

Interactive Computer Simulation for Kinesthetic Learning to Perceive Unconventional Emergent Form-bearing Qualities in Music by Crawford Seeger, Carter, Ligeti, and Others

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ABSTRACT

Embracing the notion that metaphors influence reasoning about music, this study explores a computational-phenomenological approach to perception of musical form driven by a dynamic metaphor. Specifically, rather than static metaphors (structure, architecture, design, boundary, section) instead, dynamic ones are emphasized (flow, process, growth, progression) as more appropriate for modeling musical form in some circumstances. Such models are called *dynamic form*. A pedagogical program for enhancing the perception of dynamic form is pursued, by exploiting embodied cognition through custom built simulation technology.

Adopting an interdisciplinary approach, the presentation shows some computational models of qualities that convey such dynamic form in unconventional repertoire. Since such models are quantitative, it is plausible that, with appropriate technology, listeners who do not spontaneously attend to these could learn to do so, and then subsequently demonstrate perception and cognition of such form-bearing flux. Through simulation algorithms, the paper offers Max/MSP patches and iPhone apps that enable real-time user manipulation of the intensity of such qualities. Such hands-on control is intended to kinesthetically cultivate sharper perception, cognition, attention, and interest of listeners confronting unconventional music. The presentation also offers computer animations of some theorized unconventional emergent qualities, which indeed constitute vessels of musical form.

I. INTRODUCTION

Metaphors influence reasoning about time (Boroditsky 2000, 2001) and music (Zbikowski 2002, Spitzer 2004), including analytical-interpretive judgments. Conceiving musical form in terms of flux and flow entails different approach for perceiving it, an approach not included in standard music pedagogy.

This study explores a computational-phenomenological approach to perception of musical form driven by dynamic metaphors in tandem with an open-ended notion of qualitative intensity as appropriate for unconventional repertoires.

As a theory of music listening, it focuses on the dynamism of the music-as-heard rather than the dynamism of the performer or composer. It assumes that perception of form is malleable, capable of being refined and sharpened through apt experiences with musical sound responding to self-initiated motion.

A. Reciprocal Time Metaphors

This means, referring to Figure 1, that instead of the ego-moving (subject-moving) metaphor that underlies score-based analytical theories, the time-moving metaphor

underlies dynamic form theory, though it still derives its data from scores. (See Mailman 2011c.)

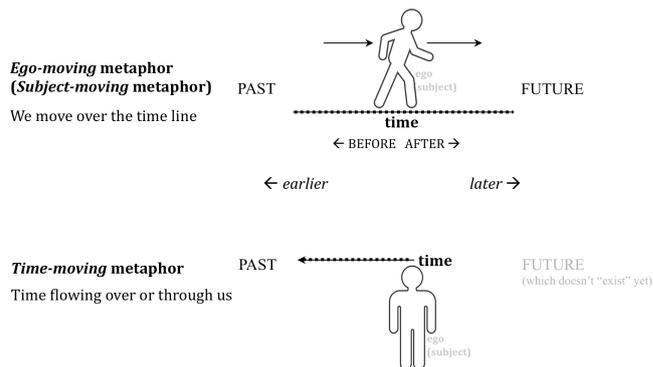
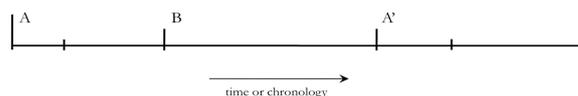


Figure 1. Two *space-time* metaphors for sequencing events in time

Specifically, rather than static metaphors (structure, architecture, design, boundary, section), instead, dynamic ones are emphasized (flow, process, growth, progression) as more appropriate for modeling musical form in some circumstances. Refer to Figure 2. (Also see Mailman 2010a.)

