AIDING THE PERFORMANCE OF TEMPO CANON: NEW TECHNOLOGY IN STUDIES 1, 2 AND 3 FOR STRING QUARTET

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ABSTRACT

This paper discusses the application of new score-reading technologies in a set of string quartet studies written for Apartment House. I highlight how the use of technology facilitates complex polytemporal relationships within the ensemble and allows these to be conveyed in a simpler and more direct manner. I demonstrate the current state of the score application and draw attention to design features that differ from existing approaches as well as changes that have been made in response to performer feedback. This follows a brief discussion of tempo canon in both my own work and its broader historical context.

1. INTRODUCTION

The three string quartet studies discussed in this paper are examples of tempo canon. This is a type of canon where the same melody is superimposed at different speeds. As a form, it poses particular challenges to an ensemble as each performer must maintain their own unique pulse that is nonetheless in a precise relationship to the other players. Individual performers may also be required to shift suddenly to distant tempi with a high degree of precision. I have developed a new networked score-reading application that overcomes these obstacles by embedding a visual metronome in each player's part. It is distributed as a Progressive Web Application and is optimised for tablet devices.

The historical precursor of the tempo canon is the prolation canon (or mensuration canon), a musical form that first became popular in the early Renaissance. Leading exponents of this style included Johannes Ockeghem and Josquin des Prez. The *Missa Prolationum* by Ockeghem is the most rigorous exploration of this form and it has been said that it "may well be the most extraordinary contrapuntal achievement of the 15th century" [1]. A section of the original manuscript is included in Fig. 1 and a transcribed excerpt is shown in Fig. 2. A single voice is written out for each canon and the mensuration markings indicate the respective alterations of the written durations. Fig. 3 translates this into modern notation, revealing the intricate ways

Figure 1. Manuscript page of the first "Kyrie" from the *Missa Prolationum* by Johannes Ockeghem

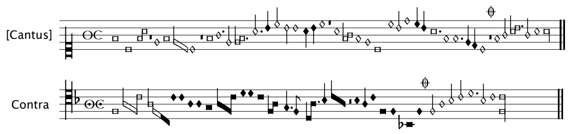

Figure 2. Excerpt from the *Missa Prolationum* (mensural notation)

in which the parts overlap and intertwine. It should be noted that the mensuration markings do not alter all note values and it is this that distinguishes prolation canon from tempo canon. In a tempo canon, all durations are scaled by the same ratio. The Agnus Dei from Josquin des Prez's *Missa L'homme arme* maintains a 2:1:3 ratio throughout and can therefore be considered a tempo canon as well as a prolation canon. [2]

During the 20th century, tempo canon was used extensively in the compositions of Conlon Nancarrow. In his works for player piano, the relationships between tempi reached ever greater levels of complexity and included rational, irrational and even transcendental numbers. An excerpt from the piano roll for *Study 49c* is shown in Fig. 4. A defining characteristic of this music is that it demands performance by machines. Though there have been significant attempts to perform some of these works in recent years [1] , the extremely intricate layering of tempi is difficult to perform accurately and Nancarrow's music for ensembles therefore favoured simpler relationships. Nancarrow did, however, theorise about the possibility of using syn-

[1] A key example is *Nancarrow: Studies and Solos - Bugallo-Williams Piano Duo*.

Figure 3. Excerpt from the *Missa Prolationum* (modern notation)

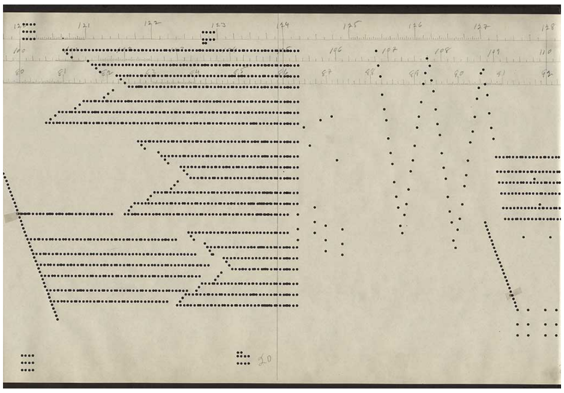

Figure 4. Excerpt from *Study for player piano no. 49c* by Conlon Nancarrow

chronised video conductors to assist performance.

