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Auditory Streams in Ligeti's *Continuum:* A Theoretical and Perceptual Approach

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Background in music theory/analysis. Musical analysis focuses primarily on aspects of compositional design, mathematical/formal relations between musical materials or on musical theoretic forms and functions that have been established as musicologically pertinent through the centuries (e.g., traditional harmonic analysis, Schenkerian analysis). Listeners' perception is not usually the explicit goal of analytical methodologies.
Background in music psychology. The coherence of a progression of tones or sonorities depends on a number of perceptual factors that have been described in the domain of auditory scene analysis. Principles of musical stream perception may be used to understand of the way a listener 'makes sense' of a musical work. The way a musical work is perceived by a listener may be significantly different from the organization of notes suggested by a score, or even from analytic results given by different musical analytic methodologies.
Aims. The aim of this paper is to show how a number of auditory streaming principles may be used to obtain a better understanding of a specific musical work, namely Ligeti's *Continuum* for harpsichord. We show that 'traditional' music analytic methodologies are insufficient to account for the listening challenges posed by the specific work, and that music perception can shed new light in our understanding of the musical structure of this piece.
Main contribution. Ligeti's *Continuum* is a representative example of his *meccanico* style, in which extremely fast isochronous pitch successions unfold gradually creating a smoothly evolving musical continuum. In the current study, auditory streaming processes based on principles such as the principles of Temporal Continuity, Tonal Fusion, Pitch Proximity, Pitch Co-modulation, and Onset Synchrony Principle and, also, aspects of sound 'grain' perception are used as an analytic tool to explain various musical phenomena appearing in the piece. Ligeti's work is analyzed both in terms of melodic/voice and harmonic evolution. It is shown that musical psychology can offer a very fruitful way of looking directly into certain structural features of music that other analytic methodologies have difficulty dealing with.
Implications. The current study shows how musical perception can play a direct role in musical analysis and how it can provide new insights in our understanding of musical structure. Moreover, it suggests that composers may benefit from research in musical perception by having knowledge of how their music is likely to be perceived by audiences. The integration of perceptual and musicological perspectives in contemporary musical analytic methodology enriches not only our understanding of musical structure, but also provides a broader and more 'scientific' framework for musical analysis that can lead to various practical applications (pedagogical, compositional, computational, and so on).

Keywords: voice separation, auditory streaming, Ligeti, Continuum.

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Introduction

Musical analysis is

> 'the resolution of a musical structure into relatively simpler constituent elements, and the investigation of those elements within that structure. … Underlying all aspects of analysis as an activity is the fundamental point of contact between mind and musical sound, namely musical perception.' (Bent, 1980, pp. 340-341)

Despite the fact that music perception research has grown significantly in the last decades and has established itself as an important discipline within musicology, links with the domain of musical analysis/theory are still relatively weak; music analytic methodologies based on perceptual/cognitive approaches cover a relatively small area of musical analysis (e.g. Meyer, Huron, Zbikowski, Temperley). Musical analysis seems to be preoccupied with aspects of compositional design (what the composer had in mind when composing a certain piece), mathematical/formal relations between musical materials (e.g. pc-set theory etc.), application of established analytic methodologies (Schenkerian, traditional harmonic analysis). 'The fundamental point of contact between mind and musical sound' in the music analytic process is not usually explicitly the goal of analysis.

Ligeti's *Continuum* is a representative example of his *meccanico* style, in which extremely fast isochronous pitch successions unfold gradually creating a smoothly evolving musical continuum. A number of papers describe aspects of the formal design of the piece and, also, refer to Ligeti's own comments regarding the *meccanico* style (e.g. Hicks, 1993), but no study addresses directly the challenging issue of how the piece is actually perceived. In the current study, auditory streaming processes based on principles such as the principles of Temporal Continuity, Tonal Fusion, Pitch Proximity, Pitch Co-modulation, and Onset Synchrony Principle (Huron, 2001) and, also, aspects of sound 'grain' perception (Roads, 2001) are used as an analytic tool to explain various musical phenomena appearing in the piece. Ligeti's work is analyzed both in terms of melodic/voice and harmonic evolution (future work should study empirically the hypotheses presented in this paper). It is shown that music psychology can offer a very fruitful way of looking directly into certain structural features of music that other analytic methodologies have difficulty dealing with.

Ligeti's Continuum is used in this paper simply as an example to show how perceptual principles of auditory organisation can be introduced in music analysis/theory to give a rich account of understanding of a musical work. Such principles are always at work during music listening as they are part of our general auditory apparatus, and underlie explicitly or implicitly common compositional practices (e.g. voice-leading practices – Huron, 2001). It is suggested that music theory/analysis may benefit from studies in music perception not only in 'exceptional' cases such as Ligeti's Continuum but also in a wide range of music such as music by Bach, Brahms, Debussy, Reich or many different kinds of traditional musics.

Below, a brief outline of the main analytic approaches presented in previous papers is given and, then, a number of fundamental perceptual principles that enable a listener to organize musical material into meaningful entities are described. In a further section, a series of examples from *Continuum* are presented that illustrate the use of perceptual principles in voice separation and auditory stream perception, and finally the harmonic plan that evolves through the piece is discussed.

Related work – Analytic approaches to *Continuum*

Considerable analytical work has been conducted and published regarding Ligeti's "pattern-meccanico" or "net-structure" works[i] (for a comprehensive bibliography see Roig-Francolí 1995, pp. 242-3). Research focusing on *Continuum* and the particular techniques used in its composition is summarized in three articles: J.P. Clendinning's "The Pattern-Meccanico Compositions of György Ligeti" (1993), M. Hicks' "Interval and Form in Ligeti's Continuum and Coulée" (1993) and M. Roig-Francoli's "Harmonic and Formal Processes in Ligeti's Net-Structure Compositions" (1995), out of which only Hicks' article includes a detailed analytical discussion of *Continuum* (for a more comprehensive analytical bibliography on *Continuum* see Hicks 1993, p. 187).

