regularly shift between tempi on this scale, creating "harmonic" tempo relationships comparable to Carter's approach. Stockhausen later drew on the same chromatic tempo scale in other pieces: in *Inori* (1973–1974), for example, successions of tempi function as "tempo-melodies" that articulate large-scale formal processes.

Pitch	ratio Cowell	**bpm Cowell**	**bpm Stockhausen**	(& rounded values used in *Gruppen*)
- C	1:1	**60**	**60**	(60)
- C#	15:14	**64 $\frac{2}{7}$ (64.3)**	**63.6**	(63.5)
- D	9:8	**67 $\frac{1}{2}$ (67.5)**	**67.4**	(67)
- Eb	6:5	**72**	**71.4**	(71)
- E	5:4	**75**	**75.6**	(75.5)
- F	4:3	**80**	**80.1**	(80)
- Gb	7:5	**84**	**84.9**	(85)
- G	3:2	**90**	**89.9**	(90)
- Ab	8:5	**96**	**95.2**	(95)
- A	5:3	**100**	**100.9**	(101)
- Bb	7:4	**105**	**106.9**	(107)
- B	15:8	**112 $\frac{1}{2}$**	**113.3**	(113.5)
- C	2:1	**120**	**120**	(120)

Figure 4.1: One octave tempo scales of Henry Cowell and Karlheinz Stockhausen

A comparison of these scales shows that the results are similar but not identical, reflecting the subtle differences between just intonation and equal temperament. Psychophysical studies suggest that we can detect much smaller changes in pitch than in the length of time intervals. Just-noticeable differences[36] in frequency are roughly an order of magnitude smaller than just-noticeable differences in duration, and this asymmetry is reflected in both musical tuning practice and the fine-grained use of pitch in speech prosody. In *Gruppen*, Stockhausen rounded most decimal values to whole numbers in rehearsal practice, since

[36] Psychophysical studies usually describe such "micro-differences" in terms of just noticeable differences (JNDs), the smallest change that can be detected reliably. For steady pure tones in the mid-frequency range (roughly 500–2000 Hz), frequency JNDs for normal-hearing listeners are typically well below 1% of the base frequency (Moore, 2012, pp. 205-7). By contrast, duration-discrimination experiments in the range of a few hundred milliseconds to a few seconds usually report By contrast, duration-discrimination experiments in the range of a few hundred milliseconds to a few seconds usually report Weber fractions, meaning the proportional change in duration ($\Delta t/t$) needed for reliable discrimination, typically on the order of 5% or more (Grondin, 2010, pp. 564, 582). In practical terms, listeners resolve smaller proportional differences in pitch height than in temporal interval length, a fact exploited both in musical tuning practice and in the fine-grained pitch movements that carry speech prosody (Patel, 2017, pp. 185-216).

standard mechanical metronomes of the period offered only a discrete series of integer tempo markings rather than continuously adjustable or decimal BPM settings.[37]

Conlon Nancarrow also worked extensively with tempo ratios in his *Studies for Player Piano*, though primarily focusing on a single relationship between two tempi rather than generating a complete scale. Examples include the following pieces (Thomas, 2000, p. 137):

- *Study No. 15* – 3:4 ratio (165 and 220 bpm)
- *Study No. 17* – 12:15:20 ratio (138, 172.5, and 230 bpm)
- *Study No. 33* – √2:2 ratio (198 and 280 bpm)
- *Study No. 40* – *e:π* ratio (tempi not specified)

In a different but related vein, Richard Barrett develops what he calls "rhythmic subdivisional grids," in which families of tempi are derived from multiplicative ratios around a chosen basic pulse rather than from a fixed global tempo scale (Barrett, 2019, pp. 18–20). In the non-hierarchical version of this system, he specifies a set of speeds that are "as far as possible all equally distinct from one another", which leads him to construct a logarithmic scale of tempo multipliers between 0.75 and 1.5 of a unit value. These multipliers are then applied to a given duration and approximated by small integer ratios (for example 12:16, 13:16, … 24:16), producing a grid of related but non-coinciding subdivision speeds that can be permuted across parts to create a finely graded rhythmic heterophony. In the complementary "harmonic" or hierarchical version, Barrett follows Clarence Barlow in ranking subdivision ratios by a kind of rhythmic harmonicity coefficient, so that simple ratios articulate an underlying pulse while more complex ones are perceived as tempo variations. Compared with Cowell's just intonation tempo scales and Stockhausen's equal tempered chromatic scale of tempi, Barrett's practice is less concerned with mapping tempo directly onto pitch systems and more with generating a continuum between coordinated and discoordinated activity across multiple layers. His logarithmic spacing and probabilistic use of ratios serve to regulate the density, distinctness, and degree of synchronization between simultaneous streams, rather than to produce "tempo harmonies" or modulatory trajectories in the sense found in Cowell, Carter or Stockhausen.

In another, more directly proportional application of ratio-related tempi, composer and guitarist Marc Sinan in *At First* creates five sections of music with durations in the proportions 5:4:3:2:1 and assigns tempi in inverse proportion. Beginning with a maximum of 180 bpm, he derived the other tempi as 36, 72, 108, 144, and 180 bpm. The choice of 180 bpm was based on his estimate of a practical performance limit for music using sixteenth notes (personal communication, 2 November 2022), a principle I also applied in *Building Music*, discussed below.

Ranges of Tempi

Another approach to choosing tempi is to create a list from slowest to fastest, without reference to a repeating scale at the octave. For example, in Ligeti's *Poème Symphonique*, he specifies a range between 50 and 144 bpm, distributed among the 100 metronomes. This approach depends on two main factors: the upper and lower limits, and the distribution of tempi within that range.

In the score, each metronome is to be wound exactly four times, meaning that faster metronomes stop sooner than slower ones. Ligeti describes the result as "a single long phrase which could be characterized as a rhythmic diminuendo" (Ligeti, 1962, p. 5). In the final minutes, only a few metronomes remain,

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[37] Standard Maelzel-type mechanical metronomes provide a fixed, non-linear series of integer BPM markings, typically from 40 to 208, in steps such as 40–42–44 … 200–208; only later digital and software metronomes allow finer-grained or "virtually continuous" tempo adjustment, including arbitrary intermediate values and decimals.

producing a single sparse yet clearly polytemporal texture. While any metronome range from 40 to 208 bpm would create the diminuendo effect, the combination of winding limitations and the desired overall duration - 15 to 20 minutes according to the score - likely informed Ligeti's choice of 50–144 bpm.

Regarding distribution, the mechanical metronomes available at the time (and specified in the score) offered the following discrete tempi: 50, 52, 54, 56, 58, 60, 63, 66, 69, 72, 76, 80, 84, 88, 92, 96, 100, 104, 108, 112, 116, 120, 126, 132, 138, and 144 bpm. This excluded both decimal tempi and many specific non-decimal values such as 51, 62, or 124 bpm.

My own approach in the three polytempo compositions discussed below also uses tempo ranges. However, unlike the closed tempo scales derived from pitch relations in Cowell and Stockhausen, or the graded grids of subdivision ratios developed by Barlow and Barrett, the tempi in my works emerge from a set of practical and perceptual constraints: performance limits, metronome availability, and the registral distribution of the ensemble. Several additional guidelines shape these choices, as will be explored in the following section.

In my first polytempo work, *Building Music,* the tempi were not drawn from a pre-existing tempo scale or subdivisional grid, but were chosen according to four guidelines.

Firstly, to impart vitality to the mixture of pulses, I set a brisk walking pace (andantino) of roughly 80 bpm as the lower limit. The upper limit is 160 bpm, aligned with the maximum practical speed for continuous articulated sixteenth notes that appear in the final section. Unlike Sinan's choice of 180 bpm in *At First*, I prefer the slightly slower 160 bpm. This preference originates in my college practice routines, where I used the long strings of articulated sixteenth notes in J. S. Bach's *Sonata in C Major* (BWV 1033) as articulation studies, and where my teacher, flutist Jeffrey Khaner, treated 160 bpm as the technical ceiling.

Second is the question of how to distribute the tempi. Given a spread between 80 to 160 bpm, a first approach might be simply to divide that range by the number of instruments, and then space them evenly throughout. 80 bpm range / 25 musicians[38] = 3.2 bpm tempo difference between each instrument, e.g. 160, 156.8, 153.6, etc… However, there are two problems with this approach. First, the possibility for setting tempi based on decimal divisions is not very common on metronomes (still in the twenty-first century), presenting a practical issue. Second, Weber's law of *just-noticeable difference*[39] specifies that perceived tempo change is proportional between two tempi, meaning that a difference of 3 bpm, for example between 80 and 83 bpm, is perceived to be greater than the 3 bpm difference between 157 and 160 bpm.[40] In order to compensate for this effect within the 80 - 160 bpm range, and also to avoid decimal tempi, I created speed differences of 2 bpm in the slower tempi, 3 in the medium tempi and 4 in the faster tempi.

The third guideline mapped slower tempi to lower-pitched instruments and faster tempi to higher-pitched instruments. This approach was intended to enhance the clarity of the polytempo texture. Traditionally, lower voices in harmonic textures articulate slower, more sustained patterns, while higher melodic voices tend to move faster and with greater surface detail, a division of labor that is consistent with findings that bass-range sounds provide a more accurate temporal reference while higher-pitched voices are perceptually

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[38] The vocalist was included in this calculation.
[39] Mahr and Cheprasov, (2022) What is Weber's Law?
[40] This effect is compensated for in the tempi scaling on traditional metronomes: it changes in increments of 2 bpm from 40 to 60, increments of 3 between 60 and 72, increments of 4 between 72 and 120, increments of 6 between 120 and 160 and increments of 8 bpm from 160 to 208. The percentage of change ranges from 3.33% to 5,26%. From 120 until 208 can be seen as a doubling of the tempos from 60 onwards.

dominant carriers of melodic information (Hove, Marie, Bruce, & Trainor, 2014; Trainor, Marie, Bruce, & Bidelman, 2014).[41]

This mapping resulted in clusters of close tempi within each octave of the ensemble's range.

Tempi of the instrumentalists of *Building Music*, in bpm:

- 160 - piccolo trumpet 1
- 156 - alto saxophone
- 152 - oboe
- 148 - piccolo trumpet 2
- 144 - flute
- 140 - cornet
- 136 - trumpet 1
- 132 - percussion 1
- 128 - voice
- 125 - electric guitar
- 122 - trumpet 2
- 119 - trombone 4
- 116 - soprano saxophone
- 113 - piano
- 110 - tenor saxophone
- 107 - trombone 3
- 104 - bassoon
- 101 - bass trombone
- 98 - trombone 2
- 96- acoustic bass
- 94 - baritone saxophone
- 92 - trombone 1
- 90 - percussion 2
- 88 - bass saxophone
- 86 - tuba

For the fourth guideline, I avoided assigning tempi very close in value, to physically adjacent musicians, in order to minimize the natural synchronization effect between neighbors. Ensembles tend to set up their stage positions by grouping families of instruments together. This can create situations in which the third and fourth guidelines directly conflict, for example when all trumpets are seated next to one another and their tempi are close in value. The solution was to separate the closest tempi from each other. The 1st trumpet is assigned a speed of 136 bpm, the cornet with a speed of 140 bpm, and they are physically separated by the 2nd trumpet at 122 bpm.

