Composing with Multidimensional Timbre Representations

LEAH REID

ABSTRACT

The author discusses her work and approach to timbre-based composition. Emergent in her works are a common theme and exploration of "timbre spaces" and "timbre *in* space." She discusses two pieces: *Ostiatim*, for string quartet, and *Occupied Spaces*, for two pianos and percussion.

My primary objective as a composer is to write beautiful and stimulating music. For me, "beauty" is embodied by temporal and, in particular, timbral attributes. In my works, timbre acts as a catalyst for exploring new soundscapes, time, space, perception and color.

The problem with *timbre* is that it is ill defined. It is more often defined by what it isn't rather than what it actually is. Unlike pitch and loudness, timbre does not have a simple, objective or single dimensional scale. One can, however, describe timbre as a multidimensional attribute of sound, where "continuous perceptual dimensions correlate with acoustic parameters, corresponding to spectral, temporal, and spectrotemporal properties of sound events" [1]. As timbre became increasingly central in my composition, I adopted a hybrid model that integrates both the "color" and "texture" of sound and incorporates both static and dynamic attributes of timbre. The "color" of sound is described in terms of an "instantaneous snapshot of the spectral envelope," while the "texture" of a sound describes the "sequential changes in color with an arbitrary time scale" [2].

Hiroko Terasawa and Jonathan Berger developed this model of timbre at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA). This view hints at two major compositional elements in a piece: (1) static, vertical pitch and chordal structures and (2) dynamic, horizontal temporal processes. While these elements are significant, this definition is still rather vague as to the descriptive factors of timbre. For this, we must look at the various parameters of timbre and observe how they interact.

I find that the multidimensionality and complexity of timbre is best illustrated in the following list by Caroline Traube [3]:

- temporal envelope
- spectral envelope
- absolute frequency position of spectral envelope
- variations of harmonic contents
- position of spectral centroid → brightness or sharpness
- harmonic and noise components ratio
- inharmonic ratio
- odd/even harmonic ratio
- synchronicity of partials
- onset effects: rise time, presence of noise or inharmonic partials during onset, unequal rise of partials, and characteristic shape of rise curves
- steady state effects: vibrato, amplitude modulation, gradual swelling, and pitch instability

What we notice from these parameters is that the spectrum of the sound is critical, as are the individual frequencies, the way the sounds change over time, their amplitudes and the way these components interact with each other. These parameters begin to give one a better idea of what timbre actually is, but they still do not give a full view of how they interact. This is where a spatial or geometric model of timbre is beneficial.

Since timbre has no single dimensional scale that describes it, when one reviews the research completed on timbre, one is most likely dealing with a multidimensional space, or rather a timbre space. A timbre space is "a model that predicts the perceptual results of auditory stream formation and timbral interval perception" [4]. Depending on the stimuli tested, different correlates are produced.

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See https://direct.mit.edu/leon/issue/54/3 for supplemental files associated with this issue.

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Timbre space studies have used a variety of impulse sounds, ranging from FM-synthesized simulations to recorded instrumental tones. The aim of these models is to "find robust descriptors that explain perceptual data across studies, [to] develop perceptually relevant acoustic distance models for measuring similarity objectively, [and to] find powerful descriptors for sound categorization and source identification" [5].

While there are many fantastic perceptual timbre models worth studying, including those of Howard Pollard and E.V. Jansson [6], John M. Grey [7], Stephen McAdams et al. [8] and many others [9], they have their limitations. For example, the aforementioned studies do not explain unpitched percussion or noise elements.

From a composition viewpoint, there haven't been that many composers who have made timbre the primary concern in their music. While the first composers that often come to our minds are from the spectral school, notably Gérard Grisey [10] and Tristan Murail [11], the timbral systems of Krzysztof Penderecki [12], Kaija Saariaho [13], Pierre Schaeffer [14] and Mathias Spahlinger [15] have particularly fascinated me [16].

I have sought a model for my own purposes that both accounts for the way we perceive timbre and allows one to work with any sound/instrumentation. In this article, I outline the conceptual timbre model I use when composing and give examples from two recent instrumental works.

TIMBRE MODELS IN MY MUSIC

I structure my works using six parameters, which I organize into a set of two interlocking spaces or "cubes," as I like to visualize them (Fig. 1). The first cube essentially controls the frequency components of the sound and has the following three dimensions: spectral flux, spectral centroid and noise-to-pitch ratio.