Clendinning (1993) provides thorough accounts of surface compositional processes in Ligeti's complex musical webs. She discusses pattern transformation procedures in works such as *Continuum, Coulée, Ten Pieces for Wind Quintet,* no. 8, the *Second String Quartet*, and the *Chamber Concerto*, using a variety of graphs to illustrate range, pattern interaction, pattern-change rate, and pattern shift. Hicks (1993) explores the relationship between form and intervallic progression in *Continuum* and *Coulée*, two compositions based exclusively on pattern repetition and transformation. Hicks' analyses are comprehensive and his theoretical framework is based on the composer's writings and interviews (see more below). Miguel Roig-Francolí (1995) examines the compositional techniques used in the building of net-structures, webs of finely-woven interacting lines or repeated patterns in a constant process of transformation. He uses pitch reductions to analyze net-structures based either on chromatic fluctuation of melodic microstructures or on constant transformation of harmonic cells by means of intervallic expansion or contraction in works such as *Ramifications,* the *Second String Quartet*, and the *Chamber Concerto* I. He also emphasizes that the main generating elements of large formal designs in net-structure compositions are harmonic and textural transformation along with proportional relationships such as the golden mean.

A "net-structure" (*Netzstructuren* as described by Ligeti) is a continuous web of finely-woven lines or repeated patterns in a constant, interactive process of transformation of one or more parameters, such as pitch, rhythm, texture, dynamics, or timbre. Harmonic transformation in net-structures results from systematic processes of chromatic fluctuation or intervallic expansion and contraction (Roig-Francolí 1995, p. 243). The papers by Clendinning and Hicks have focused on the type of net-structure based on the repetition and transformation of patterns. Neither Clendinning nor Hicks, however, have used the term "net-structure," preferring instead the terms "meccanico" and "pattern-meccanico" procedures, which allude to

Ligeti's interest on the ticking of mechanical devices. The composer himself uses both terms without clarifying the difference between them. Roig-Francolí (1995, p. 244) tries to disambiguate the terminological confusion and uses the term "net-structures" to describe the pattern-generated processes (transformation of melodic or harmonic patterns) and the term "meccanico" to describe the pitch-repetitive, mechanical style (quick mechanical reiteration of only one pitch per instrument). However, in *Continuum* both types are used (the piece features both isochronous mechanical-type note reiterations and pattern transformations) in an amalgamated way, so the present paper does not deal with this terminological distinction and considers Clendinning's term "Pattern-Meccanico" most suitable for the piece.

Selected excerpts of Ligeti's interviews or conversations (Ligeti et al, 1983) shed light to his compositional techniques regarding this particular piece:

> "What you perceive as rhythm is not rhythm coming from the succession of notes your fingers play. The actual rhythm of the piece is a pulsation that emerges from the distribution of the notes, from the frequency of their repetitions." (ibid p. 61).

This indicates his "granular" conception of sound creation and that the *perceived* rhythm is based on emerging patterns and is different from the finger-articulated rhythm.

"Composition consists principally of injecting a system of links into naïve musical ideas." (ibid p. 124). Form in his *Pattern-Meccanico style* pieces seems to rely on the 'naïve music idea' of opposition between points of clearness (interval signals) and transitory blurring areas. He also spoke about replacing "pairs of opposition in traditional music" such as *tension vs. resolution* and *dissonance vs. consonance* with a concern for textural density: "I contrast 'mistiness' with passages of 'clearing up' " (ibid p. 60).

> "… you hear an interval [signal] that gets gradually blurred and in the ensuing mist another interval [signal] appears,… 'Mistiness' actually means a contrapuntal texture, a micropolyphonic cobweb technique; the perfect interval appears in the texture first as a hint and then gradually becomes the dominant feature" (ibid p. 60).

These phrases reveal his conception about the form-creating interval signals and about his net-structure micropolyphony.

"… signals are neither tonal nor atonal yet somehow, with their purity and clarity, they constitute points of rest" (ibid p. 31). As Hicks and Clendinning have observed, these signals are mostly dyads or trichords consisting of major 2nds, minor 3rds, perfect 4ths, tritones and rarely major or minor triads. Hicks (1993, p. 174) also makes a distinction between simple, one-octave, pitch intervals (pi), and compound pitch intervals (cpi), i.e., simple intervals with one or more octaves added.

Hicks (1993, pp. 174-5) articulates three different blurring processes and four different roles that intervals can play in the construction and blurring of signals. More specifically, signals may be blurred by *filling*, a process wherein new pitches are inserted into existing intervals, by *accretion*, in which new pitches are attached to the outside of existing intervals, or by *shifting*, in which one or more of their elements are shifted in higher or lower register. These three fundamental blurring techniques may occur in various combinations within a single episode of "mistiness." For example, a signal might be blurred by accretion first, then filling, then shifting of the collection up, down, or both. Also, four types of intervals interact in the construction and blurring of signals: *boundary intervals* define spaces to be filled or partitioned, *partition intervals* delineate smaller-scale boundaries in larger boundary intervals, *projection intervals* define transpositions from one occurrence of an idea to another and *blur intervals* arise during the processes of filling, accretion, and shifting. In this repertory of intervallic functions, most intervals play multiple roles in a certain work, yet no single role is played by all. In this way Ligeti is able to achieve the sort of "network" he desires, a web of functions in which every strand touches others but no strand touches all.

None of the above analytic approaches focuses explicitly on perceptual processes and on how a meccanico style piece may be perceived by listeners. Of course, implicit in an analytic procedure is often the analyst's own intuitive understanding/listening of a musical work. However, explicit recourse to perceptual auditory principles and mechanisms may bring out new dimensions of musical structure and may give rise to a different understanding of a musical work.

Perceptual principles of auditory organization

Denis Gabor (1947) proposed a granular approach to sound analysis according to which any sound can be described by a large number of discrete sound grains or sound quanta. Iannis Xenakis was the first composer to introduce a granular approach to musical composition (e.g. Analogique A-B for string orchestra and tape described in Xenakis 1992) and Curtis Roads developed the first computer-based implementation (see overview of granular synthesis techniques in Roads 2001). Granular synthesis is based on the creation of a rapid succession of very short grains (usually less than 100ms) that give rise to dynamically evolving larger sound events/clouds/masses that are perceived as a whole that is more than the constituent microsounds.

