Over the past ten years, a growing number of composers have explored the use of performance scores which are generated in real-time and displayed for performers on laptop screens, tablet computers, or via video projection systems. The use of such scores allows performers to engage with their use as formal structural determinants, radically extending their musical possibilities.

While non-linear processes can manifest themselves in many levels of a musical work, it is perhaps their use in the large-scale structural organization of a work that has received the most attention. At their most basic level, such processes call for the performer/s to determine the sequence in which discrete musical sections of a work are performed. In Earle Brown's Available Forms I (1961), for example, the conductor determines the order of the work's various subsections, and indicates the succession to performers through hand gestures. Similarly, in Stockhausen's celebrated Klavierstücke XI (1956), it is left to the pianist to determine the order of the work's nineteen discrete musical sections all of which are arranged around a large, single page score, see Figure 1.

1. REAL-TIME SCORES, EXTENDED NON-LINEAR FORMS, AND DECISION-MAKING CONSTRAINTS

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2. APPLICATIONS

2.1. Complex orderings and coordination

In Kim-Boyle's Valises and Endz (2005, rev. 2010), for piano and computer, the score, which is generated in real-time, consists of score fragments of various works from the solo piano repertoire [6]. These fragments succeed one another according to a first-order Markov chain procedure that employs weighted probabilities to determine the likelihood that one score fragment will follow another. For example, fragment A may follow fragment B with a probability of 30%, fragment B may follow fragment C with a probability of 0%, and so on, see Figure 2. Without the automation of this selection process, it is unlikely that, during performance, the pianist would be able to implement such a desired ordering.
Lindsay Vickery’s Ubahn (2012), for two violas, two cellos, double bass, percussion, and electronics, presents another unique method of ordering musical material. In this work, fragments of common practice notation are overlaid on top of a ca. 1985 map of the Berlin Ubahn, see Figure 3.

Each performer reads their part from networked tablet computer displays, commencing performance of their individual “line” from a predetermined station. As they perform the musical material inscribed along their line, they eventually arrive at other stations and must decide whether to continue on the same line or transfer to another line. Just like the original Ubahn map, each line is distinguished with distinct colors. This facilitates legibility but also allows the audience, who also see the score, to get a sense of how performers are choosing to navigate. This navigational paradigm recalls other open-form works such as those previously mentioned in form works such as those previously mentioned in Alcorn’s work, the composer determines the musical material presented to performers via a tablet computer, see Figure 5. In addition to determining which musical fragments, which employ common practice notation, are displayed, the composer is able to attribute expressive indications affecting register, bow position and other elements, to this material during the performance [7].

The ordering of musical material may also be left to the discretion of the composer as occurs in Michael Alcorn’s Leave No Trace (2008), for string quartet and live electronics. In Alcorn’s work, the composer determines the musical material presented to performers via a tablet computer, see Figure 5. In addition to determining which musical fragments, which employ common practice notation, are displayed, the composer is able to attribute expressive indications affecting register, bow position and other elements, to this material during the performance [7].

2.2. Randomicity

Complex orderings lend themselves well to real-time generative processes. Another particularly attractive feature of real-time scores afforded by such processes is the implementation of stochastic and truly random procedures, and along with it, the transcendence of performer and composer biases.

While the use of random procedures in the creation of performance scores is not unique, see for example Yasuao Tone’s Anagram for Strings (1962) in which a performance score consisting of the intersection of various lines and circles is generated by the performers, or Cage’s Fontana Mix (1958) which uses randomly overlaid transparencies to create a performance score, such procedures often require complex score preparations prior to performance. Recognizing these limitations, the Australian new music ensemble Decibel, has created real-time scores for Cage’s Variations I, II, and III, integrating the random techniques called for in the score preparations in a live generative process [13], see Figure 6.

