About This Issue

As we are reminded by the contents of Gareth Loy's two-volume *Musimathics* (MIT Press, 2006–2007), computer music can be viewed as one of the latest developments in the centuries—indeed, millennia—of intellectual endeavor connecting mathematics and music. In particular, the ancient expression of musical intervals as integer ratios has, throughout history and to this day, fascinated musically inclined scientists and scientifically inclined musicians. Towering over most of these was the nineteenth-century physicist Hermann Helmholtz, who finally found, in the interference patterns of overtones in the cochlea, a scientifically satisfactory explanation for consonance and tonal harmony, connected to the integer ratios of just intonation. Twentieth-century modernism, however, largely viewed tuning theory, and particularly the concerns of just intonation, as anachronistic: a movement proclaiming the liberation of dissonance had no need for purer consonances. It remained for digital sound synthesis to give composers a means of transferring Helmholtz's insights to thoroughly nontraditional pitch worlds. At Bell Laboratories, John Pierce and Max Mathews experimented with synthetic spectra having corresponding, nonstandard tuning systems—a line of thinking that led to John Chowning's 1977 composition *Stria* (documented comprehensively in the preceding issue of this journal and on the present issue's DVD). William Sethares's book *Tuning,Timbre, Spectrum, Scale* (Springer, 1999) has further explored this terrain. Besides composition with synthetic timbres, though, there are other areas of computer music where tuning theory can crop up—which brings us to the first two articles in the present issue of *Computer Music Journal.* Each article treats a visible manifestation of tuning: microtonal controllers in the first case, and microtonal notation in the second.

The article by Andrew Milne, William Sethares, and James Plamondon explains, in considerable depth, the mathematics underlying certain principles of microtonal keyboard layout. One of these principles is *transpositional invariance.* On instruments having this property, geometrical shapes (e.g., chords) can be transposed intact, much like sliding a barre chord along a guitar fretboard. Such keyboards are termed *isomorphic.* (Non-microtonal examples include the chromatic button accordion and the Janko piano; the most influential microtonal example was the groundbreaking "generalized keyboard" of R. H. M. Bosanquet, whose design is described in appendices to Helmholtz's *On the Sensations of Tone as a Physiological Basis for the Theory of Music.*) Another, related principle is *tuning invariance.* This term, introduced here by Milne et al., describes the ability, on an isomorphic keyboard, to preserve geometrical shapes across a continuum of related tuning systems. The authors explain what it means for an interval to be "the same" as its tuning changes, and they provide examples of related tuning systems across which musical patterns can be tuning-invariant. Many historically (and even ethnomusicologically) relevant tuning systems can be generated from a single interval (plus the octave), as in the cycle of fifths. As the interval's tuning changes, so does the tuning of all the pitch classes in the tuning system. This means that an isomorphic instrument can feature a continuous controller for dynamically retuning all the instrument's pitches along the continuum that includes these tuning systems, without requiring the performer to learn new fingerings for different systems (or different keys). Although their article is chiefly a mathematical exposition, the authors briefly consider the educational and creative ramifications of such an instrument. Mr. Plamondon's forthcoming controller, the "Thummer," embodies these design principles.

Microtonality presents interesting challenges, not only for the design of new instruments (and, of course, for performers of traditional instruments), but also for notation. Composers have adopted different, often idiosyncratic, conventions for naming the pitches of nonstandard tuning systems and displaying them on the page. For example, Ben Johnston's music, like that of his mentor Harry Partch, employs a microtonal just intonation for which the composer developed his own notation system,

Front cover. The top illustration shows the Thummer, a portable, microtonal controller that embodies the principles described in the article by Andrew Milne et al. By default, the Thummer uses a key layout invented by Kaspar Wicki in the late 1800s. At the bottom is a screen image from the article by Andreas Stefik et al., showing Ben Johnston's microtonal accidentals.

Back cover. This illustration, from the article by Andrew Milne et al., shows how an isomorphic layout (here, the Wicki design) exhibits tuning invariance as the perfect fifth, *F,* changes in size from 4/7 of an octave to 3/5 of an octave.

which in Mr. Johnston's case is common Western music notation with added accidentals. Not only the unusual accidentals, but also the nonstandard intonation of normally notated notes, pose difficulties for performers. It comes as no surprise that computer technology can help. In "An Automatic Translator for Semantically Encoded Musical Languages," Andreas Stefik, Melissa Stefik, and Mark Curtiss describe software they developed to convert between various music representations, such as Mr. Johnston's notation and "performance notation," in which notes are annotated with their deviation in cents from equal temperament. (The Kepler Quartet has used parts of this technology for ear-training in preparation for recording Mr. Johnston's string quartets.) The authors describe their software as providing a general-purpose framework for translating between arbitrary music representations, not just notations related to tuning. As an example, they demonstrate its ability to easily incorporate a staff based on the chromatic scale. Yet encoding and decoding the semantics of microtonal systems, such as Ben Johnston's, is a substantially more difficult task to implement in translation software, according to the authors.

Software representations of music often reflect the programming paradigm of the environment in which they are implemented. Paradigms used in constructing software for music composition include object-oriented, functional, and data-flow programming, among others. The article by Patrick Hill, Simon Holland, and Robin Laney serves as an introduction to a paradigm that is new for music software, aspect-oriented programming (AOP). The authors argue that aspect-oriented music representation is well suited to compositional idioms in which musical raw materials are combined and reused in a manner that creates tangled, polyarchic relationships. After briefly explaining the concepts of aspect-oriented programming, they describe their software, called AspectMusic. Written in Smalltalk, AspectMusic consists of two parts: HyperMusic, which implements what is known in AOP as a symmetric approach, and MusicSpace, which implements an asymmetric approach.