Musical form is often conceived as: hierarchical partitioning of music into sections and subsections



But it can also be conceived as: *flux of intensity of a quality* (which may be quite smooth rather than crisply structural)

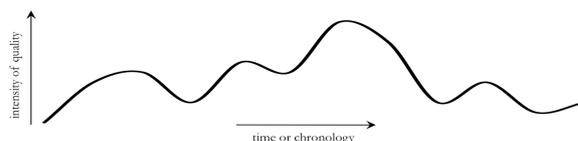


Figure 2. Static (Structural) vs. Dynamic (Flux Derived) Conceptions of Musical Form

Form interpretations based on the flux of intensity of a quality are called *dynamic form* (or more precisely: *temporal dynamic form*), which can arise in a substantial variety of ways, as shown previously (Mailman 2009, 2010a, 2010b, 2011a, 2011b). (Less formalized dynamic form theory traced back the early 20th century writings of Kurth (1925) and Mersmann (1922-23), as described by Rothfarb (2002). Static vs. dynamic orientations place different priorities and statuses on crisp as opposed to smooth interpretations of form. Related to this is a difference in the way form perception arises. In the static (structural) orientation, crisp parsing into successive

units precedes and trumps detection of change between different points in time, whereas in the dynamic (flux derived) orientation, detection of change between different points in time proceeds without regard to any specific prior parsing into successive units and it also trumps any such subsequent parsing. Static and dynamic interpretations of form may correlate closely, but do not necessarily do so. Also, they are visually represented in very different ways.

Through an interdisciplinary approach, a computational application of dynamic form theory shows some quantitative models of qualities that convey such dynamic form in unconventional repertoire, for instance that outside the common practice, such as 20th century “modernist” repertoire and music of the Middle Ages.

Since such models are quantitative, it is plausible that listeners who do not spontaneously attend to these by default could train themselves to do so, guided through embodied cognitive experience, and then subsequently exhibit perception and cognition of such form-bearing flux. They may learn by observing macro-changes in sound that are caused—as mediated through customized technology—by moving parts of their own bodies such as arms, hands, and feet.

B. Simulation Algorithms

Using simulation algorithms developed for this purpose, the present study offers two Max/MSP computer software patches and the iPhone apps that enable real-time user manipulation of the intensity of such qualities. Through embodied cognition, such hands-on control is intended to cultivate sharper perception, cognition, attention, and interest of listeners confronting unconventional music.

The present study also offers audio-synchronized computer animations of some theorized unconventional emergent qualities, which constitute vessels of musical form.

II. OBJECTIVES

The aim of this phase of research is primarily to characterize the unconventional sources of dynamic form in some sample repertoires and develop technology for a pedagogical purpose: to promote more acute hearing of unconventional emergent qualities in music. Works by Crawford Seeger, Carter, and Ligeti are considered primarily. The three audible fluctuating emergent qualities called *durational diversity*, *temporal clumpiness*, and *upward* are modeled here. Technology is developed for enabling direct manipulation of the intensity of these qualities.

III. MATERIALS AND METHODS

Mathematical models are provided for gauging the intensity of the three emergent qualities. These are then reverse engineered to produce simulation algorithms.

Using custom designed simulation algorithms, the author presents two iPhone apps and scripted Max/MSP computer software patches that enable real-time user manipulation of the intensity of such qualities through sliding, tilting, and rotating hand gestures. In this way, these technologies generate complex streams of musical sound whose flux of unconventional emergent qualities is shaped dynamically by the user-listener’s physical motion. Thus, through direct experience of manipulating such qualities, it is intended that listeners gain greater familiarity with them.

The larger scope of the research incorporates the following elements:

- Repertoire: Primarily modernist and medieval works that lack obvious form projecting repetition.
- *Cybernetic phenomenology* (phenomenology pursued and communicated with the aid of computation) applied to musical form in unconventional repertoire.
- Mathematical modeling of unconventional emergent qualities whose flux of intensity creates form.
- Statistical graphs and animations of these graphs synchronized to audio.
- Interactive algorithmic music generation, done with RTemix, Max/MSP, and custom iPhone apps, and other sensors.

IV. MODELING

Quantitative models for three form-bearing emergent qualities are presented. These relate to projection of form by *durational diversity* in Crawford Seeger’s String Quartet 1931, *temporal clumpiness* (a.k.a. *interonset volatility*) in Carter’s Quartet No.5, and *upward* in Ligeti’s Violin Concerto.

A. Crawford Seeger’s Quartet (1931), movt. 1: flux of *Durational Diversity*.

In the first section of Ruth Crawford Seeger’s String Quartet, movt. 1, the durations of the notes begin similarly but gradually diverge; initially the first violin’s durations are little more than twice as long as those of the cello, as the excerpt in Figure 3 shows.

