Music composed by a computer program

Lindblom, B. and Sundberg, J.

journal: STL-QPSR
volume: 13
number: 4
year: 1972
pages: 020-028

http://www.speech.kth.se/qpsr
III. MUSICAL ACOUSTICS AND MUSIC THEORY

A. MUSIC COMPOSED BY A COMPUTER PROGRAM
B. Lindblom and J. Sundberg

Abstract

Musical structures can be analyzed according to principles very similar to those of the generative theory of language. This is demonstrated by the properties of an improved version of a generative rule system elaborated for the description of the musical style of Alice Tegnér's nursery tunes. Thus, it is shown that a melody written by Tegnér can be described and generated with good accuracy by this rule system. A couple of other melodies generated by the rule system are presented. Some general features of the proposed rule system are discussed. It is argued that adopting a generative approach in musicology represents a productive development of research.

1. Statement of the problem

In the natural sciences, scientific work can be conceptualized approximately, as in Fig. III-A-1. An aspect of reality is picked out and is examined using some method. The task of the scientist is to find out why the data collected look as they do; hypotheses are formulated, and mathematical theories are elaborated. Using these theories as tools, predictions are made, which are then compared with the observed data. There would be little controversy over the claim that this is the way in which most physicists work. But is this also true in "humanistic" disciplines such as linguistics and musicology? In linguistics the use of mathematical models has been accepted largely as a result of the work of the American linguist Chomsky(1). In this paper we shall demonstrate that the same approach can usefully be adopted even in such a clearly humanistic and esthetically oriented discipline as musicology. When adapted for the study of musical structures, data and predictions refer to written music.

If Alice Tegnér's nursery tunes are chosen for study, the raw material appears as in Fig. III-A-2. From this sort of material we have extracted different types of data. Musicologists have traditionally named

*This paper was presented at the "S 71 Introductory Symposium", KTH, Stockholm, September 1971.
MODEL OF SCIENTIFIC INQUIRY

Fig. III-A-1.
Fig. III-A-2.
them meter (durations), harmony (sequences of chords), melody (sequences of pitches). These types of data are displayed in Fig. III-A-3. Here the notated music contains information on meter, harmony, and melody only, and in a codified form. It is these kinds of data, collected from Alice Tegnér's nursery tunes, which will concern us here. The problem can be formulated in the following way: Formulate that system of rules that gives a generative or enumerative definition of all melodies that Tegnér composed or could have composed!

Fig. III-A-3.

2. Data

In order to find the rules characterizing Tegnér's nursery tunes, we have collected a large body of data about meter, harmony, and melody. An overview of the results is provided in Fig. III-A-4, which shows the occurrence of various phenomena in different positions in 8-bar melodies written in 4/4 time. With respect to meter we can observe, for example, that in even-numbered bars long durations occur and short ones are avoided. The chords are divided into three types according to their harmonic function: introductory chords, target chords, and anticipatory chords. Introductory chords are found in bars I and V, and target chords may occur at the end of every bar. Anticipatory chords are forbidden at the end of bars IV and VIII. With melody we distinguish between chord-notes and non-chord-notes. The suspension is a special case of a non-chord-note. Suspensions seem to be avoided in approximately the same places.
Fig. III-A-4. This figure demonstrates schematically how certain metric, harmonic, and tonal features are distributed in a corpus of Alice Tegnér melodies. Shaded rectangles indicate the position in which the feature listed to the left has been observed to occur. Position is shown with reference to the bars of the period (dotted vertical lines).
where short durations are avoided. By and large, non-chord-notes occur in the same positions as suspensions, but have a greater number of forbidden positions. These positions show a symmetrical and regular pattern. With each of these three kinds of data we see traces of a segmentation of the tune. Thus bar VIII, particularly, but also bar IV, and bars II and VI, are treated in a quite special way. Periodicity occurs in all the diagrams. It is noteworthy that these regularities are associated with conceptions employed by musicologists for a long time: bar, subphrase, phrase, period.

3. Model

Fig. III-A-5 shows an attempt to integrate the observations made into a generative model. At the deepest level we find a syntactic structure. Through a prominence contour this structure determines the choice of durations, chords, and pitches. We now describe in more detail the most important properties of the generative model.

