Recombinant Music

Using the Computer to Explore Musical Style

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A computer program that creates new but stylistically recognizable music from existing works offers insights into the elusive phenomenon of musical style.

For centuries, composers have experimented with recombining existing music to create new but stylistically satisfying works. For instance, Haydn and Mozart wrote *Musikalisches Würfelspiel*, or musical dice games, pieces that could be reassembled in many different ways and remain musically viable. Thus, even a very simple piece would become the source of numerous new works, each of which, while varying in aesthetic quality, conformed generally to the style of the source.

Mozart's Köchel 516f is a particularly good example. It consists of two 8 by 11 matrices containing the numbers 1 through 176 ($2 \times 8 \times 11$). The number 8 represents the measures of eight-bar phrases (traditional classical-period forms), and the number 11 represents all possible outcomes of the throws of two dice. These numbers are then keyed to 176 measures of music. According to $N = D^R$, where R = rank and D = vertical dimension, this allows for 45,949,729,863,572,161 possible correct combinations.

The composers devising these games knew the style of their period intimately and applied that knowledge and their own ingenuity to these experiments. The word *style* in this context refers to musical properties characteristic of a particular historical-artistic period (in this case, classical), a geographical location (Vienna), an instrument (keyboard), and the composer's personal musical habits (recognizable musical motives, for instance).

This article delineates some of the elements of musical style I discovered in a research project called Experiments in Musical Intelligence (EMI). One subprogram of EMI is an expert system that employs pattern recognition processes to create recombinant music — music written in the styles of various composers by means of a contextual recombination of elements in the music of those composers.

This EMI subprogram performs much the same task as the musical dice games on music that was not written to be disassembled, reorganized, and reassembled. It separates and analyzes musical pitches and durations and then mixes and recombines the patterns of those pitches and durations so that, while each new

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composition is different, it substantially conforms to the style of the original. The new works generally inherit aspects of the style of the period and, to a lesser degree, the style of the composer of the recombined works. Called *recombinant music*, this is not just a parlor game but a serious attempt to understand how listeners recognize the style of a composer or period, one of the more elusive and difficult to describe musical phenomena.

The problems

The fundamental problems in building a program to produce effective recombinant music are

(1) into what size should the elements of the original music be disassembled,
(2) what method should be used to rearrange these elements, and
(3) how these elements should be reassembled to make musical sense.

After all, random recombination produces chaotic results, as shown in Figures 1 and 2. Figure 1 presents two examples of music from Mozart's sonatas. Figure 2 is a random recombination of the beats of Figure 1, showing the source of each reorganized beat by work (A or B), measure number, and beat number within that measure.

The new composition is musical gibberish, as can be seen (and heard, if played) in Figure 2. Neither the common practice of Mozart's period nor his own style has survived the recombination. One reason for this is that Mozart did not compose these phrases as a musical dice game. Furthermore, the disassembly and recombination were done unintelligently and unmusically. Important questions about the size of the musical elements (one beat in Figure 2) and whether harmony and melody should be taken together or separately were ignored, as was the repetition of the first two measures of each example of Figure 1 (in both cases with variation). Nor was attention paid to the manner in which the reorganized

Figure 1. From (a) Mozart's Sonata K. 283, second movement (1774); (b) Mozart's Sonata K. 330, third movement (1778).