Figure 3. Excerpt: mm.1-16 of Crawford’s Quartet, movt.1

Over the course of the section (mm.1-45) the durations within the entire texture gradually diverge, as summarized in Figure

4 and Figure 5. Thus a dynamic form for the section is projected through flux of durational diversity, which surges.

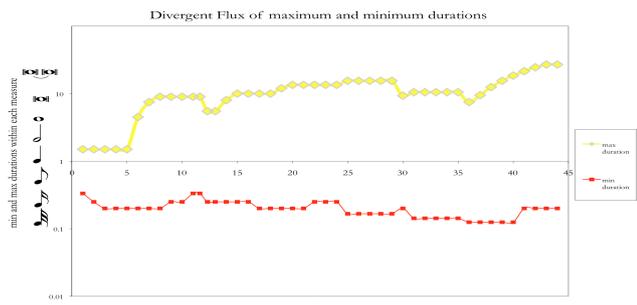


Figure 4. Diverging durational tendencies in mm.1-45 of Crawford’s Quartet, movt.10

Video Clip 1 shows an audio-synchronized animation of Figure 4.

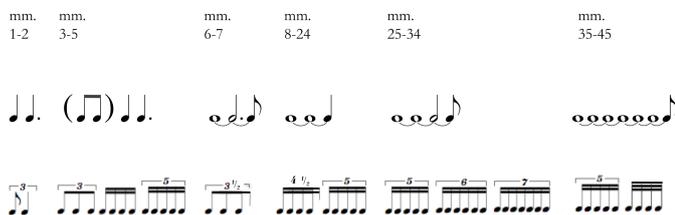


Figure 5. Divergence of durations in mm.1-45 of Crawford’s Quartet, movt.1

Thus the flux of *durational diversity* projects form. This vessel of form is defined computationally as follows:

$\sqrt{\text{Durational Diversity}}$ of a span S is defined as the *Standard Deviation* of all such durations within it.

Where u_e designates the duration of an event e

$$\sqrt{\text{Durational Diversity}}(S) = \underset{e \in S}{\text{StDev}}(u_e) \quad (1)$$

Figure 6 shows the surging dynamic form arising through the flux of durational diversity through the movement’s first section (mm.1-46), an unusual bearer of form, which is perhaps unlikely to be heard by default.

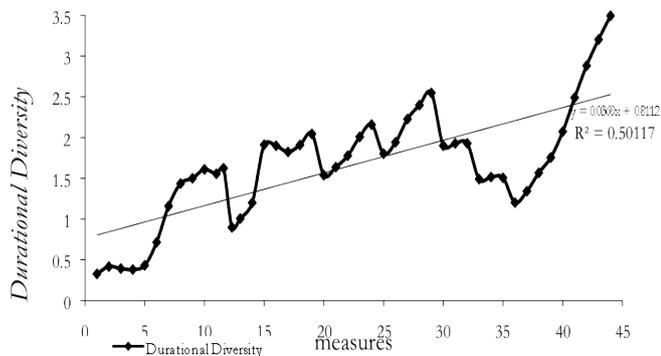


Figure 6. Flux of intensity of *Durational Diversity* in mm.1-44 of Crawford’s Quartet, movt.1 modeled with overlapping 5-measures spans (a circulating flow system)

This form-bearing flux is unobvious for two reasons (1) It is not a quality usually attended to as a projector of form; (2) Its surge is a noisy non-linear curve. (Its linear component has an R^2 correlation coefficient of only 0.50117.)

B. Carter’s Quartet No.5: flux of $\sqrt{\text{Temporal Clumpiness}}$

Movt. 10 of Elliott Carter’s Quartet No.5, presents the four string players each proceeding at its own steady pulse; a four-part polyrhythm results. A flux of interonset intervals (IOI) arises from the interference pattern of the incommensurate pulse streams of the four instruments as shown in the interonset graph of Figure 7, an excerpt of which is shown in audio-synchronized animation in Video Clip 2. (Interference patterns have been discussed previously by Schillinger (1946), though not in regard to projection of form. Their use in projecting form in music Reich, Carter, and Messiaen is discussed in my own prior work (Mailman 2010a).)