The first dimension, spectral flux, measures the Euclidean distance between two spectra, or rather the change of spectral energy over time. By extension, this dimension can be used to control rhythms or the rate of pitch changes. This analogy provides a measure of density in time analogous to spectral flux at the intra-event level. For example, in the model, a sound with high flux indicates a high rhythmic activity or that pitches are changing quickly, while a sound with low flux would be one in which either there is a low rhythmic activity or the pitches are stagnant.

The second dimension controls the noise-to-pitch ratio and is similar to Kaija Saariaho's "timbral axis," a structuring device used to create tension and replace functional harmony. On one end of the axis are sounds that are mostly "pure" pitch—that is, sounds that are close to sine waves. By contrast, the other end of the axis is "mostly noise" [17].

The third dimension controls the spectral centroid, or rather, the average centroid over time, and controls the brightness and darkness of the sound. For example, if the space was evaluating the spectral centroid for a violin sound, this axis would have four reference points—*con sordino*, *sul tasto*, *normale* and *sul ponticello*—plus every shifting possibility in between.

The first cube is, however, missing key information, namely the quality of the attack, the dynamic level and the length of the event entering into the space. To solve this dilemma, I use a second cube to inform these decisions. The second space controls the evolution of the sound and works in conjunction with cube I.

The first dimension—attack—controls how the sound or gesture's articulations are treated, ranging from no attack (or

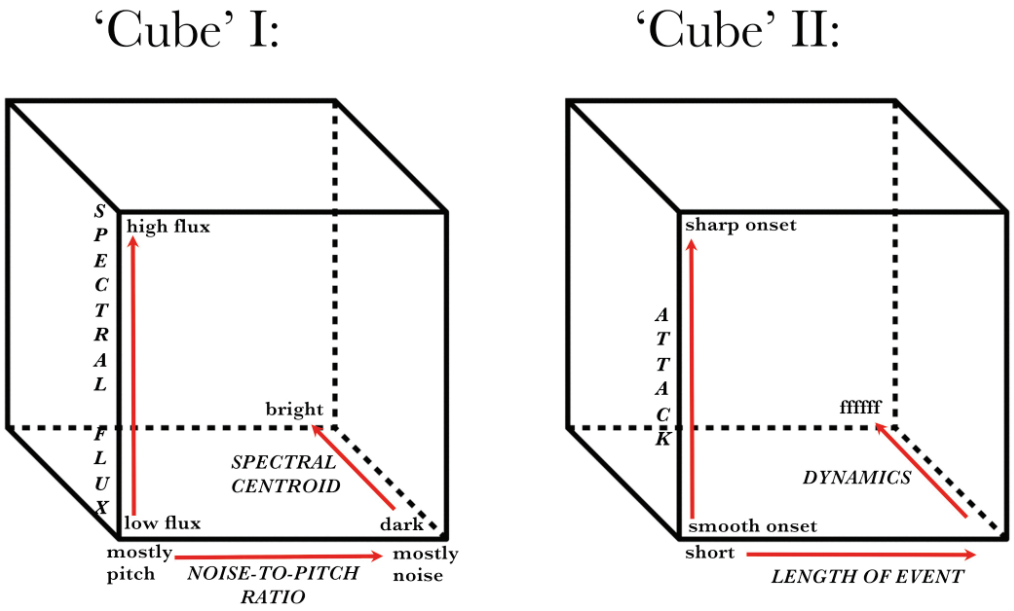

Fig. 1. Timbre spaces used in my own works. (© Leah Reid)

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a smooth onset) to a sharp attack (sharp onset); the second dimension controls the length of the event, sound or gesture that enters into the timbre cube; and the third dimension controls dynamics.

With this conceptual model, each dimension scales, depending on the source material and the function of the desired result. One could use this model to learn more about a sound's timbral characteristics or map a composition's instrumentation onto the space, thereby creating spatial coordinates for every sound they wish to use and "see" the possible relationships among them. This model can be used to derive rhythms; generate a form, harmony and rate of material; or simply inform the orchestration of the piece. With this approach, one can work with any sound or instrumentation. One can use programs such as SPEAR [18], AudioSculpt [19], OpenMusic [20], Orchids/Orchidea [21], Bach [22], etc., to analyze these parameters, or one can work with the dimensions intuitively. In either case, the model allows the perceptual properties of timbre to address many compositional elements across multiple dimensions.

To give an example of how one might use these spaces in a composition, I outline below how I used the model in two recent pieces.