Ligeti's *Continuum* can be perceived as a sound continuum that emerges through the merging of large numbers of very small grains. The composer himself states in a footnote on the first page of the score: 'Prestissimo = extremely fast, so that the individual tones can hardly be perceived, but rather merge into a continuum. … The correct tempo has been reached when the piece lasts less then 4 minutes.' This tempo implies that each sound particle (consisting of two simultaneous harpsichord notes) should last less than 75 ms. *Continuum* can be characterized as a piece based on granular synthesis. The listener perceives gradual densening and thinning out, blurring and clearing up, evolving into narrower or broader range, moving dynamically in higher or lower register, becoming more regular or more chaotic. These gradual changes rely on the organization of tiny sound grains into larger sonic events.

The composer's choice of the harpsichord shows that the composer wants the emergence of a continuous whole that preserves a clear granular texture. If a timbre with smoother attack was chosen the blurring of the individual grains would be much stronger and the emergent sound smoother.

A well-known illusionary psychological phenomenon is *apparent motion* (Eysenck and Keane, 1995; Bregman 1990). This phenomenon occurs when the illusion of motion is created via the rapid succession of static images (watching a film relies on this illusion). In the auditory domain, this illusion gives rise to the perception of streams, i.e. progressions of tones that are perceived as belonging to the same coherent sequence (which may be static or may be dynamically 'moving' in different ways). This phenomenon relies on the rate of presentation of individual events and is most clearly illustrated when events are played rapidly giving rise to a granular texture such as the texture of the *Continuum*.

The Gestalt grouping rules (Shepard, 1999) are used by the human mind for parsing sensory input into objects and events (especially when information is missing or is incomplete). These heuristic rules state that objects are grouped together due to: *Proximity* (spatial or temporal closeness/proximity), *Similarity* (similarity of appearance, shape and so on), *Symmetry* (as symmetric relations do not usually appear between unrelated objects they influence grouping), *Good Continuation* (objects arranged in such a way that they appear to continue each other tend to be grouped together) and *Common Fate* (objects that move together tend to be connected to each other and grouped together) – see examples in Fig. 1.

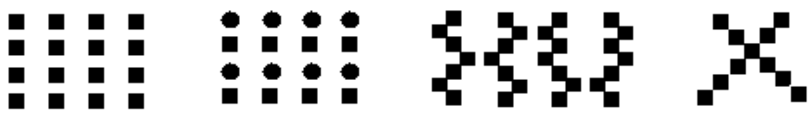

Figure 1. The Gestalt principles for the visual modality (from left to right): *Proximity* (organised perceptually in columns due to spatial proximity), *Similarity* (organised in rows due to similarity of shape), *Symmetry* (perceived as two left and right constituent parts due to symmetry), *Good Continuation* (perceived as two crossing lines due to continuation of direction) - we do not provide an example for the *Common Fate* principle as it requires motion.

Underlying these principles is our ability to detect *similarity and change*. Objects that are similar in terms of spatial/temporal location (Proximity rule), appearance, shape and other object properties (Similarity and Symmetry rules), direction and orientation (Good Continuation rule) and motion (Common Fate rule) are likely to be connected and grouped together, whereas dissimilar things remain unrelated. Our perceptual system is very advanced in detecting change. For instance, within a static visual field (e.g., a room full of objects) even a slight change is spotted without effort (e.g. a fly that flies off the couch).

Principles of Musical Streaming

Principles of musical stream perception in the domain of auditory scene analysis (Bregman, 1990) may be used to understand of the way a listener ‘makes sense’ of a musical work. The way a musical work is perceived by a listener may be significantly different from the organization of notes suggested by a score, or even from analytic results given by different musical analytic methodologies.

Auditory stream integration/segregation (in music) determines how successions of musical events are perceived as belonging to coherent sequences and, at the same time, segregated from other independent musical sequences. A number of general perceptual principles govern the way musical events are grouped together in musical streams. In this paper we will refer primarily to Huron’s (2001) presentation of a number of audiroty streaming principes adapted to a musical context – the reader can refer to Bregman’s (1990) seminal work on the general problem of auditory stream analysis (which includes musical stream segregation).

- Vertical Integration

Bregman (1990) explores in depth processes relating to the perceptual integration/segregation of simultaneous auditory components, i.e., how ‘to partition the set of concurrent components into distinct subsets, and to place them into different streams where they could be used to calculate the spectral properties of distinct sound sources of sound (such as timbre or pitch).’ (p. 213). In this paper we will focus only on three main aspects of such processes that relate to three principles presented by Huron (2001), namely the principles of *Onset Synchrony*, *Tonal Fusion* and *Pitch Co-modulation*.

Sounds that are coordinated and evolve synchronously in time tend to be perceived as components of a single auditory event. ‘Concurrent tones are much more apt to be interpreted by the auditory system as constituents of a single complex sound event when the tones are temporally aligned.’ (Huron, 2001, p. 39). Concurrent tones that start, evolve and finish together tend to be grouped together into a single sonority. For instance, in regard to ensemble playing, Bregman (1990) states that ‘for maximum distinctness, the onset and offset of the notes of the soloist should not be synchronous with those of the rest of the ensemble.’ (p. 491)

In practical terms, we can state that notes that start concurrently and have same duration tend to be merged vertically into a single sonority. We can state the following principle (relates to Huron’s Onset Synchrony Principle):

> *Synchronous Note Principle:* Notes with synchronous onsets and same IOIs (durations) tend to be merged into a single sonority (Cambouropoulos, 2008, p. 84.)

