2017

Performer Action Modeling in Real-Time Notation

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ABSTRACT

This paper discusses the application of action-based music notation, and in particular performer action modeling, to my real-time notation (RTN) work, *Terraformation* (2016–17), which uses a combination of common practice notation (CPN), fingerboard tablature, and color gradients.

1. INTRODUCTION

Physical gestures are perhaps the oldest form of human communication, predating vocal language. Recent anthropological research points to the universal phenomenon of manual sign languages and their ease of adoption by infants to suggest that such gestures were the primary communication mode of early bipedal hominins [1]. Similarly, the notation of manual action precedes any notation resembling common practice notation (CPN). Clay tablets dating to the Old Babylonia period (ca. 2000–1700 B.C.E.) depict scales on a four-stringed lyre using cuneiform tablature notation, arguably making action-based music notation the oldest form of music notation [2].

While tablatures for specific instruments (lute, guitar, organ, etc.) [3] have existed for centuries, a generalized approach to action-based music notation has only been attempted in the twentieth century. For centuries before, CPN focused on notation suitable for describing the resultant sound. Action notation is typically subsumed under the more general category of graphic music notation or text-based music notation, both of which act as extensions or replacements of CPN. These additions and expansions developed concurrently with similar trends in the visual art world. This paper will describe several ways composers have notated performer action rather than resultant sound.

Action-based music notation is a viable solution for a major problem in real-time notation (RTN), namely the need for efficient notation in order to facilitate quick and accurate sight-reading. "Pure action-based scores in fact utilize images that suggest clear instructions at first sight and need no further explanation. Such scores could literally be sight-read" [4, p. 67]. My RTN work, *Terraformation* (2016–17) for viola and computer, uses a combination of action-based notation and CPN [5]. The action-based elements are generated from a model of the physical actions required to produce sounds on the viola. The notation is designed to evoke complex and expressive musical outcomes while being as visually efficiently as possible. In this way, I propose that the application of action-based notation to RTN is both a fruitful extension of the action-based experiments in notation and a solution to one of the key problems of real-time composition.

2. NOTATING ACTION

Music notation mediates the relationship between composition and performance. Expansions of notational language correspondingly expand and modulate those relationships. The following discussion explores different expansions of CPN through the addition of abstract graphics or textual direction and their effect on compositional process and performance practice.

2.1 Resultant Sound Notation

Many notations have been developed through the twentieth and early twenty-first centuries, but not all of them refer to action. Like CPN, some notations invent new ways of notating resultant sound. John Cage's score for *Aria* (1958), for instance, uses line contours plotted on a Cartesian pitch/duration axis colored in such a way as to represent different styles of vocalization [6]. The notation uses symbols distilled from CPN to address traditional parameters of music rather than performer action.

Karlheinz Stockhausen's *Plus Minus* (1963) is another example of new notation that only addresses the resultant sound [7]. The score for *Plus Minus* asks the performer to construct the details of the piece by reconciling a complex set of instructions with several pages of abstract graphics. The work is a set of instructions for making an indeterminate number of compositions based on the number of performers and order in which the graphics are combined. Like *Aria*, Stockhausen's use of graphics and text is directed toward musical parameters like pitch, duration, tempo, dynamics, and articulation rather than performer action.

2.2 Performative Action in Notation

One of the earliest forms of performative action in CPN can be traced to textual stage directions in theatrical works [8]. Before that, several types of action-based notation existed for the purpose of communicating and preserving dance choreography [9]. Many experimental notation systems in the twentieth and twenty-first centuries ask the performer to engage in detailed bodily or instrumental action. The range of action techniques and notational language demonstrates the variety of reasons for such use: music as theater, sound

Figure 1. Line contour notation in Luigi Russolo's *Risveglio di una città* (1913–14) indicating the crank speed, pressure, and resulting dynamic of *intonarumori* instruments.

