A HIERARCHICAL GESTALT ANALYSIS

OF

MUGGLES' PORTALS

by
Larry Polansky
Toronto, Ontario
July 1978
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PREFACE

This paper is one product of several years of work by James Tenney and myself to develop a formal and computer model for the perception of hierarchical temporal-gestalts in music. The body of theory from which this algorithm proceeds was first presented in James Tenney's META/HODOS (1961) and subsequently in the same author's META Meta-Hodos (1975). The algorithm for TG-initiation and resultant computer programme is presented in "Hierarchical Temporal Gestalt Perception in Music: A 'Metric Space' Model" (1978) by James Tenney and myself.

The purpose of the current work is twofold. The first is to help illuminate a difficult musical work in which more traditional theories of musical form and perception are perhaps not so successful, especially in terms of making their a priori musical assumptions explicit with regard to the analytic results. In this respect, I must admit that the choice of Portals was not haphazard. Ruggles' work has been of considerable import to me, both in my development as a musician and a composer, and I strongly feel that his rightful position as one of America's most significant and original composers has been somewhat overlooked. This lack of recognition is evidenced by the paucity of recordings, performances, and serious consideration of his work by musical theorists (although in the latter, matters have improved considerably in recent years). It is my aim that the current work should serve the same function as any good
musical analysis: to educate and provide useful information about a piece, while making a serious attempt to make as few aesthetic judgements as possible. It is hoped that when these judgements are made, their motivations can be made as clear as possible.

The second purpose is to provide a detailed example of the analysis procedure, and to present certain possible extensions of the theory. Although many of these ideas are difficult to understand at first without having spent some amount of time considering their diverse ramifications, it is hoped that the current work is self-contained in presentation, and can be read and understood independently of the three earlier papers mentioned above. Those readers who wish to learn more and gain a deeper understanding of the subject should consult those papers, which, especially if read in their chronological order, provide a complete and detailed explanation of the topic, as well as an interesting intellectual history.

Chapter I (Introduction: Theory and Algorithm) is an introduction to the basic theory of hierarchical temporal-gestalts, and the algorithm of TG initiation. Computer and mathematical details are omitted for the most part in the interests of brevity and clarity, and for these the reader should consult "Hierarchical Temporal Gestalt Perception....". They are, in almost all cases, not essential to an understanding of the musical analysis.

Chapter II is a statistical gestalt analysis of Ruggles' Portals. It is not my intention, neither in the graphic
musical analysis nor in the accompanying 'Notes', to convince the reader that the particular analysis/segmentation made by the programme's operation using the 'optimal' weights (or for that matter with any of the variant weights), is in any way definitive, or the 'right' way to consider the piece. It is hoped that the reader will make his own decisions as to which of the computer segmentations present a reasonable picture of his own musical perception, and indeed it is this very process which arises as one of the main goals of the programme. Often it seems as if it is the musical and perceptual ambiguities, which make the piece as interesting as it is, that the analysis focuses on most strongly.

Appendix I (Some Aspects of Morphology) contains a prolegomenon to an extension of the theory into the realm of morphology, a topic which I feel to be of great importance. The first part of this appendix is necessarily extremely condensed, and is intended to simply raise some vital questions about the nature of such a formal theory. This will be expanded upon considerably in the near future. The second part of the appendix presents visually some of the interesting morphological structures in Portals, on several hierarchical levels (according to the segmentations).

Appendix II contains certain statistics for the entire piece. These statistics have proved essential in the search for an automatic method for determining weights, but they are presented here as well for their purely musical interest with regards to Portals.
Appendix III is a complete listing of the FORTRAN programme itself. Flowcharts and an extended explanation of this programme appear in "Hierarchical Temporal Gestalt Perception...".

It should be noted here that there exists one small difference between the programme used here and the one used in "Hierarchical Temporal Gestalt Perception...". Intensity weights in the current work are exactly halved with regard to equivalent weights in the earlier paper, because in the current programme they are multiplied by two within the programme itself. Thus, a nominal (input) weight for intensity of six in the earlier paper corresponds to an intensity weight of three in the current analysis. This is of interest only if one is comparing the weights used in the two papers, and is not relevant in the understanding of the current work on its own.

Appendix IV is an actual programme output showing the segmentation made by the 'optimal' weights. Also given is the input data for Portals in its entirety, a coding of the melodic line of Chapter II.

I wish to thank the National Endowment for the Humanities, whose generous support made the current work possible (NEH YOUTHGRANT #). In particular, Mr. Glen Marcus of NEH was very helpful with his quite understanding advice on the nature of the work, especially in its early stages. York University (Toronto, Ontario) generously provided me
with computer time, and for this I am grateful.

Last, but assuredly not least, I owe a huge debt of gratitude and an equal measure of respect to James Tenney, who has been teacher, friend and colleague for a number of years, and whose visionary conceptions have generated all of this work. It is my hope that this paper will make more available some of these ideas to a greater number of musicians, so that perhaps others may pursue them in their own ways.

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I. INTRODUCTION: THEORY AND ALGORITHM

In META Meta-Hodos James Tenney states that:
"In the process of musical perception, temporal gestalt units (TG's) are formed, at several different hierarchical levels" (Proposition I.)

The purpose of the present algorithm and the resultant computer programme, developed by James Tenney and myself, is to formalize this perceptual process and to devise an automatic means for its analytic use. In doing so, we have preserved many of the ideas and terminology of META-META-HODOS and META META-Hodos. However, many of the assumptions and operations of the computer algorithm involve simplifications and integrations of many concepts in the earlier papers. In this way, the current algorithm and resultant computer programme constitute a significant extension to and a specific implementation of the results of M4H and M4AH.

The concepts of temporal gestalt unit (TG), hierarchical level, and musical parameter are all used in the same fashion as in the earlier papers, and their meanings should be clear from their usage in the current paper. (The reader should refer to META Meta / Hodos for their precise definitions). TG's on the first hierarchical level are called elements, and are the smallest TG's in which no further segmentation is made. TG's on the second level are called clangs, on the third sequences, on the fourth segments, and on the fifth sections. Sequences might correspond to what are traditionally
called 'phrases', and clangs perhaps (less closely) to 'motives'. The elements of a piece are usually the notes themselves. Although the level process may extend upward indefinitely, in Portals no higher-level TG than a section was found.

The musical parameters considered by the programme are: pitch, duration, temporal density, intensity, and timbre. Pitch, intensity and duration all have the usual meanings. The temporal density of a TG is redefined now as the number of elements per unit time. Thus, it is a measure of the general 'tempo' of a TG.

Proximity has the same meaning as it had in META Meta/Hodos: "the 'nearness' in time of two TG's".¹ The proximity of a TG

¹ See the glossary of "Hierarchical Temporal Gestalt Perception in Music: A 'Metric Space' Model", for this and various other definitions.

is defined in the programme as the difference in starting-times between successive TG's. Note that whereas in MM/H, proximity was one of ".... a number of factors of cohesion and segregation" of the ".... perceptual formation of TG's at any hierarchical level" (Proposition II), in the current algorithm the proximity of a TG is treated as a parametric interval in a similar fashion to intervals in pitch, intensity, timbre and temporal density. Thus, the factors of cohesion and segregation, proximity and similarity, have been integrated into one single factor, called disjunction (see below).
The state of a TG is the statistical or global values (mean, range, duration, etc.) of its parameters, irrespective of the time ordering of the individual component values. The 'profile' of parametric values in a TG through time is called the shape of a TG, and the general processes by which these shapes affect TG formation are called morphology. Some simple morphological aspects of Portals will be considered in Appendix I of this paper. At present, the computer algorithm deals only with state, and uses only statistical information (in particular the parametric means of TG's) to effect the hierarchical segmentation. This means that motivic organization has no effect per se on the computer segmentation of the music.

The states of elements are simply the various parametric values of the different notes: pitch, duration, timbre and intensity. In the case of intensity however, the programme inputs two values for each element— an initial and final intensity. These are averaged to obtain a mean intensity for each element, and it is this mean which is used to calculate the mean interval for intensity on the element level. The initial and final intensity values are used, however, in the calculation of boundary-interval on the element level, which will be discussed below. Temporal densities of elements are computed on the element level as follows:

$$TD_{ELEMENT} = \log_2 \left( \frac{\text{MAX.}}{\text{DUR}_{ELEMENT}} \right)$$
-where MAX is an arbitrary maximum element
duration for the piece. (The reader should con-
sult "Hierarchical Temporal Gestalt Perception
In Music: A 'Metric Space' Model", for a fuller
explanation of these and other programme operations.)