Paul Nauert's article investigates complexities of rhythm, which are somewhat analogous to the complexities of intonation described in the first article, but he focuses on compositional techniques rather than mathematical details. He explores two models of rhythm familiar to ethnomusicologists—the additive and the divisive—and shows how he employs these models in algorithmically composing music for human performers that is conventionally notated but nontraditional and rhythmically sophisticated. The additive model builds up rhythms by concatenating units of possibly different sizes, whereas the divisive model divides a longer unit (e.g., a measure) into equal parts. (It might be stretching the point to find here an analogy with the contrast between just intonation and equal divisions of the octave. One could also draw a comparison between flexible intonation, which underlies the notion of tuning invariance, and the rhythmic quantization that Mr. Nauert applies to make his music more practical for performers.) The author describes a series of additive and divisive algorithms that he implemented in OpenMusic, a Lisp-based visual programming environment. He also discusses a hybrid approach with both addition- and division-based features.

The reviews in this issue cover, among other items, a "visual music marathon," the first volume of the Gareth Loy book mentioned earlier, a book on new digital instruments (focusing on controllers, sensors, biosignal acquisition, and intelligent systems), and a five-CD historical anthology from the archives of the Groupe de Recherches Musicales (GRM).

For the two-disc DVD set attached to this issue, this year's curators—Tae Hong Park, Robert Gluck, and Lonce Wyse—have assembled an interesting collection of recordings (some with video tracks) by composers having a wide variety of nationalities and cultural backgrounds. As usual, the DVD also includes sound and video examples to accompany recent articles. However, this year the examples are all by composers: Natasha Barrett, David Cope, and John Chowning. This year's DVD initiates an annual studio report presented in video, the first being by the Center for the Performing Arts and Technology at the University of Michigan. Finally, the DVD-ROM portions of the discs include, among other files, the complete quadraphonic audio for the original and newly reconstructed versions of *Stria,* optical scans of Mr. Chowning's notes and extant source code, and Kevin Dahan's source code for reconstructing the piece.

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Letters

Proof of the Equivalence of the Spiral Array and the Line of Fifths in Chew and Chen's Pitch-Spelling Algorithm

In a recent article published in this journal (Meredith 2007), I presented the results of a study in which Chew and Chen's (2003a, 2003b, 2005) pitch-spelling algorithm was re-implemented and then optimized by running it with 1,296 different parameter-value combinations on a test corpus containing 195,972 notes and consisting of 216 movements from baroque and classical works.

One of the parameters of the tested implementation of the algorithm allows the line of fifths to be used instead of the spiral array (Chew 2000) when calculating the center of effect. I reported that, in 99.54 percent of the parameter-value combinations (including the best-performing ones), the results generated by the algorithm using the line of fifths were identical to those produced using the spiral array. There were only 2 (poorly performing) cases out of 432 parameter-value combination classes where the output of the tested implementation of the algorithm using the line of fifths was different from that using the spiral array (Meredith 2007, p. 65).

However, further study has revealed that it can be proved that changing from using the spiral array to using the line of fifths while keeping all other parameter values constant should never make any difference to the output generated by Chew and Chen's algorithm. I shall now present a proof of this result.

Let P be a set of notes, let CE_S be the center of effect of P in the spiral array and let CE_L be the center of effect of P on the line of fifths. CE_S is a three-dimensional position vector, given by the following equation:

$$CE_S = \frac{\sum_{n \in P} \left(d(n) p(n) \right)}{\sum_{n \in P} d(n)} \qquad (1)$$

where $d(n)$ is the duration of the note n and $p(n)$ is the position vector within the spiral array of the pitch name class assigned to n. CE_L is a real number given by the following equation:

$$CE_L = \frac{\sum_{n \in P} \left(d(n) k(n) \right)}{\sum_{n \in P} d(n)} \qquad (2)$$

where $k(n)$ is the index of the pitch name class assigned to the note n.

Let's suppose that we wish to use Chew and Chen's algorithm to assign to a note N, whose pitch class is c, the pitch name class that is closest to the center of effect of P. Let $K_S(N)$ be the set that contains the indices of the pitch name classes that can be assigned to N that are closest to CE_S in the spiral array; and let $K_L(N)$ be the set that contains the indices of the pitch name classes that can be assigned to N that are closest to CE_L on the line of fifths. I shall now prove the following theorem.

Theorem 1 *For a given set of notes P and a given note N, the set $K_L(N)$ is always equal to $K_S(N)$.*

Proof For any note, n, whose pitch name class has been assigned,

$$p(n) = \left\langle \frac{r}{h} \sin\left(k(n)\pi / 2\right), \frac{r}{h} \cos\left(k(n)\pi / 2\right), k(n) \right\rangle \qquad (3)$$

where r/h is the aspect ratio of the spiral array and $k(n)$ is the index of the pitch name class of n. Let's further define that $p(k)$ denotes the spiral array position vector associated with the index k and that therefore

$$p(k) = \left\langle \frac{r}{h} \sin\left(k\pi / 2\right), \frac{r}{h} \cos\left(k\pi / 2\right), k \right\rangle. \qquad (4)$$

Equations 1 and 3 imply that

$$CE_S = \left\langle \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \sin\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)}, \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \cos\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)}, \frac{\sum_{n \in P} \left(d(n) k(n) \right)}{\sum_{n \in P} d(n)} \right\rangle. \qquad (5)$$

Equations 2 and 5 together imply that

$$CE_S = \left\langle \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \sin\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)}, \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \cos\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)}, CE_L \right\rangle. \qquad (6)$$