[41] It could be interesting, however, to invert this situation, or explore other relationships between tessitura and range.

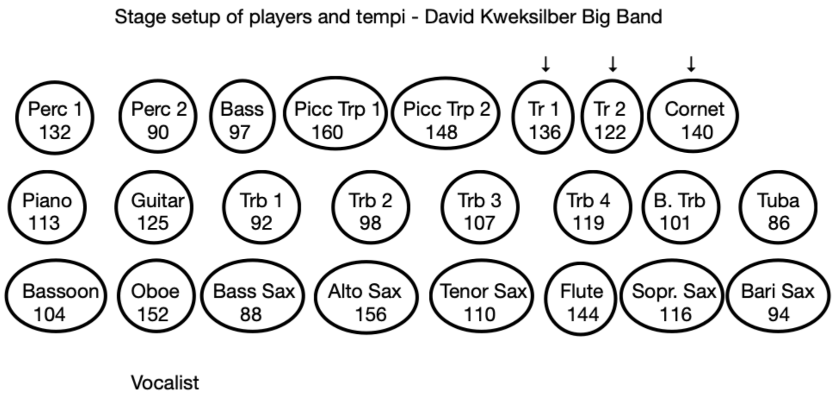

Figure 4.2: Stage setup of players and tempi

Ligeti's *Poème Symphonique* offers an interesting point of comparison: the slower metronomes are placed at the front of the stage and the faster ones at the back, presumably so that the slower, still-running metronomes at the piece's end are closest to the audience. This allows the public to hear the rich interactions between the remaining speeds at close range. Similarly, Sinan's *At First* positions its five tempo groups around the audience, creating a spatialized listening experience. Such spatialization of different tempi is a recurring theme in many polytempo works.

The combined result of all these tempo-selection processes can be heard in the following video excerpt:

Example 4.35. *Building Music*, video excerpt.

The intention for the polytempo work, *For Bob*, was to create a piece commemorating a dear friend who had passed, and I set out to see if I could use the polytempo technique to create a slower, more reflective piece. In contrast to *Building Music*, with its tempi ranging from 86 to 160 bpm, *For Bob* employs a narrower and slower range of 75 to 115 bpm. This restricted tempo span, combined with longer note values such as dotted half notes and half notes, produces a subdued and meditative quality, quite unlike the active pulsing of *Building Music*. Throughout the various arrangements of this piece, distributions of tempi between the instruments were determined by simply dividing the total range (40 bpm) by the number of instruments, and assigning each player one of the divisions. The tempo distribution of Version 1 of *For Bob* has been lost so I will detail versions 2 and 3 here.

Version 2: flutes

- 75 - flute 6
- 80 - flute 5
- 85 - contrabass flute
- 90 - flute 4
- 95 - bass flute
- 100 - flute 3
- 105 - alto flute
- 110 - flute 2
- 115 - flute 1

Example 4.36. *For Bob*, video.

Version 3: Jerboah

- 75 - contrabass recorder
- 83 - contrabass flute
- 91 - alto recorder
- 99 - electric guitar
- 107 - glockenspiel
- 115 - recorder

Example 4.37. *For Bob*, audio.

In both versions listed here, the instruments are separated by equal speed increments - 5 bpm in the flute version and 8 bpm in the Jerboah version. Since the total range of 40 bpm is considerably narrower than the 74 bpm span in *Building Music*, the proportional difference between the slowest and fastest instruments is relatively small. As a result, the exact increment size does not significantly alter the perceptual separation between tempi.

As in *Building Music* and *For Bob,* each instrument is given its own tempo, but to create *Sydney Polypulse* I conducted more thorough research into the possibilities for tempo combinations between the instruments. One consequence of two instruments repeating notes at different speeds, for example 70 and 80 bpm, is a clearly audible phasing effect.

Example 4.38. violin, 70 bpm; flute, 80 bpm, audio.

Phasing in music, as I use the term here, is a compositional technique in which the same phrase, or even a single repeated note as in some of my examples, is performed by two or more voices at slightly different tempi, so that their points of coincidence gradually change. Related ideas already appeared in medieval and Renaissance mensuration canons and isorhythmic motets, where voices proceeded at proportional speeds and slowly drift out of alignment, although in those repertories the effect was embedded in contrapuntal practice rather than presented as a foreground process. In 20th-century usage the term phasing usually refers to the technique pioneered by Steve Reich, who made the gradual change of phase itself the principal object of perception. This can occur either when two voices begin at different points but repeat with the same tempo, so that the phase difference remains constant and the result resembles an echo, or when one of the voices adopts a slightly different tempo so that the phase difference is continually transformed. In *Drumming* (1971), for percussion ensemble, Reich combines these approaches: a rhythm is first repeated in unison, then one performer marginally increases tempo until the pattern is displaced by one unit against the other part, at which point this new alignment is stabilized before a further phase shifting process begins.

Example 4.39. Reich, *Drumming*, video.

How close do two tempi need to be before their combination gives rise to a perception of phasing? Psychophysical studies on tempo discrimination suggest that listeners begin to notice a change of tempo at around four to five percent of the base tempo. Below that threshold the difference is often imperceptible in typical listening conditions, whereas above it the two streams are more readily heard as moving at different speeds rather than as a single, slowly shifting pattern (Quené, 2007, pp. 135, 183; McAuley, 2010, p. 140). Reich's style phasing tends to occupy this narrow band. The tempo difference is large enough for the alignment between patterns to drift audibly over the course of many repetitions, yet small enough so that locally the parts still fuse into a single pulse rather than separating into two clearly distinct meters. In what follows I refer to this narrow band of tempo differences as the *phasing region*.

In all of my polytempo works where musicians follow metronomes, the parts are never in unison for more than one iteration, because the tempo differences between parts place them within this phasing region and create a constant slow shifting of alignment. Speed differences in simple ratios such as 2:1 or 3:2 also involve simultaneous but different speeds, yet they do not produce the same perceptual effect. In those cases the streams are usually heard as two distinct rhythmic layers or as a proportional canon, rather than as one pattern gliding past another. In example 4.38 above the flute plays slightly faster than the violin. The two parts begin synchronized, gradually separate and eventually return to synchronization, at which point the process can begin again. Below, in section 5.5.3, I will discuss the performance practice for the various stages of the phase in more detail.

In the sextet *Sydney Polypulse*, I sought to foreground phasing itself as a compositional texture. One starting point was the choice to create three duos in order to exploit the phasing technique, matching each duo loosely according to tessitura (flute with violin, bass clarinet with cello, piano with vibraphone). The tempi of the musicians in each duo would be linked by their phase length. In the full-ensemble polytempo passages, my intention was that both the duo phases and tutti texture would be audible, in order to create a multilayered sound. With this starting point, I could begin to form a method to explore approaches to the choice of tempi. Essentially there are two parameters for each duo that determine the individual tempi: the *base tempo* of the slower voice and the *duration of the phase*, as a result of the relationship between the base tempo and the tempo of the faster second voice. To create a calm atmosphere for the beginning, exploring very subtle speed differences, I chose a relatively slow tempo, experimenting in the range between 40 and 80 bpm for the *base tempi*. Andante (walking pace) might be too fast, largo (broadly) too slow. Adagio (at ease) captures the quality I was looking for, which is around 60 bpm.[42] The *duration of the phase* refers to the time it takes for the two voices of repeated notes to complete one phase cycle as shown above in example 4.34.[43] For example, a combination of one voice at 60 bpm and a second voice at 80 bpm - a 4:3 speed ratio - is a quite short cycle, lasting three seconds in this combination of tempi. For me, there is a metrical feeling to these cycles, each completion functioning musically as a single measure. This accords with music theorist Christopher Hasty's view that meter can arise in "measures that are longer than bars" and that larger groupings may be experienced with their own sense of metrical "rightness" (Hasty, 1997, p. 182).

Example 4.40. violin: 60 bpm, flute: 80 bpm, audio.

This phase duration was too short for the longer phrases I envisioned for this piece. On the other hand, a second voice at 61 bpm would yield a ratio of 61:60, meaning a single cycle would last an entire minute.

Example 4.41. violin: 60 bpm, flute: 61 bpm, audio.

While taking such a duration to follow all the miniscule timing gradations between two notes in such a long phase is certainly fascinating, the musical phrase created would lead to a work of much larger dimensions. The commission was for a work of 8 to 12 minutes and I wanted to have space to develop a variety of approaches to the polytempo application in multiple sections.

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[42] The correlation between the Italian terms and bpm is not standardized among literature and practice.

[43] The formula to determine the duration of a phase is: time (in seconds) = 1 / ((tempo B - tempo A) / 60)

To scope out some possibilities at the base tempo of 60 bpm, the following tempi from 80 bpm down to 61 bpm are listed, along with their corresponding tuplet, duration, and audio example.

- 80, 60 bpm - 4:3 - 3 second phase
- 75, 60 bpm - 5:4 - 4 second phase
- 72, 60 bpm - 6:5 - 5 second phase
- 70, 60 bpm - 7:6 - 6 second phase
- 68.6, 60 bpm - 8:7 - 7 second phase
- 67.5, 60 bpm - 9:8 - 8 second phase
- 66.6, 60 bpm - 10:9 - 9 second phase
- 66, 60 bpm - 11:10 - 10 second phase
- 64, 60 bpm - 16:15 - 15 second phase
- 63, 60 bpm - 21:20 - 20 second phase
- 62, 60 bpm - 31:30 - 30 second phase
- 61, 60 bpm - 61:60 - 60 second phase

Example 4.42. Different phase speeds, audio.

In *Sydney Polypulse*, I deemed a phase length of 20 seconds to be a suitable compromise for the work's duration: long enough for beautiful slow phasings, but not too long to require a work of greater length. For a 20-second phase at 60 bpm, the second voice needs to be 63 bpm, which simplifies to a 21:20 tuplet relationship.

Example 4.43. 63, 60 bpm - 21:20 - 20 second phase, audio.

Elements for the perception of speed in polytempo music

Another perspective I took while choosing the tempi was to examine the question of how the phasing would *sound*. More specifically, how discernible would the phasing details between two instruments be? Would the change of the timing relationship between two voices become labored and predictably plodding, or too fast and difficult for the listener to follow, leading to a different character than intended?

The choice of tempo plays an essential role. The slower the tempo, the more time available to hear subtle differences in speed, yet, if other musical parameters are kept relatively stable, the music can feel less energetic and risks becoming overly predictable. At faster tempi, the pulse can feel more exciting, yet the subtleties are glossed over. I tested combinations in both digital audio and notation software, assessing these trials through what I call "the filter of my own body": tapping, singing, listening, and physically sensing the results while reflecting on the musical goals. The aim was to find a middle ground between the two extremes.