A syntactic structure of the type shown in Fig. III-A-6 can be ascribed to a typical melody. The entire melody is a period, consisting of two phrases. Each of them consists of two subphrases made up of bars, feet, and beats. The problem is to relate this constituent structure to durations, and to the harmonic and tonal data. In order to do this we transform the syntactic information to a string of prominence values. This procedure is illustrated, step by step, in Fig. III-A-7. The top line shows the set of beats, each embedded in pairs of parentheses in such a way that the syntactic structure is reflected in the distribution of parentheses. From this starting point we take the following steps:

1. Assign to each beat the highest order of prominence: 1.
2. Delete the innermost pairs of parentheses.
3. When two items of prominence rank 1 occur within the same parentheses a choice of priority is made: The rightmost (or leftmost) prominence remains the same, and all remaining prominence numbers fall by one step in prominence rank.

Steps 2. and 3. are repeated cyclically until all pairs of parentheses have been eliminated. The final result is given in the lowermost line in the figure: it gives the prominences of the beats along a scale where numbers refer to rank of prominence. The prominence contour provides a method of relating the syntactic structure to the metric, harmonic, and
SYNTAX

CONSTITUENT STRUCTURE

PROMINENCE RULES

PROMINENCE CONTOUR

TIMING RULES

DURATIONS

CHORD RULES

CHORDS

TONAL RULES

HARMONIZED MELODY

Fig. III-A-5.
SYNTACTIC STRUCTURE OF EIGHT-BAR PERIOD (4/4 TIME)

PERIOD

PHRASE:

OPENING PHRASE

CLOSING PHRASE

SUBPHRASE:

BAR:

FOOT:

BEAT:

Fig. III-A-6
CYCLIC DERIVATION OF PROMINENCE VALUES FOR BEATS IN AN 8 BAR PERIOD

INPUT: 

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

BEAT: 


FOOT: 


SUBPHRASE: 


PHRASE: 


PERIOD: 


Fig. III-A-7
tonal properties of the melody. It gives the raw material for the derivation of the meter and harmony and for the assignment of tones in a melody.

Now to explain in more detail the nature of the various components of the rule system (cf. Fig. III-A-5). Let us do this by starting with the following question: Have we found that system of rules which automatically and completely enumerates Tegnér's nursery tunes? If we have, the rule system would be able to generate a well-known melody such as "Dansa, min docka". How do we choose among the various alternatives, made available by the rule system at every step of the generation, in such a way as to produce a melody that approximates as closely as possible this Tegnér melody?

3.1 Meter. The first step is to generate the meter. An overview of the metric rules is given in the right column in Fig. III-A-8. These rules are applied in the order shown in the figure. In the left part of the figure the derivation can be followed step by step. The uppermost line shows the input to the rules: the string of prominence values just derived.

First, the sequence-pattern is determined. This shows which bars are to be metrically similar and which dissimilar. Two types of metrical pattern may occur, A and B, and the metrical pattern of the first four bars is obligatorily repeated in the last four bars. The next step offers three alternative choices: Delete prominence rank 5 (a) when it follows prominence rank 1, (b) when it follows prominence ranks 1 and 2, (c) when it follows prominence ranks 1, 2, and 3. We call this deletion procedure catalexis, borrowing a term from the theory of verse. In the next step we may insert additional prominences of rank 6 after prominence ranks 4 and 5 in the first bars marked A and B. Though not done in this case, it is possible at this point to dot notes immediately followed by minima in prominence ranks. After this, the insertions and dottings are transferred to the other bars in accordance with the sequence-pattern. The final step is to transform the modified prominence contour into durations. Every prominence except those of rank 6, and those which have been dotted, is assigned a duration of one beat.