Ostiatim

Ostiatim, for string quartet, comprises 15 fragments that explore the sounds produced by doors and the emotional inflections of people who interact with them. The title, meaning "door-to-door," is meant to depict the timeline of the piece. Each fragment is meant to be treated like a fleeting memory. Sometimes connections are made, and other times, the moment slips away.

In this piece, the spectral flux dimension controls the frequency and rhythm of pitch changes; the spectral centroid controls bow placement and mute usage; the noise-to-pitch ratio controls bow and finger pressure; the attack dimension controls the attack quality, ranging from crescendo *dal niente* to Bartók pizz.; the length of event ranges from short to long; and dynamics range from *niente* to very loud. Figure 2 depicts the way materials were viewed inside the space.

One can use the model to examine a static selection of parameters. For example, fragment 1 comprises small bursts of material with sharp onsets (Fig. 3). This point can be described as having a mid-spectral centroid, a mid-high noise-to-pitch ratio and a mid-high spectral flux.

One may also explore moving trajectories in segments of material. Fragment 2 exemplifies some of the possible trajectories that can be created with my timbre model (Fig. 4). The fragment has two parts: measures 8–14 and measures 15–17. In terms of articulations, the first part juxtaposes aggressive pizzicati with arco sounds, and the second part features delicate pizzicati and soft mid-noisy tremolos. Each part has differing spectral flux coordinates. The first part of the fragment has a high spectral flux, while the second part has a mid-low flux.

The spectral centroid has multiple trajectories. One can observe the motion in the second violin and the violoncello. For example, in measure 8 they move from *sul ponticello* to *ordinario*, which can be viewed as a movement from a high to a mid-spectral centroid. Another example can be seen in measure 12 with a movement back to *sul ponticello.* Here, the spectral centroid shifts back to high. In measure 13, they shift to *sul tasto*, which can be viewed as a movement to a low spectral centroid. The violoncello then does one more move-

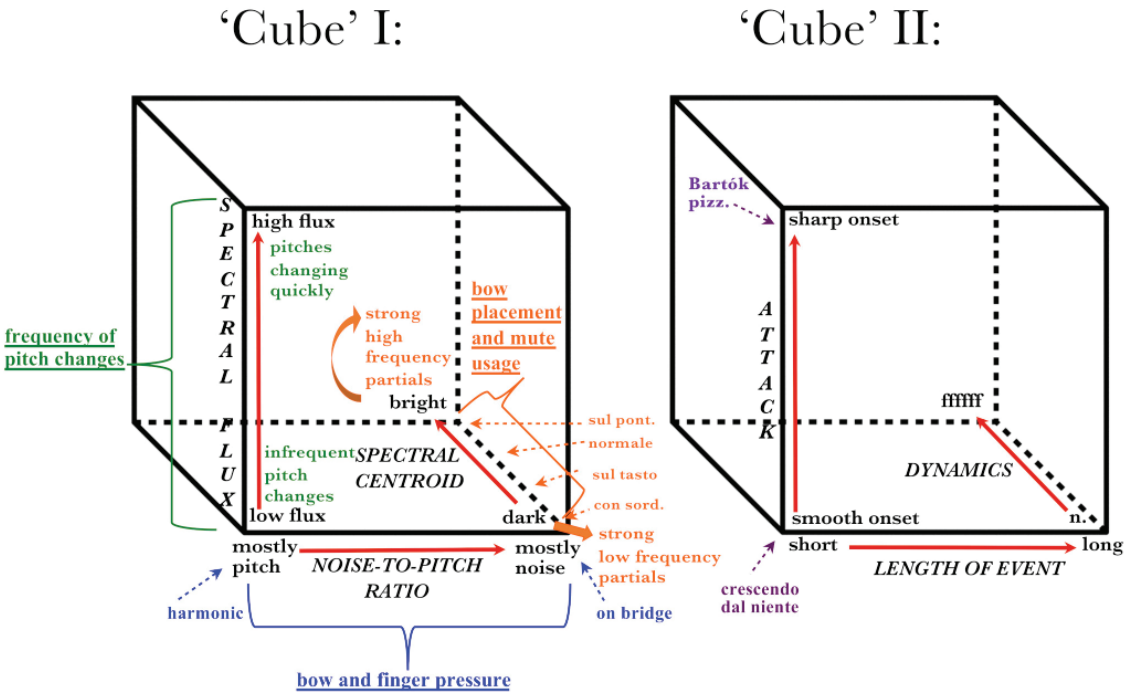

Fig. 2. Timbre cubes as they relate to *Ostiatim*. (© Leah Reid)