Randomicity also plays an integral part in the generative processes used in the real-time score of Lindsay Vickery’s ghosts of departed quantities (2010), for bass flute, bass clarinet, cello, and piano. During performance, a complex process of erasure removes sections of the score and correspondingly imposes greater and greater constraints on what the individual performers are able to perform. The duration of erased sections is randomly selected from integer multiples of predetermined durations by an algorithm. The erasure process accelerates as the work progresses, fracturing the score into shorter and shorter fragments as illustrated in the map shown in Figure 8.

2.3. Responsive and reactive notations

The ability to make notation responsive to a live performance has been explored in the work of Pedro Boyle's Valses and Etudes (2005, rev. 2010). In Boyle’s work, new levels of variety from the way in which the pianist is able to navigate through the score. Aside from the animated elements of the score, the underlying concept is similar to that employed in Earle Brown’s Four Systems (1954), see Figure 7b, in which the length and thickness of lines correspond to variations in duration and dynamics respectively. With the use of dynamic generative processes, however, Kim-Boyle’s work introduces new levels of variety from performance to performance and with its circular, continually overwritten layout, helps break the linear nature of interpretation, and more importantly the linear temporal perspective, implied in Brown’s work.
Lindsay Vickery’s Ubahn (2012), for two violas, two cellos, double bass, percussion, and electronics, presents individual “line” from a predetermined station. As they is distinguished with distinct colors. This facilitates another line. Just like the original Ubahn map, each line computer display s, commencing performance of their Each performer reads their part from networked tablet, see Figure 3.

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B. Rebelo. In his, Netgraph (2010), performers directly influence a 3D performance notation projected to various networked performance sites. Rebelo refers to these types of responsive notation as reactive notation [9]. Through subtle variations of sound quality and more direct interaction with control interfaces, performers are able to affect various properties of the 3D notation including drawing speed and various properties the object trajectories [9]. Each performance site extends the graphic notation with different colors and in addition, each site is presented with a different camera perspective on the final 3D notation [10]. A screen snapshot of the graphic notation from Netgraph is shown in Figure 9.

The overt and inherently playful quality of reactive notations is also a feature of Jason Freeman’s work Flock (2008) for saxophone quartet, video, electronic sound, dancers, and audience participation [3]. The score depicted on the saxophone quartet, which employs both graphical and common practice notation, is affected by the spatial location of the dancers and various audience groups, see Figure 10. The information derived from the motion tracking algorithms is also used to generate electronic sounds.

Nevertheless, the visual aesthetics of real-time scores introduces a number of considerations for composers that do not pertain to paper-based scores. Many of these have to do with the simple fact that the materiality and constraints of the printed page are no longer delimiting factors. It does not, of course, follow, that the score or projected score is without unique constraints of its own. McClelland and Alcorn point out that the various modes of displaying real-time scores, which they categorize as pages, scattering, and scrolling [7], impose constraints on, most notably, the relation between scrolling speed and notational legibility and by extension a work’s rhythmic qualities, see for example Vickery’s Uhuhu and Hope’s Longing, and the need to maintain visual focal points by reducing peripheral information in scattering display modes as evidenced in Kim-Boyle’s point studies no. 2 and line studies no. 1, and Rebelo’s Netgraph.

The typically lower resolution of a score section tends towards a greater reliance on graphic typographies while the relatively small display space of a screen is countered by increased reliance on animation techniques such as scrolling (Vickery, Hope), rotation (Kim-Boyle), responsiveness (Rebelo, Freeman), or simply the gradual erasure and redrawing of graphic symbols (Kim-Boyle, Vickery), all of which help transcend the somewhat limited range of information able to be displayed on a screen at any one time.

The visual appearance of real-time scores, and their overarching use of animation, mediates the ways in which performers engage with musical processes. While this is also true of fixed-media graphic notation, the mediation is foregrounded to a greater extent with the use of animation and other dynamic graphical processes. In a number of key ways, the visual design of real-time scores share many of the same concerns of those faced by painters and composers of the Ars Subtilior movement of the fourteenth century.

