Musical Rhythm: A Formal Model for Determining Local Boundaries, Accents and Metre in a Melodic Surface

Emilios Cambouropoulos

Faculty of Music and Department of Artificial Intelligence, University of Edinburgh, 12 Nicolson square, EH8 9DF Edinburgh, U.K.

Abstract. In this paper a general theory will be introduced that allows the description of a melodic surface – i.e. a score-like representation of a melody – in terms of local grouping, accentuation and metrical structures. Firstly, a formal model will be proposed that detects points of maximum local change that allow a listener to identify local perceptual boundaries in a melodic surface. *The Local Boundary Detection Model (LBDM)* is based on rules that are relating to the Gestalt principles of proximity and similarity. Then, it will be shown that the accentuation structure of a melody may automatically be inferred from the local boundary grouping structure. This is based on the assumption that the phenomenal accents of two contiguous musical events are closely related to the degree by which a local boundary is likely to be perceived between them. Finally, the metrical structure is revealed by matching a hierarchical metrical template onto the accentuation structure. It is suggested that the *Local Boundary Detection Model* presents a more effective method for low-level segmentation in relation to other existing models and it may be incorporated as a supplementary module to more general grouping structure theories. The rhythmic analyses obtained by the methods described herein are tentative, and complementary to higher-level organizational theories.

1 Introduction

Many contemporary theories of rhythm (Cooper & Meyer, 1960; Epstein, 1995; Kramer, 1988; Lerdahl & Jackendoff, 1983; Yeston, 1976) consider rhythm to be the organization/structuring of musical sounds into groups (grouping structure) of more or less salient elements (accentuation structure) that are in constant interplay/interaction with a hierarchy of beats (metrical structure). Metre receives somewhat different treatment in each of these theories and is to a varying extent integrated into the ways rhythm is defined (Moelants, 1997, this book).

For instance, Lerdahl and Jackendoff's definition of rhythm is based on two kinds of structures: namely *grouping structure* that "expresses a hierarchical segmentation of a piece into motives, phrases and sections" and *metrical structure* that "expresses the intuition that the events of a piece are related to a regular alternation of strong and weak beats at a number of hierarchical levels" (Lerdahl & Jackendoff, 1983, p.8). They define three kinds of musical accents: *phenomenal accents* which are due to local intensification such as dynamic stress, high or low register, long notes, harmonic changes and so on, *structural accents* which result from higher-level structural relations such as cadences, and *metrical accents* that correspond to relatively strong beats in a metrical context. Defining a metrical structure is finding a well-formed grid of metrical accents that fits best onto the structure of phenomenal accents: "... the listener's cognitive task is to match the given pattern of phenomenal accentuation as closely as possible to a permissible pattern of metrical accentuation. ... Metrical accent, then, is a mental construct, inferred from but not identical to the patterns of accentuation at the musical surface." (Lerdahl & Jackendoff, 1983, p.18). In their theory, grouping structure is considered to be independent of metrical structure and hence different preference rules are formulated for each: one set of preference rules for the description of groupings and a different independent set for the description of the phenomenal and structural accentuation structure from which metrical structure is inferred (Fig.1a).

The concept that rhythm relates to cognitive grouping of musical events is a Gestalt-based one. The Gestalt principles of perceptual organization are a set of rules-of-thumb that suggest preferential ways of grouping mainly visual events into larger scale schemata. Two of the Gestalt principles state that objects closer together (Proximity principle) or more similar to each other (Similarity principle) tend to be perceived as groups. These principles have been used as a basis for some contemporary theories of musical rhythm. Tenney (1964) discusses the use of the principles of proximity and similarity as a means of providing cohesion and segregation in twentieth century music and, later, Tenney and Polansky (1980) develop a computational system that discovers grouping boundaries in a melodic surface. Musical psychologists (Bregman, 1990; Deutsch, 1982a, 1982b; McAdams, 1984) have experimented and suggested as to how the Gestalt rules may be applied into auditory/musical perception and Deutsch and Feroe (1981) further incorporate such rules in a formal model for representing tonal pitch sequences. The grouping component of Lerdahl and Jackendoff's *Generative Theory of Tonal Music* (Lerdahl & Jackendoff, 1983) is based on the Gestalt theory and an explicit set of rules is thereby described – especially for the low-level grouping boundaries. The formulation of these rules has been supported by the experimental work of I. Deliége (1987).