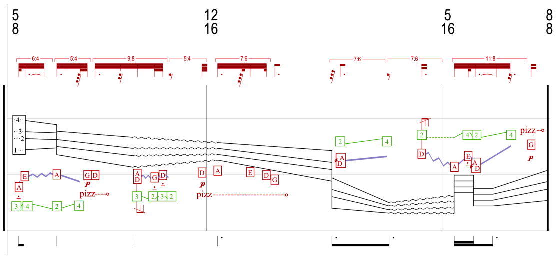

Figure 2. Decoupled string tablature in the second violin part from Aaron Cassidy's Second String Quartet (2009–10).

production, indeterminate parameters, notational efficiency, intentional complexity, or performer freedom to name a few.

The notation of some actions is directly correlated with playing. This is often the case when writing for a new instrument without an established tradition of performance practice. Luigi Russolo in *Risveglio di una città* (*Awakening of a City*) (1913–14), for example, notates the speed, pressure, and resulting dynamic of his crank-driven *intonarumori* instruments [10] (Fig. 1). Russolo combines familiar CPN elements like five-line staves and time signatures with graphic line contours similar in appearance to Cage's line contours for *Aria*. The difference, however, is that Cage's contours implicitly rely on the interpretation of musical parameters while Russolo's notations act as instrumental tablature.

Like Russolo, Helmut Lachenmann graphically notates action in his scores for the purposes of sound production. His *Pression* (1969, rev. 2010) [11] and *Gran Torso* (1971–72) [12] employ a mixture of CPN and tablature notation in order to explore new instrumental sounds in his pursuit of *musique concrte instrumentale* [13]. Lachenmann's introduction of the "bridge clef" and "string clef" enable the notation to directly mediate a non-standard action on the instrument. The resulting sounds of Lachenmann's actions are innately connected with the action required to produce the sound. The sound of ricochet bowing, for example, is impossible to produce using any other technique. Actions themselves are sometimes unintuitively related to the resulting sound. In his 2010 revision of *Pression*, "action dynamics," notated as dynamics in quotation marks, suggest the physical force of an action required to produce a sound with a disproportionate dynamic outcome.

The discrepancy between action and sound and the discovery of new modes of sound production is a hallmark of Aaron Cassidy's work [14]. He accomplishes this by decoupling and modulating a large set of action parameters in tablature notation. In his indeterminate string work *The Crutch of Memory* (2004) [15] and his Second String Quartet (2009–10) [16], Cassidy loosely specifies pitch information by providing the performer with a graphic contour of left hand position, variable finger width, and fingerboard location. Hand positions, fingerings, and pitches become less precise and more gestural as a consequence of this unusual approach to notating the left hand (Fig. 2).

2.3 Cognitive Attention Balancing

One reason a composer might employ action-based notation is for the purpose of cognitive attention balancing. This constitutes an admission by the composer that each parameter addressed in the notation requires a portion of the performer's finite cognitive function. The more parameters specified in the notation, the higher demand required of the performer's brain.

Due to the limitations of CPN, action-based notation is a potential solution to simplifying performance instructions. One might imagine how cumbersome Juraj Kojs's directions in *Revelations* (2005) to scrape, bounce, and roll a variety of circular toys across resonant plates would be if notated in CPN [17]. The opposite position, that action-based notation requires more attention from a performer, is also plausible. Take, for example, Lachenmann's use of invented clefs. Tablature notation such as the bridge clef or string clef has the potential to ignore or subvert a performer's highly developed skills of reading CPN and playing their instrument. In some regards, very little prior knowledge of notation and performance technique is required or even relevant. Contemporary experiments in tablature intend to question the validity of CPN and traditional performance practice itself; this posits a potentially oppositional relationship between composer and trained performer, which is itself a determinant of the musical result.