The fusion between synchronous notes is strongest when notes are in unison, very strong when separated by an octave, strong when separated by a perfect fifth and progressively weaker when separated by other intervals. The principle of Tonal Fusion suggests that concurrent pitches are integrated depending on the degree of tonal fusion implied by interval type rather than mere pitch proximity:

> *Principle of Tonal Fusion:* The perceptual independence of concurrent tones is weakened when they are separated by intervals (in decreasing order: unisons, octaves, perfect fifths…) that promote tonal fusion (Huron, 2001, p. 19).

Sequences of tones that move in the same direction tend to be fused into a single auditory stream. The strongest manifestation of this principle is when notes move in parallel intervals (especially in octaves):

> *Pitch Co-modulation Principle:* The perceptual union of concurrent tones is encouraged when pitch motions are positively correlated (Huron, 2001, p. 31).

This principle implicitly assumes that the onsets of the notes determining the intervals are synchronized. The Pitch Co-modulation Principle can be seen as a special case of the Synchronous Note Principle in the sense that the integration of synchronized note progressions is reinforced when pitch progressions are positively correlated (e.g., moving in parallel octaves, fifths etc.). This principle (more specifically the non-complience with this principle) enables splitting homophonic textures into more than one stream; for instance, when constituent parts of a homophonic texture move in opposite directions these parts may form independent streams (see example in Fig. 4).

- Horizontal Integration

The horizontal integration of musical elements (such as notes or chords) relies primarily on two fundamental principles*:* Temporal and Pitch Proximity. This means that notes close together in terms of time and pitch tend to be integrated perceptually in an auditory stream. These principles are described succinctly by Huron (2001) as follows:

> *Principle of Temporal Continuity:* In order to evoke strong auditory streams, use continuous or recurring rather than brief or intermittent sound sources. Intermittent sounds should be separated by no more than roughly 800 ms of silence in order to ensure the perception of continuity (Huron, 2001, p. 12).

> *Pitch Proximity Principle:* The coherence of an auditory stream is maintained by close pitch proximity in successive tones within the stream (Huron, 2001, p. 24)

The relation between temporal proximity (linked to tempo) and pitch proximity has been studied by van Noorden (1975). For slow tempo and/or proximal pitches a sequence of tones is perceived as a single stream; for fast tempo and large pitch distances a sequence is perceived as two streams; sequences in the in between grey region can be perceived as either one or two streams depending on various contextual and subjective factors.

The horizontal integration of tones affects the way tones in vertical sonorities are integrated (and the reverse). Bregman (1990) talks of 'capturing' a tonal component out of a 'mixture'. One of the strongest factors that weakens the vertical links between tones is the appearance of a tone that is proximal to one of the tones of the mixture in terms of both pitch and time. In a sense, there is a competition between the vertical and horizontal principles of auditory grouping. It is exactly this competition that makes it difficult to describe processes of auditory streaming systematically.

Perception of voices/streams in Ligeti's Continuum

The aforementioned perceptual principles play a significant role in the perceptual organization of *Continuum*. In the present paper, a theoretical-analytical discussion of the implication of perceptual principles on our understanding on the structure of *Continuum* is given – in future work, a perceptual study may be carried out testing the hypothesis of streaming in this musical piece or on newly constructed experimental material. As it is impossible for practical reasons to analyze in detail every note of the piece, a series of short excerpts have been selected (figures 2-4) that illustrate the variety of ways the isochronous rapid drilling of granular harpsichord two-note simultaneities may be organized perceptually into one or two or three (and even more) isochronous or non-isochronous independent streams.

Following the Note Synchrony Principle there is a tendency for the whole piece to be perceived as a single stream since there is no rhythmic independence between the two lines corresponding to the two harpsichord claviers ('homophonic' texture). However, this principle alone is not sufficient for merging notes into one stream as will be seen below.

The piece starts with a repeating minor third harmonic interval (beginning of Fig. 2a). This tends to be perceived as a single stream of thirds (rather than two independent lines a minor third apart). The Pitch Co-modulation principle (i.e. parallel motion) is important in consolidating fusion between the lines, along with the Tonal Fusion Principle which makes only a moderate contribution as tonal fusion is not very strong for minor thirds.

After almost 10 seconds of constantly repeating minor thirds, a new note is introduced a whole tone lower (middle of Fig. 2a). This new pitch 'replaces' some notes in the continuous flow of thirds. The stream of thirds, however, continues to be heard undisrupted 'behind' the new tone stream. It is as if the new tone 'masks' the sequence of thirds at certain points and, due to the Good Continuation Gestalt Principle, the illusion of continuity is created resulting in a continuously perceived flow of thirds (Bregman 1990).

The new repeating note is clearly heard as a new stream despite the fact that the pitch distance to the notes of the stream of thirds is very small (one whole tone). Of course the tempo is very fast (Temporal Proximity) and this assists linking the repeated notes (Pitch Proximity) into one stream. Context also plays an important role in that it helps detect *change*, i.e. the repeating new note is perceived as a new stream because the preceding musical context is static (stream of thirds). Our perceptual system is very sensitive at detecting and tracing change. As further new (different) notes appear and the texture becomes more complex the ability to follow this new stream is lost and it is gradually merged into a more complex auditory stream.