In other words, the z component of the position vector of CE_S in the spiral array is CE_L, the center of effect of P on the line of fifths. It can readily be shown that

$$\begin{aligned} K_L(N) = \{ k \mid & \left(k = 12i + (7c \bmod 12)\right) \\ & \text{and } (i \text{ is an integer}) \\ & \text{and } \left(\mathrm{Abs}(k - CE_L) \text{ is a minimum}\right) \} \end{aligned} \qquad (7)$$

where $\mathrm{Abs}(x)$ is x if $x \geq 0$ and $-x$ otherwise. Similarly, it is clear that

$$\begin{aligned} K_S(N) = \{ k \mid & \left(k = 12i + (7c \bmod 12)\right) \\ & \text{and } (i \text{ is an integer}) \\ & \text{and } \left(| p(k) - CE_S | \text{ is a minimum}\right) \} \end{aligned} \qquad (8)$$

where $|x|$ is the length of the vector x and $p(k)$ is as defined in Equation 4. From Equations 7 and 8, it follows that $K_L(N)$ is always equal to $K_S(N)$ if and only if

$$\begin{aligned} & \left(\mathrm{Abs}\left(12i + (7c \bmod 12) - CE_L\right) \text{ is a minimum}\right) \Leftrightarrow \\ & \left(| p\left(12i + (7c \bmod 12)\right) - CE_s | \text{ is a minimum}\right). \end{aligned} \qquad (9)$$

Let's define that $CE_{S,x}$ and $CE_{S,y}$ denote the x and y components of CE_S, respectively. That is, from Equation 5,

$$CE_{S,x} = \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \sin\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)} \quad (10)$$

and

$$CE_{S,y} = \frac{\sum_{n \in P} \left(d(n) \frac{r}{h} \cos\left(k(n)\pi / 2\right) \right)}{\sum_{n \in P} d(n)}. \quad (11)$$

From Equations 4, 6, 10, and 11, it follows that

$$\left| p\left(12i + (7c \bmod 12)\right) - CE_S \right| = \left| \left\langle \begin{array}{l} \frac{r}{h}\sin\left(\left(12i + (7c \bmod 12)\right)\pi / 2\right) - CE_{S,x}, \\ \frac{r}{h}\cos\left(\left(12i + (7c \bmod 12)\right)\pi / 2\right) - CE_{S,y}, \\ \left(12i + (7c \bmod 12)\right) - CE_L \end{array} \right\rangle \right|$$

and therefore

$$\left| p\left(12i + (7c \bmod 12)\right) - CE_S \right| = \left| \left\langle \begin{array}{l} \frac{r}{h}\sin\left(6\pi i + (7c \bmod 12)\pi / 2\right) - CE_{S,x}, \\ \frac{r}{h}\cos\left(6\pi i + (7c \bmod 12)\pi / 2\right) - CE_{S,y}, \\ \left(12i + (7c \bmod 12)\right) - CE_L \end{array} \right\rangle \right|. \quad (12)$$

But $\sin(2\pi j + x) = \sin x$ and $\cos(2\pi j + x) = \cos x$ for all integers j. Therefore

$$\left| p\left(12i + (7c \bmod 12)\right) - CE_S \right| = \left| \left\langle \begin{array}{l} \frac{r}{h}\sin\left((7c \bmod 12)\pi / 2\right) - CE_{S,x}, \\ \frac{r}{h}\cos\left((7c \bmod 12)\pi / 2\right) - CE_{S,y}, \\ \left(12i + (7c \bmod 12)\right) - CE_L \end{array} \right\rangle \right|. \quad (13)$$

This implies that the x and y components of $p(12i + (7c \bmod 12)) - CE_S$ are constant for all values of i. This corresponds to the geometrical fact that all the possible spellings of a given note N lie on a straight line parallel with the central axis of the spiral array. Therefore, for a given note N with a pitch class c and a given context set of notes P, $|p(12i + (7c \bmod 12)) - CE_S|$ is a minimum if and only if the absolute value of its z component is a minimum. That is,

$$\left(\text{Abs}\left(12i + (7c \bmod 12) - CE_L\right) \text{ is a minimum}\right) \Leftrightarrow$$
$$\left(| \, p\left(12i + (7c \bmod 12)\right) - CE_s \, | \text{ is a minimum}\right),$$

which, as stated above (see Equation 9), implies that $K_L(N)$ is always equal to $K_S(N)$.

[End of proof.]

Theorem 1 implies that, for a given note N and a given context set of notes P, the set of pitch name classes that can be assigned to N that are closest to the center of effect of P in the spiral array is always the same as the set of pitch name classes assignable to N that are closest to the center of effect of P on the line of fifths. Note that $K_L(N)$ has cardinality 2 if the minimum value of $\text{Abs}(12i + (7c \bmod 12) - CE_L)$ is 6; otherwise, $K_L(N)$ contains a single value.

It remains for me to explain why changing from the line of fifths to the spiral array (while keeping all other parameter values constant) in the implementation of Chew and Chen's algorithm used by Meredith (2007) caused the algorithm to generate different results in two of the 432 parameter-value combination classes tested. Table 1 shows the details for these two classes of parameter-value combinations.

As can be seen in Table 1, for the parameter-value combinations in these two classes, the note error count achieved using the spiral array with an aspect ratio of $\sqrt{15/2}$ was lower than that when the line of fifths was used and lower than that when the spiral array was used with an aspect ratio of $\sqrt{2/15}$. However, according to Theorem 1, within each of these two classes, the three note error counts should have been equal.