In the first part of this paper a systematic theory will be described that attempts to define local boundaries in a given melodic surface (see Cambouropoulos, 1996b, for a general representation of pitch intervals). The proposed segmentation model *(Local Boundary Detection Model – LBDM)* will be based on two rules: the *Identity-Change rule* (which is more elementary than the Gestalt principles of proximity and similarity) and the *Proximity rule* (which relates to the Gestalt proximity and similarity principles). The aim has been to develop a formal theory that may suggest all the possible points for local grouping boundaries on a musical surface with various degrees of prominence attached to them rather than a theory that suggests

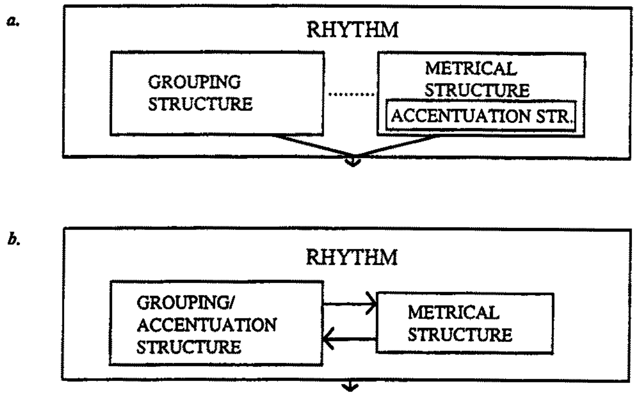

Fig. 1. (a) Lerdahl and Jackendoff's theory of musical rhythm. (b) Proposed model of musical rhythm

some prominent boundaries based on a restricted set of heuristic rules. The discovered boundaries are only seen as potential boundaries as one has to bear in mind that musically interesting groups can be defined only in conjunction with higher-level grouping analysis (parallelism, symmetry, etc.). Low-level grouping boundaries may be coupled with higher-level theories so as to produce *optimum* segmentations.

It will be shown that the formulation of the boundary discovery procedures defined by Lerdahl and Jackendoff (1983) and Tenney and Polansky (1980) have limitations and can be subsumed by the proposed theory. Some examples and counter-examples will be given mainly in relation to the influential formulation of the local detail grouping preference rules by Lerdahl and Jackendoff (1983).

In the second part of the paper it will be maintained that low-level grouping structure and phenomenal accentuation structure are strongly associated; they are actually in a *one-to-one* relation, i.e. if one is defined then the other may automatically be inferred. In other words, if local boundaries for a given melodic surface have been defined then strengths for phenomenal accents may be inferred (the reverse is also possible although not examined in this paper). It is assumed that the phenomenal accents of two contiguous musical events are closely related to the degree by which a local boundary is likely to be perceived between them. A method then is described that mechanically derives accent strengths from the local boundary strengths detected by the *Local Boundary Detection Model.*

The strong link between grouping and accentuation structures is important in that it allows one to develop a model that does not need two separate independent methods for the detection of the local boundaries and the phenomenal accents respectively. In contrast with Lerdahl and Jackendoff's model (Fig.1a) the proposed model directly links phenomenal accentuation structure with grouping structure (Fig.1b). This enables a more economic and efficient formulation of a theory for rhythm.

Once the phenomenal accentuation structure has been defined an attempt can be made to match a well-formed metrical structure to it; this may be possible for a number of hierarchic metric levels of beats or only for one level or possibly for no level at all depending on the kind of music. Metrical structure may be inferred from the accentuation structure but, at the same time, it influences the perception of the accentuation/grouping structure. The interplay between these two kinds of structures is addressed further towards the end of this paper.

In the following sections, formal methods will be described, firstly, for the discovery of local boundaries (low-level grouping structure) in a melodic surface, secondly, for the derivation of the phenomenal accentuation structure from the grouping structure and, lastly, for the selection of a metrical structure that fits best onto the accentuation structure.

2 The Gestalt Principles of Proximity and Similarity in Theories of Musical Rhythm

Some problems in the way the low-level Gestalt principles of perceptual organization have been applied in the organization of temporal musical sequences are briefly discussed below.