Adopting Pold’s analysis of gaming frameworks, see also [11], the metaphor of navigation would seem to have considerable value when considering a score’s design aesthetic. In these terms, the real-time score defines a dynamic environment that offers composers opportunities to navigate through musical gestures with the constraints of this freedom clearly demarcated by the notational system at play. Whether these constraints become material for compositional or performative investigation does, of course depend on the particular work. In Kim-Boyle’s line studies no. 1, while the path that the performer chooses to navigate through the circular score is up to them, it is dependent on the alignment of rotating arcs. It is this dynamism inherent in the score itself that is the critical difference when compared to a work in a fixed form such as Brown’s Four Systems. Indeed the manner in which dynamism is integrated within the formal structure of a real-time score becomes a defining quality of the work.

4. CONCLUSIONS

Real-time scores radically extend the musical applications of non-linear processes, and offer exciting musical possibilities. Through creating unique ways in which performers engage with musical processes, composers invariably are called upon to consider how the score mediates this engagement and creates new modes of performative inquiry. And in many ways and as discussed in [5], the role of the composer transforms to that of a designer, responsible for creating unique environments that performers sonically explore through musical dialog.

REFERENCES


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The overt and inherently playful quality of reactive notations is also a feature of Jason Freeman's work *Flock* (2008) for saxophone quartet, video, electronic sound, dancers, and audience participation [3]. The score interpreted by the saxophone quartet, which becomes a particularly pressing issue for a growing number of contemporary composers [2][12], is by no means a new phenomenon. One only need recall the work of Baude Cordier, Figure 12, and other composers representative of the Ars Subtilior movement of the fourteenth century.

3. VISUAL AESTHETICS

While concern with the visual aesthetics of a score has become a particularly pressing issue for a growing number of contemporary composers [2][12], it is by no means a new phenomenon. One only need recall the work of Baude Cordier, Figure 12, and other composers representative of the Ars Subtilior movement of the fourteenth century.

Nevertheless, the visual aesthetics of real-time scores introduces a number of considerations for composers that do not pertain to paper-based scores. Many of these have to do with the simple fact that the materiality and constraints of the printed page are no longer delimiting factors. It does not, of course, follow, that the screen score or projected score is without unique constraints of its own. McClelland and Alcorn point out that the various modes of displaying real-time scores, which they categorize as *pages*, *scattering*, and *scrolling* [7], impose constraints on, most notably, the relation between scrolling speed and notational legibility and by extension a work's rhythmic qualities, see for example Vickery's *Uhuho* and Hope's *Longing*, and the need to maintain visual focal points by reducing peripheral information in scattering display modes as evidenced in Kim-Boyle's *point studies no. 2* and line studies *no. 1*, and Rebelo's *Netgraph*.

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The visual appearance of real-time scores, and their overarching use of animation, mediates the ways in which performers engage with musical processes. While this is also true of fixed-media graphic notation, the mediation is foregrounded to a greater extent with the use of animation and other dynamic graphical processes. In a number of key ways, the visual design of real-time scores share many of the same concerns of those faced by composers in the field of interface aesthetics provides a useful framework for analyzing some of the key issues.

In his 2005 paper, Pold examines how the foregrounding of the interface has become a critical issue for the digital arts [8]. Through providing various degrees of functional realism, artists are able to draw aesthetic attention to the mediatory power of the interface in its own right. The extent to which these issues are applicable to real-time scores varies from course from work to work. Given the fairly common tendency for performances of such works to project the score for the audience, it would certainly seem to be the case that the score is foregrounded to a far greater extent than in other types of contemporary music practice, with the possible exception of live coding performances. Projection of the score would also seem to draw attention to the manner in which the performer engage with musical processes as represented in the score. With the obvious exception of reactive and responsive notations, however, and unlike traditional interfaces, real-time scores are not affected by any changes in performative input and to that extent cannot be considered interfaces in a traditional sense. Questions of interface transparency do however point to interesting convergences. While the relationship of score to musical gesture is more apparent in the work of composers such as Vickery and Hope, the visual constraints that the listener anticipate the relationship between sound and its graphical representation, the processes in a work such as Kim-Boyle's *point studies no. 2* and to a lesser extent Rebelo's *Netgraph* are considerably more opaque.