3.2 Harmony. Fig. III-A-9 presents an overview of the rule system used for the chordal interpretation of prominence ranks. Here, too, the rules are applied in the order shown in the figure. Their function is to
DERIVATION OF METER FOR 8 BAR PERIOD

THE RULES

1. SCHEME OF SEQUENCING
2. CATALEXIS
3. INSERTION
4. DOTTING
5. COPYING
6. DURATIONS

Fig. III-A-8
Fig. III-A-12. This figure shows, in somewhat compressed form, eight stages in the derivation of the final tonal sequence. Stage 1: The pattern of sequence is assigned to the input. Stage 2: Chord-notes are assigned to notes with prominence ranks less than 4. Stage 3: Suspension may be applied. Not used here though. Stage 4: Harmonic implication (HA), tonal adjacency (TA), sequencing (S) to all subphrase-initial 4’s. Stage 5: HA, TA, and S applied to all remaining 4’s. Stage 6: Chord-notes (H) or Non-chord notes (N) can be selected for prominence ranks equal to 5. (Only H’s selected.) Stage 7: HA, TA, and S applied to the notes interpreted as H at the preceding stage. Stage 8: Passing rule and auxiliary rule applied to the remaining notes which now all have prominence ranks > 5. In cases where two notes are shown the ones with upward lines were derived by rule, the others chosen by Tegnér.
**HARMONIC RULES**

<table>
<thead>
<tr>
<th>HARMONIC TEMPO</th>
<th>1: DELETION OF 4’S</th>
</tr>
</thead>
<tbody>
<tr>
<td>2: DELETION OF 5’S</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>CADENCE STRUCTURE</td>
<td>3: INTRODUCTORY CHORDS</td>
</tr>
<tr>
<td></td>
<td>(OBLIGATORY RULE)</td>
</tr>
<tr>
<td></td>
<td>4: TARGET CHORDS</td>
</tr>
<tr>
<td></td>
<td>(OBLIGATORY RULE)</td>
</tr>
<tr>
<td></td>
<td>5: INTRODUCTORY CHORDS</td>
</tr>
<tr>
<td></td>
<td>(OPTIONAL RULE)</td>
</tr>
<tr>
<td></td>
<td>6: EXTENDED INTRODUCTION</td>
</tr>
<tr>
<td></td>
<td>(OPTIONAL RULE)</td>
</tr>
<tr>
<td>ABSTRACT HARMONIC REPRESENTATION</td>
<td>7: HARMONIC FUNCTION</td>
</tr>
<tr>
<td>REALIZATION</td>
<td>8: HARMONIC DISTANCE FROM THE TONIC</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Fig. III-A-9</td>
<td></td>
</tr>
</tbody>
</table>
Fig. III-A-13. Examples of generated melodies.
DERIVATION OF HARMONY FOR 8 BAR PERIOD

INPUT:

<table>
<thead>
<tr>
<th>4 5 4 5</th>
<th>4 5 3 5</th>
<th>4 5 4 5</th>
<th>4 5 2 5</th>
<th>4 5 4 5</th>
<th>4 5 3 5</th>
<th>4 5 4 5</th>
<th>4 5 1 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 4 3 4</td>
<td>4 4 2 4</td>
<td>2 4 4 3</td>
<td>4 4 4 4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DELETION OF 5'S

| 4 4 3 4 | 2 4 3 4 | 3 4 4 1 |

DELETION OF 4'S

| 4 4 3 4 | 4 4 3 4 |

INTRODUCTORY AND TARGET CHORDS

EXTENDED INTRODUCTION

<table>
<thead>
<tr>
<th>I</th>
<th>V</th>
<th>DOM</th>
<th>M</th>
<th>DOM</th>
<th>V</th>
<th>DOM</th>
<th>M</th>
</tr>
</thead>
</table>

HARMONIC FUNCTION

<table>
<thead>
<tr>
<th>I</th>
<th>V₂</th>
<th>DOM₁</th>
<th>M₀</th>
<th>DOM₃</th>
<th>V₂</th>
<th>DOM₁</th>
<th>M₀</th>
</tr>
</thead>
</table>

HARMONIC DISTANCE FROM THE TONIC

<table>
<thead>
<tr>
<th>T</th>
<th>V₂</th>
<th>DOM₁</th>
<th>T</th>
<th>DOM₃</th>
<th>V₂</th>
<th>DOM₁</th>
<th>T</th>
</tr>
</thead>
</table>

CHORD SYMBOLS

<table>
<thead>
<tr>
<th>T</th>
<th>V₂</th>
<th>D7</th>
<th>T</th>
<th>DOM₃</th>
<th>V₂</th>
<th>D7</th>
<th>T</th>
</tr>
</thead>
</table>

CHORD SYMBOLS

<table>
<thead>
<tr>
<th>T</th>
<th>S</th>
<th>SP</th>
<th>D7</th>
<th>T</th>
<th>DOM₃</th>
<th>S</th>
<th>SP</th>
<th>D7</th>
<th>T</th>
</tr>
</thead>
</table>