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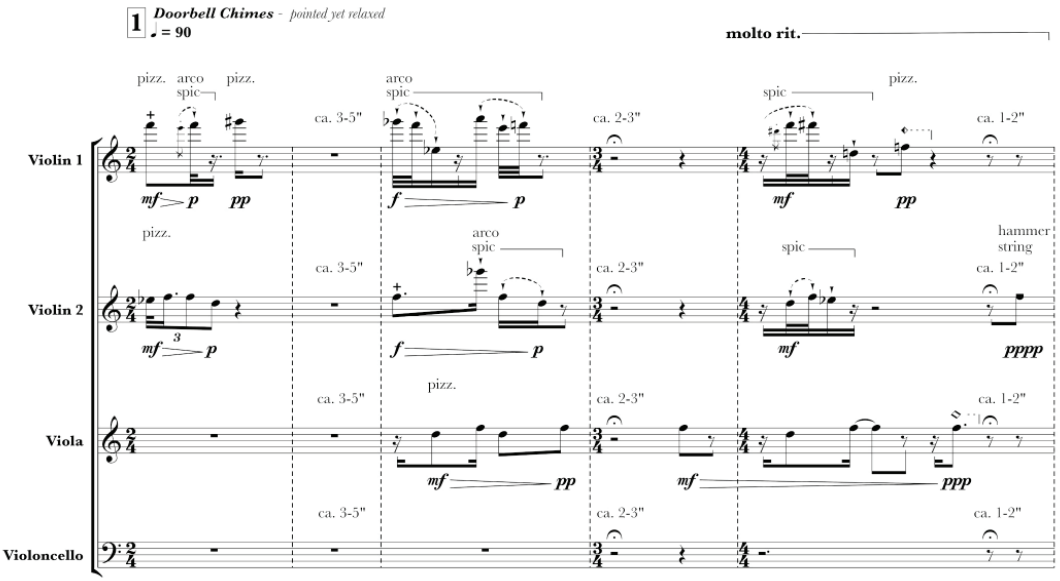

Fig. 3. *Ostiatim*'s fragment 1. (© Leah Reid)

ment to *sul ponticello* before playing *ordinario* in measures 13–15. This motion can be viewed as a trajectory of a high to low spectral centroid.

In terms of the noise-to-pitch axis, in measure 8, both the second violin and the violoncello move from overpressured bowing to *normale* bowing. This can be viewed as a movement from a high noise-to-pitch ratio to a mid-low one. The opposite motion can be seen again in measures 11–12 and 13–14. Furthermore, in the second part of this fragment (measures 15–17), the second violin and viola explore a mid-high noise-to-pitch ratio while the first violin (measures 15–17) and the second violin (measure 17) explore a mid-noise coordinate.

There are also overarching timbral poles/extremes and large-scale trajectories occurring in the piece. For example, the "brightest" fragment is number 12, while the "darkest" one is fragment 14. Also, the noisiest fragment is number 10 while the "purest" one is fragment 14.

The composition is a series of abstracted door sounds that explore both the gritty noisy aspects of these sounds and the beautiful "emotional" side of them. The finished product is not meant to be a replica of the original but rather an interpretation of it.

Occupied Spaces

My next example, *Occupied Spaces*, for two pianos and percussion, explores a series of timbral spaces, presented as "rooms," which grow, shrink and shift in shape. This piece explores the concept of timbre *in* space.

The idea for the piece originated through my interest in spatializing timbre, convolution and the topic of Normalized Echo Density (NED) as defined in architectural acoustics [23]. NED describes how the reflections of a sound in a given architectural space interact over time and the texture that results. Some of the key terms and components associated with NED are: the sound's clarity; focus and blur; the perception of smoothness and roughness, or rather, the degree of granularity of the sound; the ratio of direct to reflected

Fig. 4. *Ostiatim*'s fragment 2. (© Leah Reid)