> And I've got the idea of each performer having a small television screen, with something imitating a conductor that comes to the beat, so they can see it coming, whatever it is. I don't think it would be too complicated. It would probably be expensive, each one having his own screen. [2]

Nowadays it is commonplace for each performer to have their own screen in the form of a tablet computer. Nancarrow's idea can therefore be realised and the challenges implicit in the performance of tempo canon can be overcome.

2. THE MUSIC

My own music differs significantly in style from Nancarrow's but shares some of the same underlying principles. In particular, the concepts of *convergence period* and *echo distance* have structural importance. The convergence period is described by Kyle Gann as "the hypermeasure that exists between (potential) simultaneous attacks in voices moving at different tempos", while the echo distance is "the temporal gap between an event in one voice and its corresponding recurrence in another" [2]. These two concepts play an important role, both during the compositional process and in the way the music is perceived.

Each of the three string quartet studies has a global base tempo to which the other tempi relate. The correspondence between a local tempo and the base tempo is always a rational number expressed as a ratio of two integers.

Figure 5. Excerpt from *Study 1* (start)

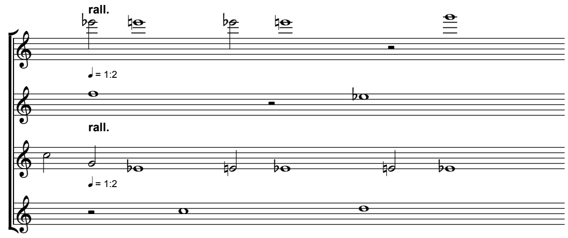

Figure 6. Excerpt from *Study 1* (second rallentando)

2.1 Study 1

The four instrumental parts of *Study 1* are derived from a two-part canon. The upper part is played by the violins while the lower part is played by the viola and cello. For the first section of the piece, violin 1 and viola maintain a static tempo while violin 2 and cello perform a controlled rallentando. The opening is shown in Fig. 5. At the tempo marking in Fig. 6, violin 2 and cello reach half the original tempo and remain there for the duration of the piece. Simultaneously, violin 1 and viola begin a rallentando, continuing until all parts coincide at the final chord. Within each rallentando, each beat has a different tempo and the durations are scaled accordingly using hidden tuplets. These are shown in Fig. 7 and reveal the underlying structure. The score-reading application allows this complexity to be hidden from the performers and for the intention to be conveyed very simply and directly. The unidirectional nature of the tempo changes in *Study 1* means that the echo distance between the two instrumental pairs continues to grow throughout. The expansion of two-part counterpoint to four independent parts is reminiscent of the *Missa Prolationum* excerpt shown in Fig. 3.

2.2 Study 2

Study 2 is the only one of the three studies that begins with staggered entries, as is typical for a canon, and is also unique in the set for having all four parts play the same melodic line. The changes in tempo are less predictable, however, with each part adhering to its own temporal scheme. The gradual changes of *Study 1* are replaced by marked changes in tempo every fifty four quaver beats. These initially become slower, once again creating a feeling of rallentando, before increasing in speed. By this point, the four parts are intertwined in a complex web of convergence periods and echo distances. An excerpt from

Figure 7. Excerpt from *Study 1* (start) with tuplets shown

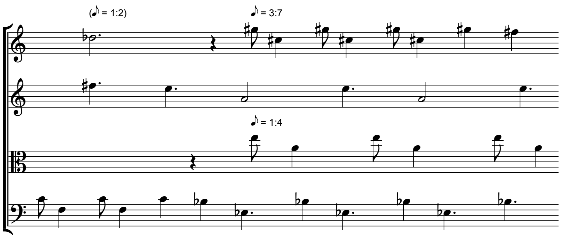

Figure 8. Excerpt from *Study 2*

the score is shown in Fig. 8.