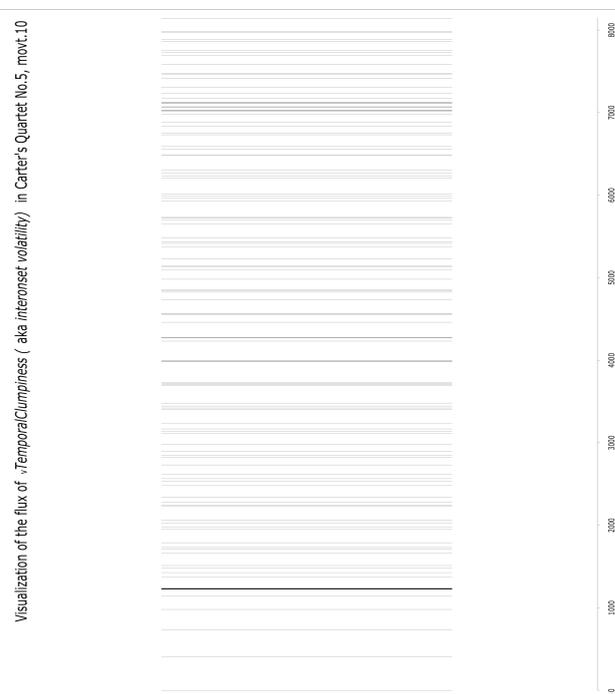


Figure 7. Interonset graph shows flux of *temporal clumpiness (volatility)* in Carter’s 5th Quartet, movt. 10.

Carter’s Quartet No.5, movt.10, has no obvious repetitions and hardly any disjunctions to project division into sections. Instead, form arises from the expansion and contraction of interonset intervals of the composite texture. Figure 8 shows the expanding and contracting oscillations of interonset interval between consecutive onsets of the composite texture.

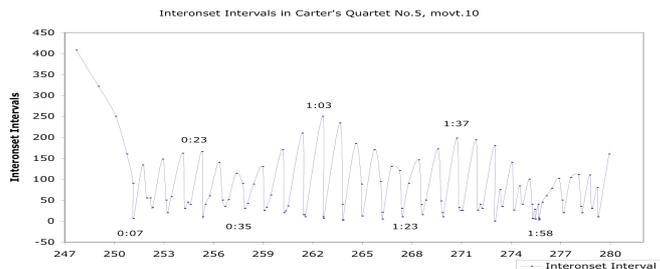


Figure 8. Expanding and contracting oscillations of interonset interval between consecutive occasions in Carter’s 5th Quartet, movt. 10

The flux itself serves as a vessel of form for the piece and is modeled as a qualitative intensity called $\sqrt{\text{InterOnsetVolatility}}$ (aka: $\sqrt{\text{TemporalClumpiness}}$ or $\sqrt{\text{RhythmicVolatility}}$) which is defined mathematically as follows: Define an *occasion* as any time t at which some event e begins, where an *event* corresponds to some action of a performer, for instance the onset of a pitch, as indicated by a note in a score or part. Let T_s denote the set of all occasions in a span S . For a span S , define the *InterOnsetIntervalArray*(S) as $\langle i_1, i_2, i_3 \dots i_n \rangle$ where $i_j = t_j - \text{Predecessor}(t_j)$ for all $t \in T_s$ (so $n = \#T_s$, the number of occasions in span S). Now define the $\sqrt{\text{InterOnsetVolatility}}$ (aka: $\sqrt{\text{TemporalClumpiness}}$) as the standard deviation of that array of intervals, thus:

$$\sqrt{\text{InterOnsetVolatility}}(S) = \text{StDev}(\text{InterOnsetIntervalArray}(S)). \quad (2)$$

The flux of the *InterOnsetVolatility* itself can be tracked as it changes over the course of the whole quartet. The standard deviation is computed for the four previous IOIs leading up to each consecutive occasion in the movement. The result is the dynamic form graph shown in Figure 9, which includes timings from the Arditti Quartet's recording.