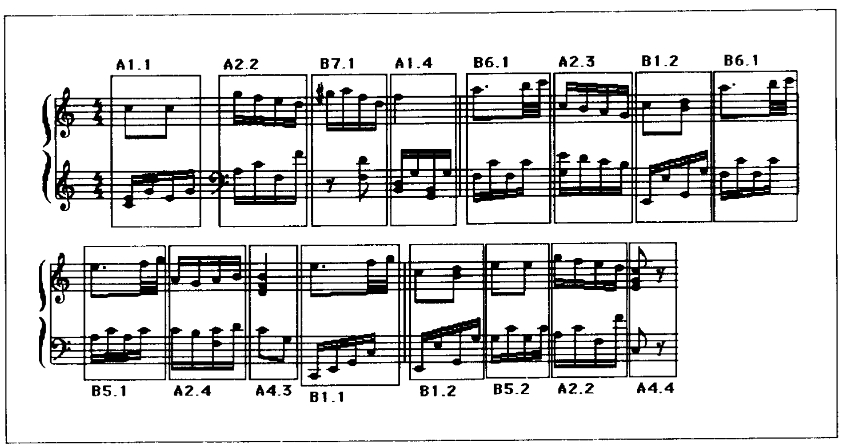

Figure 2. Random recombinant music and its analysis. "A" here refers to Figure 1a, "B" to Figure 1b; the numbers represent the location, first by the measure number and then by the beat number.

Audio examples

Readers may order an accompanying compact disk or cassette tape to hear the selections discussed in this article. See the order form on page 9.

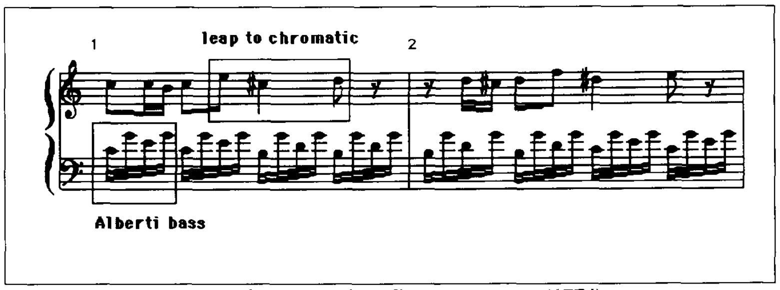

Figure 3. From Mozart's Sonata K. 279, first movement (1774).

Figure 4. Two versions of a Mozart signature from (a) K. 330 and (b) K. 547a.

material was reconnected. For example, the harmonic progressions of Figures 1a and 1b have been mutilated and no longer fit Mozart's or his period's stylistic constraints.

Obviously, great care must be taken in disassembling the original works, analyzing the various constituent parts, and reassembling the parts in a new, but musically valid, order. The EMI subprogram accomplishes this in three steps:

(1) pattern matching for characteristics of the composer's style,

(2) analyzing each component for its deep hierarchical musical function, and

(3) reassembling the parts sensitively with a technique drawn from natural-language processing.

Pattern matching

When listening to a piece of music for the first time, one usually can detect previously heard patterns even though the music is generally new to the ears. The example in Figure 3 shows how the presence of certain patterns can aid in style recognition. It demonstrates Mozart's typical use of the Alberti bass, the repeated four-note structure in the left hand. The right hand demonstrates a more subtle trait: the leap to the lower chromatic nonharmonic tones C-sharp and D-sharp from the second to third beats of the first and second measures respectively.

The musical logic of these two patterns (called *signatures* in EMI), along with the harmonic progression and the melodic sequence (the second measure being a repetition of the first, up one step with one subtle variation), combine to create an elegant bit of recognizable Mozartian craftsmanship. The constraints of the composer's period and the signatures of his personal style are both evident and abundant.

If a recombinant compositional process is to be successful, it must ensure that the signatures survive the reconstructive process in a recognizable form and in an appropriate context. Therefore, the program controlling the disassembly of the original composition must determine the appropriate size of the signatures as well as recognizing the signatures themselves. The recombination must also be contextually sensitive. Signatures must be locationally dependent and immutable to the extent that all intervallic relationships remain intact. They must, however, be transposable so that they reconnect in a variety of logical and musical ways.

The first problem inherent in recombinant music, defining a logical sampling size, is a complex process. In Mozart's and Haydn's musical dice games, each sample was usually a measure or two that began and ended in ways that allowed successful connection with other measures in the work. But how long should the samples be in the more complex recombinant process undertaken by the EMI subprogram described here? One way of determining this involves pattern matching.