Parametric states of higher-level TG's are the means of
their lower-level component TG parameters. For example, the
'pitch' of a clang is the mean of the pitches of its elements.
Note that this is in reality a weighted mean, since each
element's pitch is multiplied by its duration. Thus, the
equation for the pitch value of a clang is:

\[ P_{CLANG} = \frac{\sum_{i=1}^{J} P_i \times DUR_i}{\sum_{i=1}^{J} DUR_i} \]

-where \( i \) indexes the elements 1 through \( J \) in the
clang, and \( P_i \) and \( DUR_i \) are the pitch and duration
of the elements.

Similarly, the pitch of a sequence is the mean of the pitches
of its component clangs. For intensity and timbre, parametric
states are computed in the same fashion. In the case of
temporal density, clang states are computed in a slightly
different manner: as an unweighted mean of element TD's.
On all higher levels TD states are computed in the same way
as the other parameters. The proximity value of a higher-level
TG is not used as a factor in the segmentation process.

Although \( M_{CFH} \) and \( MM_{CFH} \) give quite a useful conceptual
framework for the consideration of hierarchical TG formation
in musical perception, no specific method is given for the
determination of TG initiations (or conclusions). In
"Hierarchical Temporal Gestalt Perception In Music....", 
such a method is given, and it is that which is used in the
present work.

Since each parametric interval in itself forms a
one-dimensional metric, or distance function, it was a natural
'next step' to seek to combine the different dimensions of the
musical space into one unified distance function which would
assign one value to the distance between two TG's, not a
separate value to each of the parametric intervals. Such
functions are quite common in mathematical contexts, but
the choice of an appropriate one for musical space was dif-
icult. The most common metric associated with the real-numbers in
several dimensions is the Euclidean metric, because it most
easily reflects physicality and our perceptual notions of
'distance', This was the metric first chosen. In the
Euclidean metric in n-dimensions:

\[ D(x_n, y_n) = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_3 - y_3)^2 + \ldots \ldots + (x_n - y_n)} \]

where \( x_n, y_n \) are points in the n-dimensional
space, and \( D(x_n, y_n) \) is the distance or metric
between them.

Note that this value is always positive (one of the char-
acteristics of any metric). Distance in the Euclidean metric
is merely the length of the hypotenuse of a right triangle
described by two points (even though those two points may be
multidimensional).

This metric was later replaced, after considerable experimentation, by another, commonly called the 'city-block' metric, which seems to more accurately reflect musical perception. In the city-block metric, the distance between two n-dimensional points is the sum of the absolute values of differences in each dimension, or the sum of the lengths of the sides of the right triangle. Thus:

\[ D(x_n, y_n) = (|x_1 - y_1| + |x_2 - y_2| + \ldots + |x_n - y_n|) \]

By using such a metric on the means of TG's on all hierarchical levels, we obtain an actual value for the mean segregation of two TG's, or the mean distance-measure.

The second factor of distance between two TG's is what we call boundary-distance, the distance between the final lower-level component of one TG and the initial lower-level component of the next. On the element level, parametric boundary-intervals are computed as follows:

**Pitch:** Boundary-interval equals mean-interval.

**Proximity:** If there is a rest, that rest is assigned to the duration of the note preceeding it. The boundary-interval of the next note is then the duration of the rest preceeding it. If there is no rest, the boundary-interval is zero.

**Intensity:** If a rest preceeds a note, then the boundary-interval is the initial intensity of the note. If the note is not preceeded by a
rest, the intensity boundary-interval is the difference between the initial intensity of the current note and the final intensity of the previous note.

**Temporal Density**: Temporal density boundary-interval on the element level is zero.

The **boundary-distance** of a TG is the sum of the parametric boundary-intervals (note that this sum is precisely the same metric as is used for mean-distance).

Once boundary-distance and mean-distance for a TG have been computed for the element level, the **disjunction-measure**, a simple sum of the two distances, may be computed. The disjunction-measure of a TG is the final measure of perceptual 'segregation' in the algorithm, and it is these values which are used to compute the hierarchical segmentation of a piece. For all higher-levels, the boundary-distance of a TG is the disjunction-measure of its initial component. In this manner, boundary-interval values (and thus lower-level disjunction-measures) are retained from the lowest level to the highest. However, for each level the value of the boundary-interval is halved, so that the weights of lower-level boundary-intervals diminish by successive powers of two.

Even with such a mechanism for computing disjunctions, however, the question still remains: how are the boundaries of TG's determined, regardless of level. Once such boundaries have been distinguished, it is clear that parametric states may be computed and, subsequently, **disjunction-measures**.
The hypothesis for TG initiation (and thus previous TG conclusion) is this:

"A new TG at the next higher level will be initiated in perception whenever a TG occurs whose disjunction (with respect to the previous TG at the same hierarchical level) is greater than those immediately preceeding and following it."²

² "Hierarchical Temporal Gestalt Perception In Music: A 'Metric Space' Model"; Chapter II.

In other words, when a greater change succeeds and precedes lesser change, the greater change will tend to initiate a new perceptual grouping. This greater value in the series of disjunction-measures, is referred to, logically enough, as a peak. The hypothesis for TG initiation is the same for all hierarchical levels.

To summarize the TG initiation algorithm: Changes in musical parameters are integrated, through a multidimensional metric, into a single valued disjunction-measure, which gives a relative value for TG segregation. These disjunction-measures are searched for peaks. When a peak is found, the TG whose disjunction-measure formed it initiates a new TG on the next higher level.

An important consideration is that numerical values of the various parameters have no intrinsic relation to one another. An interval of 1.5 in pitch (or a semitone and a half) does not necessarily perceptually correspond to an
equal numerical value for an interval in intensity, temporal density, timbre or proximity. A set of weights is used, one weight for each parameter, which scales parametric intervals in the metric to more appropriate values. Thus, each parametric interval in both the boundary-distance and the mean-distance is multiplied by its corresponding parametric weight before being summed. Weights are input in five parameters: proximity, pitch, intensity, temporal density, and timbre.\footnote{The parameter of timbre is used in the programme as a sort of 'vacant' parameter, which may be used to encode various textural aspects of the music, for it is clear that timbral parameters are not so easily quantifiable on an ordered scale as are pitch, duration, and intensity. Although this 'texture' parameter is used in the analysis of Portals, it has seldom been used on other works, and there is no consistent or even conventional coding procedure for its values. The particular system used for Portals is quite simple, dealing primarily with orchestral 'fullness', and will be explained in a later chapter.}

As yet, no precise method for assigning weights has been found, and in each piece analysed we have used sets of weights which appear to give the 'best' segmentation. Clearly, this choice of values is very much dependant upon the musical opinions of the analyst. For this reason, much attention has been paid to finding methods for the selection of 'optimal'
weights, and to the effects that weighting variants have upon the segmentation of pieces. The weightings are input by the user each time the programme is executed.

The hypothesis of TG formation does not allow for higher-level TG's to consist of only one lower-level component TG. Consequently, four TG's are needed (three disjunctions) to investigate for peak formation and higher-level TG initiation.

The algorithm used in the programme is a simple one. First, the elements (the note values themselves) are 'processed' for clang formations, computing the parametric means of clangs when initiations are found. When the element level is finished, the programme returns temporarily to the beginning of the piece, but one level higher, this time processing clangs for sequence initiation. This upward process continues until a level is reached in which too few TG's have been formed to consider initiations on still a higher level. At this point, the programme terminates and prints its results: the hierarchical segmentation, and the values of TG states and disjunctions (see Appendix IV for a sample output for Portals).

At present, the programme only works on a monophonic input, and as such, the information loss occurring when analysing a piece such as Portals is significant. However, in Portals, as in much of Ruggles' music, a well-defined melody may be easily isolated throughout the piece. Whereas we do not purport that the programme results present a definitive structural analysis of the piece, we strongly feel that they yield some extremely interesting information,
both about the individual pieces analysed and about the processes involved in musical perception itself.

Clearly, there are some important variables in the computer analysis. Coding of the score into numerical data requires a fair degree of interpretation (see Appendix IV for the complete input data for *Portals*), especially with regard to tempi, dynamics, and in the case of *Portals*, orchestral colour. The weights themselves require the analyst to have some preconceived notions of how the analysis should turn out, and although there is a great deal of learning interaction between the computer output and the analyst's notions, he must in the end rely on his own musical ideas to find the 'proper' weights.
II. AN ANALYSIS OF PORTALS.

Introduction
In the following pages, I present a hierarchical analysis of the melodic line of Carl Ruggles' Portals, for String Orchestra. As I have said earlier, this analysis is dual in function: first, to serve as a highly detailed example of the previously described perceptual theory and resultant computer programme, and, second, to use this theory to help understand some of the complexities of a major musical work.

With regard to the former, it must be said that a programme such as this is never truly finished, it merely reaches various places of rest. Morphology, an automatic method for determining parametric weightings, and even the harmonic aspects of gestalt perception might be dealt with in extensions of the theory. All these are rather large topics, however, and each awaits its own general theory before it might be programmed.