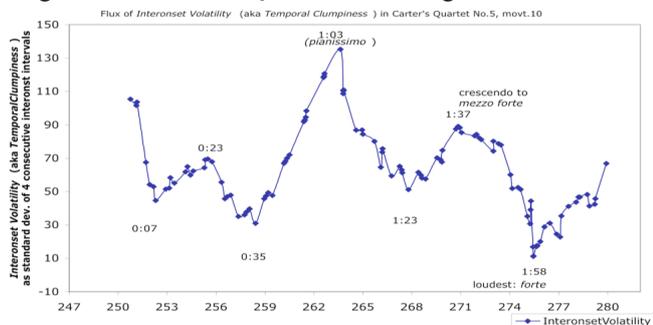


Figure 9. Dynamic form graph of Carter's Fifth Quartet, movt. 10, based on flux of *interonset volatility* (*temporal clumpiness*)

C. Ligeti's Violin Concerto

The start of movt. 3 of Ligeti's Violin Concerto, shown in Figure 10, exhibits one of his hallmarks textures: a layering of descending patterns. In this case its overall pitch height remains stable, that is, when sufficiently long span of time are considered (for instance considering one measure at a time). The result is a pseudo-descending texture.

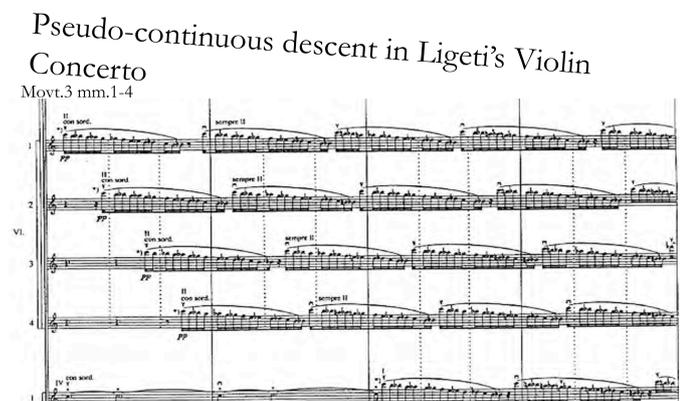


Figure 10. Excerpt from movt. 3 of Ligeti's Violin Concerto

At other times the status of the texture is unstable; the intensity of the quality is in flux, as in Figure 11, which shows mm. 34-37 of the solo violin part in movt. 1 of the concerto.



Figure 11. Excerpt from the solo violin part of movt. 1 of Ligeti's Violin Concerto, starting with upward and downward motions followed by a propensity for downward motions despite an increase and decrease of tessitura

Such flux can be modeled as a comparative (oppositional) vessel, which is a computational model based on *thetic* vs. *antithetic* contextual sets. Specifically the vessel $\sqrt{\text{Upward}}$ is a quality based on the number of ascents vs. descents, regardless of distance. Its *thetic* contextual sets are composed of events each of whose pitch is higher than that of the pitch of its predecessor.

$$\sqrt{\text{Upward}}^{\text{Thetic}} = A = \{e \mid P_{\text{Predecessor}(e)} < P_e\} \quad (3)$$

Correspondingly, *antithetic* events are each of those whose pitch is lower than the pitch of its predecessor:

$$\sqrt{\text{Upward}}^{\text{Antithetic}} = B = \{e \mid P_{\text{Predecessor}(e)} > P_e\} \quad (4)$$

$\sqrt{\text{Upward}}$ continuously compares the size of the two opposing contextual sets, over the course of the piece or excerpt. This can be defined as follows for a span S of duration w and ending at time t , with *thetic* and *antithetic* sets defined as above in equations (3) and (4):

$$\sqrt{\text{Upward}}_{(t-w, S_t)} = \text{Proportion}(t-w, t, A, B) = \frac{\#(A_{t-w})}{\#(B_{t-w})} \quad (5)$$

Figure 12 shows an excerpt that starts with a somewhat neutral degree of *upward* (almost an equal proportion of upward as opposed to downward motions) that then starts to oscillate more drastically, then tending toward a preponderance of descents.

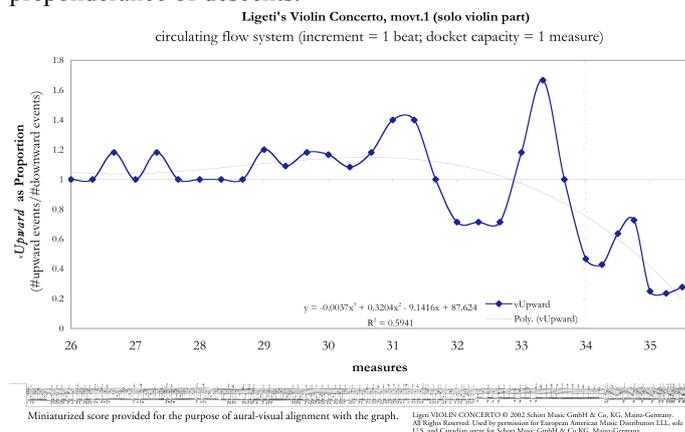


Figure 12. Increasing flux of *upward* in mm. 26-35 of the solo violin part of movt. 1 of Ligeti's Violin Concerto, movt. 1

Figure 13 shows a similar pattern over the course of the whole movement, like a driver on an icy road gradually losing control of his car, until ultimately it swerves right off the road.

