

emission rose and fell erratically. Intriguingly, the variability included a roughly periodic signal at 35 seconds.

Though short, the period could arise from the white dwarf's spin. In the AE Aquarii system, for example, the accreting white dwarf spins with a slightly shorter period of 33 seconds. Alternatively, some sort of surface wave or convection phenomenon could be at work.

Regardless of the origin of the period, it should be possible to infer how much accreted mass remained on the white dwarf after the outburst. The *Swift* team hopes do so soon.

The low ejecta mass already implies that the white dwarf in RS Ophiuchi

has held onto some of its accreted material after each outburst. Only a massive, near-Chandrasekhar-mass star could compress $10^{-7} M_{\odot}$ so much that it explodes.

Still, it's not obvious that RS Ophiuchi, when it eventually pops, will resemble type Ia supernovae. The quest to identify their progenitors continues.

Charles Day

References

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2. M. F. Bode et al., *Astrophys. J.* (in press). Also available at <http://arxiv.org/abs/astro-ph/0604618>.
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Good music unfolds in small steps

Geometry and topology allow music theorists to quantitatively analyze a technique that composers have intuitively practiced for centuries.

Even the most tin-eared of listeners would hardly confuse a Johann Sebastian Bach piano prelude with a Keith Jarrett jazz improvisation. But despite the 300 years of stylistic evolutions that separate the two masters, they and other great composers share an important musical trait: They move from chord to chord in what feels like a smooth-sounding, economical way.

That economy has manifestations on the printed musical page where, as figure 1 shows, notes of one chord are only slightly displaced to create the following chord. Likewise, Jarrett's fingers need not move much as he shifts from one chord to the next.

The printed page, however, obscures an important musical quality that is apparent when good music is heard. Music generally is perceived not merely as a series of chords sounded in succession, but also as a series of melodic

lines, "voices," unfolding in time and combining to form harmonies. So, for example, one listening to the passage in figure 1a would hear the simultaneous melodies of upper, middle, and lower voices. Part of what we admire in good music is the voice leadings—that is, how voices move from chord to chord.

Music pedagogues have been teaching how to write attractive voice leadings since before Bach. But some who study music have not been satisfied with traditional intuitive descriptions; their goal has been to quantify the notion of economical music writing. A striking example is the *tonnetz* (tone network), popularized in the late 19th century by Hugo Riemann. In the network, the major and minor triads common in canonical Western music are represented as triangles tiling a plane. The most efficient voice leadings connect triangles that are next to each other.

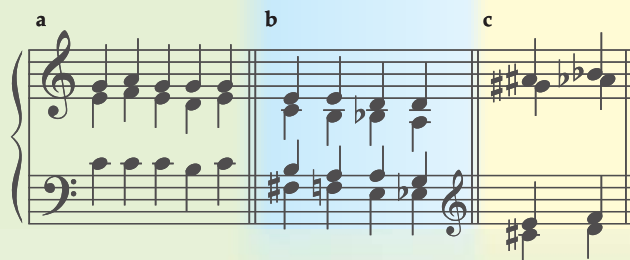


Figure 1. Economical composition uses minimal note changes to move from chord to chord. Examples shown include (a) a cadence in the 18th-century style, (b) a common jazz piano pattern, and (c) the first two chords of Claude Debussy's *Prelude to the Afternoon of a Faun*, which premiered in 1894. (Adapted from ref. 1, which includes a sound file online.)

By construction, the *tonnetz* includes only certain chords. The jazzy chords favored by Jarrett, for example, do not fit. Some modern music theorists have been searching for a scheme that would be geometrically appealing like the *tonnetz* but accommodate any chord. Dmitri Tymoczko, a composer at Princeton University, has reported just such a scheme.¹ A key element in his model is the orbifold, a mathematical construct that has also proved useful to string theorists.

When all are one

As a first step in quantifying voice leadings, Tymoczko assigns numerical coordinates to notes. The fundamental frequency, f , of a note in hertz is a good place to start, but human psychology suggests that simple frequency is not the best choice.

Theoretically, a continuum of notes is available to composers, but most make do with a discrete subset. And in conventional Western tuning, neighboring notes of that set have a frequency ratio of $2^{1/12}$. Thus, Tymoczko assigns to each frequency the number $a + 12 \log_2 f$, so that neighboring notes on a piano are separated by 1; the offset a allows for a convenient coordinate origin. The mathematically nice equal spacing reflects a reality of human perception: Neighboring notes are judged to be equally spaced, even though their absolute frequency differences greatly change through the audible range.

A second human perceptual factor motivates Tymoczko to make a topologically interesting move. Notes that differ by a factor of two in frequency sound much alike to our ears. Such notes are said to differ by an octave; in Tymoczko's enumeration they have an absolute difference of 12. The perceived similarity in two notes an octave apart is reflected by musical nomenclature, in which the two notes are given the same name. It is also reflected in the physical layout of a piano keyboard, on which 12-note octave "unit cells" are repeated.