As to the analysis' second function, the more traditional one of shedding some light on the perceptual and compositional structure of a piece of music, it need be said that when one is dealing with an 'automatic' analysis of this sort, a great degree of humility must be assumed by the analyst. The analysis is not presented as a truth about Portals nor about Ruggles' musical ideas, but rather as a commentary on the work, hopefully one leading to further investigation.
The variability of the analytical results with regard
to the different sets of parametric weightings emphasises the
necessity of humility. Although only a few sets of weights
are analysed here, many more have been tried. The set which
I call the **optimal weights**, represents those results which
I find to be most accurate perceptually, and might not
indeed be 'optimal' to someone else. For this reason, in the
accompanying notes I have tried not to judge the different
sets as much as explain them. It is hoped that by explaining
the segmentation process in detail at several points, the
reader will begin to understand to some degree what is
actually involved in the choice of such a set of weights, and,
more importantly, what their effects are on musical per-
ception.

**CODING**

Throughout most of *Portals*, there is a clear, easily
perceived melodic line. Where it was more ambiguous (e.g.
ms. 29-30; ms. 35-38; ms. 14-18; ms. 56; ms. 62) a decision
was made, solely on the basis of my own aural judgement,
as to which line to consider the melody and which the counter-
point. Although my decisions are in many cases open to some
question, I hope the reasons for them are at least under-
standable.

Pitches are coded as integers, each increment of one
representing a semitone. C below middle C is 0, and the
highest note in the piece is D-natural, 4 octaves and a
major second above middle-C, whose value is 50.
Durations are coded as real numbers. 1.2 is used for the quarter-note, because of its convenient divisibility. In the programme, durations are rescaled to an input tempo (in this case $\downarrow=60$), so that in the output durations are in fact represented in 'real-time', in terms of seconds. The variations in tempi in the piece were coded both with regard to indications in the score, and to practical performance considerations of the piece. They may be readily inspected from the input data (Appendix IV). Since the tempo value for the piece scales the durations of notes, and consequently all values of proximity and rest, changing the input tempo is equivalent to altering the proximity-weight. Note that the tempo does not affect the values of temporal density, which are computed on a relative, not an absolute, scale.

Rest values are input in the same fashion as notes. The duration of a note includes also the rest succeeding it.

Intensity values are input as real numbers, with an increment of 1.0 for each dynamic level ($p=3.0; \text{mf}=4.0; f=5.0; \text{ff}=6.0; \text{fff}=7.0$). Crescendi, decrescendi and intermediate values are interpolated and computed with consideration to the orchestral volume as well as the indicated dynamic markings. Each note has an initial and final intensity to facilitate a more accurate coding of crescendi and decrescendi.

Timbral values are coded in a similar fashion, 0.0 being the 'thinnest' melodic texture (solo), and 3.5 being the 'fullest'. Octave and melodic doublings in other instruments were the most important considerations in this
respect. Roughly, each octave doubling of the melody corresponds to an increase of 1.0 in the timbral value. In this sense, 'timbre' is perhaps a misnomer, but is used for convenience. This parameter is more accurately an approximate measure of the textural fullness of the melodic line.

Clearly, what this coding process represents is an interpretation of the piece in itself. Certain decisions, based upon a knowledge of the piece and a certain aural preconception, must be made a priori. All that can be said is that this process of coding is in itself a difficult and somewhat tedious task in which many of the analyst's ideas about the piece actually affect the final computer analysis.

COMPUTER ANALYSIS

(The melody line in the following analysis is taken from the American Music Edition of Portals, 1937, N.Y., N.Y.).
ILB Segmentation cages are used for the purposes when the segmentor differs from (all other parameters as above)

\[ \text{IW} = 3 \]

\[ \text{PM} = 6 \]

Varying weighting: \[ \text{PM}^2 = 3 \] (all other parameters as above)
NOTES

(In all cases, TG's are 'located' by the element number at which they are initiated. Note that higher-level TG numbers refer to those segmentations produced by the optimal weights:

\[ \begin{align*}
\text{PROXIMITY} & = 1.0 \\
\text{PITCH} & = .5 \\
\text{INTENSITY} & = 1.0 \\
\text{TEMPORAL DENSITY} & = 1.0 \\
\text{TIMBRE} & = .2
\end{align*} \]

Because different sets of weights produce different segmentations, the numbering of TG's differs from one set to another. For this reason, most references will be made to element numbers, which are of course invariant. Higher-level TG numbers are not given in the graphic analysis for the variant weights.

Weightings are referred to by that parameter in which they differ from the optimal weights. The three variant weightings considered are: PITCH (PW) = .3; PW = .6; INTENSITY (IW) = 3.)

SECTION I  (Elements 1-57; MS. 1-12)

Segment 2 (el. # 25): This segment is initiated by the theme in the viola (which reappears at ms. 43). Mean-intervals on the sequence level do not create much effect here, as parametric peaks do not even appear in pitch and temporal density, although sizeable peaks appear in amplitude and timbre (note the large change in this latter parameter). However, boundary intervals make
this segment break quite strong, especially in proximity, where the eighth-note rest produces a sizeable boundary-interval at the element level.

Clangs 12 and 13 (els. # 37 and 39):
Although at first glance, both of these clangs seem to be initiated at unusual places, the reasons become clear on further analysis and listening. At element # 37, proximity (the duration of element # 36) is quite strong and tends to override peaks in pitch and temporal density which appear at element # 38. However, raising pitch-weight (PW) to even .6 makes the larger pitch-interval at element # 38 a strong enough factor in the metric to override the effect of proximity at element # 37.

Similarly, at element # 39, there is a certain trade-off between effects of pitch-interval and proximity.

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>#37</th>
<th>#38</th>
<th>#39</th>
<th>#40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.88</td>
<td>.29</td>
<td>2.04</td>
<td>.29</td>
</tr>
<tr>
<td>Pitch</td>
<td>9</td>
<td>13</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>TD</td>
<td>1.59</td>
<td>2.81</td>
<td>2.81</td>
<td>0</td>
</tr>
<tr>
<td>Intensity</td>
<td>.2</td>
<td>.2</td>
<td>.25</td>
<td>0</td>
</tr>
<tr>
<td>Timbre</td>
<td>.5</td>
<td>.5</td>
<td>.5</td>
<td>0</td>
</tr>
</tbody>
</table>

(Rest and intensity boundary-interval are all zero).

Here, the peaks in proximity, intensity-interval and the near peak in temporal density-interval establish the clang initiation much more strongly, so that even raising PW (at least to .6) does not override the peak at # 39.

Segment 3 (el. # 46):
Initiated by sequence 5, segment 3 shows clear parametric
peaks in timbre and pitch, but little change in other is the parameters. More important perhaps, a boundary-distance arising from sizeable parametric intervals on the element level in all parameters (Prox. = 1.94; Rst. = .78; Pitch = 16; TD = 1.33; Int. = 1; Int. BI = 1; Tim. = 2.3. For a good idea of the relative size of these intervals, compare them with the mean parametric intervals for the entire piece given in Appendix II).

At this point one sees an interesting example of how morphological factors A enhance a statistical effect. Note that although clangs 14 and 15 are quite similar metrically, it is the repetition itself that seems to give aural strength to the higher-level initiation at element # 46. This effect seems to be characteristic of Portals, and of Ruggles' style in general- that immediate morphological repetition is often accompanied by large statistical distinction.

SECTION II (el. # 58-128; ms. 13-25)
Although it is apparent that this section, like all of the four sections into which the 'optimal' weights divide the piece, begins with a restatement of the 'theme', it must be remembered that thematic information of this kind is not within the scope of the programme at present. Thus, these section breaks are made solely on the basis of the statistics of segments, and on the mean-intervals for all lower-levels at the point of section initiation (boundary-distance). That statistical information is so well correlated with morphological is not so surprising in a composer like Ruggles, but that it should be so clearly evidenced with
such a relatively simple algorithm is.

Segment mean-intervals at section II show small parametric peaks in pitch and TD, but no peaks in intensity or timbre. However, parametric intervals for element # 58 are:
Prox. = 2.25; Pitch = 21; Rst. = .83; TD = 2.17; Int. = 1.3;
Int. BI = 1.5; Tim. = 1.2;

—all very large, especially when compared to the means of parametric intervals on the element level for the entire piece (Prox. = .95; Pitch = 4.54; Rst. = .03; TD = .71; Int. = .1). Consequently, the boundary-distance for section II is quite large. Disjunction-measures for lower-level TG's at this point are: Element #58 = 5.1; Clang #20 = 3.55; Sequence #7 = 2.9 - compared to mean disjunction-measures of .99, 1.16, 1.71 for the element, clang, and sequence levels respectively. Clearly, these statistics correspond musically to the significant change in tempo, dynamics, melodic register, orchestration, etc. at this point in the piece.