The Gestalt principles of proximity and similarity have been applied in both Tenney and Polansky's and Lerdahl and Jackendoff's models in such a way that allow one to interpret them as being different descriptions of the same phenomenon, namely a local maximum in the distance between consecutive musical events for any musical parameter e.g. pitch, start-times, dynamics and so on. Tenney and Polansky state explicitly that the similarity principle – as they define it – actually includes the proximity principle as a special case: "In both, it is the occurrence of a *local maximum in interval magnitudes* which determines clang-initiation" (Tenney & Polansky, 1980, p. 211). Lerdahl and Jackendoff's grouping rules (Lerdahl & Jackendoff, 1983) are defined in such a way that it seems rather plausible that the proximity rules can be subsumed by the change (similarity) rules and the reverse. For example, GPR3a (register rule) states that a greater pitch interval in between smaller neighboring intervals initiates a grouping boundary. This can been seen in two ways: a) that the pitches of the first and last intervals are more *similar* to each other than the pitches of the middle interval or b) that there is a greater *proximity* between the first two pitches – and the last two – rather than between the middle pitches (Handel, 1989, p.198).

In the current paper it will be maintained that although this formalization of the Gestalt principles provides the most important factor for discovering local boundaries a more general approach should account for any change in interval magnitudes. For example, in the following sequence of durations: ♩ ♩ ♩ ♪ ♩ ♩ ♩ a listener easily hears a possible point of segmentation for which neither the Tenney and Polansky nor the Lerdahl and Jackendoff formalisms suggest any boundary. For this reason a different, more elementary rule will be introduced based on the principle of Identity-Change. This issue will be discussed further in the next section and it will be shown that the above example can naturally be accommodated within the proposed model.

The low-level Gestalt principles of proximity and similarity are usually applied on symmetrical non-directional spaces. On applying them to musical temporal spaces, one has to make certain concessions by removing all possible asymmetrical directional properties (e.g. direction of pitch-intervals). There is though one aspect of musical asymmetry that cannot be avoided. This relates to the fact that musical objects are asymmetric objects themselves – even the most simplified homogeneous description of a note distinguishes between its attack and the rest of its body. This asymmetry is reflected in that, for instance, the temporal grouping rules can never give an identical grouping structure to the original and the retrograde form of a melody. It relates to the way that rules of perceptual organization give different grouping boundaries for musical duration sequences and for start-time interval sequences. It will be shown below how the interaction between these duration and start-time interval groupings results in the asymmetric perceptual organization of a sequence of musical events.

We will now attempt to define the Identity-Change rule and the Proximity rule which will form the basis of the *Local Boundary Detection Model.* These rules will be discussed initially for any sequence of two or three objects and then will be applied to longer sequences of musical objects.

3 The *Local Boundary Detection Model*

A formal model that attempts to determine local boundaries in a given melodic surface will now be presented. (For or a detailed description, see Cambouropoulos, 1996a).

3.1 The Identity-Change and Proximity Rules

As we have seen above, the Gestalt principles of proximity and similarity can be interpreted as being different sides of the same coin. In the *Local Boundary Detection Model (LBDM)* an elementary rule will be introduced based on the principle of identity. The Identity-Change rule is more elementary as it can be applied to a minimum of two entities (i.e. two entities can be judged to be identical or not) whereas the Proximity/Similarity rule requires at least three entities (i.e. two entities are closer or more similar than two other entities). This Identity-Change rule, in conjunction with the Proximity rule, forms the basis of the proposed low-level segmentation model.

General Identity-Change Rule: Grouping boundaries may be introduced only between two different entities. Identical entities do not suggest any boundaries between them. This rule is supported by an experiment realized by Garner (1974) wherein an eight-element pattern composed of two different pitch elements, for example XXXOXOOO, is looped indefinitely and listeners are asked to describe the pattern they perceive. Various preferential ways of organization were recorded (there are eight possibilities starting on each element of the sequence) but hardly ever did any listener break a run of same elements.

If the entities compared are intervals (intervals for pitch, start-times, dynamics, etc.) then this rule can be formulated more specifically:

Identity-Change Rule (ICR): Amongst three successive objects boundaries may be introduced on either of the consecutive intervals formed by the objects if these intervals are different. If both intervals are identical no boundary is suggested. When the application of ICR on two consecutive intervals detects a change and suggests a local boundary, this boundary is ambiguous (i.e. the boundary can be placed on either side of the middle object) and each interval receives the same boundary strength value. The second rule (PR) resolves the ambiguity by giving preference to the larger of the two intervals.