Unfortunately, I have so far been unable to reproduce the results in Table 1. I re-compiled and ran the code used by Meredith (2007) using two different versions of Lisp (MCL on Mac OS 9.2 and SBCL on openSuse Linux 10.2). For both versions, the note error count was 10,403 for all the parameter value combinations in class 1 in Table 1 and 12,457 for all the parameter value combinations in class 2 in Table 1. These new results are consistent with Theorem 1, which suggests that the discrepancies in Table 1 were the result of an error whose source I have, unfortunately, not yet been able to identify. If further investigation does not provide an explanation for the discrepancies in Table 1, then, clearly, the complete experiment reported in my recent article (Meredith, 2007) will have to be re-run and the statistics recomputed in order to confirm the conclusions drawn. The results of these further investigations will be reported in a future letter to the editor.

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References

Chew, E. 2000. "Towards a Mathematical Model of Tonality." PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Chew, E., and Y.-C. Chen. 2003a. "Determining Context-Defining Windows: Pitch Spelling Using the Spiral Array." *Proceedings of the Fourth International Conference on Music Information Retrieval.* Baltimore, Maryland.

Chew, E., and Y.-C. Chen. 2003b. "Mapping MIDI to the Spiral Array: Disambiguating Pitch

Table 1. Parameter-Value Combinations in Two Classes in Which Changing from SA to LOF Made a Difference in the Experiment Reported by Meredith (2007).

Class	*ws*	*wr*	*f*	*AspectRatio*	*ChunkSize*	*StartOrSound*	*SAOrLOF*	*(MinSAIndex MaxSAIndex)*	*Note error count*
1	4	4	1	$\sqrt{2/15}$	500	Starting	LOF	(–15 19)	10,403
	4	4	1	$\sqrt{2/15}$	500	Starting	SA	(–15 19)	10,403
	4	4	1	$\sqrt{15/2}$	500	Starting	SA	(–15 19)	9,760
2	4	4	1	$\sqrt{2/15}$	500	Starting	LOF	(–22 26)	12,457
	4	4	1	$\sqrt{2/15}$	500	Starting	SA	(–22 26)	12,457
	4	4	1	$\sqrt{15/2}$	500	Starting	SA	(–22 26)	12,031

Spellings." *Proceedings of the 8th INFORMS Computer Society Conference.* Norwell, Massachusetts: Kluwer, pp. 259–275.

Chew, E., and Y.-C. Chen. 2005. "Real-Time Pitch Spelling Using the Spiral Array." *Computer Music Journal* 29(2):61–76.

Meredith, D. 2007. "Optimizing Chew and Chen's Pitch-Spelling Algorithm." *Computer Music Journal* 31(2):54–72.

Elaine Chew responds:

I have followed with interest the evaluations of the Chew and Chen (2003a, 2003b, 2005) pitch-spelling algorithm in Meredith and Wiggins (2005) and Meredith (2007), as well as Meredith's recent letter regarding the equivalence of the use of the pitch-class helix in the spiral array and the line-of-fifths representation in the Chew and Chen pitch-spelling algorithm. The purpose of my response here is not to verify the correctness of Meredith's algebraic proof; I write to provide some context for the use of the spiral array, and geometric interpretations of the equivalence of the pitch-class helix in the spiral array and the line of fifths, and the situations under which this holds true.

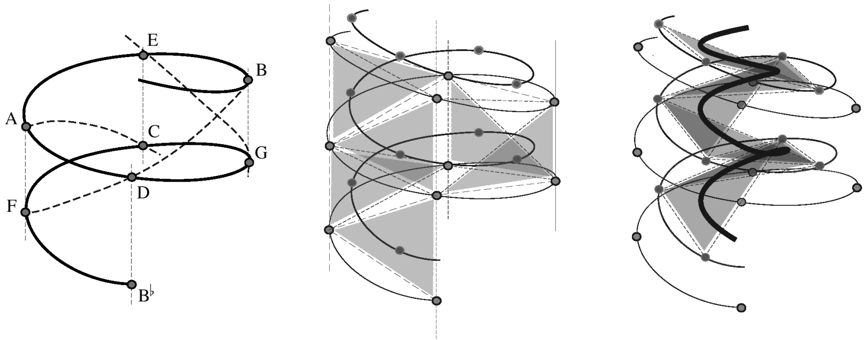
For the benefit of the reader who may not be familiar with the spiral array, I make a clear distinction between the pitch-class helix, a component of the spiral array model, and the spiral array, a model consisting of a number of nested helices and an interior-point approach to a traditional representation (Chew, forthcoming). I shall place the spiral array in the context of pitch representations in Western tonal music, provide reasons for the selection of the aspect ratio in the spiral array model, and present evidence of the benefits of higher- (than one) dimensional representations of pitch classes for chord and key recognition. I present the motivations for, and advantages of, the spiral array representation for pitch spelling in the context of a system for tonal analysis. Finally, I give geometric interpretations for why the line of fifths is sufficient for the particular task of pitch spelling.

Meredith has evaluated the Chew and Chen pitch-spelling algorithm with admirable thoroughness on a large corpus of baroque and classical works. In Chew and Chen, we proposed a pitch-spelling algorithm designed to handle the pitch-spelling challenges (key changes, particularly abrupt ones) posed by a late Beethoven sonata, *Op. 109,* and tested it with 19 parameter-value combinations. The parameter values consist of the local window sizes for phase one and two of the algorithm, and the relative weight on local versus global information in phase two. Meredith reimplemented and tested the Chew and Chen algorithm with 1,296 parameter-value settings. In addition to these parameter values, he also varied the aspect ratio (r/h) for the pitch-class helix in the spiral array, including setting it to the limit value as $h \to \infty$ or $r \to 0$, which results in the line of fifths.