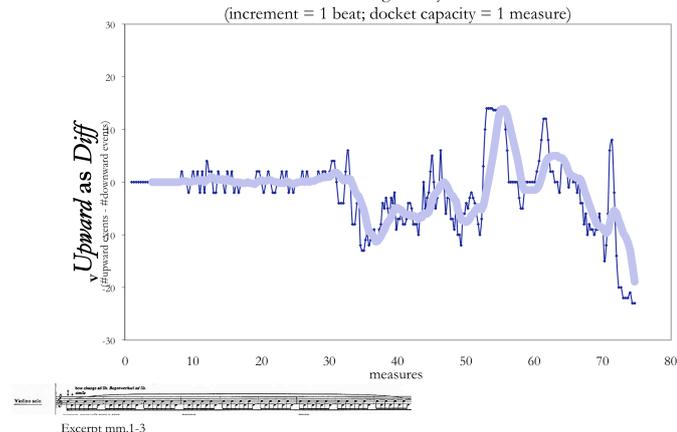


Figure 13. Dynamic form graph based on flux of the emergent quality upward in the solo violin part of Ligeti’s Violin Concerto, movt.1

What the three qualities *durational diversity*, *temporal clumpiness* (*interonset volatility*), and *upward* have in common is that they project form in non-repetitive music and that the perception of their flux is non-obvious.

V. SIMULATION AND KINESTHETICS

To cultivate sharper attention to such unusual kinds of flux, simulation algorithms are developed, such that their input parameters are dynamically controlled through kinesthetic interaction. Specifically, simulation algorithms written in the RTmix computer music language are embedded in Max/MSP patches and an iPhone app to enable immediately responsive manipulation of qualitative intensities of *durational diversity*, *temporal clumpiness* (*rhythmic volatility*), and *upward*. These are controlled with raising and lowers sliders and by tilting motions of the wrist.

A. Max patch embedded RTmix score script for manipulating *durational diversity*

Shown in Figure 14, a Max/MSP patch, running an RTmix score script, allows independent control of *durational diversity* by a slider. (Other parameters can also be controlled independently.) A stochastic stream of musical sound is continuously generated. Its features are controlled by sliders on an interface developed in Max/MSP. The actual duration of notes in the stream is determined by the following equation.

$$Duration = IOI \times DefaultDuration \times \frac{rand(1, DurDiversity + 1)}{rand(1, DurDiversity + 1)} \quad (6)$$

The default (baseline) duration can itself be varied independently as can the IOIs. Thus the durations can vary from much shorter to much longer than the IOIs. Listen to Audio Clips 1, 2, and 3, which demonstrate low, medium, and high degrees of *durational diversity*. Audio Clips 4 and 5 demonstrate smooth flux of *durational diversity* increasing from low to high and decreasing from high to low.

Though it creates music that sounds different from Crawford’s Quartet, the patch is meant to enhance awareness of *durational diversity* through hands-on manipulation of it.

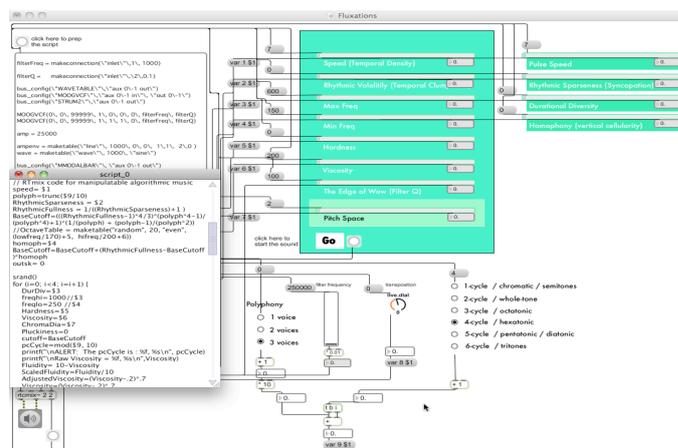


Figure 14. RTmix score script in a Max/MSP patch that enables control of *durational diversity* as an input parameter to the script