It comes as no surprise, then, that through notation some composers purposely create a work of staggering difficulty, overwhelming the performer with a multitude of (sometimes contradictory) tasks. This is often the case in the works of Brian Ferneyhough, Richard Barrett, and others composing so-called complex scores, and is almost inevitable in the decoupled notations of Cassidy and others. The opposite situation of requiring very little specific parameter control from the musician leaves room for performers to interpret, improvise, and interact with other performers. There is evidence of this in the text-based works of John Cage — such as *Empty Words* (1974) [18] —, the group improvisation pieces of Christian Wolff — such as *For 1, 2, or 3 People* (1964) [19] —, and jazz lead sheets. Here the

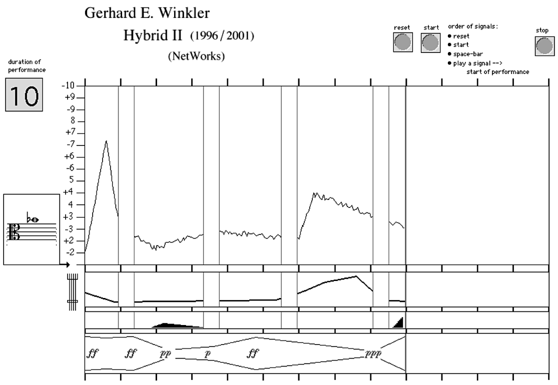

Figure 3. Line contour notation in Gerhard E. Winkler's *Hybrid II (NetWorks)* (1996, rev. 2001) indicating glissandi, bow contact position, and dynamic profile.

composer relies on the performer's creative abilities to collaboratively complete the music. A wide breadth of creative work lies between the extremes of notational vacuum and parameter overload, with composers often attempting to balance one difficult parameter by making the other remaining parameters correspondingly easier. This is my approach to action-based notation in my work *Terraformation*.

3. PERFORMATIVE ACTION IN REAL-TIME NOTATION

3.1 Purposes of Action-Based Notation in Real-Time Notation

Many of the earliest works using RTN are action-based. Gerhard E. Winkler's *Hybrid II (NetWorks)* (1996/2001), for example, uses several real-time line contours to direct the solo violist's glissandi, bow contact position, and dynamic profile (Fig. 3) [20]. Likewise, Karlheinz Essl's *Champ d'Action* (1998), uses descriptive on-screen text to direct a group improvisation [21]. The choice to use text and moving line segments was no doubt partially due to computer limitations. However, these early works reveal an attempt to streamline the notational elements in order create compelling music that is efficient to sight-read. As Winkler states, "In general a mixtures of *symbolic* (e.g. a "main-pitch") and *graphic elements* (e.g. Glissando-lines) has turned out to be the clearest way of Realtime-notation. It depends on the idea of the piece and the aesthetics of the composer, which elements these will be.... Which *aspects of playing* have to be notated up to which extend of precision (The range goes from *full realtime-notation*, — using all the "in-time" — possibilities of the computer-screen —, to *partly fixed and prenotated elements*, — e.g. rhythmic patterns, which can be prepared in advance —, up to *fully notated score-fragments*) [22, p. 3]." These first RTN works demonstrated efficient notation methods and prefigured a fascination with directing performer action in real-time.

Composers currently writing RTN pieces continue to use the techniques established by Winkler, Essl, and others. The radial scores of David Kim-Boyle [23] and Ryan Ross Smith [24], for example, which display a clock hand-like play head sweeping over attack points situated on a clock

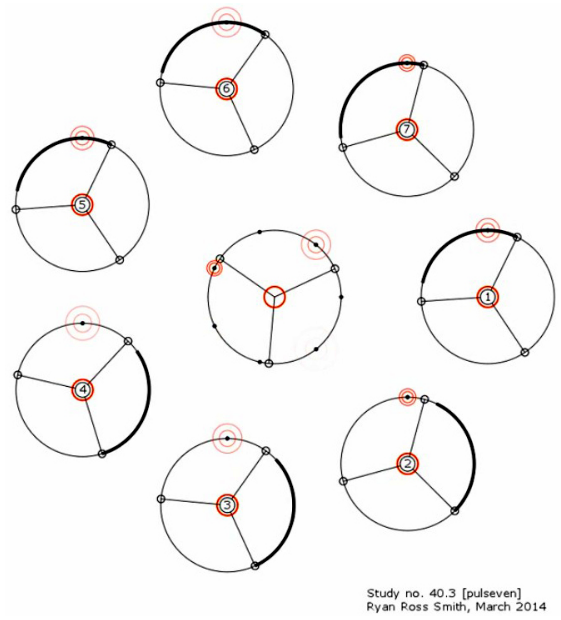

Figure 4. Radial notation indicating attack and sustain points in Ryan Ross Smith's *Study no. 40.3* (2014).