CHORD SYMBOLS

<table>
<thead>
<tr>
<th>T</th>
<th>S</th>
<th>SP</th>
<th>D7</th>
<th>T</th>
<th>T7</th>
<th>S</th>
<th>SP</th>
<th>D7</th>
<th>T</th>
</tr>
</thead>
</table>

CHORD

Fig. III-A-10
determine how often and in which way the chords change. The derivation is illustrated in Fig. III-A-10. Once again the topmost line shows the input material, i.e., the set of prominence ranks. An obligatory rule deletes all items of prominence rank 5. After this some items of prominence rank 4 may be deleted. Next, introductory chords and target chords are distributed. It would be possible to return to the introductory chord at the beginning of the closing phrase but this has not been done in the case of "Dansa, min docka". As a fundamental principle of the harmonic function of chords we propose that anticipatory chords must alternate with rest chords. Given the function of a chord, its harmonic distance from the tonic is determined by its relationship to the following target chord. These distances lie along a scale of integer numbers and in the figure they are given as indices. The abstract representation of the harmony obtained is then transformed, step by step, to chord symbols in a completely automatic way: when the harmonic functions and distances from the tonic have been determined for a set of chords, the chords themselves can be chosen automatically.

3.3 Melody. The output of the metric and harmonic rules provide the material required for the generation of pitches. The rules applied to determine melody are those given in the right part of Fig. III-A-11.

\textbf{TONAL RULES}

\begin{center}
\begin{tabular}{ll}
\textbf{Order:} & \textbf{Contents of rules:} \\
1. Pattern of sequencing & Harmonic implication \\
2. Prominences $\leq 4$ & Harmonic implication \\
3. Prominences $= 4$ & Tonal adjacency (Short-cut principle) \\
4. Prominences $\geq 4$ & Sequencing \\
\end{tabular}
\end{center}

Fig. III-A-11.

First a sequence-pattern is assigned, determining which bars are to be melodically similar. After this, pitches are assigned in an order corresponding to the order of prominence ranks. The various lines in Fig. III-A-12 show, step by step, the stages of the derivation. After the sequence-pattern has been determined, the pitches for prominence ranks 1, 2, and 3 are assigned in turn. The main rule allows nothing but
chord-notes in these cases. After this pitches are assigned for prominence ranks of four. Here the guiding principles are harmonic implication (the pitch signals the underlying chord), tonal adjacency or the "short-cut principle" (when two pitches have been assigned, intermediate notes will - other things being equal - receive intermediate pitches), and the sequence-pattern. At this point it is possible to insert suspensions, which is a special case of the principles of harmonic implication and tonal adjacency. In the present example this possibility has not been used. The next step is to choose chord-notes for the introductory tones in every phrase, observing the principle of tonal adjacency. Using the same principles and taking account of the sequence-pattern, pitches are determined for the remaining notes of prominence rank 4, as illustrated in the next line of the figure. For example, the sequence-pattern dictates that the tonal relations between the tones in bar III be the same as those in bar I.

The last step produces the realization of lesser prominence ranks - numbers greater than 4. For tones which have been assigned the role of chord-notes, the rules already mentioned are applied. For non-chord-notes the principle of tonal adjacency is applied. These notes are related by a scale-step to the following note. The derivation is now complete and the result is given in the lowermost line in the figure. The melody obtained differs in only a few details from "Dansa, min docka". These differences can all be accounted for by our rigorous use of the sequence-pattern. Evidently Tegnérs' realization of the sequence-pattern is less rigid. We conclude that our rules can indeed generate a close approximation to one of Tegnérs' melodies.

Fig. III-A-13 shows a series of melodies generated by making a completely randomized choice among the alternatives available at the various steps in our rule system. These melodies were submitted to Bengt Hallberg, a professional musician and arranger of music. In the Appendix we present examples of the arrangements he made. He has written two versions of every melody, the first in four-part harmony and the second slightly freer.