During this process, I discovered that the duration of the phasing has a direct impact on the overall perception of speed, independent of the tempo:

- Short phase duration → music feels faster
  For example: Example 4.44. 80, 60 bpm - 4:3 - 3 second phase, audio.

- Long phase duration → music feels slower
  For example: Example 4.45. 61, 60 bpm - 61:60 - 60 second phase, audio.

I believe that this experience results from two intertwined factors: the evolving relationship between the two voices across iterations, and the subsequent metrical length. For the 4:3 combination (80 and 60 bpm), the substantial speed difference between the voices leads to a marked change in their rhythmic relationship with each repetition, instilling a feeling of rapidity. That high rate of change also culminates in a shorter cycle, and thus also a sensation of shorter measures. Shorter measures evoke a quicker pace compared to extended measures, like those produced by a 61:60 combination.

Another determinant of the identity of speed in a polytempo duo is the individual tempi (in bpm) of the voices. An 80 and 60 bpm duo encompasses both adagio and moderato simultaneously. When the tempi are closer together, such as 63 and 60 bpm, the dual temperament is reduced and the overall sound aligns more closely with adagio.

To sum up, the factors influencing the sensation of speed in this polytempo music include:

- the rate of change between iterations in the distance between two notes
- the phasing duration between the voices, leading to varied metrical lengths
- the tempi of the voices

The first two elements are interconnected, influencing each other, while the third operates autonomously. This implies that the base tempo can be selected to either accentuate or counteract the phasing speed. For instance, a piece with a 4:3 ratio, having a brief phase length, can be executed at a brisk tempo to amplify its brevity or at a languid pace, opposing its inherent speed.

- 4:3 at 120 bpm
- 4:3 at 50 bpm

Example 4.46. 4:3 at different speeds, audio.

In a 61:60 ratio, which has a very long phase length, the same options yield similar results: a fast-tempo pulsing with two slightly different speeds at the same time, or a slow tempo study into miniscule changes between the timing of two repetitive notes.

- 61:60 at 120 bpm
- 61:60 at 50 bpm

Example 4.47. 61:60 at different speeds, audio.

As the effect shown by the different Beethoven speeds, the choice of faster or slower overall tempi profoundly influences how the material is experienced, determining which musical details are foregrounded and which are backgrounded.

Three duos of Sydney Polypulse

When one or more further layers are added, the polytempo takes on several additional qualities. Primarily, multiple different phases occurring at the same time create a multilayered sound with many more audible details. However, as more layers are added the density of information can become overwhelming, leading the listener to shift focus from the individual details to the overall texture - seeing the "forest" rather than each individual "tree." At this scale, I appreciate the beauty of a composite sound made from many interlocking parts, where regularity remains perceptible yet embedded within a complex, almost incomprehensible, mathematical structure. This balance between recognizability and intricacy is one of my primary goals in these polytempo works.

As outlined earlier, I chose phases of approximately 20 seconds for *Sydney Polypulse*. The next step was to determine how to implement this within three duos, each with a different base tempo. I explored three scenarios in which the duos' base tempi were:

- a) far apart,
- b) moderately close, and
- c) very close together.

All examples revolve around a general tempo centre of 60 bpm.

- a) Example 1, widely spaced: Example 4.48. 40, 42, 60, 63, 80, 83 bpm, audio.

    Duo 1: **40** - 43 bpm (13:12)
    Duo 2: **60** - 63 bpm (21:20)
    Duo 3: **80** - 83 bpm (27:26)

- b) Example 2, moderately spaced: Example 4.49. 50, 53, 60, 63, 70, 73 bpm, audio.

    Duo 1: **50** - 53 bpm (17:16)
    Duo 2: **60** - 63 bpm (21:20)
    Duo 3: **70** - 73 bpm (23:22)

- c) Example 3, closely spaced: Example 4.50. 60, 61, 62, 63, 64, 65 bpm, audio.

    Duo 1: **60** - 63 bpm (21:20)
    Duo 2: **61** - 64 bpm (21:20)
    Duo 3: **62** - 65 bpm (21:20)[44]

With six distinct tempi, there are 15 simultaneous phasings: each voice interacting with the other five (5+4+3+2+1). In example 3 the close speeds between all the players create a number of longer phases of around 60 seconds. However, as mentioned above, in order to make space in the sound for the 21:20 phases within each duo I put each one into an octave separate from the other duos.

Finally, I chose to have all the voices as close together as possible, as reflected in example 3. At first it may sound as though all the players are playing at the same speed, yet as time passes, the relationships of the articulated notes between players change subtly. The sound is quite different from the mix of many disparate speeds at the same time when the tempo areas of the duos were spread apart (examples 1 and 2).

[44] While the percentage of difference of 3 bpm varies in different speed areas, e.g. 63 is 5% faster than 60 bpm and 163 is only 1.8% faster than 160 bpm, in the relatively similar speed-options I was exploring, the differences were negligible.

After establishing a close series of tempi, I explored one further option: stacking all the tempi 3 bpm apart, which leads to phases of around 20 seconds between all adjacent speeds.

Example 4.51. 60, 63, 66, 69, 72, 75 bpm, audio.

This setup yielded an overall sound that felt too brisk for the slower character I sought. Consequently, I devised a second version, slowing the base tempo by 10 bpm:

Example 4.52. 50, 53, 56, 59, 62, 65 bpm, audio.

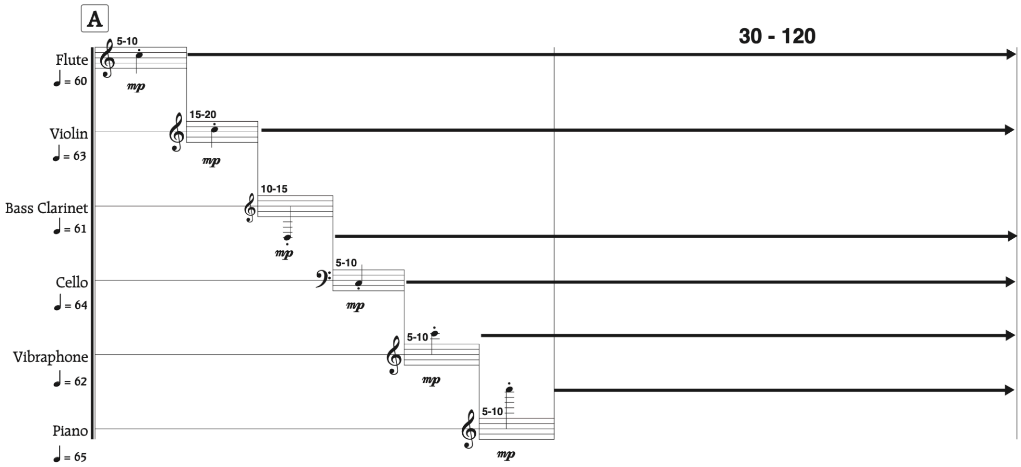
While this captured a slower overall tempo, there was still a wide disparity in speeds between 50 and 65 bpm in the outer voices, creating a somewhat chaotic texture. Maintaining 65 bpm as the fastest tempo, I came back to the smaller stacking of tempi: 60, 61, 62, 63, 64 and 65 bpm.

Example 4.53. 60, 61, 62, 63, 64, 65 bpm, audio.

This configuration captured, finally, the slow moving system of polytempo I was looking for. To emphasize the 20-second phases, I opted for a 3 bpm difference for each duo from the start. This led to the chosen tempi for the piece:

- Duo 1: 60 (flute) - 63 bpm (violin)
- Duo 2: 61 (bass clarinet) - 64 bpm (cello)
- Duo 3: 62 (vibraphone) - 65 bpm (piano)

Sydney Polypulse begins with all the instruments simply repeating the pitch 'C' at their own tempo. The entrances are sequential, each one after 5 to 10 seconds. Once all the musicians have entered the phasing texture simply runs its course for 30 seconds up to 2 minutes.



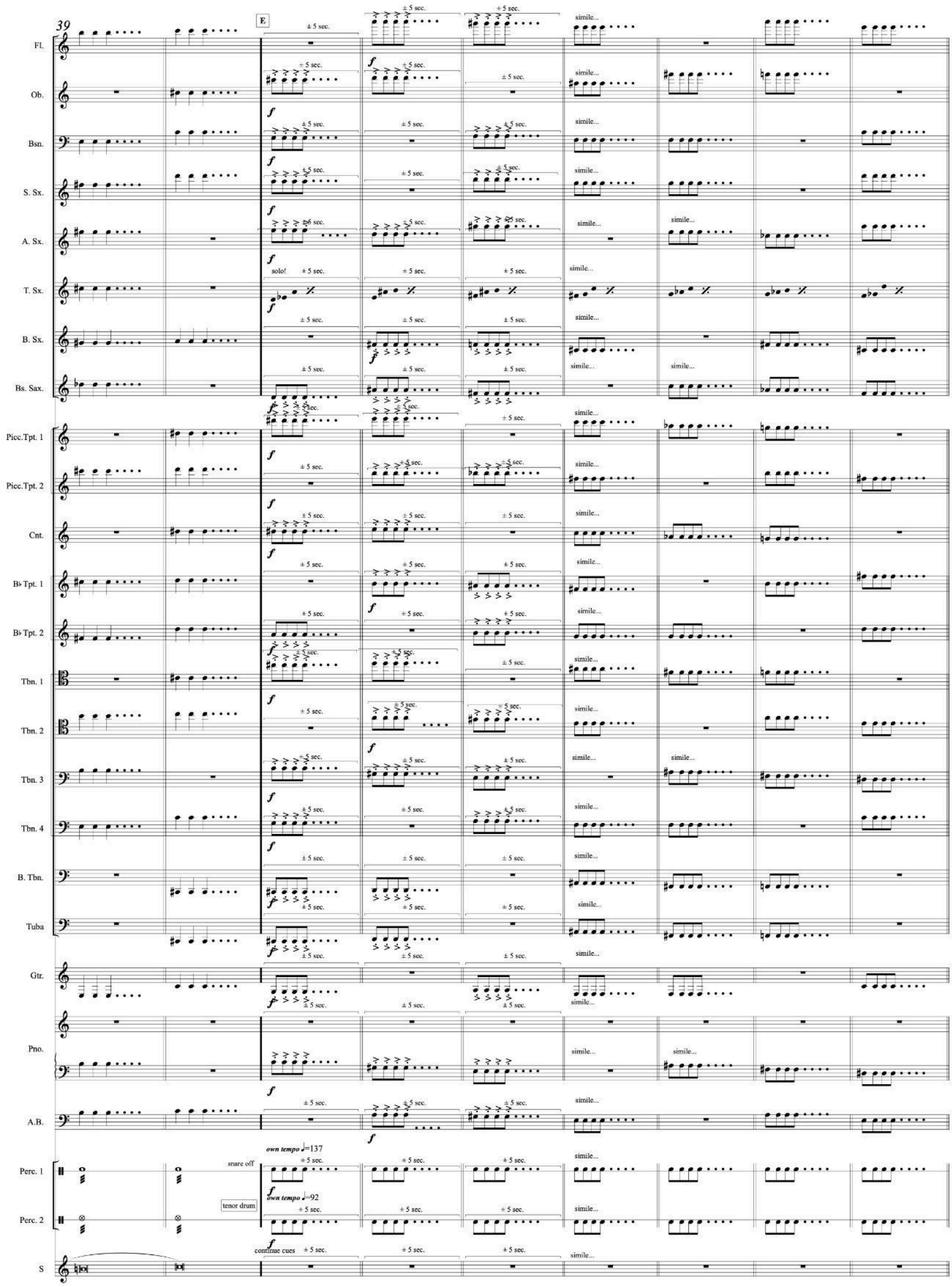
Example 4.54. *Sydney Polypulse*, video.