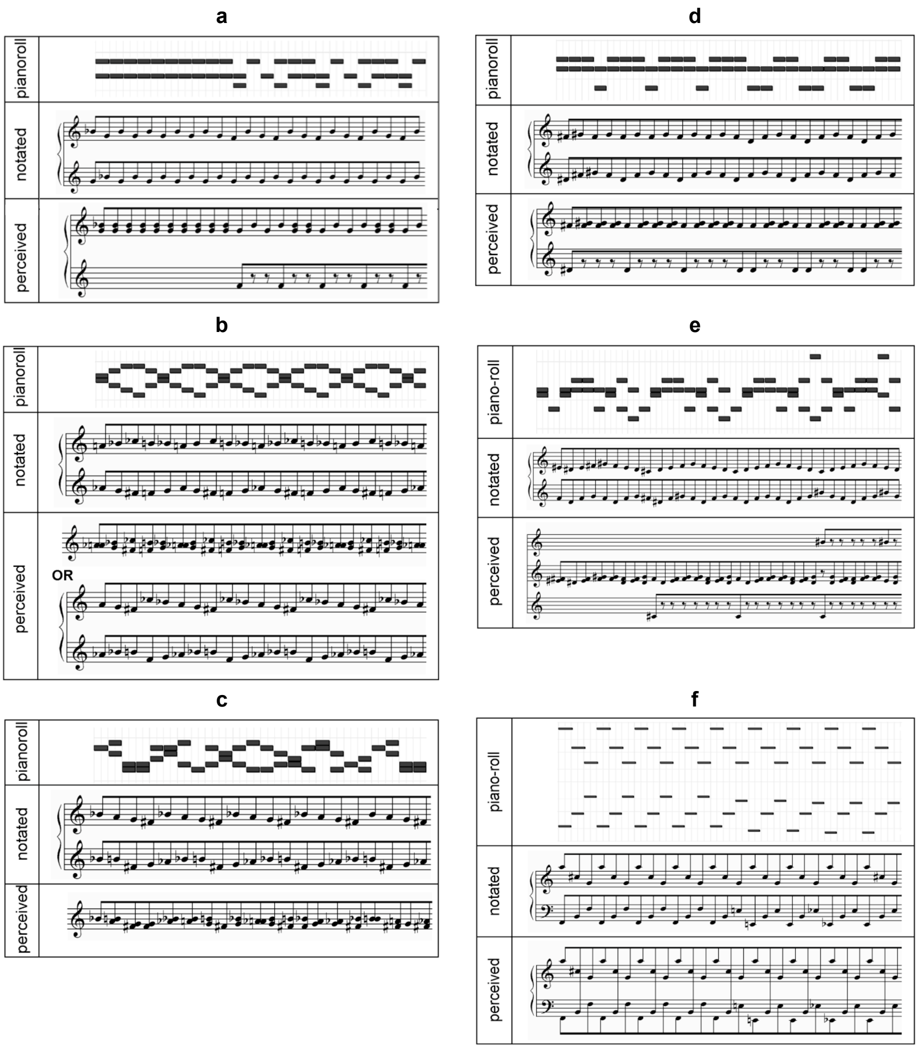

Figure 2. Excerpts from Ligeti's *Continuum*. On the upper row the piano-roll notation is given, in the middle row standard score notation and in the lower row suggestions as to how a listener may perceive each excerpt (different staves indicate different auditory streams).

In the passage depicted in Fig. 3, each time a new note is introduced a new perceptual stream is detected. In some cases the new stream quickly disappears, in other cases it remains independent. For instance, the entry of the second new note is clearly heard, but the new stream it introduces quickly vanishes. It is interesting that this stream is heard at all, since the new note appears in an inner voice extremely close to the preexisting notes in terms of pitch. The stable preceding context enables a listener to spot the new note (detect change) and to follow the change briefly before the note is integrated in a larger stream. In the case of the last new top note, the new stream introduced is stable and can be heard for a while as the new note forms a relatively large interval in relation to the rest of the notes and is also an outer top voice (the perceptual salience of outer voices, especially the top voice, has been reported in studies such as Palmer & Holleran, 1994; Thompson & Cuddy, 1989).

In Fig. 2e (illustrating a fragment in the second box of Fig. 3), it is suggested that the two new lower and higher notes can be heard as new independent streams, and that this passage may be split into three streams.

The Pitch Co-modulation principle is probably the most important factor that enables a homophonic passage (Synchronous Note Principle) to be perceived as more than one independent voices or streams. In the passage of Fig. 4, a listener can clearly hear a stream breaking into two substreams moving in opposite directions. The notes that have parallel or near-parallel motion are merged into a single stream whereas notes moving in opposite directions (contrary motion) tend to be heard as forming independent streams. At a smaller structural scale, the notes in Fig. 2f moving downwards in parallel octaves (Tonal Fusion Principle) are merged into a single stream and are segregated from the rest of the notes that form a static stream of sustained repeating notes (oblique motion).

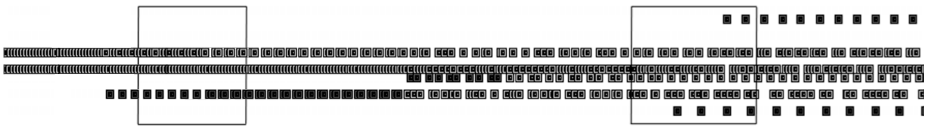

Figure 3. Piano-roll notation of Ligeti's *Continuum* (mm. 50-74) – new streams (bold) appear against a preceding 'static' background and fade out or remain independent (see text) – Excerpt in first box corresponds to Fig. 2d and second box to Fig. 2e.

Figure 4. Piano-roll notation of *Continuum* (mm. 104-121)

The piece consists of two isochronous lines of notes – all the notes have the same duration. In this sense, it may seem that any notion of rhythm and rhythmic pattern is abolished. However, this is not true as notes get organized in higher-level 'wholes' that give rise occasionally to things such as beat and rhythmic patterns. For instance, in the example of Fig. 2b, notes get organized into groups of five due primarily to the Gestalt principle of similarity (the same five-note pattern repeats many times). This higher-level pattern introduces a pulsation to the music that can easily be considered a beat (a pulsation of around 300ms falls within a perceptually acceptable beat rate – see Fraise, 1963). On the contrary, in Fig. 2c, there is no such pulsation as there is no emergent beat-level pattern - the two musical lines contain repetitions of 5 and 6 notes respectively resulting in a complex pattern with a much longer period that does not imply a beat.

Apart from regular pulsations appearing at the beat or higher level, non-isochronous rhythmic patterns may also emerge. For instance, in Fig. 1e the lower repeating note can be perceived as a separate stream as it has just been introduced against the preceding upper stream of thirds (see first box in Fig. 3). The notes in this stream start out in an isochronous fashion and then evolve into a characteristic dotted (3:1) rhythmic pattern.