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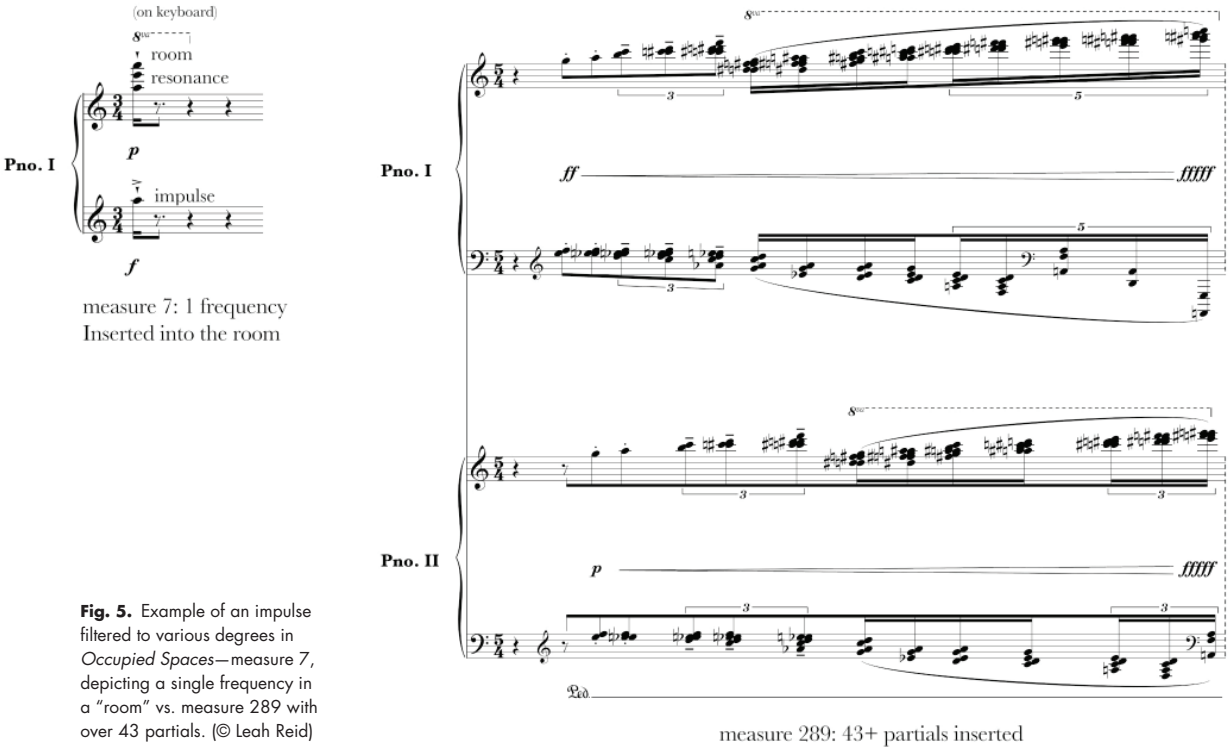

Fig. 5. Example of an impulse filtered to various degrees in *Occupied Spaces*—measure 7, depicting a single frequency in a "room" vs. measure 289 with over 43 partials. (© Leah Reid)

signal in the sound; the dryness or wetness of a signal; and the description of the number of reflections per second of an acoustic signal. For example, noises with low NED would be perceived as "sputtery" and noises with high NED would be perceived as "smooth."

The work explores timbre through a series of 11 "rooms" or conceptual spaces. Some of these spaces were modeled after physically existing rooms; others were imagined and do not follow the rules of physics and/or occur inside one's mind/head.

There are three impulses in the piece: a zipper, a clap and a balloon pop. These impulses form the material that is inserted into the various rooms. These sounds are filtered to various degrees, and over the course of the piece frequencies are added to the impulses, thereby creating an increasingly dense and, by analogy, noisy texture [24]. For example, in measure 7, only a single frequency is present within the "room." By contrast, over 43 partials are present during the climax in measure 289 (Fig. 5).

In my research, I looked at impulse responses of various rooms, analyzed reverbs, created delay patterns and considered the resonant properties of different spaces. Similar to the NED properties discussed above, I came up with room classifications that I based on the following specifications: the dryness/wetness of the sound, the number of reflections, the degree of granularity, the characteristics of the overall sound and the resonance of the space. To create clear timbral poles, I decided that the two room-extremes would be an anechoic chamber and an imaginary room with infinite reverb. The other rooms fit between these extremes. By convolving impulse responses with my original clap, balloon pop, zipper sound and a single pitch (B4), I found each room's specific resonant properties, determined the rhythm of reflections (if there were any) and analyzed the rooms' dynamic curves. After completing this process, I orchestrated the results, choosing the instrumentation that best followed the rooms' characteristic properties. Figure 6 shows the resulting analyses with notes on orchestration.