4.5.5 Implementations of note values

As mentioned above, using merely quarter notes at different speeds results in a limited palette of speed to work with. In this section I outline the development of my approach to creating different speeds through the use of tuplets and rhythms. Quarter notes, a tuplet of 1 note per beat, can be exchanged for other tuplets, such as triplets or 16th notes, and rhythms can be implemented to give the individual lines more character.

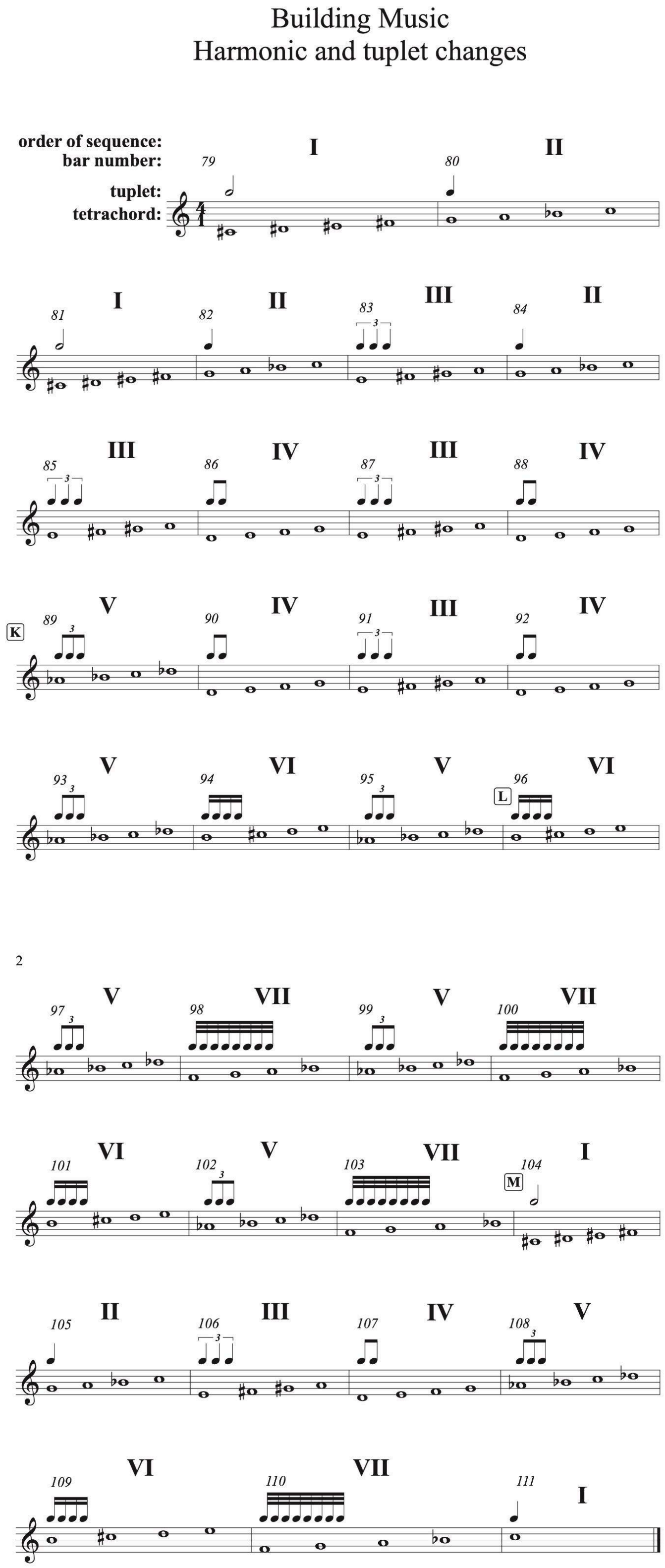
The repeated notes in *Building Music* begin as quarter notes but other note values are used later in the work, from whole notes up to 32nds. While the 16th note speed is taken as the upper limit for the range of tempi, as mentioned above, that is the case only for the piccolo trumpet 1, who plays at 160 bpm. 16ths at this tempo equate to individual notes at 640 bpm (160 bpm x 4 (16ths per beat)). When 32nds are employed in the work, they always surpass this maximum speed. Given that the slowest player's tempo is 86 bpm, this equates 32nds to 688 bpm (86 bpm x 8 (32nds per beat)). The practical result is that when 32nds are notated, they are simply to be played as fast as possible. This also generates a polytempo texture, since each musician will have a different personal limit to their speed of articulation.

In *Building Music* I kept the tuplets in all parts the same, only changing to another tuplet simultaneously in all the voices, which creates textures that shift in blocks; there is no mixing of different tuplets between the players. For example, at the first shift (at letter E, see below), the polytempo texture transitions from quarter notes to 8th notes for all players, effectively doubling the density.



Example 4.55. Building Music switch to double speed, score excerpt. Video excerpt.

In the final section, where there is both a harmonic shift and speed change for each bar, their correlation was mapped out in a straightforward one-to-one ratio. Each of the six harmonies - tetrachord clusters distributed among all the players - is sequentially linked to one of six tuplets, increasing in speed. The passage unfolds as a sequence of those combinations.

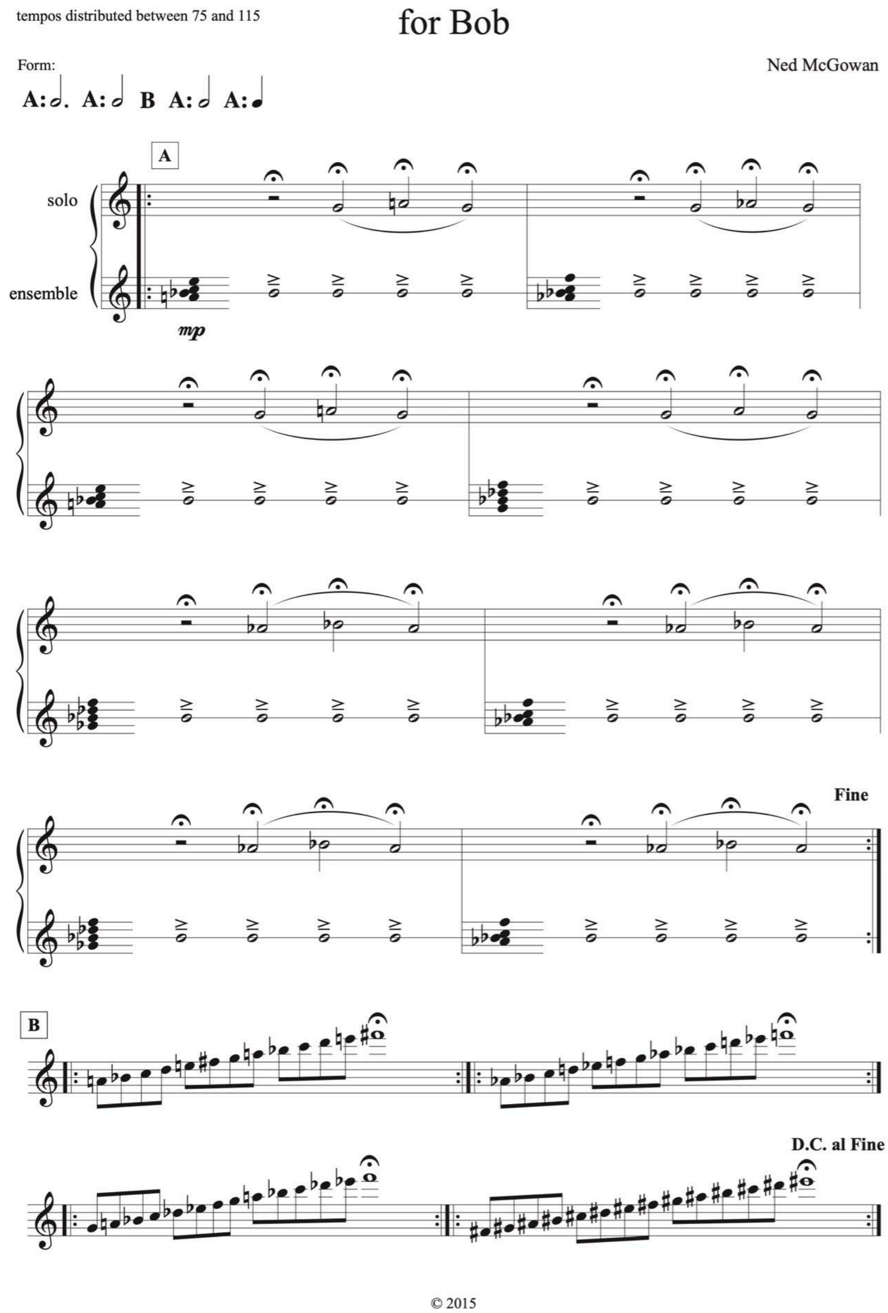


Example 4.56. *Building Music,* Part 4, harmony and speed switches, score. Video excerpt.

The calm texture I was aiming for in *For Bob* called for relatively longer durations. This can be achieved in two ways: with very slow tempi or through the use of notes longer than quarters. I chose longer note values for several reasons, the first being that the opening section combines multiple tempi with dotted half notes. The chosen tempi range is 75 to 115, which equates to notes of 25 to 38 bpm (⅓ of 75 to 115). While metronomes can produce these tempi, the long durations are difficult to synchronize because of the extended temporal gaps between cues. Dotted half notes at 75 bpm offer three times the synchronization information compared to quarter notes at 25 bpm. A further reason was that this approach enabled a progressive acceleration of the texture in subsequent iterations of the A section (see example 4.58 below), moving from dotted half notes to half notes and finally to quarters.

In the contrasting B section, the players switch to runs of faster eighth notes at their individual tempi.

Here is the one-page score of *For Bob:*



[45]

Example 4.57. *For Bob*, score.