These few examples show the wealth of structures that may emerge from a 'simple' rapid sequence of pitches. A single isochronous sequence can be viewed as a dynamically evolving continuum consisting of one or more independent streams that appear or disappear at various stages, each stream with distinct temporal properties/patterns, pitch content, direction and so on. The auditory system tries to 'disentangle' complex pitch structures into simpler constituent parts, based on a number of fundamental perceptual principles. The composer is aware (consciously or unconsciously) of the abilities of the human auditory system and has composed the piece in such a way that a rich network of possibilities arises from the seemingly trivial 'mechanical' sequence of notes.

Harmonic evolution in Ligeti's *Continuum*

The sound continuum, as discussed in the previous section, can be split into perceptually independent streams. How does, then, an overall harmonic structure/plan emerge? If auditory streaming is responsible for breaking down a complex sonority into simpler concurrent parts, what role does it play in combining these simpler parts into an overall harmonic stream? We suggest that the last question is simply misleading. It is not the case that the simpler parts are combined to give rise to larger harmonic plan, but rather the reverse, i.e. the overall musical stream is prior to individual musical 'voices'. Auditory scene analysis (Bregman, 1990) enables grouping together musical sounds that relate to a specific musical work, and allows segregation of the emerging overall musical stream from other environmental sounds that may occur in parallel to the musical sounds. Timbral differentiation, source localization, tonal fusion, note synchronisation and other auditory streaming principles enable a listener to group musical sounds together into a single auditory stream as opposed to other co-occuring sounds (e.g. speech, machine sounds, etc.).

The overall musical stream is perceived as possessing certain ‘global’ characteristics, such as textural characteristics or harmonic properties. Take for instance a contrapunctal musical work that consists of a number of independent voices, such as a fugue by J.S. Bach. A fugue can be heard as a single musical stream that evolves in time; such a stream can be described by changes in note density/activity, range, tonal qualities, harmonic rhythm. Harmony, in compositional terms, is an emerging property of the combination of voices, however, perceptually, a listener can follow harmonic evolution prior to or at least concurrently with independent horizontal voices.

In *Continuum*, blurring vs clearing processes or the evolution of harmony can be considered holistic properties of the overall musical stream, emerging prior to independent ‘voices’. This stream can be perceived as a continuously evolving harmonic texture, that can be organized in an overall formal plan (see below). Rapidly repeating pitches (referred to as meccanico patterns by Clendinning 1993) are perceived as constituent harmonic voices of the local harmony (for a discussion regarding similarities/differences between harmonic voices and independent perceptual voices/streams see Cambouropoulos 2008). The overall harmonic progression integrates such harmonic voices that are often difficult (if not impossible) to discern independently.

There is evidence that things such as harmonic pitch intervals, chords or larger configurations such as tone clusters are commonly perceived by listeners as wholes rather than combinations of atomic lower-level components. For example, especially for pitch, it has been suggested that the majority of listeners, for whom musical pitch is relative, perceive pitch intervals categorically prior to individual pitches (Dowling and Harwood, 1986; Handel, 1989). Tenney suggests that larger sound complexes such as tone-clusters or other dense chords ‘cannot usually be analyzed by the ear into constituent tones, and are not intended to be analyzed.’ (Tenney, 1961, p. 6). Co-sounding notes (synchronous or overlapping) are integrated to a lesser or greater degree depending on a number of factors (some discussed in this paper), giving rise to musical harmony.

The metaphor of ‘blurring’ can be related to a number of perceptual principles. The degree of ‘clarity’ or ‘blurriness’ of a sonority relates to at least three perceptual principles, namely, the Principle of Tonal Fusion (see previous section), Minimum Masking Principle (auditory masking is reduced as spacing between notes is increased - this is especially important for lower registers) and Principle of Limited Density (the number of voices should be three or fewer if voice independence is sought) (Huron 2001). Harmonic ‘clarity’ might be associated with relatively higher tonal fusion (e.g. octaves, fifths, thirds), wider spacing between individual tones especially at the lower register[ii], and lower density (i.e. fewer pcs), whereas ‘blurring’ occurs when tonal fusion is low (e.g. chromatic or diatonic clusters), spacing is narrow and density of pcs is high. The gradual transition between regions of high tonal fusion, wide spacing and low density to regions of low tonal fusion, narrow spacing and higher density can be referred to as ‘blurring’. The effect of these factors is most dramatic in the abrupt transition between sections III and IV (see transition after the middle of Fig. 5) where we have an abrupt transition from a dense sonority comprising of two narrowly spaced chromatic clusters to widely-spaced chords of higher tonal fusion (only four pcs due to octave doublings).

The overall form of the piece has been represented graphically by Clendinning (1993, p. 202, see Fig. 5). Her diagram is a simple two-dimensional graph of time (x axis) and pitch (y axis), with black bars indicating meccanico patterns (continuum) and shaded bars indicating sustained pitches.

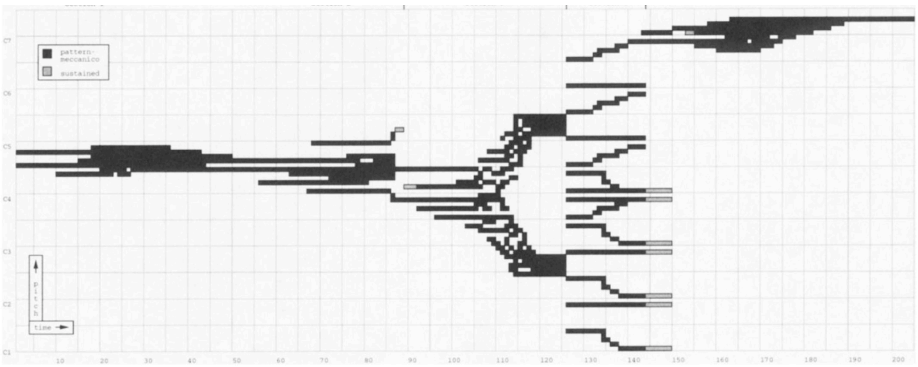

Figure 5. Overall form and pitch structure of the piece in schematic representation (black: pattern-meccanico, grey: sustained; x-axis: time, y-axis: pitch) (from Clendinning 1993, p. 202)

Although very intuitive and helpful, this graph does not communicate the harmonic structural plan of the piece and its interaction with form, so a reductional analysis was considered necessary and was carried out (the reduction is depicted in Fig. 6). The proposed reductional analysis presents harmonic evolution in a simplified manner that highlights key harmonic elements and transitions between them.