2.3 Study 3

Whereas *Studies 1 and 2* are unbarred, *Study 3* has bar lines and a static 4/4 time signature. In contrast to *Study 2*, all four parts play different melodic material. These are derived from the same six bar melody and constitute the four specular transformations: original, retrograde, inversion and retrograde inversion. This piece is influenced by the music of Aldo Clementi, a composer who made extensive use of canonic techniques. The transposition levels were decided with the aid of an algorithm derived from analysis of Clementi's compositional methods [3]. As in *Study 2*, each part moves between tempi independently, though here the order of tempi is itself canonic. An excerpt from the score is shown in Fig. 9.

3. THE APPLICATION

When designing the score-reading application, a range of criteria were taken into consideration. I wanted it to function both standalone and in a networked environment so that it would be equally well suited to practice, rehearsal and performance. It was also important for the timing to be as accurate as possible and for the embedded visual metronome to maintain a consistent frame rate of 60 frames per second. For these reasons, I decided the score and associated timing data should be preloaded onto the device and all events should be scheduled locally. This contrasts with other existing approaches such as INScore [4] and Drawsocket [5] where each event is communicated in real-time over a network. In my application, network traffic is kept to a minimum and the only data that is transferred are transport commands (start, stop and snap) and a periodic synchronisation algorithm. This avoids potential issues with network latency and has the added benefit

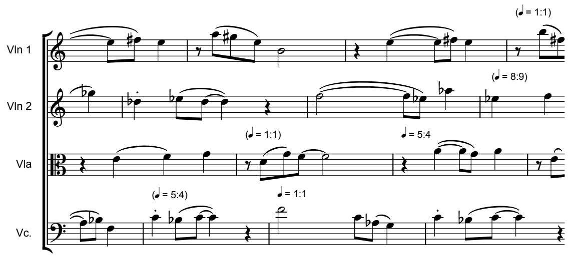

Figure 9. Excerpt from *Study 3*

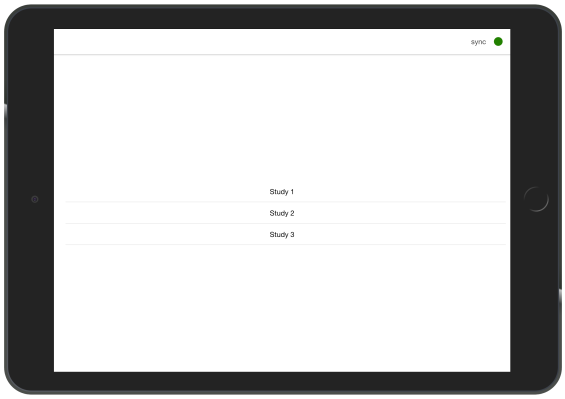

Figure 10. Application home screen

that the system is very robust in performance. If the network fails, the performance can still continue. The application is packaged as a Progressive Web Application and can be hosted on the internet for easy access by individual performers. It is well suited to use without the composer present as no additional technical knowledge is required.

3.1 Navigation and Layout

The home screen of the application is shown in Fig. 10. The synchronisation status is displayed in the header. The circle next to this is green when the device is connected to the server and red when disconnected. When red, it can be tapped to reconnect. In the centre of the screen, the available scores are listed. Selecting a score takes the user to the screen shown in Fig. 11. This displays the available parts as well as adding a back button and the selected score to the header. On selecting a part, the user is taken to the score-reading screen shown in Fig. 12. The main area is then occupied by two systems of score. Additionally, transport controls and the selected part name have been added to the header, and a footer is displayed containing a slider. This slider displays the current position during performance and otherwise allows the performer to navigate the score.