Segment 5 (el. # 90): At element #90, not only are boundary-intervals quite substantial, but sequence mean-intervals help to significantly effect the segment initiation. Note that although sequence 10 (el. #90-94) is of radically different timbre and overall temporal density than the sequence preceding it, sequence 11, where violins rejoin the texture and where there are some shorter duration values, is less different. That is, on the sequence level, Ruggles follows a radical change by a smaller one. The aural effect should be obvious, and it is reflected by the algorithm's segmentation.
Clang 32 (el. #93):
The partitioning of sequence 10 is quite sensitive to changes in
weightings, being solely dependant upon the peak in
pitch-interval at element #93. When PW is lowered to .3,
this clang is removed, as the peak in TD-interval at element
#94 overrides the lessened pitch-interval peak. A look at
the disjunction measures for this point under two weights
shows this great sensitivity:

<table>
<thead>
<tr>
<th>Weight</th>
<th>DM(#93)</th>
<th>DM(#94)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW = .3</td>
<td>.78</td>
<td>.79</td>
</tr>
<tr>
<td>PW = .5</td>
<td>.84</td>
<td>.91</td>
</tr>
</tbody>
</table>

Sequence 11 (el. # 95):
Again, boundary-intervals, especially in proximity (note the
length of element #94), rest, and pitch produce a sequence
break here which is relatively strong (DM of clang initiator: 2.79)
and fairly invariant under different weights.

Section III (el. # 129-261; ms. 26-49):
This section break, though clearly a major structural point
in the music, is highly sensitive to changes in weightings.
Segment mean-intervals at this point show a peak only in
pitch, and if PW is lowered, larger intervals in the other
parameters at surrounding segments override it. Boundary-
distance, mostly caused by large pitch, proximity, and rest
intervals at the element level, is quite strong. However,
this is not sufficient to insure this section break when PW
is lowered significantly. That this point should be so
tenuous statistically is surprising, for the literal repetition
of the theme seems to be quite a strong indication of Ruggles'
formal intentions. It is clear that the incorporation of morphological factors into the programme, particularly with regard to motivic repetition, would make this section break less ambiguous.

Clang 42 (el. # 132):
Proximity (duration of element #131) is quite strong here, and overrides the effect of a pitch-interval peak at element #133.

Clang 44 (el. #137):
Although there is a small peak in the proximity values at element #138, peaks in pitch, TD, and timbre intervals at element 137 tend to override it.

Clang 46 (el. # 144):
Repeated pitches are quite unusual in any of Ruggles' music, and the effect statistically is to tend to place a TG initiation at the first of these pitches, since the second will have pitch interval of zero. This is the case at this point, and it overrides the negating effects of a proximity peak at 145 itself.

Sequence 17 (el. # 162):
Note the sizeable boundary-interval in proximity (2.25 seconds, one of the longest durations in the piece), which makes the element level disjunction quite strong.

Clang 53 (el. # 164):
The clang break here is an example of one that is impossible to alter through weighting changes. All parametric intervals are zero for elements #163-165, except for pitch and timbre which have peaks at 164.
This is also the case at clang 58 (el. #178) where there is a very slight pitch-peak, and all other surrounding parametric intervals are zero.

Element # 183:
That no clang break occurs here is explained by the relation of proximity values for elements #184 and 183, which is two to one. Although a peak in pitch interval occurs at 183, PW would have to be enormous to produce a clang break there and would undoubtably have disagreeable effect elsewhere.

Segment 7 (el. #189):
In this case, clear mean-interval peaks appear at the sequence level in pitch, intensity and timbre, but the higher-level break, as evidenced by the other weightings (PW = .3; IW = 3) is quite sensitive.

Where PW = .3, no clang even appears at this spot.

Investigating the element intervals at this point:

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>188</th>
<th>189</th>
<th>190</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.25</td>
<td>.25</td>
<td>1.0</td>
</tr>
<tr>
<td>Pitch</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>TD</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Intensity</td>
<td>0</td>
<td>1.25</td>
<td>.5</td>
</tr>
<tr>
<td>Int. BI</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Timbre</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

-we find relatively small peaks in TD, intensity, and intensity boundary-interval, but no peaks in pitch, proximity or timbre. Where pitch is concerned, under the optimal weights, the interval at #189, though not a peak, is still
large, and does not inhibit the clang formation as much as when its effect is lessened (PW = .3). Disjunction-measures under the optimal weights as compared to when PW = .3 show the extreme sensitivity of even the clang break:

<table>
<thead>
<tr>
<th>WEIGHTS</th>
<th>#188</th>
<th>#189</th>
<th>#190</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW = .5</td>
<td>.64</td>
<td>1.02</td>
<td>.95</td>
</tr>
<tr>
<td>PW = .3</td>
<td>.47</td>
<td>.89</td>
<td>.90</td>
</tr>
</tbody>
</table>

Thus, in the optimal weights even clang and sequence peaks are relatively small (where clang 61 and sequence 19 initiate the segment) as the disjunction-measures show:

<table>
<thead>
<tr>
<th>CLANGLS</th>
<th>60(.78)</th>
<th>61(1.02)</th>
<th>62(.92)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEQUENCES</td>
<td>18(.80)</td>
<td>19(1.10)</td>
<td>20(.72)</td>
</tr>
</tbody>
</table>

-making the segment break at element # 189 quite tenuous.

Segment 8 (el. # 208):
Initiated by sequence 21, this break is sensitive to changes in PW, as the segmentation of the music shows. The boundary effect of the rest at element # 207 is quite important, as is the high value for pitch-interval at the element level. However, a large mean-interval for pitch at sequence 23:

Seq. 21 (2.31) Seq. 22 (1.56) Seq. 23 (3.78)

-tends to produce the segment break at element #215 if PW is even raised to .6. The peak in the sequence disjunction-measures under the optimal weights at sequence 21 is also quite small (.72; 1.25: 1.08; - for sequences 20,21,22).
Element # 224:
Raising PW here produces a clang break, for obvious reasons:

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>#223</th>
<th>#224</th>
<th>#225</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.33</td>
<td>.67</td>
<td>1.33</td>
</tr>
<tr>
<td>Pitch</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>TD</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

—but note that there exists a sensitive relationship between the effects of pitch and proximity.

Clang 73 (el. # 226):
The effect of raising intensity-weight to 3 is to negate the very slight proximity peak at element # 226, thus removing the clang break. This seems to be musically, a better solution, and one more in keeping with Ruggles' attempts to achieve the continuous line.

Sequence 23 (el. # 229):
This point appears to be one of the most anomalous aspects of the optimal weights. Whereas at element # 25, a segment was produced, here only a sequence is initiated. Clearly, the introduction of the role of motivic recognition into the programme would be important here.

One cause of the lower-levelled break here is that element # 229 is preceded by both a ritardando and a decrescendo, diminishing significantly the effect (both aurally and in terms of the programme) of its relative change.
On the sequence level, sequence 23 only shows a peak in temporal density. However, boundary-intervals (though not in pitch!) are fairly strong, and even with the optimal weights it is extremely close to producing a segment initiation here:

Disjunction-measures: **Seq. 22 (1.08); Seq. 23 (1.08); Seq. 24 (.85)**

-so that any increase in the temporal density weight at all would produce a peak (note that the algorithm requires a peak to be strictly greater than its adjacent values). Such a relative increase can be effected by diminishing PW as well, as seen in the example of PW = .3.

Clang 78 (el. # 241):
Parametric intervals at this point are:

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>#240</th>
<th>#241</th>
<th>#242</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.29</td>
<td>.88</td>
<td>.29</td>
</tr>
<tr>
<td>Pitch</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>TD</td>
<td>1.59</td>
<td>1.59</td>
<td>2.81</td>
</tr>
<tr>
<td>Timbre</td>
<td>0</td>
<td>.5</td>
<td>.5</td>
</tr>
</tbody>
</table>

The effect of the weightings is clear: raising PW, even slightly, removes the clang (as would raising the TD-weight).

Segment 9 (el. # 250):
Both a large sequence mean-interval peak in pitch and timbre, and large boundary-intervals in **all** parameters combine to produce this segment break, which is quite strong,
and seems to remain so under several different weightings.

SECTION IV (el. # 262-408; ms. 50-75):

Again, disjunction-measures for lower-level TG's are quite large at this point (Element # 262 - 3.47; Clang 86 - 3.01; Sequence 27 - 2.96) and these are clearly a larger factor in the segmentation than the segment level mean-intervals, in which only a peak in TD appears at segment 10. However, as in Sections I-III (beginning at els. # 1;58;129) the clear restatement of the theme supports the statistical segmentation, though of course the programme has no 'knowledge' of it.