Musical pattern matching entails the discovery of musical patterns, particularly those that occur in more than one work of a composer and are hence recognizable as important elements of the composer's style. This requires a program that not only recognizes that two patterns are exactly the same, a fairly trivial feat, but also that two patterns are *almost* the same.

The EMI subprogram accomplishes musical pattern matching by means of controllers that define how closely a pattern must resemble another for it to register as a match. If we resolve these controllers too narrowly, the patterns that are one aspect of a composer's style will not pass. If we resolve the controllers too broadly, elements that are not patterns identifying a composer's style will be allowed to pass. If we set these controllers correctly, only signatures will pass.

Figure 3 shows a simple example of pattern matching to find signatures. Imagine that these two measures of music have been found in two different works rather than in the same work and that a pattern-matching program is attempting to determine whether they constitute a signature. It is improbable that a nonmusical pattern matcher would find these two measures very similar except in rhythm. They share less than 50 percent of common pitches (that is, [C C B C E C-sharp D] [D C-sharp D F D-sharp E]), with none of these falling in the same location with respect to associated beats within the measures. One measure has fewer notes than the other. But to our ears, they are easily identifiable as simple variations of the same pattern.

What we need is a musical pattern matcher that can reduce the patterns to similar organizations. The EMI subprogram does this by reducing pitches to intervals. In the first case, the distances between notes in the patterns are calculated in half steps, giving [0 –1 1 4 –3 1] for the first measure and [0 –1 1 3 –2 1] for the second measure with rests represented by zero. Notice that the intervals immediately show the similarity of the two patterns in both direction and amount of motion.

A single controller that determines interval accuracy proves the patterns to be musically alike enough to be a signature. By allowing, for example, any interval to be off by just one half step in either direction, the controller enables the program to recognize the musical similarity of the patterns. Such a variation, by the way, is very common in tonal music, where composers, in order to remain within a diatonic framework when sequencing, often substitute whole steps for half steps and vice versa. Thus, an allowance for these variations helps the pattern matcher find musical similarities.

My research has shown that these signatures are typically two or more beats in length and occur near the ends or cadences of musical phrases. They are thus locationally dependent and size specific. Apparently, most tonal composers tended to write more freely at the beginnings of phrases and to end with style-identifying signatures. Figure 4 shows two versions of a Mozart cadential signature with choice of key, number of notes, and type of accompaniment as variations. The intervallic movement of the melodies of both examples is exactly the same, with variations in the rhythm. The harmony is likewise the same functionally, although there are discrepancies in the voicing and doubling.