3.2 Rehearsal and Performance Considerations

There are several respects in which the practical aspects of a rehearsal are taken into account in the design of the application. Each player can navigate the score independently in order to look through their part. If a player wishes to move everyone to the same location, they can use the snap feature. In addition, the start and stop controls are available to all players, giving each member of an ensemble

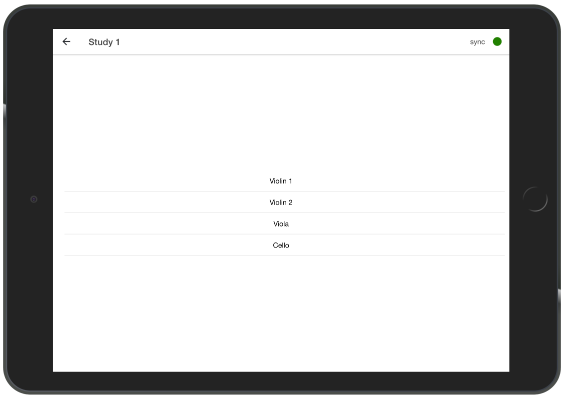

Figure 11. Part selection screen

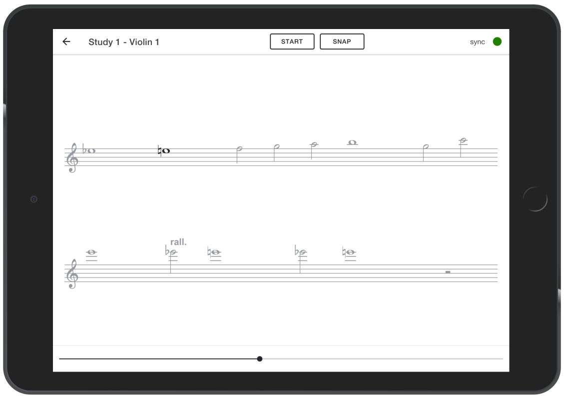

Figure 12. Score-reading screen

equal control. The original tempo markings, expressed as ratios, are translated into literal metronome marks determined according to the base tempo. The base tempo can be altered and this will automatically adjust the metronome marks for all players. This allows the overall speed to be adapted during rehearsals.

There are other design features that ease both rehearsal and performance. The performer always reads from the top system. The bottom system allows the player to look ahead in the music and the top system is replaced by the bottom system as the music proceeds. Performers find this to be very natural and appreciate being able to look ahead in the music. It was decided that the current system should always be at the top rather than alternating as this maintains a consistent distance between the notation and the visual metronome. Additionally, the current event in the score is always highlighted (as shown in Fig. 12). This is useful, both when navigating the score and during performance, and overcomes the main drawback of unbarred music, that the absence of regular visual cues makes it harder to keep one's place.

3.3 Visual Metronome

The key distinguishing feature of the application is the visual metronome. This is crucial to the performance of the three studies as it provides a visual reference for the current pulse and this pulse is often unique to each part. The design of the metronome went through several versions of varying

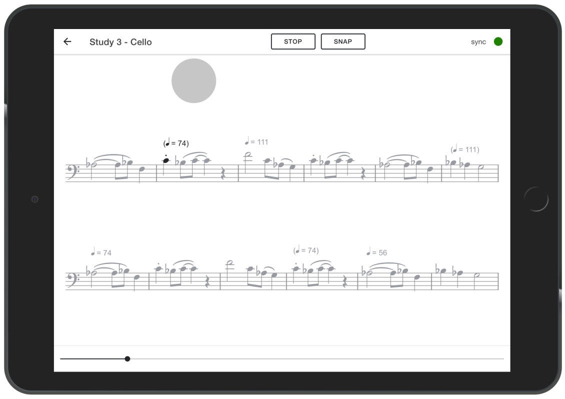

Figure 13. Score-reading screen during performance

degrees of complexity. These explored different kinds of motion and some simulated more closely the movements of a real conductor. In the end, however, I reverted to one of the simplest designs. This is a dark grey circle that fades linearly to white over the duration of a beat. I settled on this after establishing some important criteria in response to performer feedback. These were: it must be clear and simple enough to be used as a reference in peripheral vision; the start of each beat must be completely unambiguous; and the speed of the beat must be clearly and quickly discerned. Practical comparisons and performer feedback led to the current design being favoured over the 'bouncing ball' approach used in applications such as ZScore[6] and Comprovisador[7]. It also became evident through working with the musicians that the visual metronome works in combination with the event highlighting in conveying a clear sense of pulse. Fig. 13 captures the metronome partway through a beat.