Clang 89 (el. # 270):
When PW is raised to .6, the clang is 'shifted' to element # 269, as the pitch-interval/proximity relationship is very sensitive at this point (note the greater proximity of # 270 as compared to the greater pitch-interval of # 269). The clang break at # 270, for reasons of musical phrasing, seems to more accurately reflect my own musical perception of this point. Note that an intensity-weighting of 3 goes even farther, and places a sequence break at # 270, which also seems perceptually valid, in that it makes elements # 266-269 one sequence, instead of two when PW= .6.

Segment 11 (el. # 293):
Clearly, boundary-interval for pitch is strong, but so is mean pitch-interval for the sequence level, so strong that
even a diminished PW still produces a segment here. In the optimal weights, disjunction-measures on lower-levels are large (1.31 on the element level, 2.5 for the clang level), but significantly, disjunction-measures for the initiating sequences are 1.5 for the optimal weights, and .84 when PW is reduced to .3.

Clang 99 (el. # 307):
Here, pitch-interval is undoubtedly the strongest factor in the initiation. When PW = .3, the clang is initiated instead on # 308.

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>#306</th>
<th>#307</th>
<th>#308</th>
<th>#309</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.75</td>
<td>1.25</td>
<td>1.33</td>
<td>.33</td>
</tr>
<tr>
<td>Pitch</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TD</td>
<td>.74</td>
<td>.1</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Again, one sees a very clear trade-off between pitch-interval and proximity (and temporal density) peaks. Disjunction-measures for the two weights at this point are:

<table>
<thead>
<tr>
<th>WEIGHT</th>
<th>#306</th>
<th>#307</th>
<th>#308</th>
<th>#309</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW = .5</td>
<td>.75</td>
<td>1.36</td>
<td>1.27</td>
<td>.32</td>
</tr>
<tr>
<td>PW = .3</td>
<td>.7</td>
<td>1.2</td>
<td>1.22</td>
<td>.29</td>
</tr>
</tbody>
</table>

Segment 12 (el. # 321):
Although there are no peaks in any of the parametric mean-intervals, boundary-intervals, especially in proximity and rest, are quite strong. Even so, this segment is not a strong break - the disjunction-measure of the initiating sequence being 1.66 as compared to 1.49 of the following
sequence. It's musical validity is also in some doubt, as another strong candidate for a segment break would be at element # 329. Indeed, a lower PW (.3) helps negate the importance of pitch-interval on the clang level, and removes the segment break there.

Clang 108 (el. # 338):

Pitch-interval is the main factor in this clang initiation, overriding the negative effects of larger intervalic values for intensity, proximity, and temporal density at element # 339. However, this clang is quite weak (DM = .64) and even weaker when PW = .3 (DM = .47). It is slightly stronger, of course, when PW = .6 (DM = .72).

Clang 113 (el. # 352):

Note the 'shift' when intensity-weight = 3, possibly producing a more reasonable clang break.

Sequence 34 (el. # 355):

The fact that a segment is not initiated here by sequence 34 may be clearly understood by looking at sequence level parametric mean-intervals at this point:

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>33</th>
<th>34</th>
<th>35 (sequences)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>.97</td>
<td>6.26</td>
<td>9.65</td>
</tr>
<tr>
<td>Intensity</td>
<td>.76</td>
<td>.5</td>
<td>1.33</td>
</tr>
<tr>
<td>TD</td>
<td>1.05</td>
<td>.95</td>
<td>.99</td>
</tr>
<tr>
<td>Timbre</td>
<td>1.08</td>
<td>1.08</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Boundary-intervals are also not strong enough to override the greater parametric-interval values of sequence 35.
Clang 119 (el. # 371):
When PW = .6, this clang is shifted back to element # 370, once more a sensitive balance is evidenced between pitch-interval and proximity effects, reflecting the perceptual ambiguity at this and other points.

Clang 120 (el. # 373):
That elements # 373-377 form only one clang seems somewhat indicative of Ruggles' quest for a line which seems to continually propel itself forward, where no change is perceptibly larger than its neighbors.

Sequence 37 (el. # 387):
Where PW = .3, no sequence occurs here, for boundary-interval for pitch (on the element level) is significantly lessened in importance. The proximity value for element # 388 is quite strong, and if PW is lessened, proximity will override the effect of pitch-interval at # 387 to produce a higher-level (sequence) initiation. However, the effect of pitch-interval at the element level on this sequence break seems to be of some musical significance.

Element # 392:
With PW = .6, a clang is produced here, which seems to be more consistent than the absence of such at this point, since this coda consists essentially of variations on the descending major second, itself taken from the main theme.

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>#391</th>
<th>#392</th>
<th>#393</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td>.75</td>
<td>1.25</td>
<td>1.75</td>
</tr>
<tr>
<td>Pitch</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>TD</td>
<td>.74</td>
<td>.47</td>
<td>0</td>
</tr>
</tbody>
</table>
GENERAL COMMENTS

The larger hierarchical segmentation resulting from the optimal weights is as follows:

<table>
<thead>
<tr>
<th>SECTION</th>
<th>SEGMENT</th>
<th>EL. #</th>
<th>MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>1-24</td>
<td>1-6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>25-46</td>
<td>6-9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>46-57</td>
<td>10-13</td>
</tr>
<tr>
<td>II</td>
<td>4</td>
<td>58-89</td>
<td>13-19</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>90-128</td>
<td>19-25</td>
</tr>
<tr>
<td>III</td>
<td>6</td>
<td>129-188</td>
<td>26-35</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>189-207</td>
<td>36-38</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>208-249</td>
<td>39-46</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>250-261</td>
<td>47-50</td>
</tr>
<tr>
<td>IV</td>
<td>10</td>
<td>262-292</td>
<td>50-54</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>293-320</td>
<td>54-59</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>321-379</td>
<td>59-69</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>380-408</td>
<td>70-75</td>
</tr>
</tbody>
</table>

Thomas Peterson, in *The Music of Carl Ruggles*, states that Portals has "... a certain semblance to rondo form, since the principle idea recurs (albeit in freely varied fashion) four times during the course of the work, as well as providing the material for the coda. A plausible attempt at conventional analysis might be made as follows:

<table>
<thead>
<tr>
<th>A</th>
<th>1-6</th>
<th>B</th>
<th>43-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>6-13</td>
<td>D</td>
<td>50-62</td>
</tr>
<tr>
<td>A'</td>
<td>13-19</td>
<td>A³</td>
<td>62-70</td>
</tr>
<tr>
<td>C</td>
<td>19-26</td>
<td>CODA</td>
<td>70-75</td>
</tr>
</tbody>
</table>
| A²  | 26-43|     | (based on A)"¹
1 Peterson, T.E.; The Music of Carl Ruggles; pages 57-58.

There are some clear similarities, and some interesting differences as well, between Peterson's more traditionally motivated analysis and the computer version. Clearly, our SECTION I corresponds to his A and B, although B is further broken into segments 2 and 3 by the machine. Peterson's A' and C also correspond nicely to our SECTION II, wherein the computer even matches segments with his divisions (A' and C). However, the middle section of the work raises some significant differences between the two segmentations. Where Peterson sees measures 26-62 (A²,B,D) as a major section of the 'rondo', the programme does not correspond except in measure 50, in which the restatement of the theme occurs. Here the programme finds the initiation of the fourth major section, whereas Peterson sees it as a secondary rondo theme. Nicely enough, Peterson's coda corresponds nicely to Segment 13, whose disjunction is quite strong and probably only lacks sectional status for the sole reason that it would be a one-segment section, which is not allowed by the algorithm.

That Peterson's segmentation is made under different criteria is clear, for it uses both motivic information and a more traditional idea of musical structure. In one case, his segmentation (B at measure 43) seems more reasonable than that of the computer, although I believe that there probably exists a weighting which would 'fix' this spot
in the programme's segmentation. However, both analyses serve useful purposes, as does their comparison: to raise structural questions about this highly complex piece of music. One of the advantages of the computer analysis is that its reasons for decisions are always clear, and may be accepted or discounted on the basis of such. In disputing a segmentation made by the computer, one can discern numerically the reasons for its decision, and can often find a similar justification for one's own decision. The various points which appear to be sensitive to changes of weights are also quite instructive about musical effect, in that they point clearly to certain ambiguities which are often aurally obvious, but whose underlying structures are less clear.
APPENDIX I: SOME ASPECTS OF MORPHOLOGY

Whereas the parametric states of two TG's containing the same components are equal, regardless of the temporal ordering of these components, the parametric profiles, or shapes, are not. In fact, the shape of a TG can be defined as the relations of its component parametric values (states) through time.