Proximity Rule (PR): Amongst three successive objects that form different intervals between them a boundary may be introduced on the larger interval i.e. those two objects will tend to form a group that are closer together (or more similar to each other).

3.2 Applying the ICR and PR Rules on Three Note Sequences

We will assume that for each parametric feature of a musical surface we can construct a sequence of intervals on which the ICR and PR rules may be applied. We will start by presenting the application of the rules to the following parameters: pitch, dynamics, rests and articulation (slurs, staccatti, breath-marks etc. are considered to be expressional rests and are inserted between the notes they mark as normal rests that have a value that is a fraction of the preceding note). The grouping boundaries resulting from the sequence of start-time intervals and durations will be presented at the end of this section.

The relation between two intervals can be of two types: *identity* or *change*. For reasons of asymmetry that will be introduced later on we will depict the change relation in two directional forms: "+" and "-" (Fig.2b and 2c). In the following Figures, dots represent parametric values of musical events and the distances between the dots the interval sizes between these values (Δx, Δy are interval values and are placed at the left-hand side of the interval). In Fig.2a $\Delta x = \Delta y$ and the identity relation is represented by a zero. In Fig.2b

$\Delta x > \Delta y$ and in Fig.2c $\Delta x < \Delta y$, and the change relations are represented by the "+" and "-" signs respectively.

At this stage we will introduce numeric values for the strength of the ICR and PR rules (more research is necessary for the selection of the most appropriate values). A numeric value is given to each interval as indicated below:

ICR: 0 for the identity relation (0 for each interval)
2 for the change relation (1 for each interval)
PR: 0 for the identity relation (0 for each interval)
1 for the change relation (1 for the larger interval)

We get thus the total interval boundary strengths as depicted in Fig.2 (bottom line).

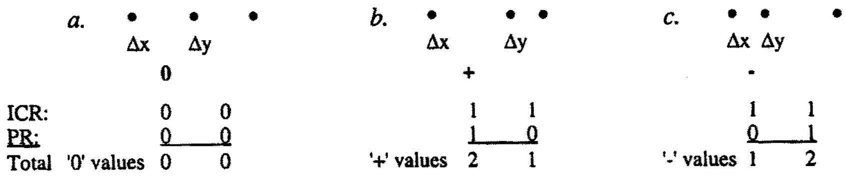

Fig. 2. Boundary strengths (last row) calculated by the use of the ICR and PR rules for three parametric values (e.g. pitch, dynamics etc.) separated by two intervals

We can now examine the duration and start-time interval sequences. The duration of a musical event is an internal attribute of that event whereas start-time intervals are temporal distances between two different successive events. We have thus the application of the ICR and PR rules for the start-time intervals exactly as described above and, additionally, the application of the General ICR for the sequence of durations (numeric strength 2). We now have the following kinds of relations (Fig.3 for two start-time intervals delimited by 3 start-time points (dots) and the two corresponding durations (rectangles) Fig.3. It is now clear that the "+" and "-" change relations are not symmetric. It is not possible to apply the principles of perceptual organisation in the musical temporal domain without introducing local asymmetry.

3.3 Applying the ICR and PR Rules on Longer Melodic Surfaces

For a given parametric interval profile of a musical surface one finds all the kinds of interval relations (0, +, -) that exist between every two successive intervals. If there are 3 or more consecutive "+" or "-" relations (e.g. +++, - - - - -), then only the ones at the ends are considered – the others do not contribute to the numeric strengths. Then, the numeric strengths for each kind of relation are calculated and added for each interval. For a single

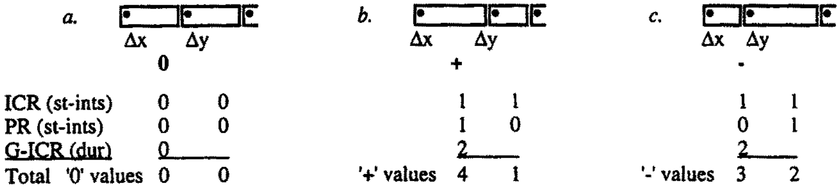

Fig. 3. Boundary strengths (last row) calculated by the use of the ICR and PR rules for three start-time values separated by two start-time intervals and durations

numeric strength sequence the local maxima suggest the most preferable local boundaries (when a local maximum consists of more than one same or almost the same values then an ambiguous boundary is suggested).