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[45] From the score instructions: "At the beginning of each bar all the instruments, except the solo lines, will choose a note from the chord and keep it throughout the whole bar. Chordal instruments could choose more notes or the entire chord. In sync with your metronome, you repeat your note until the next cue. The length of your repeated note for all the bars in A, either a dotted half note, a half note or a quarter note, is determined by which part of the form you are in (AABAA)."

Sydney Polypulse begins similarly to *Building Music*, with quarter notes for each musician at their own tempo. Although this worked well for the opening unison section, I sought techniques to create a larger palette of speeds, driven by the research detailed above and my goal to achieve a form with varying levels of tension.

The specific problem was how to move beyond the single-speed limitation of quarter notes in order to create a broader range of perceived motion within the ensemble texture. My solution was to introduce tuplets as a tool to extend the speed range. For example, applying a 3:2 ratio to a tempo of 60 bpm produces an effective tempo of 90 bpm. The set of tuplets I used, arranged in order of increasing speed, was:

- 4:3 (dotted eighth notes)
- 3:2 (triplet quarters)
- 2:1 (eighth notes)
- 3:1 (triplet eighth notes)
- 4:1 (sixteenth notes)
- 6:1 (sixteenth-note sextuplets)
- 8:1 (thirty-second notes)

As previously discussed regarding *Building Music*, all the voices (in their different tempi) took on the same tuplet at the same time, creating a uniform speeding up and slowing down. One focus of *Sydney Polypulse* is on the specific relationships between individual voices, and I aimed to mix tuplets between voices, achieving greater speed separation than the initial 1 bpm difference.

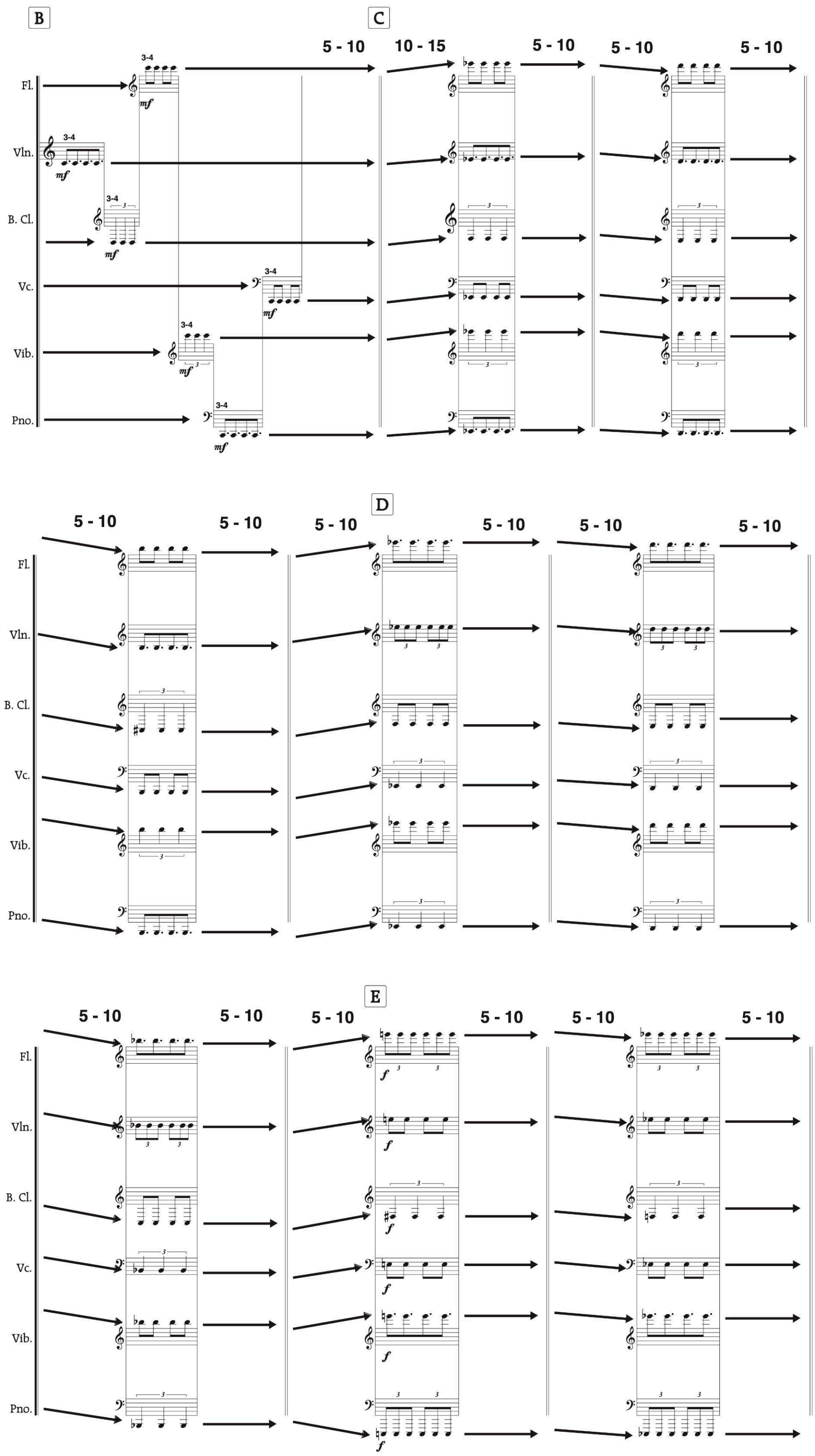
Letter B (score below) introduces several tuplets on different octaves of the opening pitch of C, and then, beginning at rehearsal letter C, harmonic developments begin to occur. As the ensemble progresses through the pitch unisons of Eb, D, B, Eb, D, Bb, E, Eb and A, the mix of speeds among the instruments periodically changes, creating a different texture each time.

To streamline the compositional process, I translated each tuplet ratio into its decimal equivalent:

- 3:1, triplet 8th notes = **.33**
- 2:1, 8th notes = **.5**
- 3:2, triplet quarter notes = **.67**
- 4:3, dotted 8th notes = **.75**

This conversion provided a clear framework for planning speed changes across instruments at different rehearsal letters. The chart below shows the tuplet-decimal assignments for each instrument, along with the resulting bpm in parentheses.

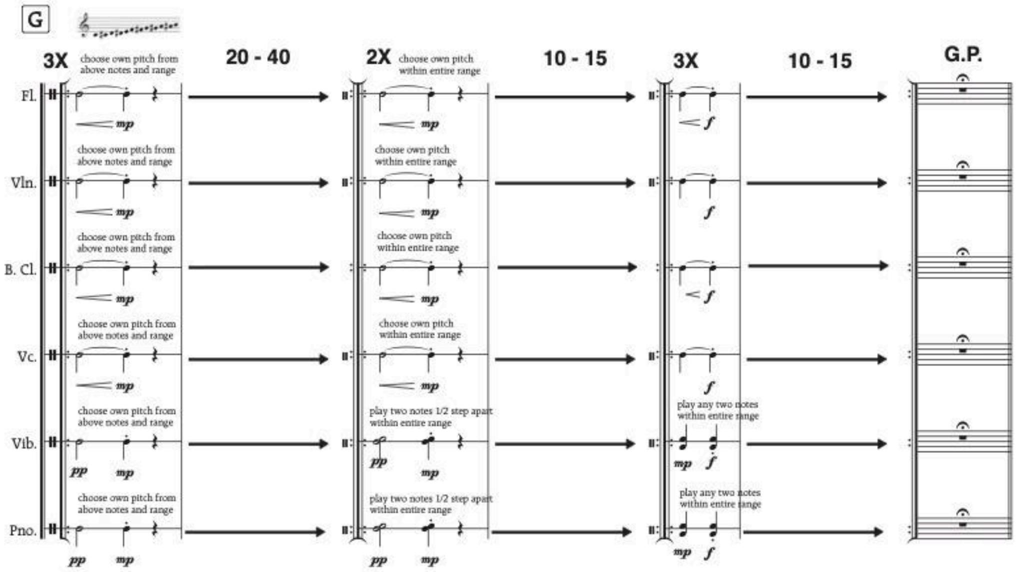
Rehearsal letter	A	B	C	D	E
- flute	**1** (60 bpm)	**.5** (120 bpm)	**.5** (120 bpm)	**.75** (80 bpm)	**.33** (180 bpm)
- violin	**1** (63 bpm)	**.75** (84 bpm)	**.75** (84 bpm)	**.33** (189 bpm)	**.5** (126 bpm)
- bass cl.	**1** (61 bpm)	**.67** (92 bpm)	**.67** (92 bpm)	**.5** (122 bpm)	**.67** (92 bpm)
- vlc.	**1** (64 bpm)	**.5** (128 bpm)	**.5** (128 bpm)	**.67** (96 bpm)	**.5** (128 bpm)
- vibraphone	**1** (62 bpm)	**.67** (93 bpm)	**.67** (93 bpm)	**.5** (124 bpm)	**.75** (83 bpm)
- piano	**1** (65 bpm)	**.75** (87 bpm)	**.75** (87 bpm)	**.67** (98 bpm)	**.33** (195 bpm)



Example 4.58. [*Sydney Polypulse*, B to E], score excerpt, video excerpt.

From letter C through letter E, the players have unison pitches (in different octaves) but the switches between tutti unisons are staggered as players choose to switch at their own time (the angled arrows). The result is a slow dissonant appoggiatura effect between each new pitch (the straight arrows), creating moments of tension and resolution.

Later in the piece, longer notes, such as half notes and rests, are also used to create basic rhythms.



Example 4.59. *Sydney Polypulse*, G, score excerpt. Video.

4.5.6 The use of metronomes

During performances of both *Building Music* and *For Bob*, one important aspect of my own experience was a compulsive focus on achieving a perfect equal polytempo, inspired by the computer models I had assembled in the testing phase. Even with the ensemble's massive sound, when players maintain uniform repeated notes, one can discern the repetitiveness of individual voices. In this texture, the phasing relationships between layers can be too overwhelming to fully track as a listener. For the polytempo texture to produce the polyphonic effect I intend, each player must follow their metronome with unwavering precision, maintaining their own distinct speed. From observation, even slight inaccuracies cause audible irregularities in the repetitions, disrupting the intended polytempo sound.

In *Building Music*, I instructed musicians to follow the blinking light of silent metronomes placed on their music stands. The metronomes would be in silent mode and the players could see the blinking in their peripheral vision while looking at their parts. This provided players with a visual pulse, keeping the sonic space uncluttered for the music.

Example 4.60. blinking metronome, video.

Although generally successful, this setup occasionally produced timing errors between players. These errors become audible during synchronizations, particularly when two voices rhythmically align for several iterations. This effect shouldn't occur, of course, since the natural result of any two voices in different tempi is a constant phasing. The large ensemble in *Building Music* somewhat masked this issue with its massive sound. However, in thinned-out sections, this unintended synchronization was evident.