Since profiles are sets of ordered relations, comparisons between profiles must be point-by-point comparisons of these relations, or some reduction of that information. In this sense, two pitch profiles in which one is the exact transposition of the other might well be considered to be 'equal', or at least equivalent. The search for invariants of this type and a measure of similarity (and, even further, of disjunction) between parametric profiles, and eventually one integrated profile, is essential to the proper understanding of the types of musical and perceptual processes with which the programme deals. That these morphological factors significantly affect gestalt organization in composition and perceptual processes is certain. In fact, it is somewhat surprising that statistical information by itself should yield such a reasonable segmentation, when traditional ideas of musical form deal so much more directly with morphological factors: melodic shape, thematic and motivic development, tri-partite and variation forms, and even the 'axioms' of invariance (inversion, transposition, retrograde
motion) of serial music. That certain operations upon an ordered parametric set, like pitch inversion and transposition, duration augmentation and diminution, and equivalent processes in other parameters have become invariants, or at least equivalences to our ears is evidence that: there must exist certain fundamental principles governing the perception of shape. The quest for these rules, is, in a sense, the study of morphology.

One possibility is that the idea of a metric might be applied to the realm of shape. Such a metric would seek to preserve traditional notions of motivic similarity, as well as illuminating more subtle aspects of shape transformation and similarity. The concept of distances between shapes is not well-defined at present however, and many fundamental problems arise at even the simplest formulation of such a metric function. For example, if we reasonably assume that the distance between a pitch profile and its exact transposition is zero (and it can be argued that without this assumption any concept of shape with regard to invariance is virtually meaningless), and that the distance between that same profile and one in which only one value is slightly altered is some small arbitrary value: what then is the distance between a transposition of that alteration (to the same degree as the original transposition) and the original profile. Perceptually it would seem that the transposed alteration is 'further' from the original than the un-transposed alteration. But this is clearly paradoxical, or at least inconsistent as the following equalities show:
By assumption,
\( D(P, T_P) = 0 \) (prime and tranposition).

Let,
\( D(P, P') = \varepsilon \) (prime and alteration)
\( D(T_P, T'_P) = \varepsilon \) (transposition and altered transposition)
- where \( \varepsilon \) is some arbitrary small value.

Since, by the metric axioms, \( D(P, T_P) = 0 \) implies
\( P = T_P \), we reach the conclusion that:
\( D(P, T'_P) = D(P, P') = \varepsilon ! \)

Even this extremely simple example raises numerous questions about the feasibility of such a metric on shape, in which single values are assigned to distances between a set of objects whose relations are quite complex. The general structure of the set of distances between shape does not appear to be simple, and one in which a 'well-ordering', necessary for a simple metric, is possible, for many of the distances seem to involve differences in 'kind', not easily expressed as simple numerical quantities. This becomes even clearer when we consider the role of directional change (inversion), and types of permutation (of which retrograde is the most important specific example). In the case of inversion, one needs to decide whether to consider both negative and positive parametric intervals or, as is the case with state, to consider only absolute values. If the latter, then a prime is of course equal to its inversion, and problems like the one with transposition (only worse!) arise quickly.

In the case of retrograde, it is difficult to produce a metric which recognizes any similarity in shape between a
prime and its retrograde (although many of their parametric states are of course the same).

Even with the idea of a metric, many questions about the role of shape in gestalt organization remain unanswered. In what ways does the repetition of morphological information tend to initiate new TG's, and in what ways does it tend towards cohesion? What role does recognition of lower-level shapes play in the formation of higher-level TG's? Can shapes of higher-level TG's be treated in the same fashion as those on the element-level, with which we are so accustomed to dealing?

Although these questions (and many others) remain unclear at the present, it is suggested that statistical information is a necessary beginning to a consideration of morphological information. This is obvious in the case of higher levels, for the states of TG's, and thus temporal-successions of their states, can not be known until lower-level segmentations have been made and statistics computed. Thus, a dependancy of shape upon state is developed which in turn raises further questions. To what extent do segregative tendencies in shape and state counteract, and in what ways do they support each other? Are statistical segmentations to be made a priori, so that the necessary boundaries are drawn in which shapes in turn might be considered? And, most important perhaps: is there a mechanism for integrating the two types of information into one method for the analysis of gestalt organization?

SELECTED PROFILES IN PORTALS

In the following pages of charts, made by the statistical
segmentation of the optimal weights, some of the morphological structures in Portals are illustrated. A detailed analysis of this information is beyond the scope of this paper, and is perhaps better left to the interested reader. For this reason, no conclusions (other than the graphs themselves!) are drawn regarding the shape-structure of the piece.

Investigations of correlations between parametric profiles, general tendencies of shape (periodicity, rise and fall, etc.) and comparisons of these shapes to others both in Ruggles' own music and to those in other music can all be done visually without difficulty, and with interesting results. My intention in presenting this information is to allow the reader to form his own opinions about larger questions of form and aesthetics in Portals.

Actual parametric values may be obtained from the programme output, as well as profiles for the piece other than those charted. Note also that shifts in weightings produce corresponding shifts in higher-level profiles (see charts XII-XIV).

Charts I-IV present various parametric profiles for all levels of the piece, each chart a different parameter and section. Chart V shows the disjunction-measure profile for SECTION I, in all levels. Charts VI-IX show the parametric profiles of the entire piece at the segment level, and it is these charts which perhaps most closely reflect a 'traditional' notion of form. Chart X shows the disjunctions for these segments, and although the significance of this chart is not as immediately obvious as # VI-IX, it also gives
important illustrations of the formal structure of the piece, though with regard to change in parameters rather than the actual parametric values. Chart XI shows the parametric profiles for sections of the entire piece in three parameters, and its relative smoothness is not surprising for statistical information at this level.

Charts XII-XIV show dijunction-measure profiles for all levels for the first section for each of the three varying weights. These may be compared to chart V to help visualize the shifts effected by changes in weights.
Temporal Perception Profiles: all legs
Chase I

Time (in seconds)

Direction: Measure Profiles: all Leeds

Section I
APPENDIX II: SELECTED GLOBAL STATISTICS OF PORTALS

1) Means of element level parametric values.

Duration  .75
Pitch    29.56
Intensity 5.30
Rest Duration  .03
Temporal Density 3.84

—where intensity values are themselves means of initial and final element intensities.
Note that in pitch and intensity, means are weighted by the durations of elements.

2) Ranges of element level parametric values.

<table>
<thead>
<tr>
<th>Parametric Value</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>.17</td>
<td>5.75</td>
<td>5.58</td>
</tr>
<tr>
<td>Pitch</td>
<td>-2.00</td>
<td>50.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Intensity</td>
<td>3.00</td>
<td>7.50</td>
<td>4.50</td>
</tr>
<tr>
<td>Rest</td>
<td>0.0</td>
<td>1.08</td>
<td>1.08</td>
</tr>
<tr>
<td>TD</td>
<td>.48</td>
<td>5.58</td>
<td>1.18</td>
</tr>
</tbody>
</table>

3) Mean deviation of parametric values.

Mean deviation for intensity and pitch is given by the equation:

$$MD_p = \frac{\sum_{i=1}^{N} |(DUR_i \times V_i) - M_p|}{\sum_{i=1}^{N} DUR_i}$$

—where \(DUR_i\) is the duration of element \(i\);
\(V_i\) is the parametric value of element \(i\); \(M_p\) is the parametric mean; and \(N\) is the # of elements.
In the case of duration, rest, and temporal density:

\[
MD_p = \frac{\sum_{i=1}^{N} V_p - M_p}{N}
\]

Duration \(0.46\)
Pitch \(7.89\)
Intensity \(0.82\)
Rest \(0.05\)
TD \(0.895\)

4) Means of element level parametric intervals.

Proximity \(0.75\)
Pitch \(4.54\)
Intensity \(3.10\)
TD \(0.71\)

5) Maximum element level parametric intervals (minimums are all zero).

Proximity \(5.75\)
Pitch \(29.00\)
Intensity \(3.00\)
TD \(4.33\)

6) Mean deviations of element level parametric intervals.

These are computed as the sum of the absolute values of differences between element level intervals and the mean parametric interval, divided by the number of intervals.

Proximity \(0.46\)
Pitch \(3.04\)
Intensity \(0.15\)
Rest \(0.05\)
TD \(0.20\)
7) Element level disjunction-measures.


8) Means of parametric intervals for higher-levels.