face, The intersection of two graphic elements is an immediately clear paradigm for complex rhythmic actions (Fig. 4). In their simplest form, these radial scores tell the musician when to perform an action. When duplicated to direct large ensembles, the radial score efficiently notates dense polyrhythmic textures.

When musical parameters are decoupled through an efficient graphical language, the performer is freed to focus their attention on the most musically challenging elements on a momentary basis. As described above, decoupling performative actions has the potential for revealing new modes of sound production. One drawback is that it also has the potential for increasing strain on the performer. Finding the equilibrium between these two objectives in RTN is a delicate task.

3.2 Performer Action Modeling in *Terraformation*

Terraformation for viola and computer uses action-based notation for the following purposes: for efficiency in sight-reading, to enable an interactive formal structure, and to reveal new modes of sound production. The performative actions required in the piece are based on a study of physical and psychological mechanisms at work in the musician's manual contact with the instrument. The resulting notation is carefully designed to ease the cognitive translation from graphic representation to bodily action.

The notation used in *Terraformation* resulted from an active collaboration with violist Michael Capone. His experiences and reactions in reading early versions of the work helped determine the present state of the piece. In particular, Capone helped me rank the difficulty of left hand positions and balance the weighting applied to the algorithm when moving the left hand from one position to another. He also narrated his sight-reading thought process as he correlated the different forms of notation used in *Terraformation*, re-

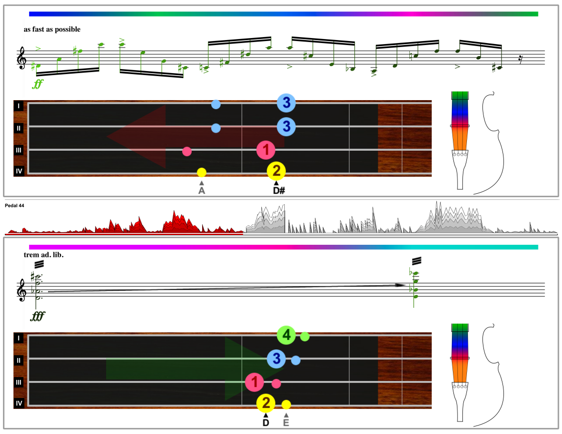

Figure 5. The aggregate notation and performance interface for *Terraformation* (2016–17).

lating when certain notations were beneficial and when they were extraneous. His guidance regarding an open-ended parameterization of the physical actions required to play the viola helped determine the parameters I chose to address in the work.

3.2.1 Overview of Notation Used in Terraformation

There are three distinct forms of notation in *Terraformation* (Fig. 5). One type of notation is a five-line staff with standard clefs capable of showing common music notation symbols. Elements of this staff can be hidden so that one of three different modes can be displayed at any given time: specific pitches and rhythms using standard symbols, specific pitches with proportionally spaced rhythms, or approximate pitches (displayed as stems without note heads) with specific rhythms.

The second type of notation is a tablature depiction of the viola's fingerboard. Instead of fret-like gradations of position, just the one-, two-, and three-octave positions and the approximate end of the fingerboard are marked. Each of the musician's fingers is notated on the fingerboard as a color-coded encircled number. An open or unplayed string is shown as a grayed out zero at the far left-hand side of the diagram. In addition, the lowest string with a finger down is marked with the letter name of the specific pitch for quick reference.