This problem persisted even with the spatializing of closely matched tempi, as previously mentioned. One solution would be to spread the players of the ensemble even further apart. Another approach could involve eliminating the ensemble, recording each voice separately, and playing them back together, through a multiarray speaker setup. However, both options undermine one of my central artistic aims: maintaining ensemble cohesion through the musicians' ability to hear and respond to one another - a core value in chamber music and equally important in my polytempo works. As such, I did not pursue these approaches further.

At this point I was unsure how to correct the problem beyond simply "more practice." When I embarked on my next polytempo piece, *For Bob*, I gained insights that shed light on aspects of both the problem and its solution.

Here is an example in the flutes version of *For Bob* where the (undesired) synchronization between the players is clearly audible.

Example 4.61. *For Bob*, for flutes, problem spot 1, video excerpt.

The fourth arrangement of *For Bob* was for the 31-tone Fokker Organ and solo flute/contrabass flute. The unique technical possibility of this organ is that it is controllable via MIDI, making it a suitable acoustic instrument for the strict polytempo technique, being driven by a computer. As a reference, here is a clip from the MIDI version with the Fokker Organ.

Example 4.62. *For Bob*, for Fokker Organ, spot problem spot, video excerpt.

Since it was controlled by a computer, the accuracy of polytempo speeds by the MIDI Fokker Organ was ideal, and all of the multiple simultaneous layers and their interactions were audible. It missed, however, the color of human interpretation: individual dynamics, articulations, tone colors, and interaction between the players, to name a few qualities.

In the Jerboah version, the musicians opted to play the piece using earbuds to *hear* their metronomes, instead of watching the blinking lights. The resulting rhythmic polytempo sound was stunningly accurate.

Example 4.63. *For Bob*, for Jerboah, audio.

This version opened the question of whether pulses given by sonic cues can be more accurate than visual cues, which led to investigate the different possible modalities for metronomes: auditory, visual, tactile, and combinations thereof.

Sensory modalities for metronome cues

Auditory cues are sounds, musical or non-musical, that we hear and synchronize with, such as the playing of nearby musicians or the click of a metronome. Synchronizing with a recording of a drummer, or with a cellist who maintains steady timing, is typically straightforward.

Visual cues may come from a conductor, the violinist's bow, a blinking metronome or some other visual chronometer. Research has shown that spatial-visual information is more reliable than flashes (Grahn, 2012, p. 51-61). Examples include the approach of a timpani mallet to the drumhead or the animated pendulum on some digital metronomes.

Tactile cues are sensations we feel within or on our bodies, manifesting as either kinesthetic or haptic forms. Kinesthesia is the awareness of the location and movement of a foot, finger or head, for example. We track them either in repetitive and non-repetitive motions. Repetitive movements, like moving a foot up and down, facilitate better time-keeping as they can be easily standardized. Haptic sensations are felt vibrations located on one's skin.

According to psychologists Katherine Ammirante, Aniruddh Patel, and Frank Russo, our ability to synchronize with a metronome pulse is much more accurate with auditory clicks than visual flashes, suggesting an enhanced auditory-motor coupling for rhythmic processing (Ammirante, Patel & Russo, 2016, pp. 1882-1890). This study aligns with my experiences in *Building Music*, where I noted rhythmic challenges with flashing metronomes, and observed improved accuracy with earpiece metronomes in the Jerboah rendition of *For Bob*. Further, when comparing the results from auditory stimuli to tactile stimuli (delivered to the fingertip), Ammirante, Patel and Russo found no significant difference in response time, suggesting that a tactile metronome can also be more effective than flashing metronomes. This finding is pertinent to polytempo music performance methods, especially since a new tactile metronome, the Soundbrenner, was introduced in 2014 (Ammirante, Patel & Russo, 2016, pp. 1882-1890).

The Soundbrenner, a watch-like device worn on the body, produces a vibration that can be felt. It has several different placement possibilities: on the wrist, on the leg, or with a body strap. After testing these options, I favor the body strap because it creates a pulse close to where I feel my inner pulse - at the center of my torso. The other musicians wore their Soundbrenners on their wrists or ankles and at least one musician claimed that the wrist placement was too distant to effectively follow. This aligns with Ammirante, Patel, and Russo's findings that performance can vary significantly based on the location of a tactile cue, be it on a fingertip or toe (Ammirante, Patel & Russo, 2016, pp. 1882-1890). While other musicians adapted well to the wrist placement, drawing a direct correlation between practice and the study proved elusive.

Even while feeling the tactile sensations of the Soundbrenner, I experimented with including the visual flash given by my smartphone. However, psychologists Rachel L. Wright, Laura C. Spurgeon, and Mark T. Elliott showed that combining both auditory and visual cues produces slightly better results than auditory cues alone (Wright, Spurgeon & Elliott, 2014). While this multisensory attention to both tactile and visual modalities of the metronome improved rhythm, I felt musically constrained to a singular focus on the metronome. By omitting the flashing and focusing solely on the metronome's vibration, I could devote more attention to surrounding sounds and musicians. This makes sense since I can look elsewhere while still feeling the pulses. Given that interaction is fundamental to chamber music and my polytempo compositions, the benefits of a visual connection with fellow musicians surpass the slight edge of multisensory cues. Furthermore, vision is needed to follow the score. If hearing concentrates on the music and instrument, and sight on the score and fellow musicians, it naturally positions touch as the best strategy for following the metronome's pulse. For live music, the haptic metronome is preferable because of its superior accuracy over a flashing metronome, and its silence. In other words, there is no audible click interfering with the sounding music. For *Sydney Polypulse,* I decided to use the Soundbrenners as an integral part of the performance.

Undoubtedly, factors like practice, adjustment, individual abilities such as improved focus or foot-tapping influenced the final choices. The availability of Soundbrenner straps, with only one body strap, was also a consideration. While there weren't studies addressing all the variables, as is typical for musicians, we found a way. We began by testing methods, evaluating whether challenges could be addressed with practice or if a different approach was necessary. Although one study indicates haptic metronomes lose effectiveness the farther they are from the brain (Ammirante, Patel & Russo, 2016, pp. 1882-1890), our percussionist preferred it on her ankle, allowing her wrists freedom to play the vibraphone. At times, choices that may seem physiologically less optimal are made for practical reasons, with any ensuing challenges tackled through practice, concentration, and expertise. This illustrates how practice-based inquiry can offer insights and pragmatic solutions that complement and add value to findings in other scientific fields.

4.5.7 Coordinating musicians in polytempo music

Coordination strategies in other polytempo works

When each musician follows a different tempo, metric coordination across the ensemble, for example aligning "four beats per bar," quickly becomes untenable. Four beats at one tempo necessarily occupy a different duration than four beats at another tempo. The first compositional decision in polytempo music therefore concerns the basis of coordination. The layers may meet at predetermined points; one layer may function as a reference, or coordination may remain largely local and contingent.

One established solution is to distribute authority across tempo groups through multiple conductors. Works such as Stockhausen's *Gruppen* and Earle Brown's *Available Forms II* employ more than one conductor so that different subsections can maintain independent tempo trajectories. The approach is effective for a small number of tempo strata, but it does not scale to situations in which each individual player inhabits a distinct tempo. In that case, a conductor per musician would be required, which is impractical in an ensemble of twenty-four.

A second solution relocates coordination from interpersonal entrainment to a mechanically fixed temporal mapping. In *New Musical Resources*, Henry Cowell proposed ratio tempi and noted that the player piano roll allows rhythmic complexities to be cut directly into a time bearing medium. This remark catalyzed Conlon Nancarrow's exploration of polytempo relationships in the *Studies for Player Piano*, where temporal positions are encoded spatially as punched holes in the paper roll. Because note speeds translate straightforwardly into distances on the roll, the instrument can realize tempo ratios with a precision that would be difficult to sustain in a human ensemble. György Ligeti's *Poème Symphonique* offers a related example in which a technology designed to produce a uniform pulse becomes the generator of a complex temporal field when multiplied. A metronome is built to enforce steadiness, yet a group of metronomes produces a shifting polytempo texture through the inevitable divergence of their mechanisms and decay times.

A third family of solutions emerges with computers, which enable individualized tempo streams to be delivered to performers via electronic click tracks. In Kyriakides's *Wavespace* and Sinan's *At First*, a computer distributes separate click tracks so that each musician can follow a dedicated tempo line while remaining aligned with a global timeline shared by the system. This approach makes coordination explicit without requiring performers to negotiate tempo relationships in real time. It also shifts the rehearsal problem from aligning beats on the page to developing a reliable bodily and attentional relationship with the click, especially when tempo changes or phase relationships are complex.

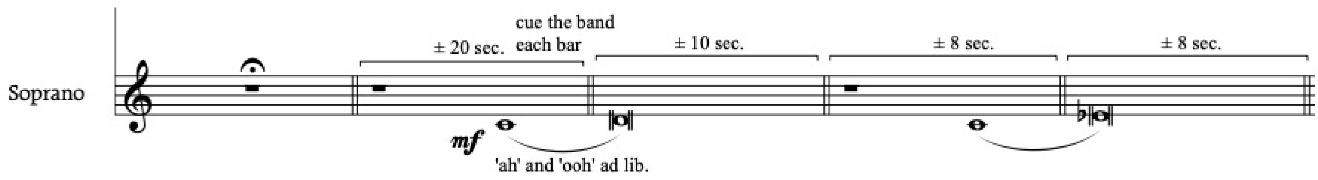
A fourth possible approach is to treat coordination as an emergent outcome of a performer's agency and rehearsal practice, rather than as an externally imposed synchronization mechanism. In my work "Telescopic Ladder," from the work *Tools* I tap into the potential of musicians realizing polytempo relationships via improvisation. The musicians are asked to choose and perform their own tempo that differs from the other musicians. While practice is essential, this directive proved simpler for musicians than realizing comparable temporal complexity through extensive tuplet notation within a single shared metric framework.

Example 4.64. *Tools*, "Telescopic Ladder", random speed section, video excerpt.

Coordination strategies in my three works

In the three polytempo works I have focussed on in this chapter, the possibility to have the metronome cue the musicians was an essential starting point. The synergy between concept and technique in creating feasible polytempo music occurred at the initial conceptual stages of the compositional process.
As mentioned, in *Building Music* each musician has a metronome giving them their tempo, but structuring the global changes from bar to bar and from section to section requires a cueing technique for the entire ensemble. The option exists to have all the players led by a click track computer system coordinating all the different speeds, as is done in *Wavespace*. But because the piece's dense, overlapping speeds quickly create a stable "chaos texture," exact simultaneity across all players isn't necessary. The texture sounds consistent whether or not the bars align perfectly, so the metronomes alone suffice.

My solution to cueing the bars was to time their lengths in approximate number of seconds and to have the soprano cue each bar with her arm. In this case the singer can time the harmonic flow with her melodic lines, which are also in part determined by how long she can hold a note before needing to take a breath.



Example 4.65. *Building Music*, score excerpt.

This process can be seen here:

Example 4.66. *Building Music*, video excerpt.