The piece's uninterrupted form-sound stream-structure can be divided into five overlapping sections, which connect through common harmonic elements[iii]. The formal boundaries are the "interval signals", areas of relative harmonic clarity interconnected through "blurring" transitory areas. The only non-overlapping transition is the one from section III to IV, which occurs abruptly. This transition corresponds to the *Golden Mean* of the whole piece (bar 126 out of 204 bars, 204/126=1.618).

Section I: bars 1-50, Section II: bars 50-87, Section III: bars 87-125, Section IV: bars 126-143, Section V: bars 143-204.

Section I**:** The first interval signal is the dyad G-Bb (m3), which blurs through *accretion* and *filling* until it becomes a tritone-spanning chromatic cluster (F-F#-G-G#-A-Bb-Cb). This gradually thins out to another chromatic cluster (spanning a major 3rd, F#-G-G#-A-Bb) and finally clears out to the dyad F#-G# (M2), which is the next interval signal.

Section II: The previous signal (F#-G#) is initially blurred through *filling* and *accretion* into a diatonic six-note cluster (C#-D#-E#-F#-G#-B#). The inner pitches of this diatonic cluster gradually blur through *filling* to a chromatic six-note cluster (E-F-F#-G-G#-A) while its outer pitches -upper B# and lower C#- shift chromatically to upper D# and lower B respectively. This gradual shift, combined with the abrupt release of the chromatic cluster, leads to the next interval signal, which is a B major triad in open position (B-F#-D#).

Section III: The open B major triad becomes minor in closed position (B-D-F#) through a transfer of the outer D# to an inner D natural and then a temporarily stable tetrachord appears (A-B-D-F#), as the beginning of the next "blurring" area. Then gradually both hands *fill* diatonically (the right hand uses the B major scale diatonic collection while the left hand the D Dorian collection) with simultaneous upward and downward accretion. A combination of chromatic (semitonal) *shifting-accretion* and a symmetrical separation of the two hands leads to the cadential harmonic structure of this section, which is a two-part symmetrical chromatic cluster (D to F# for the right hand and F# to A# for the left hand - both clusters span major 3rds). This dramatically evolved dissonant double cluster functions as a climactic element.

Section IV: The beginning of this section (b. 126) corresponds to the *Golden Section* of the piece and is the only non-overlapping transition between sections. The harpsichord uses the 16'+8'+4' combination resulting in multiple octaves for each key pressed, so this section is the only one that uses cpi's (compound pitch intervals) instead of pi's (pitch intervals). Both hands continue the symmetrical two-directional chromatic shift (semitonal motion with a major 3rd range) initiated in the previous section (using only the *shifting* blurring process - no filling or accretion) until they both reach the next interval signal, which is the dyad B-C# (major 2nd). Immediately after the arrival of the final multi-octave dyad, which is the culmination of this short climactic section, octave doublings cease abruptly and the dyad is prolonged in the highest register.

Section V: The final section leads through *accretion* and *filling* from the previous interval signal (B-C#) to the final signal, which is a unison (high E enharmonically spelled as Fb). This section functions as a relaxing counterpart to the previously built climax, but structurally it is not a coda (prolongation of the final event), since it shifts the upper structural pitch from C# to E.

Certain intervals or pc sets gain structural importance by being part of the form-creating "signals" or by defining the range of vertical chromatic clusters or horizontal chromatic shifts. Structural intervals are the minor 3rd (ic 3), the major 2nd (ic 2), the major 3rd (ic 4) and the tritone (ic 6), while structural pc sets are [025] (the typical Ligeti signal according to Hicks[iv]), [037] (the minor-major chord) and [0358] (which derives directly from [025] by symmetrical inversion and union).