The spiral array (Chew 2000) is a geometric representation for tonality. It consists of an array of nested helices, representing tonal elements at different hierarchical levels (pitch classes, major and minor triads, major and minor keys, etc.) in the same space (see Figure 1). The representations on each inner spiral are derived mathematically as convex combinations of their lower level constituents. Each interior point thus defined is called a *center of effect* of its constituents. The aspect ratio of the pitch-class helix, and the weights for defining higher-level representations, are determined so that the spatial organization of the objects reflects their perceived closeness. The Chew and Chen algorithm uses only the pitch-class helix in the spiral array, and the general concept of the center of effect. The aspect ratio in the spiral array is selected to satisfy the perceived relative closeness among the pitch classes represented—for example, pitches related by intervals of perfect

Figure 1. Pitch class, major triad, and major key representations in the spiral array, an example of an array of nested helices. (Reproduced from Chew 2005.)

Figure 2. The line of fifths with C-major triad pitch classes highlighted, and a possible C-major triad center of effect indicated. (c.e. = center of effect.)



pitch class representations

major triad representations

major key representations

Figure 1

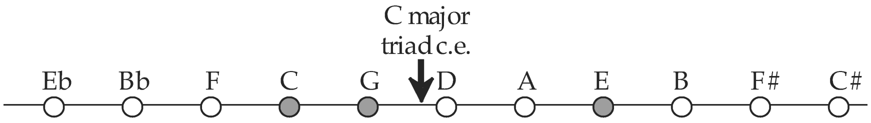


Figure 2

fifths and fourths are considered to be as close as, or closer than, those related by major thirds and minor sixths, modeled as mathematical constraints (Chew 2000, pp. 61–97). Hence, we chose not to modify this parameter.

The pitch-class representations in the spiral array model can be thought of as the line of fifths wrapped in an ascending helix on a cylinder of radius *r,* one pitch class per quarter turn, so that pitches related by an interval of a major third line up vertically one above another. The pitch-class helix is a three-dimensional configuration of Longuet-Higgins's (1962a, 1962b) Harmonic Network. The Harmonic Network is, in turn, related to the Tonnetz, which has been attributed to Euler, and which researchers have used for charting triadic movements in Western tonal music (Cohn 1997, 1998). Both the Harmonic Network and the Tonnetz have, embedded in their representations, lines of fifths in one dimension; in addition, they also include lines of thirds (major or minor) in another dimension to emphasize the other interval fundamental to the triad.

The concept of the center of effect was inspired by Longuet-Higgins's and Steedman's (1971) key finding algorithm, which is based on the fact that pitches in a key form compact clusters in the Harmonic Network. Like the interior-point approach to solving linear programming problems in operations research, the center-of-effect method uses the interior space, rather than the discrete points on the lattice, to identify the closest key by a nearest-neighbor search (Chew 2000, 2001). The closest triad is located in a similar fashion (Chew 2000).

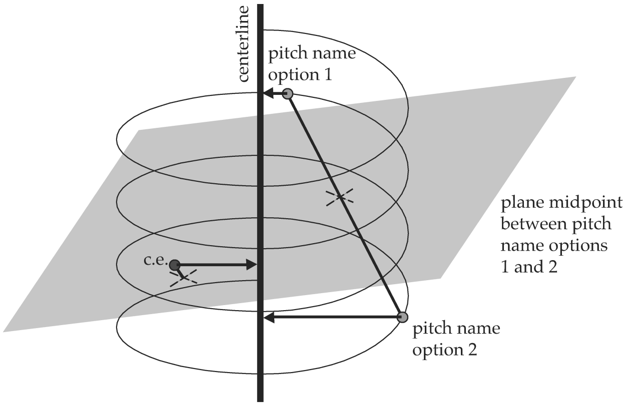
The advantage of the added major/minor third dimension in both 2D and 3D allows the center of effect of subsets of pitch classes in a triad to be located inside the convex hull of its constituents for easy recognition. Similarly, the 2D and 3D configurations of the Harmonic Network allow the center of effect of subsets of pitch classes in a key to be located within the convex hull of the constituent pitches of that key for robust identification.

Consider the same center-of-effect method applied to chord recognition on a line of fifths, shown in Figure 2. The pitches of the C-major triad are C, E, and G, shown as gray discs, with a possible center of effect near D. If only C and G are sounded, then the closest major-triad center of effect is likely to be F, instead of the more appropriate C. Thus, the line of fifths does not possess sufficient depth of representation for chord recognition using the center-of-effect method. In a higher-dimensional representation where the pitch-class representations of a triad form a compact set, any subset of the pitches would result in a center of effect inside the convex hull of the triad components, thus enabling chord identification by nearest neighbor searches. The same concept extends to key finding.

The Chew and Chen pitch-spelling algorithm came about when we realized that, to create a real-time system for analyzing music from live performance, we need a robust way to convert numeric pitch representations to pitch names for mapping to the spiral array, so as to perform tonal analysis on the pitch information using the spiral array key-finding and chord-tracking algorithms. The system for which the Chew and Chen pitch-spelling algorithm was originally designed, MuSA, evolved into MuSA.RT (Chew and François 2003, 2005), an interactive, real-time tonal analysis and visualization system, which has been demonstrated in live performance.