In *For Bob*, again a single musician (or conductor) cues the bars where the harmonies switch. While the piece has a recurring vocal melody, in this piece the melody begins and ends in the middle of each bar. This allows bar lengths not limited by a singer's breathing. The polytempo motor simply keeps running until the cue is given for the switch. There are no elements to indicate any length of phrase and the music gives no further clues as to how long each bar will last. This allows for longer bars, which can contribute to the sense of timelessness intended with this piece.

Example 4.67. *For Bob*, bars 1 to 3, video excerpt.

For the MIDI-controlled Fokker Organ version, however, I had to pre-program bar lengths. This meant committing to durations before the performance, which sometimes caused the melody to be cut off.

Example 4.68. *For Bob*, for Fokker Organ problem spots, video excerpt.

The fix was to build a Max MSP patch that kept the organ's polytempo running indefinitely, letting me, as the flutist in the performance, trigger harmonic changes with a MIDI pedal in real time. This restored the flexibility I wanted, making the cues responsive to the moment rather than predetermined.[46]

Example 4.69. *For Bob*, for Fokker Organ, with Max patch control, audio excerpt. Video excerpt.

[46] These factors are discussed in Chapter 2.

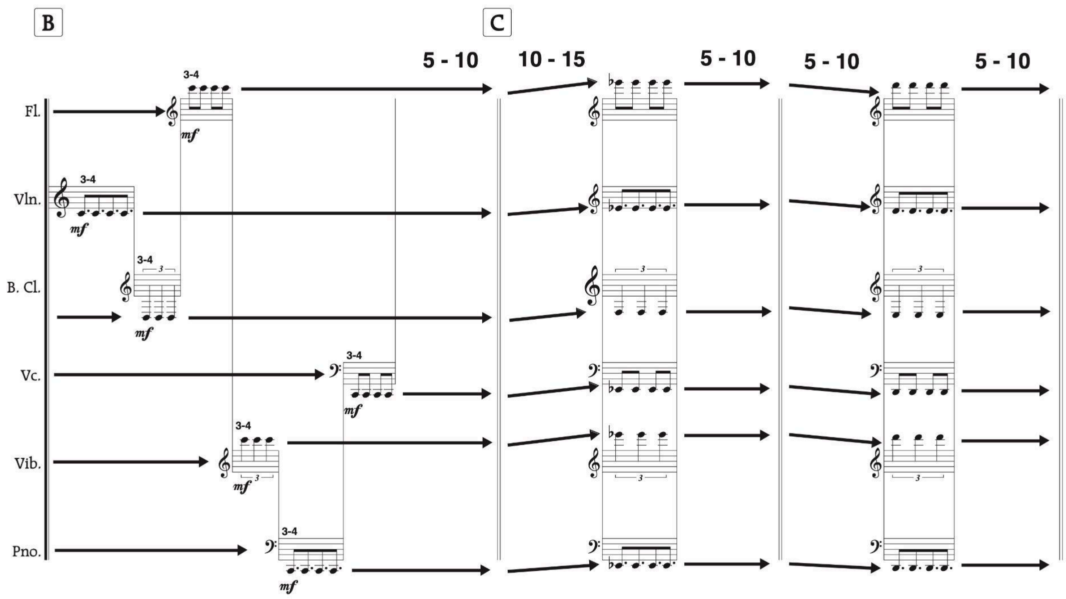
In *Sydney Polypulse* a number of different strategies for cueing are utilized. In section A (Example 4.55), musicians enter on their own, guided by time intervals given in seconds, similar to *Building Music*. Letter C focuses on a morphing effect I had first noticed in *Building Music*: when everyone changes pitch at a cue, their individual tempi mean the change doesn't happen all at once. Each player switches on their next beat, creating a gradual blend of old and new pitches. In *Building Music*, with faster tempi, this morph can be perceived as unfolding within the span of a single beat.

Example 4.70. [*Building Music*, morph transitions], video excerpt.

In *For Bob* the effect is more pronounced due to the slower tempi and longer notes.

Example 4.71. [*For Bob*, morph transitions], video excerpt.

In *Sydney Polypulse*, I made this gradual change a core feature. Here, musicians take 10–15 seconds to move from C to Eb, creating an audible appoggiatura effect - a momentary tension as both pitches coexist, resolving only when all have changed. Since the timing is up to each player, they can shape that tension individually.



Example 4.72. *Sydney Polypulse*, score excerpt. Video excerpt.

From section F to J, bar changes are cued by a single ensemble member, keeping the group connected even while the underlying polytempo runs independently.

Example 4.73. *Sydney Polypulse*, transition from E to F, video excerpt.

Again, as in Ligeti's *Poème Symphonique* and my own "Telescopic Ladder," strategies devised to handle the practical constraints of coordination with the available instruments and technologies become integral to the identity of the piece rather than remaining background solutions.

4.5.8 performance practice of Sydney Polypulse

In February 2022, I rehearsed and performed *Sydney Polypulse* with five master's students from the Fontys Academy of Music and Performing Arts in Tilburg. Joining the ensemble on the flute part, I was able to experience first-hand the performative aspects of the piece and to gain an understanding of it from the player's point of view. Here I outline a number of topics that came up during the rehearsals and performance.

Polytempo with different instruments: finding your "inner robot"

During the rehearsals we observed the different ways each of us plays our instrument and how that affects the articulation of the polytempo, how exactly the sound is created. For example, the motions of the piano, percussion and string instruments are binary in nature: up and down or left and right. These movements can be mechanized in a repetitive robotic manner, much like the binary movement of many time keeping devices: pendulums, pulsing quartz, oscillating atoms, etc. This can reduce variability in the timing of their notes.

As percussionist Russell Hartenberger, with over 50 years of experience performing Steve Reich's *Drumming*, describes it:

> I am reminded of the yogic principle of the elimination of outside distractions in focusing on simple physical actions, and for a percussionist, the attention to a single stroke is sound creation at its most fundamental level. […] The concentration, energy, endurance, repetition, rhythmic awareness, and physical motions in phasing are at the core of the performance practice of all Reich's music. (Hartenberger, 2016, p. 107)

The string instruments are somewhat more complex due to the variety of ways sound is produced. For example, sound can be created either by placing the bow on the string and creating a sudden fast movement, or by a circular action in the bow-arm. In the latter, the string is activated by the bow in motion, and the speed and contact time dictate the specific articulation and volume. The simpler hitting movement of the piano and percussion makes it easier for those players to synchronize with their metronomes. The flute and bass clarinet require setting the embouchure and starting the air, which involves an extensive set of muscles in the mouth and torso. While this is seemingly less directly binary in nature, earlier studies have also demonstrated that wind players have less variability than string players (Rasch, 1979).

In short, in polytempo, whatever the instrument, the goal is the same for performers: precise, repetitive motion with as little drift as possible. This is what I call finding your "inner robot."

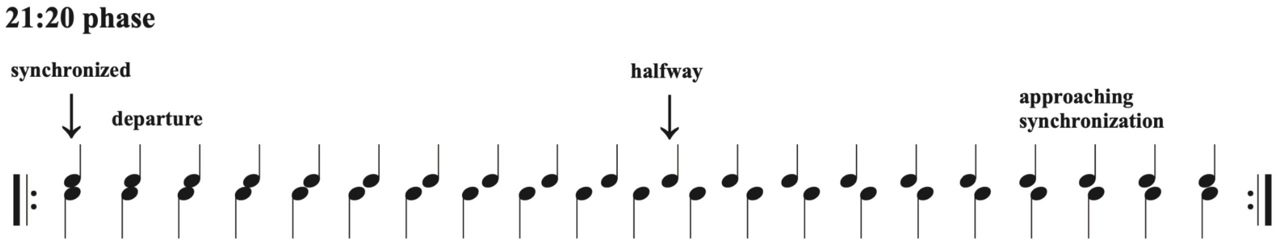
Subdivision

We also experimented with subdividing the pulse to improve steadiness. In theory, subdividing the pulse, whether physically or cognitively, provides more information to determine the steadiness of the pulse. The primary options for division are 8ths, 16ths, or 32nds. Dividing into many small units with 32nds, however, creates more events to keep track of, and at a certain density the demands on cognitive load outweigh any gained accuracy. At first, 16th notes seemed to be the best resolution. However, several musicians found tapping 8th notes more effective, alternating their feet in a left-right sequence. One student remarked that this might be because we are used to the movement of walking and maintaining a pace. Marcel Andriessen, percussionist and teacher at Fontys, believed that this was effective because of its physicality. He contends that we can sense time through our movement, a view supported by controlled experiments showing that moving along to a perceived beat improves timekeeping precisely when the external signal is absent, and that when movement during the silent timekeeping interval is withheld the advantage disappears (Manning & Schutz, 2011, p. 125). These results help to explain why tapping 8th notes in a left and right sequence, akin to walking, stabilized the pulse for several musicians in our trials.

Andriessen posited that subdividing the beat into 8th notes is effective due to the resultant afterbeat, which can be audibly and/or physically perceived. 16ths or 32nds might become too difficult to maintain, as mentioned above. Conversely, 8th notes create an upbeat in the note's articulation, a technique regularly demonstrated by percussionists and violinists using their sticks or bows. For wind instruments, which don't have a binary movement, the backbeat is generated bodily, through mechanisms like foot tapping or breath. In my own practice I use both. Control of small breaths to delineate time is natural for me as a flutist, and when that is not possible, for example while playing notes, then I switch to tapping my toe.

Concentration and the stages of a phase

As explained in the section about selecting tempi, the phasing duration between two voices stems from their tempo relationship. In *Sydney Polypulse*, I opted for a 21:20 phase for the duos, indicated strictly by metronomes set to 63 and 60 bpm. Working on playing this phase led to realizations about its structure. There are clearly audible markers in the phase, starting with the moments of synchrony and the halfway point. Hartenberger identifies these markers along with the ¼ and ¾ points in the long phases of that piece (Hartenberger, 2016, p. 97). In my experience with *Sydney Polypulse*, the areas demanding the most focus were those of departure from and return to synchrony between the two voices. These were challenging due to the proximity of the voices in timing.



Example 4.74. 21:20 phase.

Several factors may account for the difference between my experience and Hartenberger's in *Drumming*: in *Sydney Polypulse* we used metronomes; I chose a single repeated note rather than a patterned figure; and of course his depth of experience is exceptional. Artistically, *Sydney Polypulse* aims for a lucid, gradual phasing of single notes by six players, organized as three duos. This stands in contrast to the in-and-out-of-focus shimmer that arises in Reich's phased patterns in *Drumming*.

Example 4.75. *Sydney Polypulse,* introduction, video excerpt.
Example 4.76. Reich, phase from *Drumming*, video excerpt.

In the Fontys rehearsals we noticed a strong tendency to "stick" at the unison point. Pairs would remain synchronized for several beats, in some cases up to five beats, which already accounts for roughly a quarter of the 20-second phase, before they reasserted their metronomes and the phase continued. Although the following examples come from early rehearsals, the sticking effect is clearly audible.