<table>
<thead>
<tr>
<th></th>
<th>CLANGS</th>
<th>SEQUENCES</th>
<th>SEGMENTS</th>
<th>SECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>6.42</td>
<td>10.41</td>
<td>7.62</td>
<td>1.62</td>
</tr>
<tr>
<td>Intensity</td>
<td>.335</td>
<td>.741</td>
<td>.846</td>
<td>.25</td>
</tr>
<tr>
<td>TD</td>
<td>.469</td>
<td>.576</td>
<td>.430</td>
<td>.237</td>
</tr>
<tr>
<td>Timbre</td>
<td>.353</td>
<td>.800</td>
<td>1.095</td>
<td>.193</td>
</tr>
</tbody>
</table>

9) Ranges of parametric intervals of higher-levels.

<table>
<thead>
<tr>
<th></th>
<th>CLANGS</th>
<th>SEQUENCES</th>
<th>SEGMENTS</th>
<th>SECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch Max.</td>
<td>21.35</td>
<td>32.53</td>
<td>21.74</td>
<td>2.75</td>
</tr>
<tr>
<td>Pitch Min.</td>
<td>.07</td>
<td>.97</td>
<td>.71</td>
<td>.01</td>
</tr>
<tr>
<td>Pitch Range</td>
<td>21.28</td>
<td>31.56</td>
<td>21.03</td>
<td>2.74</td>
</tr>
<tr>
<td>Intensity Max.</td>
<td>2.91</td>
<td>2.89</td>
<td>2.26</td>
<td>.36</td>
</tr>
<tr>
<td>Intensity Min.</td>
<td>0.0</td>
<td>.09</td>
<td>.02</td>
<td>.12</td>
</tr>
<tr>
<td>Int. Range</td>
<td>2.91</td>
<td>2.8</td>
<td>2.24</td>
<td>.24</td>
</tr>
<tr>
<td>TD Max.</td>
<td>2.39</td>
<td>1.83</td>
<td>1.01</td>
<td>.49</td>
</tr>
<tr>
<td>TD Min.</td>
<td>0.0</td>
<td>0.0</td>
<td>.03</td>
<td>.06</td>
</tr>
<tr>
<td>TD Range</td>
<td>2.39</td>
<td>1.83</td>
<td>.98</td>
<td>.43</td>
</tr>
<tr>
<td>Timbre Max.</td>
<td>2.88</td>
<td>3.18</td>
<td>3.10</td>
<td>.55</td>
</tr>
<tr>
<td>Timbre Min.</td>
<td>0.0</td>
<td>0.0</td>
<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Timbre Range</td>
<td>2.88</td>
<td>3.18</td>
<td>3.09</td>
<td>.54</td>
</tr>
</tbody>
</table>
10) Disjunction-measures of higher-levels.

<table>
<thead>
<tr>
<th></th>
<th>Elements</th>
<th>Clangs</th>
<th>Sequences</th>
<th>Segments</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>(.996)</td>
<td>1.165</td>
<td>1.717</td>
<td>1.508</td>
<td>1.12</td>
</tr>
<tr>
<td>Max.</td>
<td>(7.31)</td>
<td>4.9</td>
<td>3.33</td>
<td>2.40</td>
<td>1.38</td>
</tr>
<tr>
<td>Min.</td>
<td>(.19)</td>
<td>.24</td>
<td>.72</td>
<td>.76</td>
<td>.91</td>
</tr>
<tr>
<td>Range</td>
<td>(7.12)</td>
<td>4.76</td>
<td>2.61</td>
<td>1.64</td>
<td>.47</td>
</tr>
</tbody>
</table>
APPENDIX III: PROGRAMME LISTING

40  WATFIV YFA018MS, LINES=60, PAGES=175, T=180
   REAL PI(1000), DUR(1000), RST(1000), AMP(1000),
   1 TIM(1000), TD(1000)
   REAL LLEV, HLEV
   REAL TITLE(15)
   REAL A1(1000), A2(1000), P1(1000), P2(1000), TD1(1000)
   1, TD2(1000)
   REAL DM(1000), DMS(1000), DM1(1000), DM2(1000)
   REAL DMIN
   INTEGER ISTART(1000), IEND(1000)
   INTEGER NEXT(10), COUNT(10), NUMBER(10)
   INTEGER HCNT, FLAG, TEMPO1

   INITIALIZE AND READ IN SCORE
   TLOG(A)=ALOG(A)/ALOG(2.0)
   READ(5, 30) TITLE
   FORMAT(15A4)
   READ(5, 40) NUMBER(1), CMIN, TEMPO1
   FORMAT(15, F5.2, 14)
   TEMPO=FLOAT(TEMPO1)/50.0
   TEMP=0.0, CMIN TO PREVENT FORTRAN ACCURACY ERRORS
   CMIN=CMIN+.001
   WRITE(6, 41) TITLE
   FORMAT(1H1, 15A4)

   WRITE(6, 55) TEMPO1
   FORMAT(1H0, 'TEMPO (MM) = ', 18)
   WRITE(5, 38) CMIN
   FORMAT(1H0, 'CMIN= ', F5.2)

   EPS1=0.0001
   N=NUMBER(1)
   DO 67 I=1, N
   READ(5, 60) P(I), DUR(I), A1(I), A2(I), TIM(I), RST(I)
   FORMAT(5X, 6F5.0)
   CONTINUE

   DO 9725 I=1, N
      P1(I)=P(I)
      DUR(I)=DUR(I)/TEMPO
      TD(I)=3.0-TLOG(DUR(I))
      TD1(I)=TD(I)
      RST(I)=RST(I)/TEMPO
      AMP(I)=(A1(I)+A2(I))/2.0
      P2(I)=P(I)
      CMIN=CMIN/TEMPO
   READ(5, 7C) NPASS
   FORMAT(14)
   DD 9600 ILOC=1, NPASS
      N=NUMBER(1)
   READ(5, 72) DW, PW, AW, TDW, TW
   FORMAT(15F6.2)
   WRITE(6, 74) DW, PW, AW, TDW, TW
   FORMAT(1H0), 'WEIGHTINGS: PROXIMITY=',
   1 F5.2, ' PITCH=', F5.2, ' INTENSITY=', F5.2, ' TEMPORAL DENSITY=',
   2 F5.2, ' TEMPORAL DENSITY=', F5.2)
   SUM=PW+DW+TDW+AW+TW
   PW=PW/NSUM
   DW=DW/NSUM
$\text{Aw} = \text{Ah}/\text{hSum}$
$\text{Tw} = \text{Tw}/\text{hSum}$

DO 76 $K = 1, 10$
COUNT($K$) = 0

DO 78 $K = 1, 1000$
DM($K$) = 0.0
DMD1($K$) = 0
DMD2($K$) = 0
IEND($K$) = 0
ISTART($K$) = 0

$\text{Dw} = \text{Dw} + 1.0$
$\text{Aw} = \text{Aw} + 2.0$

INITIALIZES BOUNDARIES ON FIRST LEVEL

DO 1777 $I = 2, N$
PI = PW * (PL(1) - P2(1-I))
TDI = 0.0
DI = DW * (RST(I-1))
IF (RST(I-1) .EQ. 0.) ALAST = A2(I-1)
IF (PST(I-1) .GT. 0.) ALAST = 0.
AI = Aw * (A1(I) - ALAST)
DMD(I) = ABS(DI) + ABS(PI) + ABS(TDI) + ABS(AI)

DMD(I) = DMD(I) * 2.0

CONTINUE

DO 80 $I = 501, 1000$
PL(I) = 0
DUR(I) = 0
AMP(I) = 0
TIM(I) = 0
RST(I) = 0

CONTINUE

LEVEL = 0

MAIN PROGRAM

SETS NEW LEVEL, CLEARS COUNTER(CHECK), AND INITIALIZES
FLAG, WHICH TELLS YOU IF YOU'VE FINISHED ON A LEVEL.
CHECK IS A VARIABLE WHICH SEES IF THERE ARE ENOUGH
TC'S CURRENTLY TO COMPUTE FOR INITIATION.