The Chew and Chen algorithm is motivated by the fact that pitch spellings, for the most part, follow the assignment of accidentals in a key: If one knows the key, one can

Figure 3. Hypothetical situation in which representations of pitch-name options do not fall on a vertical line. (c.e. = center of effect.)



then spell the pitches correctly. Conversely, if one knows the correct pitch spellings, one can then have better information with which to determine the key. Thus, pitch spelling is very much related to key finding. Because the key can be identified, in the spiral array, by a nearest neighbor search for the key representation closest to the present center of effect, we use the current center of effect as a proxy for key, and determine the best pitch spelling using a nearest neighbor search among the candidate pitch-class representations. This approach has two advantages: it is parallel to the music theoretic and a musician's conceptual process for pitch spelling, and the consistency of use of representation among the analysis (pitch spelling, chord recognition, key finding) and visualization modules in the MuSA.RT system.

Given the theoretical underpinnings of the Chew and Chen algorithm, the links between key finding and pitch spelling, and the proven advantage of using a higher-dimensional representation of the tonal system for music analysis, why would a line of fifths be sufficient for the pitch-spelling algorithm? Meredith's result can be understood as a particular outcome of the geometric structure of the options for spelling any pitch in the Western tonal system: The multiple options are aligned vertically in the pitch-class helix, parallel to its centerline. For example, the options for spelling MIDI note 61 are { . . . , B##, C#, D♭, . . . }. On the pitch-class helix, the pitches { B##, C# } and { C#, D♭ } are separated by three cycles of the spiral each, to line up vertically above each other. Thus, given a center of effect, the spelling of the note closest to that center of effect can be found by a nearest neighbor search after projecting the center of effect and all pitch classes onto the centerline; the projected pitch class representations would then form the line of fifths.

The same result would not hold if the pitch-name options do not fall on a vertical line. Consider the hypothetical situation shown in Figure 3, where two pitch-name options are not vertically aligned. These two pitch name options are shown as gray discs, and the present center of effect is given by the black disc. The plane represents all points equidistant from the two pitch-name options. When considering the center of effect in the three-dimensional space, it resides above the plane, and thus is closer to the pitch-class representation that is higher up on the pitch-class spiral (option 1). After projecting the center of effect and the representations of the two pitch names to the centerline, the pitch class that is lower on the helix (option 2) is the one closer to the center of effect.

When the pitch-name options are aligned vertically, the equidistant hyperplane is perpendicular to the centerline, and finding the closest pitch name in the three-dimensional space is equivalent to finding the closest pitch name on the line of fifths. It would seem that it is this property of pitch spelling in the Western tonal system, the vertical alignment of pitch-name options, that makes the line of fifths representation sufficient for pitch spelling in the Chew and Chen algorithm. Once the process of spelling is started with the same center of effect, and the pitch-class helix and line-of-fifths representations have been established to be equivalent for pitch spelling, the subsequent center-of-effect determination and spelling assignments should continue on the same track. Any discrepancies should be due only to the way the processes are initialized.

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References

Chew, E. 2000. "Towards a Mathematical Model of Tonality." PhD thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Chew, E. 2001. "Modeling Tonality: Applications to Music Cognition." *Proceedings of the 23rd Annual Meeting of the Cognitive Science Society.* Edinburgh, Scotland, UK, pp. 206–211.

Chew, E. 2005. "Regards on Two Regards by Messiaen: Post-tonal Music Segmentation Using Pitch Context Distances in the Spiral Array." *Journal of New Music Research* 34(4):341–354.

Chew, E. Forthcoming. "Thinking Out of the Grid and Inside the Spiral—Geometric Interpretations of and Comparisons with the Spiral Array Model." *Computing in Musicology* 15.

Chew, E., and Y.-C. Chen. 2003a. "Determining Context-Defining Windows: Pitch Spelling Using the Spiral Array." *Proceedings of the Fourth International Conference on Music Information Retrieval.* Baltimore, Maryland.

Chew, E., and Y.-C. Chen. 2003b. "Mapping MIDI to the Spiral Array: Disambiguating Pitch Spellings." *Proceedings of the Eighth INFORMS Computing Society Conference.* Kluwer Academic Publishers, OR/CS Interfaces Series 21, pp. 259–275.

Chew, E., and Y.-C. Chen. 2005. "Real-Time Pitch Spelling Using the Spiral Array." *Computer Music Journal* 29(2):61–76.

Chew, E. and François, A. R. J. 2003. "MuSA.RT: Music on the Spiral Array. Real-Time." *Proceedings of the ACM Multimedia '03 Conference.* Berkeley, California, pp. 448–449.

Chew, E. and François, A. R. J. 2005. "Interactive multi-scale visualizations of tonal evolution in MuSA.RT Opus 2." *ACM Computers in Entertainment* 3(4):1–16.

Cohn, R. 1997. "Neo-Riemannian Operations, Parsimonious Trichords, and their Tonnetz Representations." *Journal of Music Theory* 41(1):1–66.

Cohn, R. 1998. "Introduction to Neo-Riemannian Theory: A Survey and a Historical Perspective." *Journal of Music Theory* 42:167–180.

Longuet-Higgins, H. C. 1962a. "Letter to a Musical Friend." *Music Review* 23:244–248.

Longuet-Higgins, H. C. 1962b. "Second Letter to a Musical Friend." *Music Review* 23:271–280.

Longuet-Higgins, H. C. and Steedman, M. J. 1971. "On Interpreting Bach." *Machine Intelligence* 6:221–241.

Meredith, D. 2007. "Optimizing Chew and Chen's Pitch-Spelling Algorithm." *Computer Music Journal* 31(2):54–72.

Meredith, D. and Wiggins, G. A. (2005). "Comparing Pitch Spelling Algorithms." *Proceedings of the Sixth International Conference on Music Information Retrieval.* London, UK.