Because of that psychological similarity, Tymoczko assigns the same coordinate to all notes that differ only in their octaves. Every note that a musician would call "C" is assigned the coordinate 0. Thus, all notes are assigned a nonnegative number less than 12. The space on which the continuum of notes lives is a circle: As you proceed upward

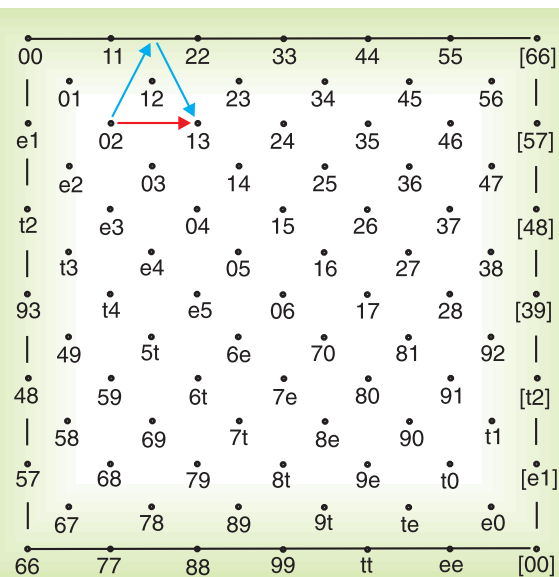


Figure 2. Two-note chords may be depicted as points on a Möbius strip. In this flat representation, the points (x, y) on the left edge are identified with the equivalent points (labeled in square brackets) on the right. The symbols "t" and "e" are shorthand for 10 and 11, respectively. The red and blue arrows illustrate two voice leadings as described in the text. Leadings such as the longer, reflecting blue one typically contain voice crossings in which an initially lower voice becomes a final higher one. (Adapted from ref. 1.)

in frequency from C, the coordinate value increases from 0, but after passing coordinate 11, you arrive again at C, right where you started.

Chords are built from notes. So an n -note chord can be represented as an n -tuple. If the ordering of the notes were important—if for example (1, 3) were to be regarded as different from (3, 1)— n -note chords could be described as living on n independent circles. But when the notes 1 and 3 are simultaneously played on a piano, the same sound is produced as when the notes 3 and 1 are played. Thus, Tymoczko regards the tuples (1, 3) and (3, 1)—indeed any two n -tuples differing by permutation of their elements—as describing the same chord. Such an equivalence, determined by a finite group of operations, is the characteristic feature of orbifolds.

Figure 2 shows in detail the space that includes all two-note chords. Given only the octave equivalence, the chords would live on a torus, the surface of a donut. But the points (x, y) and (y, x) , different on the torus, are the same in Tymoczko's orbifold. Conceptually, one can imagine starting with a donut and gluing the identified pairs together. The nonobvious result is a Möbius strip.

Voice leadings are defined by stating

how the individual notes in a chord are connected to the notes in the following chord. The two voice leadings that connect the chords (0, 2) and (1, 3) are shown in the figure. The horizontal line illustrates the case in which 0 leads into 1 and 2 leads into 3; in the figure, the leading is depicted as proceeding via a continuous path. For the other possibility, 0 leads into 3 and 2 into 1. (To fix the bounce off the upper edge of the Möbius strip, choose the shortest path by equating the angles of incidence and reflection.) The quantitative measure of a voice leading's efficiency is the length of its corresponding line segment. Thus, by visualizing two-note chords as points on the Möbius strip, Tymoczko can quantify the efficiency of any leading. Moreover, his approach can be readily generalized to music that employs unconventional tunings or that divides the octave into other than 12 notes.

For chords with three or more notes, the orbifolds are more complicated, but they require no new conceptual machinery. Those more complicated orbifolds, however,

provide additional insights into the structure of canonical Western music. As with the *tonnetz*, commonly employed chord progressions move through orbifold points that are close together; they can be connected with efficient leadings. Conversely, given the Western traditions of tonality and efficient voice leadings, composers can choose only a limited number of paths through the orbifold. Tymoczko's model thus gives a geometric picture of the constraints composers face.

But will it help the working composer? "Every composer ends up with a physical understanding of musical space in one way or another," says Tymoczko. "What the theory can help you do is systematize that knowledge, to put together practical knowledge in a slightly more organized way."

A musical smorgasbord

In the early 20th century, Arnold Schönberg and his students began writing music that eschewed the tonal principles composers had applied for hundreds of years. The "atonal" music of Schönberg's school employs a richer harmonic palette than does the classical Western canon. And throughout the 20th century and into the 21st, any

number of compositional techniques have been tried.

Is the idea of efficient voice leadings, then, a hopelessly dated concept? Not necessarily, says music theorist Richard Cohn, though it's difficult to generalize about modern music. Schönberg himself wrote a pedagogical treatise in

which he describes how to lead voices. And given the chords he chose to use, Schönberg often took pains to connect them economically.

Steven K. Blau

Reference

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Tectonic-plate flexure may explain newly found volcanoes

The form and chemical composition of their lavas add to our growing understanding of where on Earth volcanoes can form.

The reduction of pressure in the mantle is a central reason behind Earth's volcanism. Mantle rock that rises adiabatically to a low enough pressure melts without any added heat source. The ascent may be actively driven by convection, as in mantle plumes, where hot, buoyant jets from the deep interior are thought to provide a rich source of material to fuel the volcanism. Or it may be passive, as at mid-ocean ridges, where magma forms from the upwelling of rock into the gaps left by the spreading of tectonic plates. Deglaciation can also trigger volcanic pulses, as it did in Iceland at the end of the last ice age when the elastic plate rebounded from the melting of the ice cap. Meteorite impacts that excavate large craters at Earth's surface are yet

another cause of pressure release.

A group of researchers from Japan and the US has now discovered a class of volcanoes that apparently formed from pressure release of a different kind—one based on the flexure produced in one lithospheric plate as it is forced beneath another. Naoto Hirano of the Tokyo Institute of Technology and colleagues found clues to the volcanoes a few years ago during deep-sea exploration off the coast of Japan. They analyzed what turned out to be young basalt—erupted lava—hundreds of kilometers from where the Pacific plate dips below Japan.

“Complete serendipity” is how coworker and geochemist Stephanie Ingle of the University of Hawaii describes their find. The researchers were