B. iPhone app for manipulating *temporal clumpiness* (a.k.a. *interonset volatility*)

Two iPhone apps enable manipulation of *temporal clumpiness* (*interonset volatility*) and *upward*. One of them, called *Fluxations*, is shown in Figure 15. (See Mailman 2012c



Figure 15. The iPhone apps enable user manipulation of algorithmic parameters through sliders and through tilting actions detected by the iPhone’s built-in accelerometer

The rhythmic strategy is to enable the user to control the stream’s *attack density* (*temporal density*) and the *interonset volatility* independently of each other (as shown in Figure 16.) This is done by defining an underlying pulse grid that could be adjusted according to either user-controlled changes of *attack density* (*temporal density*) or *interonset volatility* (*temporal clumpiness*) while holding the other stochastic parameter constant.



Figure 16. Increasing *temporal clumpiness* (a.k.a. *interonset volatility*, or *rhythmic volatility*) with *attack density* held constant

The timing scheduled for each note event (and therefore the resulting rhythm) is decided as follows, such that *interonset volatility* and *attack density* are controlled independently of each other, given their definition in equations in (7) and (8).

$$IOI = \text{interonset interval} \quad (7)$$

$$Density_{Pulse} = \frac{1}{IOI_{Pulse}} \quad (8)$$

The attack density (in equation (9)) can be held constant while the probability of attack is varied to create more or less volatility. In other words, as in equation (10), the underlying pulse IOIs are made smaller in proportion to the increasing interonset volatility, so that the overall attack density remains constant.

$$Density_{Attack} = \frac{1}{Avg(IOI_{Pulse})} = Density_{Pulse} \times Prob(Attack) \quad (9)$$

$$Adjusted_IOI_{Pulse} \approx \frac{IOI_{Pulse}}{1 + Volatility_{Attack}} \quad (10)$$

Therefore the algorithm creates rhythm responsively as follows: The stochastic character of the rhythm is realized by placing an absence of attack on some pulses whenever the user adjusts the rhythmic volatility to a value greater than zero. The chance of an attack on a given pulse is inversely proportional to the rhythmic volatility as adjusted by the user. At slower tempos (lower attack density settings) this creates an irregular energetic syncopated rhythm; at faster tempos (higher attack density settings) this creates a frenetic erratic series of sounds, a virtually uncontrolled chaos. When the durations, increasing *interonset volatility* creates and preponderance of rests. Although this is not the way flux of *interonset volatility* arises in the Carter Quartet, the effect is similar. To hear the algorithm in action, listen to Audio Clips 6, 7, and 8 (which demonstrate low, medium, and high degrees of *interonset volatility*) and Audio Clips 9 and 10 (which demonstrate smooth flux of *interonset volatility* increasing from low to high and decreasing from high to low).

C. iPhone app and RTcmix equipped Max patch for manipulating upward.

The interface for manipulating the intensity of *upward* is implemented as both a Max/MSP patch and an iPhone app, called *Vortex*, both using the same algorithm programmed as an RTcmix score script. On a chromatic pitch space, within successive spans of time *S*, it chooses chromatic stepwise ascent vs. descent by a probability set by the user corresponding to equation (5) above, which represents the intensity of the quality *upward*. Whenever it moves in the opposite direction, it does so by a leap which compensates for the propensity for steps in the dominating direction, whether it be up (*upward* > 0) or down (*upward* < 0). The details of the algorithm and its implementation are beyond the scope of the present paper, though a sketch of it is offered here in Table 1. Listen to Audio Clips 11, 12, 13, 14, and 15, which demonstrate minimum, medium-low, neutral, medium-high, and maximum degrees of *upward*. Audio Clips 16 and 17 demonstrate smooth flux of *upward* increasing from minimum to maximum and decreasing from maximum to minimum.

A simplified version of the Max/MSP patch is shown in Figure 17. Notice the *upward intensity* slider has its midpoint

labeled *neutral* corresponding to *upward*=0, the baseline. In the iPhone implementation, *upward* is controlled by the tilt of the phone itself, as detected by the iPhone's built-in accelerometer, as demonstrated in Video Clip 3.