News

Mathematics and Computation in Music

The newly founded Society for Mathematics and Computation in Music presented its first international conference in conjunction with the National Institute for Music Research in Berlin, Germany, 18–20 May 2007. Sessions included "Metalanguages and Representation," "Computational Models in Music Psychology," "Computational Models of Musical Instruments," "Comparative Computational Analysis," and "Mathematical Approaches to Composition." The conference was also the occasion for the presentation of the first issue of the *Journal of Mathematics and Music.*

Web: www.mcm2007.info

Society for Music Perception and Cognition

The Society for Music Perception and Cognition held its annual conference at Concordia University in Quebec, Canada, 30 July–3 August 2007. Al Bregman (McGill University) delivered the keynote address on auditory scene analysis. Symposia were organized around music as a multimodal experience, motion capture approaches to studying music performance, probabilistic models and music cognition, music in multimedia, beats and metrical processing, and performance preparation. A satellite workshop, "Motion Capture Data Exchange and the Establishment of a Preliminary Database of Music Performance," was organized at the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT) at McGill University.

Web: alcor.concordia.ca/~smpc2007

Audio Mostly

Audio Mostly 2007, the Second Conference on Interaction with Sound, was hosted by the Fraunhofer Institute for Digital Media Technology in Ilmenau, Germany, 27–28 September 2007. The conference targets content creators, interaction designers, and behavioral researchers interested in furthering the interactive potential of applications such as games and music through the use of sound. The keynote speakers include Raymond MacDonald, professor of music psychology at Glasgow Caledonian University, and Juergen Herra of the Fraunhofer Institute, a key contributor in the development of MP3 perceptual coding.

Web: www.audiomostly.com

Bergen Interactive Music Conference

The first Bergen International Music Conference (BIMUC) was held in Bergen, Norway, 25–29 April 2007. The conference hosted teachers, performers, and researchers discussing and presenting work on music learning and on the creative and artistic development of young people. Presentations included "Evaluating Creative Work in Digital Musics" by Ian Stevenson and "MusicDelta – an Interactive, Internet-based Learning Resource for Music Education" by Yrjan Tangenes and Gesle Johnsen.

Web: www.bimuc.no

Victorian Music Machines

The 41st annual Association for Recorded Sound Collections Conference took place in Milwaukee, Wisconsin, 2–5 May 2007. Presentation topics ranged from the study of automatic musical instruments to an audio necrology of musical figures lost during the year 1957. There were several sessions on special collections and a pre-conference workshop on the preservation of audio in the digital domain.

Web: www.arsc-audio.org/conference2007.html

Signal Processing and Audio

The 2007 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics was scheduled to be held 21–24 October 2007 in New Paltz, New York. In addition to topics on spatial coding, Internet audio, musical signal analysis, synthesis tools, and the creation of musical sounds, the focal area for this year's workshop was acoustic scene analysis. Simon Haykin (McMaster University) was scheduled to deliver a keynote address on a cognitive cocktail party processor based on "cognitive dynamic systems." The other scheduled keynote speaker was Al Bregman (McGill University) with a talk on progress in the study of auditory scene analysis.

Web: www.kecl.ntt.co.jp/icl/signal/waspaa2007

Computational Models and Flamenco Music

The Fourth International Workshop on Computational Music Theory, "Computational Models for Music Similarity applied to Flamenco Music," was held 16–20 July 2007 in Barcelona, Spain. The conference was hosted by Escola Superior de Música de Catalunya in collaboration with the Music Technology Group of the Pompeu Fabra University. The intention of the conference was to facilitate collaborative problem-solving on musical similarity, with special attention to flamenco music.

Web: www.esmuc.net/sonologia/iwcmt07/index.html

electro-music in Philadelphia

The electro-music 2007 festival took place at the Cheltenham Art Center in Philadelphia, Pennsylvania, 1–3 June. The festival consisted of concerts, jam sessions, lectures, demos, and workshops. The scope of the event includes experimental music, circuit bending, computer music, *musique concrète,* improvisation, and algorithmic music. Seminar, demonstration, and workshop presenters included Rebecca Mercuri, Doctor T (Emile Tobenfeld), Howard Muscovitz, and Ge Wang. The conference is an extension of the activity of a community built around the electro-music Web site.

Web: electro-music.com

Figure 1. A jam session at electro-music 2007. (Photo: Hong Waltzer.)

Sound Travels

The ninth edition of the Sound Travels Festival of Sound Art was scheduled for 1 July–1 October 2007 at venues in and around Toronto Island, Canada. Sound Travels includes the Sign Waves series of sound sculptures and installations, outdoor and indoor concerts, site-specific performances, soundwalks, artist talks, and workshops. Featured artists included Kristi Allik and Tony Ka Tung Leung. Trevor Wishart and Barry Truax were composers-in-residence for the festival and served as mentors for the creation of new works by emerging local artists. Trevor Wishart premiered his work *Angel,* commissioned by the festival host, New Adventures in Sound Art. Barry Truax performed a set of solo and collaborative works with instrumentalist Randy Raine-Reusch combining Asian instruments and electroacoustics.

Web: www.naisa.ca/soundtravels

Música Viva

The Música Viva Festival 2007 expanded its venue this year to include Lisbon and Porto, Portugal, and was scheduled to be held 11–22 September. This year's festival was entitled "Perception and Aesthetics within Musical Creation; Transmutations of Sound and New Technologies." The conference included concerts and lectures, presentations for children, and the presentation of prizewinners of the annual Música Viva composition competition. The festival presented 80 musical works, including 13 world premieres, and 37 pieces from Portuguese composers. Among the featured events were performances by Electroacoustic Theatre, Electric Voice Theatre, Sond'Ar-te Electric Ensemble, and the Loudspeaker Orchestra.