CHECK = 0
ET = 0.
FLAG = 0
LEVEL = LEVEL + 1

SETS ARRAY INDICES.
LOLEV = (2.0 ** (LEVEL - 1))
HILEV = (2.0 ** (LEVEL))
K1 = 1000.0 - ((1.0 / HILEV) * 1000.0)
K2 = 1000.0 - ((1.0 / HILEV) * 1000.0)
WRITE(6, 5375)
TO TRY AND MAKE DISTINCTIONS. SO PROGRAM TERMINATES.
IF (NUMBER(LEVEL).LT.4) GO TO 9000
HICNT=1
ISTART(K2+1)=K1+1

SPECIFIC PLANAR COMPUTATION

COUNT(LEVEL)=COUNT(LEVEL)+1
TCOUNT=TCOUNT(LEVEL)
CHECK=CHECK+1
IF (TCOUNT.LE.NUMBER(LEVEL)) GO TO 550
FLAG=1
GO TO 700

KEEPS TRACK OF ELAPSED TIME IN TG.
ET=ET+DUR(TCOUNT+K1)

CHECKS FOR 'ONE ELEMENT CLANGS'.
IF (CHECK.LT.2) GO TO 500

COMPUTE INTERVAL (DISJUNCTION MEASURE)
IND=(TCOUNT+K1)

MEAN INTERVALS
PL=P*(P(IND)-P(IND-1))
DI=DU*DUR(IND-1)
IF (LEVEL.GT.1) DI=0
TDI=TDW*(TD(IND)-TD(IND-1))
AI=A**(AMP(IND)-AMP(IND-1))
TI=TW**(TIM(IND)-TIM(IND-1))

SUMS MEAN INTERVALS.
ABSUM=ABS(PL)+ABS(TDI)+ABS(AI)+ABS(TI)+DI

"CITY-BLOCK" METRIC.
DM(IND)=.5*DM(IND)+ABSUM

GO TO 600

COMPLETES DIFFERENCE OF PEAK WITH SURROUNDING DM'S TO GIVE
ROUGH IDEA OF STRENGTH OF INITIATOR.
DM1(IND-1)=1.0-(DM(IND-2)/DM(IND-1))
DM2(IND-1)=1.0-(DM(IND)/DM(IND-1))

IF (CHECK.LT.4) GO TO 500

CHECKS MINIMUM TG LENGTH.
ETCHK=ET-(DUR(IND-1)+DUR(IND))
IF (ETCHK.LE.CMIN) GO TO 500

TESTS FOR PEAK.
IF ((DM1(IND-1).LT.EPS1).OR.(DM2(IND-1).LT.EPS1))
GO TO 500

IF DMST POSITIVE, THEN PEAK. IF ZERO, THEN NOT PEAK.
COMPUTE PEAK STRENGTH.
DMST(IND-1)=(DM1(IND-1)+DM2(IND-1))/2.

IF PEAK, VALUES ARE STORED FOR NEXT LEVEL STATES.

TIMSLM=0
AMPSLM=0
DURSLM=0
TDSUM=0
JEND=TCCOUNT+K1-2
IF(FLAG.EQ.1)JEND=TCCOUNT+K1-1
HYIND=HICTN+K2
JBEGIN=ISTART(HYIND)

DO 800 I=JBEGIN,JEND
    DURSUM=DURSUM+DUR(I)
    TIMSUM=TIMSUM+(DUR(I)*TIM(I))
    AMPSUM=AMPSUM+(DUR(I)*AMP(I))
    PITSUM=PITSUM+(DUR(I)*P(I))
    IF(LEVEL.EQ.1)TDSUM=TDSUM+TD(I)
    IF(LEVEL.NE.1)TDSUM=TDSUM+(DUR(I)*TD(I))
    CONTINUE
800 CONTINUE

ADJUSTS ELAPSED TIME W.R.T NEW TG JUST COMPUTED.
ET=ET-DURSUM

STORE VALUES AS NEXT LEVEL STATES.
DUR(HYIND)=DURSUM
P(HYIND)=PITSUM/DURSUM
AMP(HYIND)=AMPSUM/DURSUM
TIM(HYIND)=TIMSUM/DURSUM
IF (LEVEL.EQ.1)TD(HYIND)=TD(HYIND)+(JEND-JBEGIN+1)
IF (LEVEL.NE.1)TD(HYIND)=TD(HYIND)+TDSUM/DURSUM
P1(HYIND)=P(JBEGIN)
P2(HYIND)=P(JEND)
RST(HYIND)=DUR(JEND)
A1(HYIND)=AMP(JBEGIN)
A2(HYIND)=AMP(JEND)
TD1(HYIND)=TD(JBEGIN)
TD2(HYIND)=TD(JEND)
DM(HYIND)=DM(JBEGIN)

RESETS COUNTERS FOR NEW TG, REMAINING ON CURRENT LEVEL.
NUMBER(LEVEL+1)=HICTN
JEND(HYIND)=TCCOUNT+K1-2
IF (FLAG.EQ.1)JEND(HYIND)=TCCOUNT+K1-1
IF (FLAG.EQ.1) GO TO 100
HICTN=HICTN+1
CHECK=2
HYIND=HICTN+K2
ISTART(HYIND)=TCCOUNT+K1-1
GO TO 500

PRINTING SUBROUTINE.

500 K1=LEVEL
J=NUMBER(1)
CN 9010 K=1,10.
NEXT(K)=1
DO 9500 I=1,J

WRITE(6,9050)I,OUT(I),RST(I),P(I),TD(I),
A(I),A2(I),TIM(I),DM(I),DMST(I),DMDI(I),,MD2(I)

FORMAT(1H,14,9F6.2,5X,2F6.2)

IREF=I

DO 9400 M=2,K1

N=NEXT(M)

W5=INT(2.0*(M-1))

K6=1000-((1/W5)*1000)

INDX=N+K6

INDEX=INDEX-(1/W5)*1000+N

IF (INDX .GE. IREF) GO TO 9500

GO TO (9500,9100,9150,9200,9250,9300),M

CLANGS

WRITE(6,9125)

1 NEXT(M),OUT(INDX),RST(INDX),P1(INDX),P2(INDX),

2 P(INDX),TD1(INDX),TD2(INDX),TD(INDX),

3 A1(INDX),A2(INDX),AMP(INDX),TIM(INDX),

4 DM(INDX),DMST(INDX),DMDI(INDX),DM2(INDX)

FORMAT(1H0,8X,14,14F6.2,4X,2F6.2)

IREF=NEXT(M)+K6

NEXT(M)=NEXT(M)+1

WRITE(6,9375)

GO TO 9400

SEQUENCES

WRITE(6,9175)

1 NEXT(M),OUT(INDX),RST(INDX),P1(INDX),P2(INDX),

2 P(INDX),TD1(INDX),TD2(INDX),TD(INDX),

3 A1(INDX),A2(INDX),AMP(INDX),TIM(INDX),

4 DM(INDX),DMST(INDX),DMDI(INDX),DM2(INDX)

FORMAT(1H0,14X,14,14F6.2,4X,2F6.2)

IREF=NEXT(M)+K6

NEXT(M)=NEXT(M)+1

WRITE(6,9375)

GO TO 9400

SEGMENTS

WRITE(6,9225)

1 NEXT(M),OUT(INDX),RST(INDX),P1(INDX),P2(INDX),

2 P(INDX),TD1(INDX),TD2(INDX),TD(INDX),

3 A1(INDX),A2(INDX),AMP(INDX),TIM(INDX),

4 DM(INDX),DMST(INDX),DMDI(INDX),DM2(INDX)

FORMAT(1H0,24X,14,14F6.2,4X,2F6.2)

IREF=NEXT(M)+K6

NEXT(M)=NEXT(M)+1

WRITE(6,9375)

GO TO 9400

SECTIONS
WRITE(6,9275)
  1 NEXT(M),DUR(INDX),RST(INDX),P1(INDX),P2(INDX),
  2 P(INDX),T01(INDX),T02(INDX),TD(INDX),
  3 A1(INDX),A2(INDX),AMP(INDX),TIM(INDX),
  4 DM(INDX),DMST(INDX)
    75 FORMAT(1H0,15,14F6.2)
    IREF=NX1(M)+K6
    NEXT(M)=NEXT(M)+1
    WRITE(6,9375)
    GO TO 9400

WRITE(6,9325)
  1 NEXT(M),DUR(INDX),RST(INDX),P1(INDX),P2(INDX),
  2 P(INDX),T01(INDX),T02(INDX),TD(INDX),
  3 A1(INDX),A2(INDX),AMP(INDX),TIM(INDX),
  4 DM(INDX),DMST(INDX)
    325 FORMAT(1H0,15,14F6.2)
    IREF=NX1(M)+K6
    NEXT(M)=NEXT(M)+1
    WRITE(6,9375)
    GO TO 9400

FORMAT(11,1)

CONTINUE
CONTINUE
CONTINUE
STOP
END
ENTRY
Final parametric values of the next-lower-level components in pitch

For class level and higher, P1, P2, P12, P12, P12, P12 are the integral and

these values, which are not integral to the programme's operation.

positive, indicate a peak. The programme itself is set for detection on

are also relative measures of destruction strength, which, when both

next-lower-level component. DMSL is a relative measure of peak

strength, which is non-zero only when there is a peak. DMSL and IM2

The rest duration of a higher-level TG is the duration of its final

components, and the indentation shows the hierarchical level.

destructions of TGs are shown. The are printed after their lower-

Appendix: In the output data, the hierarchical segmentation and the states and
References


Tenney, J.C., with Polansky, L.  Hierarchical Gestalt Perception In Music: A "Metric Space" Model 1978 (To be published in a forthcoming issue of the J. Experimental Aesthetics, also available from the authors.)