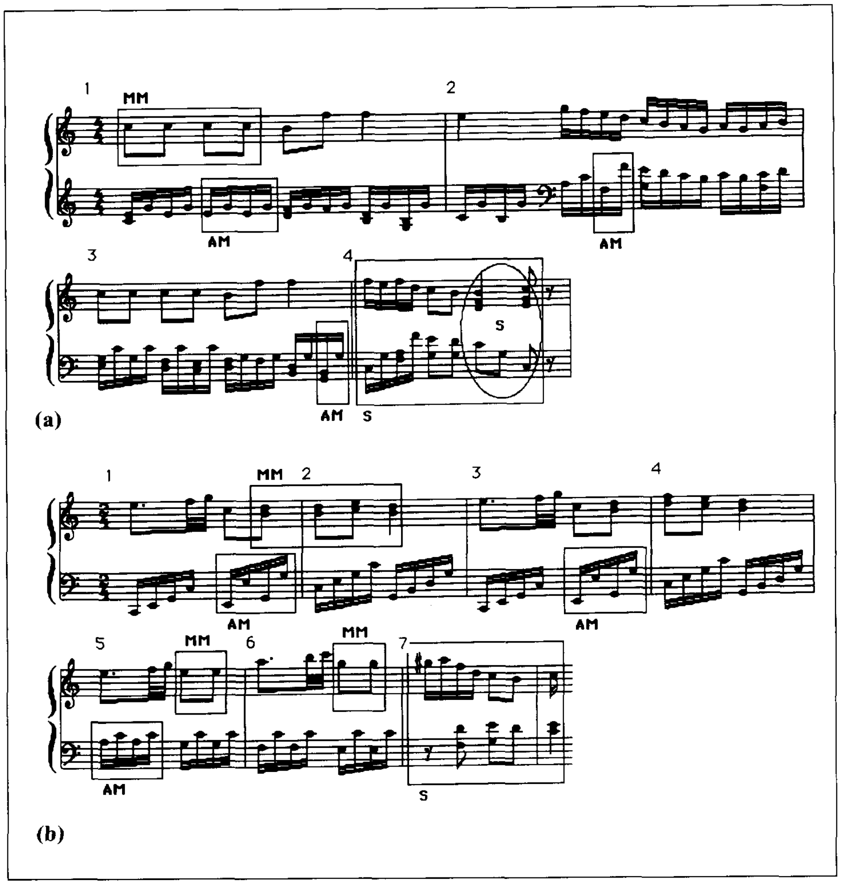

Figure 5. Some characteristics of the Mozart excerpts shown in Figure 1.

Figure 5 shows two complete phrases from the same Mozart sonatas given in Figure 1, with signatures shown in boxes. The harmonic signatures are labeled "S," with "AM" standing for accompaniment motives and "MM" for melodic motives. The latter two matching elements comprise a pattern-matching subprogram that gives the analysis portion of the program information about the dominating melodic and accompaniment models. Observe that the cadential signature in Figure 5b is the one shown in Figure 4a and that the melodic part of the signature in Figure 5a resembles the melodies shown in Figure 4.

The two musical examples shown in Figure 5 (that is, the music of Figure 1) have very much in common. This is critical to the pattern-matching process just described. The compositions chosen for EMI must be reasonably similar, including key and meter. The last category is particularly important. For example, imagine a single work written first in quarter notes with the metronome set at the quarter note equal to 60 (one quarter note per second) and then rewritten in eighth notes with the metronome set at the quarter note equal to 30 (one eighth note per second). Performances of both pieces would sound the same. Yet, they would look and analyze very differently, particularly if the program being used assumed certain beat constraints were in effect. Thus, entered music must be coerced to look the same, in both musical and numerical notations.

Once EMI discovers signatures, it freezes them to their location and then protects them during recomposition. Without this protection, signatures would get lost in a Pandora's box of confused musical ideas. Once signatures are frozen, the remainder of the music is fragmented fairly freely in size, since at this stage the idea is to create a new instance of the composer's style, with the original works being unrecognizable.

Hierarchical analysis

Successful recombinant music must retain the musical logic inherent in the original works upon which it is based. Therefore, the program at this point analyzes all the musical groupings, including signatures, for hierarchical function. In the initial stages, this analysis is a traditional analysis of harmonic function, using functional categories theorists call "tonic" or **I** (C triad in C major), "dominant" or **V** (G triad in C major), and so on. The analysis is made prior to the mixing of groupings, because the protocol, or ordering of functions, is critical to the reorganizing of groupings. When mixing does take place, it follows the form of a fixed sequence of functions with free substitution of the actual music the functions represent. Thus, the tonic function remains in the same location in the new work, but it can exchange music with other analyzed music of that same function (that is, other tonics). Again, signatures do not move nor can they be replaced.

The hierarchical analysis can be quite deep. That is, fragments can be keyed by strata of information, such as "cadence-tonic" or "tonic-6-incipient," which indicate the original location and nuance of function. With a large number of works for analysis, the program can choose from hundreds of different categories, each with numerous musical subphrases, so that successive parts of the new work can be musically tied together and not just randomly chosen.

The program also must analyze the original works for proper connectiveness before the elements of the music are fragmented and mixed. This analysis falls into three main categories:

- melody
- accompaniment
- harmony

Rising melodies, for example, can be followed by falling ones for balance. Accompaniments, which otherwise would be a pastiche of various motives, can be made rhythmically consistent so that they flow regularly with the melodic line. Harmonies can be successfully juxtaposed according to the traditions of the tonal common practice. Harmonic analysis includes measuring the strength of chord functions so that stronger cadences can be saved for the last chord of new works. This measurement also produces contextual connectivity so that each fragment is spliced into a logical location.