In Fig.4 we give a first example of how one can use the ICR and PR rules to calculate the strengths of grouping boundaries for - + sequences. As it happens, almost all of the grouping preference rules of Lerdahl and Jackendoff (1983) (exception: GPR3d (equal note length) and the articulation changes form legato to staccato and the opposite, fall under the *0 + 0* and *0 - 0* combinations), and all the grouping rules suggested by Tenney and Polansky (1980) fall under the - + category of sequences (see Cambouropoulos, 1996a, for the application of the *LBDM* rules to the local detail examples of Lerdahl and Jackendoff's grouping theory). The formulation of the boundary discovery procedures defined by Tenney and Polansky and Lerdahl and Jackendoff are specific instances of the proposed theory. The boundaries in

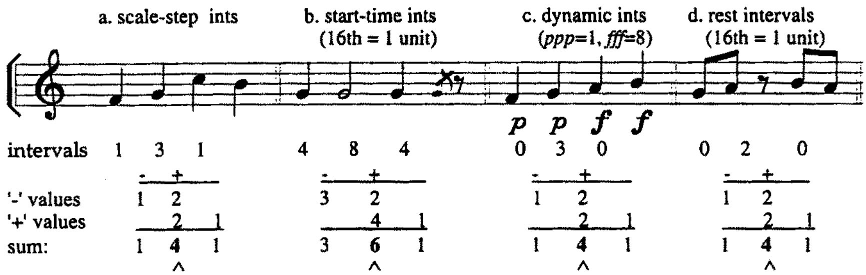

Fig. 4. Examples of boundary strengths (last row) determined by the *LBDM*

the examples of Fig.4 are detected by Tenney and Polansky's and Lerdahl and Jackendoff's methods whereas their models do not suggest any boundaries for the examples in Fig.5. In contrast, the *LBDM* suggests ambiguous boundaries for all the examples of Fig.5 (such ambiguous boundaries may be resolved if higher-level grouping organizational principles are taken into account). The above procedure is realized for every parametric interval pro-

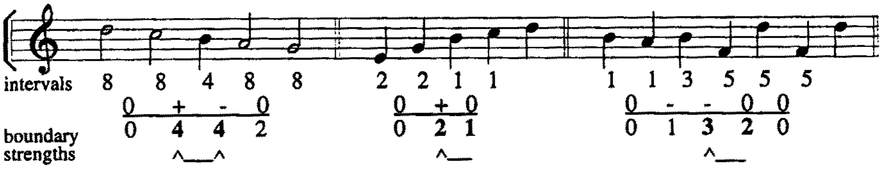

Fig. 5. Examples of boundary strengths (last row) determined by the *LBDM*. These are ambiguous boundaries which may be resolved if higher-level organizational principles are taken into account

file of interest. Then the total sum of all the numeric strength sequences is calculated (weighted or not). The local peaks are the points in a melodic sequence at which boundaries may preferably appear. In Fig.6 the preferred grouping structure is presented for Mozart's opening of the *Symphony in G minor*. The boundary strengths for each parametric interval profile are calculated and then added to produce the total boundary strength sequence A. Sequence B is given by a refined version of *LBDM* which takes in account the degree of difference between two intervals and other factors discussed in Cambouropoulos (1996b). *LBDM* has been successfully applied to many kinds of melodic surfaces – from traditional tonal melodies to contemporary atonal surfaces; see Figs.8-9 and also Cambouropoulos (1996a). This method can be further enriched if, for example, harmonic chord distance or scale-degree tonal distance profiles of the melodic surfaces are incorporated.

4 Phenomenal Accentuation Structure

In this paper it is maintained that local grouping and phenomenal accentuation structures are not independent components of a theory of musical rhythm but that they are in a *one-to-one* relation, i.e. accentuation structure can be derived from the grouping structure and the reverse. If, for instance, one develops an elaborate model of local grouping structure (such as *LBDM*) then, from this, the accentuation structure can automatically be inferred. This hypothesis is fundamentally different from much common practice whereby one set of rules are given for the detection of grouping boundaries and a different set for the determination of accents of musical notes.