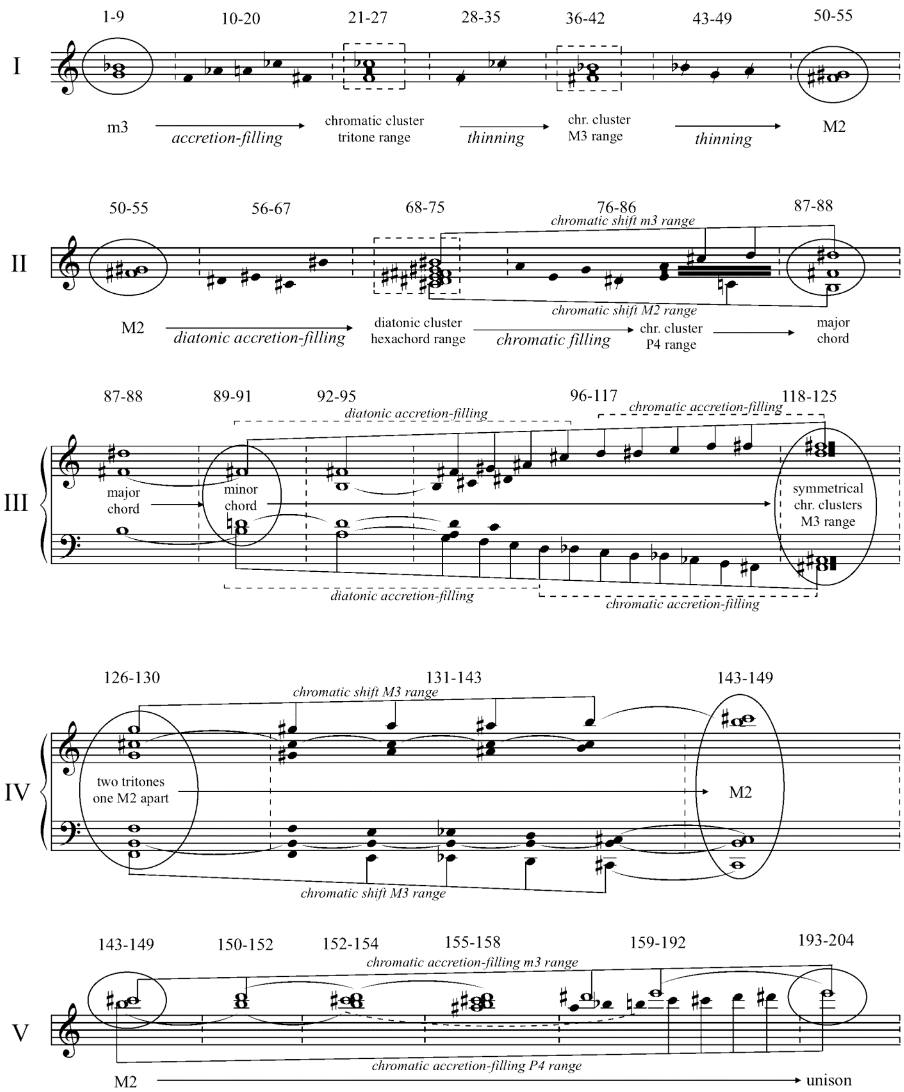

Figure 6. Reductional analysis of Ligeti's *Continuum*

The overall harmonic structure of the piece appears in the deeper reduction of Fig. 7. This reduction reveals the structural dyads G-Bb (beginning) and C#-E (end) and the continuous diatonic or chromatic shift that leads to the structure's registral expansion. The overall outer pitch-interval structure is symmetrical (G-Bb-C#-E is the symmetrical set [0369]) and corresponds to a diminished 7th chord. An interesting structural element of the piece, revealed in this deep reductional level, is the fact that this diminished chord, if spelled enharmonically (as A#-C#-E-G), can be considered as carrying a dominant function that refers to the central harmonic element of the piece, the B major-minor chord (b. 87-91)[v]. This structural relation cannot be perceived by listeners, since the diminished chord is split and its parts are placed at the beginning and ending of the piece, while its "resolution" is placed in the middle of the piece at a different register. Of course, the structural plan of every musical work may contain elements that are *not meant* to be perceived by the listener, but are nevertheless important components of the work's architectural conception and internal structural coherence.

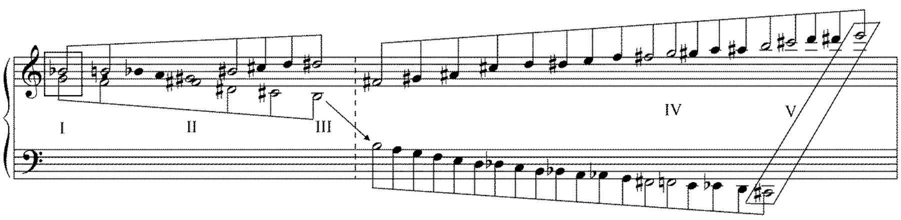

Figure 7. Overall pitch structure of *Continuum*

Equally interesting is the use of the Fibonacci Sequence numbers and ratios for the placement of interval signals (as is well-known each pair of Fibonacci numbers approximates the golden mean ratio – the first 11 members of the sequence are: 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144): The first signal (G-Bb) comes at b. 1, the first section lasts 55 bars, the second signal (F#-G#) ends at b. 55, the third signal (B minor chord) appears at b. 89 and the next simple signal (B-C#), which is also the culmination point of section IV, comes at b. 143 (approximately 144). As already mentioned, the use of cpi's (onset of section IV) begins at b. 126, which is the golden mean of the whole piece. Such mathematical ratios and proportions do not directly relate to the perceptual streaming principles presented in this paper; however, they can be linked to other aspects of perception that relate to notions of balance, symmetry and expectation.

Conclusions

In this paper a number of perceptual principles have been employed in the description of the musical structure of Ligeti's *Continuum.* Drawing on knowledge of basic human auditory processes, we have attempted to show how a continuum of rapid isochronous notes is transformed into a rich network of musical relations. The human mind actively organizes the 'mechanical' sequence of notes into one or more independent streams, it identifies beats and rhythmic patterns, it perceives dynamic harmonic progression, and it transforms the seemingly amorphous mechanical surface into a multi-faceted structure. The composer has carefully woven a rich network of musical threads into the *Continuum* allowing a unique musical listening experience.

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[i] Representative compositions of this type are - apart from "Continuum" for harpsichord (1968) - *Ten Pieces for Wind Quintet,* no. 8 (1968), *Coulée* for organ (1969), the *Double Concerto* for flute and oboe (1972), *Ramifications* for string orchestra (1968-69), the *Second String Quartet* (1968), and the *Chamber Concerto I* (1969-70).

[ii] There is a seeming contradiction here: large pitch intervals support stream segregation (pitch proximity principle) and, at the same time, wide spacing assists harmonic cohesion and clarity (minimum masking and, also, tonal fusion principles). This seeming contradiction is resolved if one notes that pitch proximity principle relates primarily to *horizontal* integration/segregation, whereas the minimum masking and tonal fusion principles to *vertical* integration/segregation. For instance, a melodic octave or ninth interval (as opposed to a unison or second interval) may introduce stream segregation/segmentation, whereas a harmonic octave or ninth interval supports tonal clarity (as opposed to a second interval in a low register).

[iii] This specific five-part form was proposed by Hicks (1993). The present structural analysis uses Hicks' analysis as a point of departure, but deviates from it at various aspects. Also, Hicks' analysis does not provide a harmonic plan of the whole piece (fig. 6) nor does it arrive at the overall structure of fig. 7.
[iv] However, Roig-Francoli (1995, p. 250) remarks that the structural importance of this set has been overestimated.
[v] We thank our colleague Kostas Siembis for his remark about this background tonal relation.

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