Adopting Pold's analysis of gaming frameworks, see also [11], the metaphor of navigation would seem to have considerable value when considering a score's design aesthetic. In these terms, the real-time score defines a dynamic environment that performers explore through movement and gesture while the constraints of this freedom are considerably more opaque.

5. REFERENCES


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**Figure 9.** Score snapshots from Rebelo's *Netgraph* (2010).

**Figure 10.** Screen snapshot of the saxophone quartet from Freeman's *Flock* (2010).

**Figure 11.** Screen snapshot of the score for Kim-Boyle's *point studies no. 2* (2012).

**Figure 12.** Excerpt from the score of Cordier's *Tout par compass s'ay composé* (ca. 1400).
MULTI SENSOR TRACKING FOR LIVE SOUND TRANSFORMATION

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ABSTRACT

This paper demonstrates how to use multiple Kinect™ sensors to map a performer’s motion to music. We merge skeleton data streams from multiple sensors to compensate for occlusions of the performer. The skeleton joint positions drive the performance via open sound control data. We discuss how to register the different sensors to each other and how to smoothly merge the resulting data streams and how to map position data in a general framework to the live electronics applied to a chamber music ensemble.

1. INTRODUCTION

In 2006 Peter Burwik and the XXth Century Ensemble Vienna (exxj) started a project with the goal of developing an interactive environment for a dancer and an instrumental ensemble, interacting through live electronics. The main idea was to track the dancer’s movement and to use the motion data for the control of live electronic sound transformation of the ensembles instrumental playing. Already in the beginning of experimentation Peter Burwik invited Johannes Kretz to participate and consequently to develop the technical basis for further experimentation. Since Kretz became director of the Center for Innovative Music Technology (ZiMT) of the University for Music and Performing Art Vienna, “exxj” and ZiMT cooperated in several concerts with this project.

2. OBJECTIVES

The particularities of the project require a tracking system with the following characteristics:

High Precision A relatively high precision of motion tracking is needed, because even small movements of the dancer should have noticeable effects on the acoustic results. The reason for this is that when

collaborating with chamber musicians playing contemporary music, the sensitivity and accuracy of the musician’s actions and their sounding results is usually extremely subtle and accurate. Therefore a system, which would require relatively large movements of the dancer (in the range of 20 cm or more), would create a disturbing imbalance between the expression of the dancer and the ensemble and therefore not deliver satisfying artistic results.

Low Latency For the same reason, the latency of the system should be relatively small, so that the causality of the acoustical effects introduced by the dancer’s movements are obvious to the audience.

Ease of Use The system should ideally be easy to set up and to transport (for tours of the ensemble). The performer should be able to move freely, without cables or unwieldy tracking targets.

Low Cost As always, cost was a determining factor. Most commercially available motion capturing systems cost in the range of $10,000 and above. We wanted an inexpensive system consisting of easily replaceable, off-the-shelf components.

3. PROPOSED SOLUTION

After experimenting with Local Position Measurement through radio waves [12] and optical infrared tracking with rigid-body targets [9], we finally decided to explore a system of connecting multiple Kinect sensors, which is less expensive than the above mentioned systems (by magnitudes) and still offers a reasonable quality and stability of tracking data.

The inexpensive Kinect sensor [7] has already been proposed as a musical interface device [13], and it does not require any rigid-body targets, which improves the visual aesthetics of the performance a lot.

For our project we use skeletal information from the sensor, especially the position of the skeletons extremities: head, hands, and feet. The Microsoft Kinect™ SDK