The above hypothesis is based on the observation that group boundaries are closely related to the accented/salient events between which they occur. A perceived boundary in a given continuum indicates that the elements that delimit it are more prominent than other events further away. Epstein states:

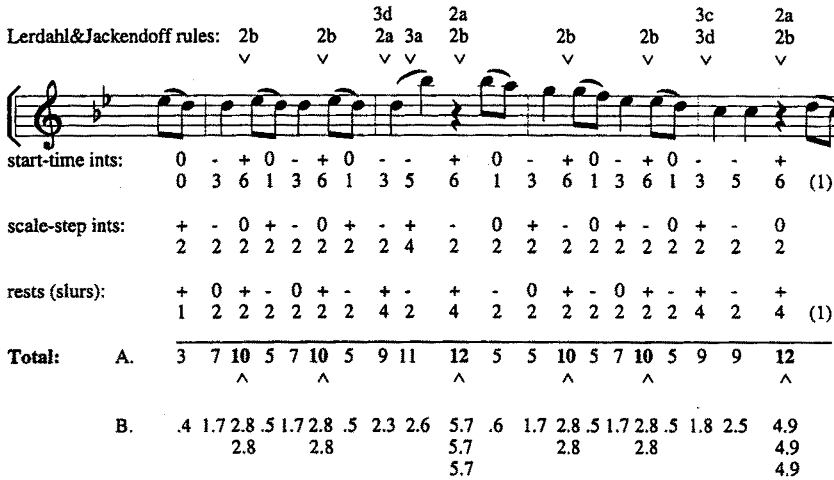

Fig. 6. Low-level grouping structure for the theme of Mozart's *Symphony in G minor*. The boundary strengths sequence A is determined by the *LBDM* whereas sequence B is determined by the refined version of *LBDM* described in Cambouropoulos (1996a)

"Demarcation in effect means emphasis – the emphasis required at that moment when a border of some time segment is to be delineated" (Epstein, 1995, p.24).

In Fig.7 the local boundary strengths are given according to the *Local Boundary Detection Model*. It is hypothesized that *if the boundary strength values are added for every two successive intervals the local accentuation structure of the surface is revealed.* The local maxima in this sequence of accent strengths indicate the elements in the surface that are perceived as being more prominent. In particular, the events delimited by two approximately equal local boundary values (e.g. Fig.7d) are considered to be most salient, i.e. an element that is preceded and followed by a significant boundary indication (ambiguous boundary) tends to be unambiguously highlighted into perception. For the cases where the two events delimiting a boundary receive equal (or almost equal) accent strength values (Fig.7c) there is a general tendency to consider the element that initiates a group as more intense although there are cases where this isn't true (Handel, 1989, Chap.11). As the proposed formal model is considered merely to be complementary to other organizational principles (e.g. metre, parallelism, symmetry, learned structural schemata etc.) these ambiguities are left unresolved at this low level. For example, a given metrical context for the melodic excerpt of Fig.7c may assist in resolving the ambiguity by adding metrical accent to one or the other of the two accented notes. The accentuation structure has been calculated

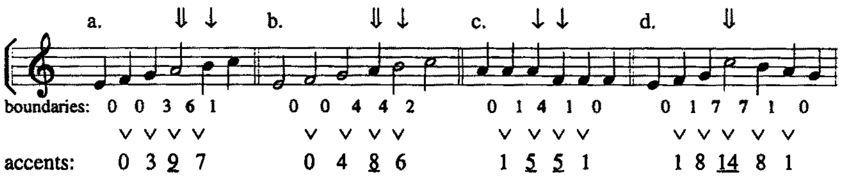

Fig. 7. Examples of phenomenal accent strengths derived from the LBDM boundary strengths by merely adding every two adjacent boundary strength values