The third type of notation is two sets of color gradients. The first stretches across the horizontal width of the five-line staff and is used to indicate bow contact position. The specific position at any given moment corresponds to the color sharing the same vertical alignment as the current rhythm on the five-line staff. The color blue indicates molto *sul tasto*, green is *normale*, red is *molto sul ponticello*, and yellow is behind the bridge. Any gradient between those colors represents a bow contact point between the endpoints of that continuum. The second color gradient is applied to each of the note heads on the five-line staff. Ranging from black to light green, these indicate a continuum between normal left hand finger pressure to light finger pressure (as light as possibly makes a difference, slightly lighter than harmonic finger pressure).

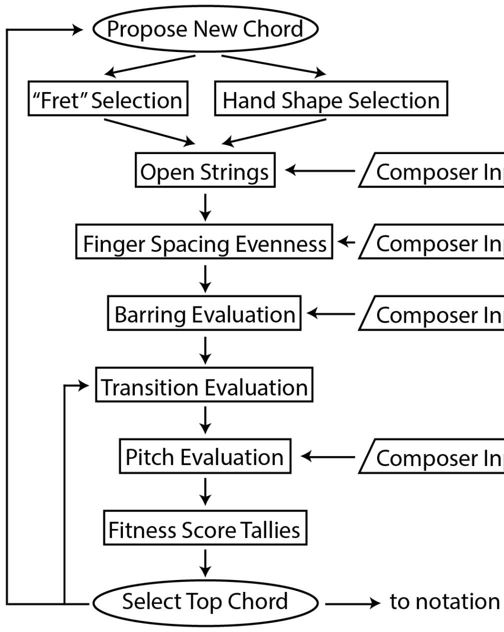

Figure 6. The algorithm for generating new chords in *Terraformation*.

These three types of notation comprise an aggregate notational system, although two of the three types are subject to display at any given moment. While the five-line staff system remains on-screen throughout the piece, the fingerboard and color gradients can be independently hidden when not required. Additionally, two aggregate systems of notation occupy the performer's screen-based score. The top aggregate system shows the notation for the current musical activity and the bottom system shows the subsequent material. Between the two aggregate systems is a graphic indicating the performers current location in the form.

3.2.2 Fingering Positions on the Fingerboard

The algorithm driving musical material in *Terraformation* is built on a series of constraints that model the physical action required to produce a quadruple stop on the viola, referred to hereafter simply as a "chord." The general sequence of chord creation is illustrated in Fig. 6.

This sequence of operations iterates a number of times to generate a pool of potential chord candidates. At the end of the process, the algorithm proposes the best possible choice to follow the current chord based on inputs governing the model. The action-based logic behind each of these subroutines is explained below.

3.2.3 "Fret" Selection and Maximum Finger Stretch

The term "fret" is used here as a method of conveniently locating the finger on the fingerboard and also as a way to avoid more conventional position-based string pedagogical practice. The model first randomly selects a fret and assigns it to the lowest-fretted finger (see Fig. 7). For all practical purposes, the lowest-fretted finger in a quadruple stop is always the first finger. Similarly, the highest-fretted finger is always the fourth finger. The exact fingers are not specified in the algorithm so as to allow for non-quadruple stopped

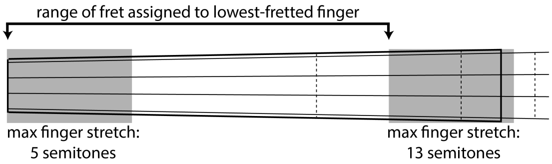

Figure 7. The range of possible "fret" positions and maximum finger stretch in those positions.

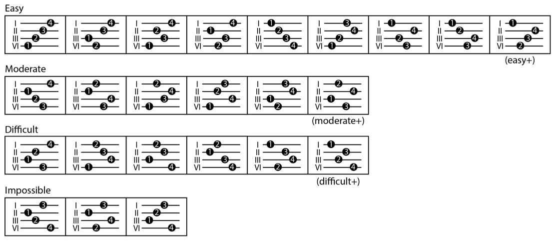

Figure 8. All twenty-four unbarred left hand positions ranked by difficulty.

possibilities where an open string or rest on the first or fourth fingers changes which finger is playing the lowest fret.