We can see how EMI's hierarchical analysis works by analyzing the various beats in Figures 5a and 5b and performing some basic steps to enhance the relationships. Both of these sonatas begin on a tonic chord that can be interchanged successfully with the application of musical transposition to the left hand (that is, moving Figure 5b, measure 1, up one octave). Figure 5a, measure 1, beats 3 and 4 are dominant in function and either could be substituted for the dominant of Figure 5b, measure 2, beat 2, with no ill effects and no transposition necessary. Likewise, the first two beats of Figure 5a, measure 1, could be interchanged with the first two beats of measure 1 of Figure 5b with no damage. On the other hand, taking the second bar of Figure 5b and interchanging it with the first two beats of Figure 5a would cause serious problems. Not only do the functions not match, but beginning the work on an unprepared dissonance would be stylistically uncharacteristic.

Also notice in Figures 5a and 5b that the program separates harmony (accompaniment) from melody with nonsignatures. The separation occurs after the hierarchical function analysis, however, so that melodic groupings retain their harmonic implications. This is very important for the reassembling process.

Since music often contains structural repeats at various levels, analysis of the substructural repeats in the original music must occur at this point in the process. For this analysis, the EMI program uses a pattern matcher similar to the one described earlier but with a different function. This pattern matcher informs the reassembly part of the program as to where internal (to the phrase) repeats take place so that similar repeats can take place in the final output.

Once all elements of the music have been analyzed, harmonic functions of the same type are stored together in lexicons and randomly mixed (the shaking of the dice). Access to each lexicon is then controlled by the functional succession of one of the original works, as described in the next section.

Reassembling according to the ATN

The refitting of juxtaposed elements of a work back into logical and musical orders can be enhanced by using augmented transition networks (ATNs), a technique developed by researchers in natural-language processing. ATNs are programs designed to produce logical sentences from sentence bits and pieces that have been stored according to sentence function. These parts are reused to produce correct sentences in various forms with basically the same meaning. For example, "The prognosis for Jill is good" and "Jill has an excellent possibility of recovery" say the same thing in different ways. ATNs are typically used in computer applications in which variation in the form, but not the substance, of the output (for example, medical prognosis) facilitates communication. ATNs can be applied to the recombinant music problem in much the same way as to language: analyze and store musical elements and then reuse them in compositions that vary but have essentially the same musical meaning (variations within a set style).

In EMI, the ATN initially takes the form of an organizer. It first takes the set of functions from the analysis of one of the works being used. For example, one possible analysis of the first three beats of Figure 1a is "tonic-Alberti-repeat, tonic-6-Alberti-repeat, dominant-Alberti-up," and so on. The ATN then uses this analysis as a template for creating a new work by gathering applicable groupings of music from collections stored previously by the analysis portion of the program. For example, exactly the same "tonic-Alberti-repeat" given above could be logically chosen. The chance of that happening obviously depends on the amount of analyzed music available — the larger the amount, the greater the chance for variety. This process is very similar to the ATN language model upon which the EMI subprogram is based.

When the organizing is complete, EMI's ATN then becomes a smoother of transitions. Musical lines that previously had been stepwise must again be made so. The ATN does this by diatonic transposition. In layman's terms, the ATN fixes the positions of the notes according to the key of the work in as close a proximity to those that precede and follow them as was found by the analysis of the original works. For Mozart this proximity is seconds and thirds. Accompaniment figures usually adapt by octave transposition to fit the local range of the music, since the type of figure is determined by the setting of the function types (for example, the use of Alberti in the naming and storing of hierarchical function). In addition, melodies and harmonies previously located elsewhere may require refitting so that they don't overlap in range or uncharacteristically fall out of proximity.