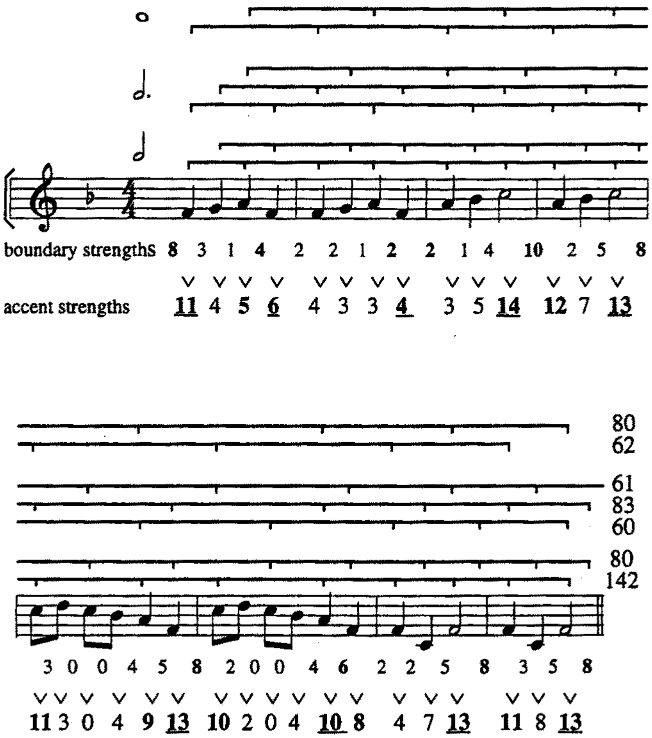

Fig. 8. Accentuation and metric structure for the song *Frère Jacques*

Fig. 9. Accentuation and metric structure for the beginning of J.S.Bach's *Concert for Harpsichord in D minor*

for a variety of melodic surfaces and has produced very reliable results. In Figs.8-9 the accentuation structure is presented for two melodic examples. The local maxima – and the relatively large numeric strengths – indicate the most accented events. Note that most of the strong accents correspond to events that a listener may perceive as most prominent and that the ones that may be considered counter-intuitive (e.g. accent on the 4th quarter-note of *Frère Jacques*) are due to the fact that metrical accents and higher-level principles of organization have not been taken into account (especially for *Frère Jacques*, parallelism/repetition plays a paramount role in the determination of grouping structure).

In the next section it will be shown that the rudimentary phenomenal accentuation structures revealed with the help of the simple mechanism described above may be sufficient for the derivation of the melodic metrical structures – whenever such metrical structures do exist. This further supports the validity of the proposed method for determining accentuation structures.

5 Metrical Structure

Musical time is structured around a cognitive framework of well-formed hierarchically ordered time-points (at least for metric/tonal music). Metrical structure is an abstract system of reference that facilitates the ordering/structuring of sequentially emitted/received musical events (Clarke, 1987).

A metrical structure consists of a number of levels of steady patterns of beats (the beat level at which listeners might tap their foot or clap their hands will be referred to as the tactus). The simplest and most *natural* tactus is when beats are separated by equal time-span units and are delivered at a rate in the neighborhood of 1.7 beats/sec (not much slower than 1 beats/sec, not much faster than 4 beats/sec) (Handel, 1989). It is possible though to have a tactus where beats are separated by non-regular time-span units as in much of the traditional music of the Balkans (e.g. dance songs in 7/8 metre are usually danced/clapped at 1.5:1:1 beat time-span ratios). Time-spans between beats may be further divided into smaller units down to the elementary unit or *fastest pulse* (Seifert, Olk, & Schneider, 1995). Above the tactus beats may be organized into larger measures (usually in regular binary/ternary patterns) and, often, into even larger hypermeasures. In Fig.10 some well-formed metrical structures are presented. It should be noted, though, that some music doesn't have metric structure at all (e.g. much contemporary music) or only a tactus without higher-level metrical hierarchies, e.g. much of African music – see Arom (1991).

A metrical hierarchic grid may be matched onto the accentuation structure of a musical piece (more on template-matching models in Parncutt, 1994). It is asserted that if the grouping/accentuation structure of a piece has been defined then the most appropriate metrical structure may be induced. But, conversely, the metrical structure – once a listener has made a selection – strongly influences and resolves ambiguity in the grouping/accentuation structure. Metrical accents are added onto the accentuation strengths and thus regulate the grouping structure of a piece. Metre is not simply a mental artefact induced from the music but actually has an autonomous psychological existence that is developed within a cultural context and influences actively the way music is performed/perceived (see Clarke, 1985, for an experiment that highlights the influence of different metrical frameworks on the performance of the same melody).