- *Sydney Polypulse rehearsal clip 1*
- *Sydney Polypulse rehearsal clip 2*
- *Sydney Polypulse rehearsal clip 3*
- *Sydney Polypulse rehearsal clip 4*

Example 4.77. *Sydney Polypulse*, synchronizations, video examples.

At first, polytempo is unintuitive, and players must prioritize their focus on playing in time with the metronome, resisting influence from the timing of others. During the learning process, I proposed concentration strategies such as aiming to hit one's first note perfectly in sync with the metronome, then restarting with the same goal for the subsequent note. This type of focus creates an "in the moment" awareness which resets for each note.

I found this particularly difficult at these moments, especially when approaching synchrony. With practice, however, my attentional stance began to shift: near synchrony I focused more intensely on the metronome, while in the middle of the phase I allowed myself to relax that focus and instead listen to and enjoy the interaction of the two pulses. Developing the "inner robot," meaning the ability to lock attention onto an external timing reference when required while staying aware of the other musicians, is essential to bring polytempo performance to life.

Even when following a metronome, however, we are not machines. Microtiming deviations remain and typically fall in the range of about 50 to 100 ms relative to the metronome's ideal timing (Repp, 1999; Madison & Merker, 2002). In *Sydney Polypulse*, the stepwise difference between successive dyads in the phase is also on the order of tens of milliseconds, around 50 ms for many combinations.[47] This numerical overlap matters. It places the natural human fluctuation and the musical phase increment in the same temporal neighborhood, a region where fine control becomes difficult for conscious correction. Deviations in this band are not always expressive choices. They can also arise from physical and instrumental constraints, as discussed in section 4.5.8. Because the phase step and the microtiming variance occupy similar ranges, the pull toward synchronization exerts disproportionate influence on the progress of the phase. At times it becomes hard to distinguish whether one is hearing an intended phase step or an unintended microtiming drift.

Further, while playing I sometimes try to clarify salient phase moments by nudging timing forward or backward by very small amounts, with the intention of putting a temporal magnifying glass on those instants so they feel extended and legible. This works only if the partner does not make a similar adjustment at the same time. If both players "help," the nudges can cancel or compound in confusing ways, because both actions live in the same 50–100 ms corridor as the phase step itself. This is another concrete instance of the interaction between multiple rhythmic grids outlined in section 4.2: the fundamental grid, the expressive grid, and the partner's grids. In practice, only when the metronomes are separated by about 500 ms, which occurs toward the middle of the 20-second phase, do players feel genuinely unstuck and free from the syncretic pull.

This raises questions of performance strategy: should a player use microtimings to highlight certain parts of the phase, perhaps lingering at a particularly beautiful moment? Or should the focus remain solely on the metronome, letting the music unfold on its own terms? In *Sydney Polypulse*, I find it especially difficult to ignore the other musicians, likely because the repeated-note material brings the phasing relationships to the foreground. That was precisely my intention in this composition.

[47] The two voices of the 21:20 phase are at tempi 63 and 60 bpm.
Duration of a beat at 63 bpm: 60,000 milliseconds / 63 beats = 952.38 milliseconds/beat
Duration of a beat at 60 bpm: 60,000 milliseconds / 60 beats = 1,000 milliseconds/beat
Difference = 1,000 milliseconds - 952.38 milliseconds = 47.62 milliseconds
With each iteration (or beat), the relationship between the two voices will shift by 47.62 milliseconds.

Hartenberger identifies a number of related qualities:

> [...] the ambiguity in the music creates interest and the repetition can create a meditative state; but these qualities also require the player to develop heightened concentration in order to play the part correctly and still enjoy listening to the sound of the ensemble. (Hartenberger, 2016, p. 133)

At first, the texture can seem static, a mass of repeated notes. Given time, however, the timing relationships themselves come forward, and movement and contour become audible. This connects to a broader point in music cognition and aesthetics: perceived complexity is shaped not only by the intrinsic structure but also by the time allowed for it to unfold. Research on form, expectation, and processing time suggests that extended durations and repetition enable listeners, including performers, to perceive details that would be missed in shorter spans (Margulis, 2007; Huron, 2006). What first appears static gradually reveals a nested activity that propels the music forward.

Hartenberger's concept of "relaxed intensity" is especially apt here (Hartenberger, 2016, p. 134). One attends with vigilance but without strain, allowing the structure of the phase to emerge while maintaining tempo discipline.

In sum, the most reliable practice combines three elements. First, a clear internal mapping of the phase landmarks - departure, midpoint, and return - so the ear has defined targets. Second, an adaptive attentional profile that tightens around synchrony and loosens in the middle of the phase, opening space for ensemble listening. Third, restraint in expressive microtiming near salient points, or at least a shared understanding within the duo of who will shape and who will hold, ensuring that well-intended gestures do not collide. Within this framework, the "inner robot" is not an aesthetic of rigidity but a scaffolding that supports expressive listening and ensemble interplay.

4.5.9 Reflection on computers, expression and interactivity

As established, the difficulty for players to maintain slightly different tempi next to each other is formidable, and that affects the quality of performances. Given the rhythmic precision achieved by the computer in the fourth arrangement of *For Bob* for the MIDI-driven Fokker Organ, why not pursue that path further and utilize computers in crafting more polytempo works? The rhythms are beautiful, as can also be heard in all of the mock-up tests made in Finale throughout this chapter.

The issue for me with this approach is that it lacks the expressive nuances of live players. My experience as both performer and listener leads me to the belief that the metronome takes away one of our greatest expressive tools: microtiming, where musicians can push and pull their notes against each other, choosing to play on the front side or back side of the beat, depending on how they interpret the music at each moment. Rather than being metronomic inaccuracies, these kinds of actions can enhance the musical content of a performance.

Returning to the question of using computers, a fascinating development in some of today's popular music is the exploration of microtiming in DAWs, creating grooves which place notes distinctly outside of the rhythmic grid (Brøvig-Hanssen, Ragnhild, Aareskjold-Drecker & Danielsen, 2021). However, there is much more to live performance than just microtiming. I have tried to create compositional strategies that leave room for personal choice in other parameters of the music, such as articulations, dynamics, tone color, intonation, exact note lengths, and sound projection.

In my polytempo works, particularly in *Sydney Polypulse,* I have tried to find a way to marry the beauty of the rhythm with the expression of the live players and their interactions. In comparison to the large polytempo textures of *Building Music* and *For Bob*, a main goal of *Sydney Polypulse* was to explore interactivity between the individual players. While *Sydney Polypulse* is largely predetermined in pitch, rhythm, and form, it leaves much room for the ensemble to create its own interpretation of each section through individual choices. A player will have an idea to play a note a certain way and then the others can react to it. This is a possibility afforded by the haptic metronome: it leaves the ears available to listen. Thus, musicians can simultaneously maintain synchronization with their click tracks and attune to how the sounds blend in the space. While the polytempi driven by metronomes put the musicians in rhythmic handcuffs, the music still invites them to express their unique interpretations using the other variables. Players use these parameters to shape their performance, influenced by their own intentions and the performances of their fellow musicians. When executed well, synchronization emerges not from merely aligning notes in time, but from harmonizing musical approaches to the piece's interpretation.

The challenge in these polytempo pieces is not only to combine restriction with freedom, but rather freedom *within* restriction. While this paradox applies to nearly all notated music, it takes on a particular significance when the rigidity of clock time is introduced into live performance.

4.6 Conclusion

This chapter outlined my approaches to polytempo, weaving together analysis and conclusions, artistic intentions, practical experimentation, scientific literature, study of best practices, and interventions into my own methods to create works of music.

The chapter began by delving into a general theory of the rhythmic grid in practice. Through an analysis of its components, I created a new permutation of approaches to those elements. This conceptual framework allowed me to generalize about different kinds of polytempo and to propose structural strategies that may inspire new pathways for future compositions.

From there, the focus shifted to the sound of polytempo and the artistic motivations that shaped my own practice. The bulk of the chapter documented how I developed and refined these approaches across three works, through processes of experimentation, discovery, and intervention. By articulating these processes in detail, I aimed above all to clarify the compositional decisions that underlie my polytempo pieces, and to show how they emerge from concrete encounters with instruments, performers, and performance situations.

Several interrelated insights emerged over the course of the chapter. The basic rhythmic grid was shown to be a hierarchical structure of tuplets, beats, and bars through which monotemporal music is organized. Extending this concept into polytempo provided a new theoretical lens for understanding layered rhythmic systems, while the addition of expressive timing introduced a further, superposed grid. In chamber music, musicians continually coordinate both fundamental and expressive grids with one another. Polytempo places pressure on this coordination and, in doing so, opens up new performance practices and listening modes. The permutation of pulse, tuplet, and meter classifications was proposed as a practical tool through which composers can generate structural possibilities in this expanded temporal field.

The chapter also clarified two broad types of polytemporality: static configurations of fixed multiple tempi and dynamic configurations based on tempo modulation. This distinction helps both composers and analysts to frame polytempo strategies more precisely. Across the case studies, I showed how the synergy of concept and technique occurs at the earliest stages of composition, as creative ideas about layered time interact with practical issues such as the use of metronomes, spatial setups, and notational decisions. Attention to the upper and lower limits of tempi emerged as a defining factor in shaping musical character. These bounds are set not only by stylistic conventions but also by performers' physical capacities, emphasizing that the body itself draws important lines around what kinds of polytempo are feasible.

Further conclusions concern the ways in which polytempo is staged and supported in performance. Spatialization of instruments on stage plays a central role in how listeners perceive layered tempi, suggesting that decisions about placement and movement are not merely presentational but structural. Experiments with different kinds of metronomes led to the finding that haptic devices offer a particularly productive balance between rhythmic accuracy and the freedom to listen, a conclusion that is relevant not only to composers and performers but also to designers of future music performance tools. In addition, the discussion of tuplets and rhythmic figuration showed how speed in music cannot be reduced to tempo alone. Patterns of subdivision and density extend the range of perceived motion, offering broader palettes of speed, flow, and resistance for composers to work with.

Finally, the chapter reconsidered ensemble coordination under polytempo conditions. Synchronization was expanded to include the deliberate non-synchronization of sounds, reframing ensemble playing as the management of controlled asynchrony as much as the achievement of exact simultaneity. Subdivision strategies, repetitive motions, and attentional techniques were described as concrete methods through which performers can achieve accuracy in phasing while remaining musically engaged. Even when musicians aim for "computer-like" precision, the expressive qualities of live performance - microtiming, tone colour, interaction, and situated responsiveness - remain indispensable. Polytempo thus appears not only as a compositional technique but also as a performance practice that brings human and mechanical time into a productive and sometimes tense dialogue.

In sum, this chapter has contributed a conceptual framework, practical methods, and artistic reflections on polytempo. It can support composers in structuring polytempo works, performers in realizing them, teachers and students in developing rhythmic awareness and ensemble strategies, and music psychologists in studying how humans perceive and produce layered temporalities.