The piece's overall form is divided into an introduction and six main sections. Each section determines which rooms are used, how many rooms can be present at any one time and the degree of the noise-to-pitch ratio. Figure 7 shows a visualization of the piece's form and timings of each room.

In *Occupied Spaces* the impulses interact with the rooms. Both are essentially convolved. The rooms morph the inserted material and provide their own timbral trajectories. The finished piece is the result of the collision of two formal elements: the rooms themselves and the material inserted into them.

CONCLUSION

I am fascinated with how we perceive timbre, "timbre spaces," and the relationship between reverberant space and timbre, or rather the concept of "timbre *in* space." Over the past 13 years, I have worked toward a conceptual compositional model in which the "color" and "texture" of available sounds are derived from multidimensional perceptual timbre representations.

This model is essentially six parameters, organized into two interlocking spaces, or cubes. The first cube controls the spectral flux, the spectral centroid and the noise-to-pitch ratio; the second cube controls the quality of the attack, the dynamic level and the length of the event entering into the first cube.

This method is a result of my admiration of and research into spectral and postspectral concepts, perceptual studies,

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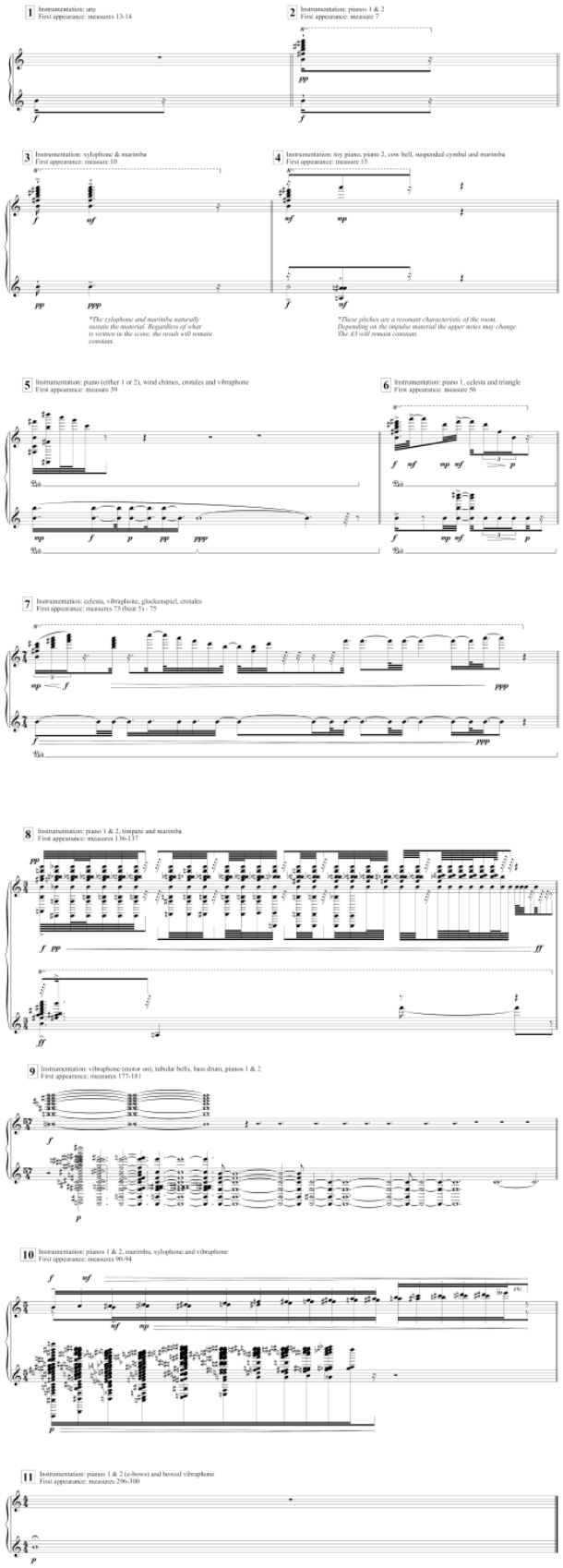

Fig. 6. Analytic transcriptions of the 11 "rooms" in *Occupied Spaces*. The image depicts what results when a 16th note B4 is inserted into each room. Pitches are altered, orchestration is informed and rhythms are generated [43]. (© Leah Reid)

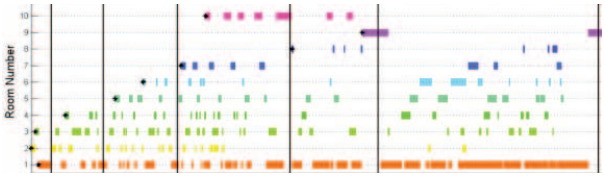

Fig. 7. Graphical illustration of the temporal room spatialization in *Occupied Spaces*. (© Leah Reid)

Schaefferian concepts and many composers' approaches to timbre. It expands upon and combines these ways of thinking. It allows composers to use sounds as acoustic models and to structure both small- and large-scale elements in a work using timbre perception as a guide. With this approach, timbre may be used as a lens through which many compositional elements may be explored.