4. Conclusions and outlook

What, then, are our conclusions? We have seen that the rule system is capable of describing an existing melody, "Dansa, min docka". We
can also use it to generate new melodies. The rule system can be said to describe, and at least partly, to explain the more important formal properties of Alice Tegnér’s nursery tunes. The melodies are generated by following various principles. We have set forth hypotheses about the way in which the syntactic structure is revealed in meter, harmony, and melody by a prominence contour. Evidently a primary task of the rules is to produce a sort of marking of constituents, that is, to reveal the form of a "parsing tree" of the underlying syntax. The catalexis rule can be regarded as one possible way of indicating the end of the period, the opening and closing phrases, and the bar-pair. The restrictions in the distribution of eighth-notes seem to have a similar function: The melodies are also "segmented" with respect to harmony. In the progression of chords the bar is, as a rule, used as the time unit. Bars IV and VIII are treated in a special way, since they can contain only the most fundamental target chords, the tonic and the dominant. The marking of constituents is also assisted by the principle of harmonic implication, which is applied obligatorily to tones having a high prominence. The marking of constituents is illustrated in Fig. III-A-4, which shows the occurrence of various phenomena in the music. The rule system can be said to constitute an explanation of why Fig. III-A-4 looks as it does.

However, explanations often reveal new problems. We may proceed to further questions: Why do the nursery tunes possess a constituent structure and why is this structure so carefully marked for the listener? These questions are in the domain of the psychology of perception. At present we lack satisfactory answers to them. Are unstructured acoustic events (e.g. completely randomized sequences of pitches, durations, and chords) in some way not only more difficult to remember but also to perceive and understand than events possessing a clear structure? Might our evaluative and esthetic reactions to music be partly explained in terms of the limitations of perception, cognition, and memory? Such an approach does not seem unreasonable. In other papers we have pointed out a series of similarities between the logical structure of a nursery tune and a sentence. Both possess a constituent structure and both can be described with an arsenal of technical and mathematical conceptions called phrase-structure grammar and transformational rules. That this should be possible is not at all obvious. It can be
interpreted as support for the hypothesis that linguistic and musical phenomena rely, in part, on common psychological mechanisms.

What kind of investigation might reveal the psychological basis of music? The generative approach offers a good starting point. The attempt to construct strictly formal theories forces us to postulate various explicit principles which organize the melodies - harmonic implication, tonal adjacency and constituent marking. The construction of explicit rule systems is the way to detect principles of this sort. In addition, the generative method - that is, a fully formalized theory - is the only method providing a strict and precise test of how well a theory describes the formal organization of a group of melodies. It is just this test of a theory's relevance which is needed in a meaningful effort to search for the psychological basis of musical form. It also provides a foundation for developing music theory as a branch of psychology. Our knowledge of the processes that are used in the composition and perception of music is still severely restricted. In view of our relative ignorance of these matters we must view with skepticism the attempts that have been made and are still being made, to replace the composer, fully or partly, by the computer. The computer should, rather, be regarded as a valuable tool which today's musicologists can use to increase the accuracy of scientific description, and to strengthen and expand it to the point where it can be applied in other fields.

Our comments have taken the form of a declaration of the proper goals of a scientific musicology. Our conception closely resembles Morris Halle's view of linguistics. As a kind of summary, we quote Halle's formulation inviting the reader to apply his remarks to music and music theory.

"The ultimate objective of our research is to gain a better understanding of man's mental capacities by studying the ways in which these capacities manifest themselves in language. Language is a particularly promising avenue because, on the one hand, it is an intellectual achievement that is accessible to all normal humans and, on the other hand, we have more detailed knowledge about language than about any other human activity involving man's mental capacities. .... for while it is logically conceivable that the structure of language might be quite distinct from that of the organism that is known to possess the ability to speak, it is much more plausible that this is not the case, that the structures that appear to underlie all languages reflect quite directly features of the human mind. To the extent that this hypothesis is correct - and there is considerable empirical evidence in its favor - the study of language is rightly regarded as an effort at mapping the mysteries of the human mind."
Acknowledgments

The authors are indebted to Bengt Hallberg for his kind cooperation in arranging the melodies and to Dr. Ian Firth, Kensington, Australia, for his assistance in translating and editing the manuscript. The work was supported by the Bank of Sweden Tercentenary Fund and National Institutes of Health under Research Grant NS 04003.

References

APPENDIX

GENERATED MELODIES

ARRANGED BY BENGT HALLBERG

Nr 1