Table 1. Algorithm for generating a pitch stream contingent on the intensity of upward passed as an input parameter.

```

/* Algorithm for choosing the next pitch, given input
parameters: Upward, max, min, and previousPitch */

range = max-min
proportion = (Upward-min)/range

if (proportion >= 0.5) {
    traversalProportion = 1/ ( (1/ (1-proportion)) -1 )
} else {
    traversalProportion = (1/ (1-proportion)) -1
}
r = rand(-1, 1)
if (Upward >= 0) {
    if (r < Upward) { change = trunc(traversalProportion)}
    else { change = (-1) * range }
} else {
    if (r > Upward) { change = trunc((-1.0)*traversalProportion )}
    else { change = range }
}

pitch = previousPitch + change
    
```

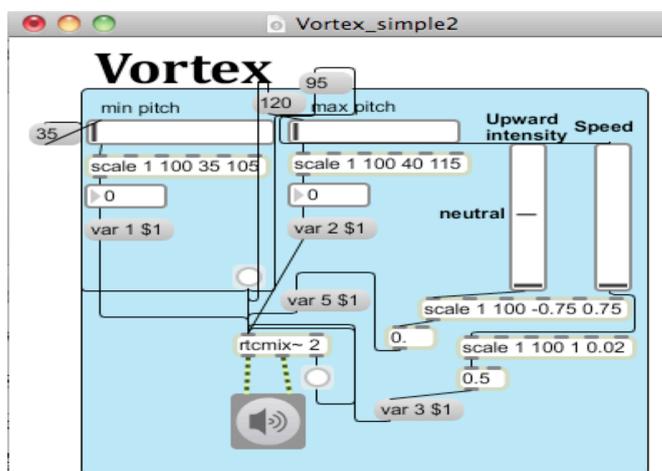


Figure 15. RTcmix score script in a Max/MSP patch that includes control of upward

VI. IMPLICATIONS

The research presented here is only a preliminary step in a potentially wide ranging program to expand aural training pedagogy beyond the fixed ontologies of conventional music. A kinesthetic learning approach is pursued by harnessing the flexibility of mapping various bodily motions to various emergent properties in music. The approach expands on the long standing traditions of teaching music theory through keyboard and solfege exercises, both physical activities. In some ways it parallels the holistic kinesthetics of Dalcroze Eurhythmics. Finally, the kinesthetic learning approach

resonates with the recent attention scholarly music discourse has paid to cognitive metaphor and embodied mind theory.

VII. FUTURE DIRECTIONS

Future work emanating from the current research will extend in the directions of empirical psychology (specifically music cognition) as well as interactive technology and algorithm development.

Empirical psychological experiments may be designed to test the extent to which user manipulation of the qualities sharpens perception of the them in subsequent listening to repertoire and artificial stimuli. Such experimentation may involve developing recommendations for protocols for using the technology prior to testing its efficacy. It may also involve choosing and developing appropriate testing stimuli.

In regard to the development and use of the technology, several important questions remain unanswered. Among them: (1) Which interfaces are optimal for kinesthetic learning of unconventional emergent qualities in music? Does it vary depending on the quality? (2) What are the optimal settings for qualities held stable while a user manipulates another targeted emergent quality?

Kinesthetic learning through various other sensors may be explored. For instance Donnarumma's (2011) *Xth Sense* technology uses the detection of muscle movements as control data for real-time sound processing. Donnarumma's *Xth sense* technology might also be used to feed input to the simulation algorithms discussed above in this paper, that is for kinesthetic learning of unconventional emergent properties.

My collaborative work, the *Fluxations Human Body Interface* (Mailman and Paraskeva 2012), gathers continuous analog input from wireless sensor gloves and an infrared camera using motion tracking technology to provide over ten streams of data deployed as input parameters to a music generating algorithm. The same interface, or a modified version of it, may be used for kinesthetic learning, as described above.

Finally, in addition to the three unconventional form-bearing emergent qualities discussed above (*durational diversity*, *temporal clumpiness*, and *upward*) my previous work (Mailman 2010a) identifies dozens more emergent qualities that bear form in repertoire. Many of these could be reverse engineered into simulation algorithms to be controlled through bodily motions, to cultivate keener perception of diverse musical properties through kinesthetic learning.

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