The possible range for the lowest-fretted finger is bounded on one end by the open strings at fret-0 and at the other end by fret-18. Based on the selected fret, the algorithm randomly chooses the distance between the lowest- and highest-fretted fingers. At the lowest end of the fingerboard, the maximum stretch between the lowest- and highest-fretted finger is five semitones. This stretch increases to thirteen semitones at fret-18, extending approximately to the end of the fingerboard [25].

3.2.4 Hand Shape Selection

A parallel process chooses a hand shape from a predetermined set of twenty-one options ranked by difficulty. A total of twenty-four (4! = 24) hand positions are theoretically available, but three are physically impossible (see Fig. 8).

The hand positions are selected based on a weighted transition table that prefers easier hand positions. Once chosen, the hand position is coupled with the fret selection and finger stretch parameters described above to generate a specific finger and fret combination for the lowest- and highest-fingered frets. The two central fingers' exact positions remain to be determined. In addition, a corresponding penalty is applied to the chord's overall fitness score based on the difficulty of the hand position. This score is tallied and ranked at the very end of the process.

3.2.5 Open Strings

Before fixing the exact fret positions of all of the fingers, the algorithm randomly allows for the selection of open strings. Open strings are applied to both finger and string, ignoring the fret parameter in the subsequent routines related to finger spacing. An input value governs the percentage chance of open strings at each chord request.

3.2.6 Evenness of Finger Spacing

The remaining two central fingers' positions are determined in connection with an input value that corresponds to finger spacing evenness. At low-fretted positions on the fingerboard, little variation is possible for the central fingers due to the limitations of the maximum finger stretch. At higher-fretted positions, a higher concentration of pitch possibilities in condensed physical space yields more options. Two factors govern the evenness of the finger spacing. The first is a decreasing amount of flexibility between adjacent pairs of fingers from the first-second pair to the third-fourth pair. In other words, the variation in finger spacing is most flexible between the first and second fingers and least flexible between the third and fourth fingers. The second factor is that asking the player to stretch the space between one pair of fingers inhibits stretching in other fingers.

On the whole, even spacing of the two central fingers between the outer fingers is the most comfortable and therefore the more playable solution. Increasing the uneven input value randomly deviates away from even spacing using the two-factor model of finger spacing just described.

3.2.7 Barring Evaluation

At this point, the algorithm has generated a complete chord with specific finger and fret locations. Many chords are still highly impractical from a physical perspective and undesirable from a musical perspective. Several evaluation processes examine the fitness of the chord and assign it a score that when tallied rates its viability.

The first evaluation looks for chords with two fingers on the same fret, commonly referred to as barring. An input value controls whether or not two adjacent strings can be barred. Chords with three or more fingers on the same fret or with two non-adjacent strings on the same fret are immediately rejected.

3.2.8 Chord Transition Evaluation

The second stage of evaluation examines the transition between the current chord and the proposed subsequent chord. The algorithm tracks the movement of each finger from the current chord to the proposed chord and generates a score that considers the following: whether or not a finger changes strings, the direction of the move up or down the fingerboard, and the dexterity of each finger. Moving a finger from one string to another incurs a significant scoring penalty, with changes going from a higher-numbered string to a lower-numbered string being more severe than a lower- to higher-numbered string (to be clear, a lower-numbered string, ie. String I, produces higher pitches than a higher-numbered string, ie. String IV). The reason for this is that it is more difficult to contract a finger to a new position than to extend a finger. Next, the average fret positions of the current and proposed chord are compared. More distant average fret movement acquires a higher scoring penalty. Finally, each of the scoring mechanisms accounts for differences in finger dexterity by using a finger-specific weighting, with movements in the fourth finger generating higher penalties. This finger-specific weighting reflects an overall ease of movement in the first finger with each subsequent finger diminishing in dexterity.