With each composition, I find new ways to approach my model. *Ostiatim* explores the orchestration of noise, and *Occupied Spaces* explores timbre *in* space through filtered impulses and a series of rooms or spaces.

I have also explored these concepts with electronic media (see *Ring, Resonate, Resound* and *Crumbs*), used timbre as a structuring device (see *Clocca*) and developed new ways to work with timbre and the voice (see *Apple* and *Single Fish*). My interest in "timbre in space" has also led to significant experiment with sound spatialization (see *Sk(etch)* and *Reverie*) and collaborations with dancers—exploring relationships between physical and perceptual spaces. Further information [25], examples and recordings may be found at www.leahreidmusic.com.

References and Notes

1 Stephen McAdams et al., "A Meta-Analysis of Acoustic Correlates of Timbre Dimensions," *The Journal of the Acoustical Society of America* **120**, No. 5, 3275 (2006): www.doi.org/10.1121/1.4777215.

2 Hiroko Terasawa and Jonathan Berger, "A Hybrid Model of Timbre Perception," *The Journal of the Acoustical Society of America* **124**, No. 4, 2448 (2008): www.doi.org/10.1121/1.4782593.

3 Caroline Traube, "Instrumental and Vocal Timbre Perception" (2006): www.academia.edu/38557836/Instrumental_and_vocal_timbre_perception (accessed 1 May 2020).

4 McAdams et al. [1].

5 McAdams et al. [1].

6 Howard Pollard and E.V. Jansson, "A Tristimulus Method for the Specification of Musical Timbre," *International Journal of Acoustics* **51**, No. 3, 162–171 (1982).

7 John M. Grey and James A. Moorer, "Perceptual Evaluations of Synthesized Musical Instrument Tones," *The Journal of the Acoustical Society of America* **62**, No. 2, 454–462 (1977).

8 Stephen McAdams et al., "Perceptual Scaling of Synthesized Musical Timbres: Common Dimensions, Specificities, and Latent Subject Classes," *Psychological Research* **58**, No. 3, 177–192 (1995).

9 In addition to the timbre models outlined in the article, I recommend studying those of Peterson and Barney [26], Singh and Woods [27], Von Bismarck [28], Pratt and Doak [29], Wessel [30], Krum-

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shansl [31], Iverson and Krumhansl [32], Lakatos [33], the IPA vowel space [34] and the *Timbre Is a Many-Splendored Thing* conference proceedings [35].

10 Gérard Grisey, "*Tempus ex Machina*: A Composer's Reflections on Musical Time," *Contemporary Music Review* **2**, No. 1, 239–275 (1987).

11 François Rose, "Introduction to the Pitch Organization of French Spectral Music," *Perspectives of New Music* **34**, No. 2, 6–39 (1996).

12 Danuta Mirka, "To Cut the Gordian Knot: The Timbre System of Krzysztof Penderecki," *Journal of Music Theory* **45**, No. 2, 435–456 (2012).

13 Kaija Saariaho, "Timbre and Harmony: Interpolations of Timbral Structures," *Contemporary Music Review* **2**, No. 1, 93–133 (1987).

14 Pierre Schaeffer, *Traité des Objets Musicaux: Essai Interdisciplines* (Paris: Éditions du Seuil, 1966).

15 Philipp Blume, "Mathias Spahlinger's *128 erfüllte augenblicke* and the Parameters of Listening," *Contemporary Music Review* **27**, No. 6, 625–642 (2008).

16 This list is not exhaustive. For a few additional examples, I recommend the reader refer to research by Cogan [36], Erickson [37], Lerdahl [38], Slawson [39], Terasawa [40], Thoresen [41] and Wishart and Emmerson [42].

17 Saariaho [13].

18 SPEAR is a sinusoidal partial editing analysis and resynthesis tool, available at www.klingbeil.com/spear (accessed 1 May 2020).