Web: www.misomusic.com/ingl/circul/mviva/2007.html

Sound in Space at ZKM

The *next_generation* festival was held 21–24 June 2007 at the Zentrum für Kunst und Medientechnologie (ZKM, Center for Art and Media) in Karlsruhe, Germany. The theme of this year's festival was "Music in Space." Concerts and symposia on new aesthetic directions and technical developments were presented, along with new works by young composers that were analyzed and discussed. A focal point of the festival was the *Klandom* instrument with over 50 channels of sound and custom "room-control" software for spatialization.

Web: on1.zkm.de/zkm/stories/storyReader$5704

Synthèse in Bourges

The Institut International de Musique Electroacoustique de Bourges presented the 37th annual Synthèse festival 1–10 June 2007 in Bourges, France. Some concert sessions were devoted to themes such as video music, young composers, or a particular instrument, whereas others were devoted to music from specific countries including China, Poland, and Canada. The winners of the 34th International Competition of Electroacoustic Music and Sound Art were announced (see the accompanying news item), and the winning compositions were performed. Composers whose work was presented included Jon Appleton, Francis Dhomont, Louis Dufort, Denis Dufour, Beatriz Ferreyra, Max Mathews, Barry Truax, and Hans Tutschku. Francis Dhomont presented his work *Premières traces du Choucas.*

Web: www.imeb.net

Bourges Competition Winners

The winners of the 34th International Competition of Electroacoustic Music and Sound Art have been announced. In the Residence section for composers between 18 and 25 years of age, the prizewinners included Bryan Jacobs for *Within Scenes of Hurt,* Damian Ryan for *Configurational energy landscape #3,* Yukari Uto for *Nigero,* Oliver Carman for *Amorphous Materials,* Peng Guan for *Extremer,* and Gregory Cornelius for *Earth and Green.*

The Trivium/Quadrivium section for composers over 25 years of age is broken down in to different categories. The prize for abstract music went to Antonino Chiaramonte for *Riflessioni* and Krzysztof Wolek for *Mobile Variations.* The prize for program music went to John Young for *Ricordiamo Forli.* For electroacoustic music with instruments, the prize was given to João Pedro Oliveira for *Beyond.* Two prizes for works for dance and theater were given, one to Costa Simao for *Subterrâneos C Corpo,* and the other to Todor Todoroff for *The familiar ones of the labyrinth.* The prize for multimedia went to Bérangère Maximin for *Black ink.*

The Magisterium prize for composers with over 25 years of professional experience was given to Roger Doyle for his work, *The Ninth Set – Sector 4.* Honorable mentions for the categories can also be found on the Web site of Institut International de Musique Electroacoustique de Bourges.

Web: www.imeb.net

JTTP 2007 Competition Winners

The winners of the composition competition *Jeu de temps* (Time Play, or JTTP), organized by the Canadian Electroacoustic Community, have been announced. The competition encourages and promotes Canadian sound artists. The top five winners for 2007 are Dominic Thibault for *Nuit noire, Nuit grise* (2006), Georges Forget for *Orages D'acier* (2007), Thierry Gauthier for *Cycles* (2007), Olivier Girouard for *Le pont du souvenir* (2007), and Félix Lebrun-Paré for *La volonté du périscope* (2007). Winners will have their works performed in the ÉuCuE concert series and broadcast over several Internet radio stations. An online issue of eContact! dedicated to the competition contains more information about the music as well as downloadable sound files of each piece.

Web: eContact.ca

Prix Ars Electronica 2007

Prix Ars Electronica has announced the 2007 winners of its International Competition for CyberArts. Categories include computer animation, hybrid art, interactive art, digital communities, freestyle computing, and digital musics. The Golden Nica for digital musics this year went to Masahiro Miwa for the work *Reverse Simulation Music.* A discussion about the work on Mr. Miwa's Web site (aloalo.co.jp/nakazawa/method/method020_e.html) says that his experiments seek "to reverse the usual conception of computer simulations. Rather than modeling within a computer space the various phenomena of the world based on the laws of physics, phenomena that have been verified within a computer space are modeled in the real world."

Awards of distinction in digital musics were given to Israel Martínez for *Mi Vida,* and to Drumcorps for *Grist.* There were an additional twelve honorary mentions for the digital musics category, the details of which can be found on the Ars Electronica Web site.

Web: www.aec.at/en/prix/winners.asp

Giga-Hertz Composition Award

The winner of the Giga-Hertz award for electronic music for 2007 is Jonathan Harvey for his extensive oeuvre at the crossroads between electronic and instrumental music. The award is sponsored by ZKM, the EXPERIMENTALSTUDIO for acoustic art, the Association of the SWR (Southwest Broadcasting), and the city of Karlsruhe, Germany. The total prize money for the awards is €48,000, currently the largest such prize for electronic music composition. Four special prizes went to Mark Andre, Daniel Mayer, Flo Menezes, and Vassos Nicolaou, each of whom will receive support for the realization and production of artistic projects either at the ZKM Institute for Music and Acoustics or at the EXPERIMENTALSTUDIO for acoustic art.

Web: www.giga-hertz-preis.de/preistraeger07_e.html

Gaudeamus Music Week and Competition

The International Gaudeamus Music Week took place in Amsterdam 3–9 September 2007. The festival is designed to provide young composers with opportunity and exposure. As part of the festival, compositions nominated for the Gaudeamus Prize are premiered. The categories of music for the prize include chamber orchestra, chamber music, and electronic music. The nominees in electronic music at this year's event were Hugo Morales Murguia for *Top your buffer,* Stelios Manousakis for *Do Digital Monkeys Inhabit Virtual Trees?,* and Juan Andrés Verdaguer for *Embryen.*

Web: www.gaudeamus.nl