3.2.9 Pitch Evaluation

The third stage in the evaluation process scores each chord according to a specified pitch-class, pitch-class set, or combination of both. Chords that contain one or more matches are given a higher ranking as more desirable. Each evaluation routine — pitch-class, pitch-class set, or both — can be activated or deactivated. In any given iteration of the algorithm, the pitch-class evaluator finds the most matches and the both evaluator finds the least. By requesting that chords fulfill both pc and pcs requirements, the algorithm will sacrifice ease of chord transition and playability for more desirable pitch content.

3.2.10 Fitness Score Tallies

Following generation and evaluation, a list of proposed chords are finally collected and their corresponding fitness scores tallied. The list is sorted first by chords that fit the requested pitch requirements. Within that list, chords are arrangement by the difficulty of the chord's physical production. The chord with the top score (ie. the least amount of penalties) is displayed for the musician to perform and is fed back into the chord algorithm for comparison with subsequent chord candidates. In addition, the fitness score follows the chosen chord through the creation of the remaining musical parameters — rhythmic figures, dynamic contour, bow contact position, and left hand finger pressure, to name a few. The difficulty of these parameters is inversely related to the chord's fitness score. So, for example, as the difficulty of the chord increases, the difficulty of the rhythmic figure decreases. In this way, the fitness score mediates the amount of attention that the performer is likely to spend on any single parameter.

3.3 Efficiency in Hybrid Notation

The performative action model in *Terraformation* attempts to balance the cognitive demands on the musician by using a hybrid combination of notation types. The aggregate notation display is designed to give the performer instructions that are immediately readable while also providing a depth of detail. Comments from violist Mike Capone following a rehearsal of *Terraformation* revealed the specific sequence of information gathering that he executes each time the display is refreshed. The performer first deduces the hand position from the fingerboard diagram. While he generally replicates the hand position on the instrument he is assessing the position of the lowest-fretted finger. He then finalizes hand position by checking it against the CPN, making small adjustments where necessary. The moment he spends looking at the CPN also gives him an approximate understanding of the rhythmic character of the current staff system. As he begins to perform the material, he is constantly correlating the four-color gradient that represents bow contact position and the two-color gradient that represents left hand finger pressure with the current rhythmic figure, pitch, and dynamic. Finally, in moments of minimum cognitive strain — in rests or during repeating figures, for example — he may look below the current aggregate staff system to the upcoming system in order to read ahead. In this way, through efficiency of a hybrid notation display, the musician is able to link information gleaned from different types of notation into a cohesive, continuous performance.

4. CONCLUSION

While my work modeling the physical actions required to play the viola led to the creation of *Terraformation*, this research also yields a general tool for composers writing for violins and violas. Composers, especially those without a background in string playing, spend considerable time determining the feasibility of double, triple, and quadruple stops. To solve this problem, I am developing a general tool for assessing the difficulty of any given multiple stop for violin or viola and suggesting alternative or subsequent multiple stops based on the pitch-filter criteria described above. This utility will incorporate the performative action modeling research explained in this paper to aid composers writing multiple stops in their own music.

The fascination with action-based music notation in the twentieth and twenty-first centuries has yielded a variety of alternate ways of mediating musical performance. Some of the key benefits of this category of notation include clarity of sound production techniques and immediately recognizable instructions that reduce cognitive strain on the performer. These are important factors when asking a musician to sight-read during performance as in the case of RTN. While incorporating action-based music notation into a work using RTN is not a new endeavor, the methods and benefits of doing so are still an incredibly rich area for exploration. In *Terraformation*, an algorithm modeling the physical actions required to produce sound creates, ranks based on difficulty and pitch content, and notates musical material. Finally, by using several types of notation to instruct the performer — a combination of action-based notation and CPN — the musician is able to efficiently extract and unify the instructions into a cohesive musical gesture.

Acknowledgments

I would like to thank violist Mike Capone for his guidance concerning the physical actions required to play the instrument and his insight into the mental processes involved in fast sight-reading.

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