19 AudioSculpt is an IRCAM software for viewing, analyzing and processing sounds described at http://anasynth.ircam.fr/home/english/software/audiosculpt (accessed 1 May 2020).

20 OpenMusic is a visual programming language based on Common Lisp and developed at IRCAM. The program is a useful environment for music composition and is described at http://openmusic-project.github.io (accessed 1 May 2020).

21 Orchids/Orchidea is a computer-assisted orchestration program developed at IRCAM and available at http://forum.ircam.fr/projects/detail/orchidea (accessed 1 May 2020).

22 Bach is a source library providing Max/MSP for computer-aided composition, available at www.bachproject.net (accessed 1 May 2020).

23 Patty Huang et al., "Reverberation Echo Density Psychoacoustics," *Proceedings of the Audio Engineering Society's 125th Convention* (San Francisco, 2008).

24 While the densification of frequencies in itself does not equate with an increased level of noisiness, in the case of *Occupied Spaces*, the impulses themselves are different noises. Therefore, as more frequencies are added, by analogy, the true "noisy" nature of the sound is revealed, thus creating an increasingly noisy texture.

25 Leah Reid, "Composing Timbre Spaces, Composing Timbre in Space: An Exploration of the Possibilities of Multidimensional Timbre Representations and Their Compositional Applications" (Stanford University, DMA final project, 2013).

26 Gordon E. Peterson and Harold L. Barney, "Control Methods Used in a Study of the Vowels," *The Journal of the Acoustical Society of America* **24**, No. 2, 175–184 (1952).

27 Sadan Singh and David R. Woods, "Perceptual Structure of 12 American English Vowels," *The Journal of the Acoustical Society of America* **49**, No. 6, 1861–1866 (1971).

28 Gottfried Von Bismarck, "Timbre of Steady Sounds: A Factorial Investigation of its Verbal Attributes," *Acustica* **30,** No. 3, 146–159 (1974).

29 R.L. Pratt and Philip Ellis Doak, "A Subjective Rating Scale for Timbre," *Journal of Sound and Vibration* **45**, No. 3, 317–328 (1976).

30 David Wessel, "Timbre Space as a Musical Control Structure," *Computer Music Journal* **3**, No. 2, 45–52 (1979).

31 Carol Lynne Krumhansl, "Why Is Musical Timbre So Hard to Understand?" in S. Nielzén & O. Olsson, eds., *Structure and Perception of Electroacoustic Sound and Music* (Amsterdam: Excerpta Medica, 1989) pp. 43–53.

32 Paul Iverson and Carol Lynne Krumhansl, "Isolating the dynamic attributes of musical timbre," *Journal of the Acoustical Society of America* **94,** No. 5, 2595–2603 (1993).

33 Stephen Lakatos, "A Common Perceptual Space for Harmonic and Percussive Timbres," *Perception & Psychophysics* **62**, No. 7, 1426–1439 (2000).

34 IPA Vowel Chart: www.internationalphoneticassociation.org/sites/default/files/IPA_Kiel_2015.pdf (accessed 1 February 2021).

35 Etienne Thoret, Meghan Goodchild and Stephen McAdams, eds., *Timbre 2018: Timbre Is a Many-Splendored Thing* (Montreal, QC: McGill University, 2018).

36 Robert Cogan and Pozzi Escot, *Sonic Design: The Nature of Sound and Music* (Cambridge, MA: Publication Contact International, 1984).

37 Robert Erickson, *Sound Structure in Music* (Berkeley: University of California Press, 1975).

38 Fred Lerdahl, "Timbral Hierarchies," *Contemporary Music Review* **2**, No. 1, 135–160 (1987).

39 Wayne Slawson, *Sound Color* (Berkeley: University of California Press, 1985).

40 Hiroko Terasawa, "A Hybrid Model for Timbre Perception: Quantitative Representations of Sound, Color, and Density" (Stanford University, PhD thesis, 2009).

41 Lasse Thoresen, Andreas Hedman and James Grier, *Emergent Musical Forms: Aural Explorations* (London, ON: Department of Music Research and Composition, Don Wright Faculty of Music, University of Western Ontario, 2015).

42 Trevor Wishart and Simon Emmerson, *On Sonic Art* (Austria: Harwood Academic Publishers, 1996).

43 These analyses were created using AudioSculpt and OpenMusic.

Manuscript received 1 May 2020.

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