Let's examine now how a metric grid may be matched onto a given accentuation structure. Computational models of the perception of metre – mainly for plain sequences of inter-onset intervals – are described in Lee (1991), Longuet-Higgins and Lee (1982, 1987), Povel and Essens (1985), Rosenthal (1992), and Steedman (1977). In the current model, the total accent strength

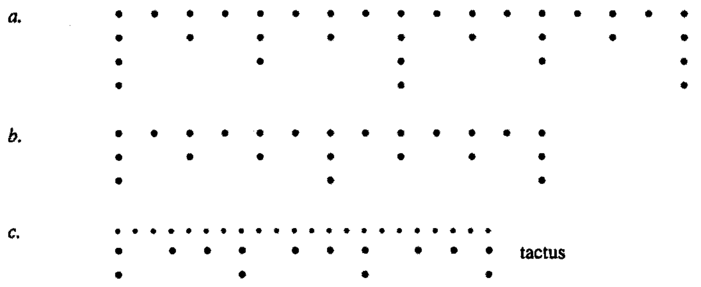

Fig. 10. Examples of well-formed metrical grids

that corresponds to a given metric grid can be calculated by adding the accents of all the events whose inception coincides with the points of the grid. If between different positions/displacements of a metric grid one finds a *significantly* greater total value, then this is considered to be the best fit. If the various placements of a grid receive similar values, then metrical ambiguity is suggested as to that grid.

The two examples presented above (Figs.8-9) are taken from the Western metric/tonal musical tradition, so we would expect that a regular metre of binary/ternary beat patterns would be appropriate (Figs.10a-10b). For both of these examples we consider that the tactus appears at the quarter-note durational value (depends on the tempo). Below is a discussion on the metrical structure of these two melodies.

In Fig.8 we see that at the half-note metric level the total accent strength (indicated at the end of each metric grid) of the binary grid that starts on the first note is much stronger than that of the one that starts on the second quarter-note. This agrees with the metrical perception listeners have and the way metre is indicated on the score. Ternary metrical grids do not suggest any strong preferences (and obviously parallelism considerations would immediately rule them out). Once a binary grid is established, we can examine the next metric level of a whole-note grid. There is no strong preference (there is ambiguity) between the two possible arrangements although the one that starts on the third note is slightly preferred i.e. if articulation and the song word prosody are not taken into account the structure of the piece suggests a gavotte-like metre (bar-lines shifted to the right by two quarter-note beats). Interestingly enough, the prosodic structure of the Greek version of the song adheres to this alternative metrical structure.

The first six bars of Bach's *Concert for Harpsichord in D minor* (Fig.9) are already ambiguous at the tactus; the metrical structure becomes clear only after the seventh bar. The quarter-note beat grid that starts on the first note and the one that starts after an eighth durational value have almost the same total accent strengths (the ambiguity is maintained at the half-note level as well). The first two notes are heard as an upbeat and the listener makes a first selection of a metrical structure that considers the 3rd, 5th and 7th notes as metrically stronger. This assumption is overturned in bar 2 – where the metrical grid is in-phase with the metre indicated on the score – and the beginning of bar 3 is perceived as a suspension. But as more information arrives there is a tendency to shift the metre again and place strong metrical beats on the *suspended* notes. The section that comprises of sixteenth notes is metrically ambiguous. The second half of bar 5 and the first half of bar 6 suggest a metrical structure that conforms with the metric grid that is displaced/shifted by an eighth-durational value. From the second half of bar 6 onwards the metrical structure becomes clear matching the metre indicated in the score. In Fig.9 (top) the melody has been segmented in such a way that the accentuation strength difference in each segment is maximised for the two alternative positions. This metrical analysis seems to correspond to the metrical ambiguity that the composer has intentionally implanted in the melodic surface and that is perceived by the listener.

6 Conclusion

In this paper a formal theory for the low-level rhythmic description of a melodic surface has been presented. The *Local Boundary Detection Model* is based on the *Identity-Change* and *Proximity* rules and detects points of maximum change that allow a listener to identify local boundaries in a melody. This model is more general than the grouping models of both Tenney and Polansky (1980) and Lerdahl and Jackendoff (1983); it can easily be implemented as a computer program and may readily be incorporated as a supplementary module to higher-level theories of rhythmic organization.

It has also been maintained that grouping and accentuation structures are very closely related. Once a grouping structure is defined, the accentuation structure emerges naturally and, from this, the metrical structure may be inferred. It is suggested that the proposed theory is more economic and coherent than most theories of rhythm that treat grouping and accentuation structures as independent components. The evidence presented in this study accounts only for low-level structural features of grouping and accentuation organization. It may be the case that at higher-levels of organization these structures may be partially independent and conflicting. It still is very interesting to see how much is embodied in and can be inferred from a well defined local grouping structure (namely accentuation and metrical structures).

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