Examples of output

Combining the concepts of pattern matching, hierarchical analysis, and ATN gives us a process that can create new examples of a given style. Figure 6 shows a machine replication with one possible analysis of this replication (the program itself is sufficiently complicated to make the determination of the origins of these segments in the original music difficult at best). Note that the music here is logical and even musical to a degree. The opening motive seems balanced by direction, with the two two-beat groupings in the melody of the first measure acting in typical classical-period antecedent-consequent motions. The cadential signature is a real signal of Mozart's style. In typical fashion, it is just over two beats in length. Transposition is fairly routine, while variation is used only sparingly. The repetition of bar 1 in bar 3 contributes to stylistic recognition. This EMI subprogram achieves such repetition by means of the previously discussed analysis of the original music, which indicates how much repetition should occur in the output.

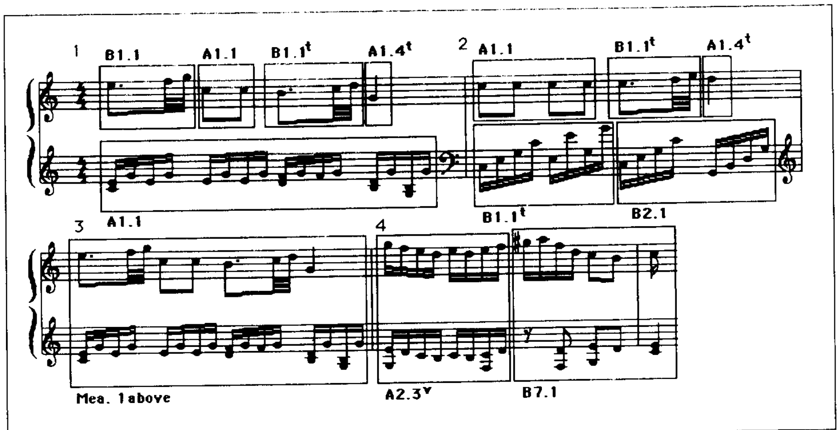

Figure 6. EMI's recombination of segments in Figure 5, with signature (B7.1) and suggested sources (t = transposition; v = variation).

The signature presented in Figure 3, that of the lower chromatic neighboring tone, appears transposed in the recombinant example shown in Figure 7, measures 2 and 4, an EMI-composed theme. This example is sparse (two voices) and simple (mostly scales). Yet, it has many Mozartian traits. For example, the harmonic rhythm moves by measure. The harmonic functions follow a straightforward **I-V-V-I-I-ii-V-I** order typical of Mozart's style.

Figure 7. The beginning of an EMI-Mozart sonata movement.

The music shown in Figure 7, the result of EMI pattern matching, hierarchical analysis, and ATN recombination of all the Mozart sonata third movements, demonstrates the composer's subtle implied harmonies and voicing. By the time all the computational processes have taken place, it is virtually impossible, save for the obvious signatures, to absolutely identify the origin of each element. I prescribed the form (that is, the amount and location of phrase repetition and contrast), and the key choice was random. However, the important ideas, signatures, and the harmonic protocol were formed completely by the recombinant processes described here.

Musical style is a very complicated phenomenon. Recognizing a particular style is linked, at least in part, to the presence of fundamental musical signatures in a composer's work. Reusing such signatures, while sensitively reorganizing other elements of the music, allows for the creation of new music with recognizably the same style as the original. Similar experiments with the music of Bach, Joplin, Chopin, Gershwin, and many others seem to verify the results reported here (see Cope, 1991, in the "Further reading" section).

Works produced by this EMI subprogram still suffer from problems of stylistic anomalies. Future research will aim at eliminating such anomalies by enhancing the hierarchical analysis program. In addition, dynamics and phrasing will become a part of the matching processes, refining the program substantially. If EMI has been moderately successful at creating new music in established styles, it is due in no small part to the music incorporated for recombination. In short, EMI has had great teachers: the classical masters themselves. ■

Further reading

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