3.4 Technology

The score-reading application was created using web technologies and is distributed as a Progressive Web Application. This allows it to be accessed on any platform with a standards-compliant browser, including both iOS and Android mobile devices. The app can be added to the user's home screen and will then open in a full-screen window.

3.4.1 User Interface

The user interface is built using *React* [2], an open-source Javascript library that was originally developed by Facebook. *React* makes it possible to build an application by combining small, encapsulated components and declaring how these respond to changes in state. It is well suited to musical scores where the state is changing over time or in response to events. The score itself is rendered using the SVG format. Each system comprises a top-level group and, within each system, the score elements are grouped in the hierarchical tree structure shown in Fig. 14. The score SVGs were created using the *Dorico* [3] music notation software. The groupings were applied manually using *Affinity*

[2] https://reactjs.org/
[3] https://new.steinberg.net/dorico/

```
<staff>
  <layer>
    <event>
      // event data
    </event>
    ...
  <\layer>
  ...
</staff>
...
```

Figure 14. Score data structure

```
interface EventInput {
  duration: number
  tempo: {
    numerator: number
    denominator: number
  }
}
```

Figure 15. Typescript interface for event input

Designer[4] as *Dorico* does not include semantic data in exported SVGs. A compilation step interprets this structure to assign a unique identifier to each musical event. The entire SVG is loaded into the DOM and the bounding box coordinates are used to set the SVG viewBox to the current system. This has significant performance advantages as adding and removing lots of elements to and from the DOM can be slow, causing a drop in the browser frame rate and visible stuttering.

3.4.2 State Management

The application logic is built with *Redux*[5], an open-source Javascript library for managing application state. This enabled me to keep state management distinct from the user interface layer, preventing overdependence on a single library and easing testing and development. This decoupling also allows the core timing logic to run in different environments, including both client and server. In my composition *Eluvium*, for clarinet and live electronics, this meant I could use the same core application to create an electronic score, running in *Node.js*[6], that sent commands to *SuperCollider*[7]. The score timing data is stored in the JSON format and mirrors the hierarchical structure used in the SVG (Fig. 14). Each event is an object with the shape shown in Fig. 15. The duration is a decimal expressing the number of beats and the tempo is a fraction expressing the relationship to the base tempo. The client application then converts this into an object with the shape shown in Fig. 16, determined according to the current base tempo. The values are all decimals representing seconds.

[4] https://affinity.serif.com/en-gb/designer/
[5] https://redux.js.org/
[6] https://nodejs.org/
[7] https://supercollider.github.io/

```
interface EventOutput {
  start: number
  duration: number
  end: number
}
```

Figure 16. Typescript interface for event output

3.4.3 Server

In an ensemble setting, each performer uses WiFi to access the same local area network and connect to a WebSocket server. This is running in *Node.js* and is responsible for relaying transport commands to all connected clients and synchronising each client to a master clock. The clock synchronisation is done using the open-source *@ircam/sync*[8] Javascript library. This periodically compares the client clock to the master clock and compensates for any drift [8]. In practice, this means that all connected clients can share a common master clock to synchronise events. When a performer presses 'play', this sends the command to all connected devices along with a start time in the future. By default, the start time is a tenth of a second after the 'play' command is sent. This ensures that all devices start at the same time. The local clocks continue to stabilise as the performance proceeds.

4. CONCLUSIONS

The score-reading application presented in this paper has proved itself to be a practical and effective aid in the performance of tempo canon. Practice and rehearsal scenarios have been considered on an equal footing with performance and the performer experience has been carefully factored into the design. New works will present further challenges and I look forward to continuing to use and develop the application. One feature that has been frequently requested by performers is the ability to annotate a score and I hope to incorporate this in the future. I would also like to make the application publicly available so that it can be used by others. At present, the main obstacle to wider use is the process of grouping events in the score SVG, which is laborious and error prone. Though there are applications such as *Verovio*[9] that can encode semantic musical data in the SVG output [9], I find these too restrictive when compared to full featured score-writing applications such as *Dorico* and *Sibelius*. I will therefore continue to research and develop methods to streamline this process.

Acknowledgments

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[8] http://collective-soundworks.github.io/sync/
[9] https://www.verovio.org/

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