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Dynamic Form: Models for Analyzing Processive Form in Spectral Music

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Abstract
This chapter discusses dynamic form—form arising from the flux of a designated property, with the retrospective contour of such flux representing the dynamic form as experienced and remembered. To forge this representation, quantitative models called *vessels*, which are proxy listener scanning functions, relate an idealized listener directly to the score, traversed automatically, thus emulating an idealized real-time hearing. A vessel of dynamic form focuses on features of texture, rhythm, pitch, or timbre, or any appropriate combination of these. The chapter discusses listener phenomenology and compositional poetics and planning. It also discusses smooth or gradated change arising from interpolation, frequency modulation, and ring modulation, as well as their relations to proto-spectralist techniques of Reich, Murail, Ligeti, and Saariaho. It considers granularity and ontology of sound and score. Excerpts are drawn from Grisey's *Partiels*, Ligeti's *Atmosphéres*, Reich's *Drumming*, Murail's *Territoires de L'oubli*, and Saariaho's *Io*, *Lichtbogen*, and *Papillon II*.

Keywords: analysis, process, form, computation, Grisey, Murail, Reich, Saariaho, phenomenology, texture
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Of all the facets of spectral music, the one that is most straightforward and transparently appreciated is *form*. Paradoxically, form is also one of its most intriguing facets. Far from being simplistic or lacking subtlety, on the contrary: the focus and clarity of thought of spectral composers in regard to form perhaps accounts for the relatively wide appeal of their music among listeners, despite its employing rough noise and lacking both melodious tonality and steady pulse. In fact, of all named styles of music ever, spectralism is one of the only ones to have explicitly stipulated an approach to form as a central component of its style, rather than a side effect of other priorities.[1]

Although it has not been declared as an aspect of form, spectralists' emphasis on gradual and incremental change serves as the de facto guiding principle. It is exemplified in Grisey's (1978) concepts of "*difference*" and "pre-audibility," which push the awareness of successive similar changes (based on comparing the present to the past) to the forefront of the composer's and listener's consciousness.

All this notwithstanding, there are three significant gaps in the current understanding of form in spectralism, which this chapter attempts to address:

1. Despite being built on new principles, form in spectral music resonates very strongly with what may be called processive form, brought about by certain textural procedures (that are not specifically spectralist), found in other styles of music throughout the ages (Medieval, Renaissance, Baroque, and so forth[2]), especially in the twentieth century[3]; these resonances have not been adequately shown.
2. Analyzing spectralist formal processes does not require spectral analysis, signal processing, or the analysis of acoustical audio data. That is, although rich enticing timbres and resonant microtones (signature facets of spectralism) are aptly modeled as acoustic or psychoacoustic phenomena, the recipes for producing these are inscribed in written scores; spectralism's perceived/perceivable formal processes often could be realized without such timbres, and moreover can actually be modeled directly from their notation, bypassing a reliance on audio analysis.
3. As articulated especially in Grisey's writings, spectralism's focus on processes and temporality seems to owe a debt of inspiration, at least indirectly, to the processive "creative evolution" ontology of philosopher Henri Bergson, as evident from Grisey's emphasis on time asymmetry.[4] Yet form in spectral compositions, when analyzed technically, is typically discussed in terms of static diagrams of pre-compositional architecture.[5] An appropriate processive model of analysis for spectral music has not been previously offered.

By presenting demonstrations of analytical techniques for dynamic form, this chapter addresses these three gaps in terms of the concept *dynamic form*. These are addressed in five sections, as follows: First, a preliminary section providing definitions and theoretical bases; second, demonstration of dynamic-form analysis with Reich's *Drumming* and Murail's *Territoires de L'oubli*; third, explanation of *channeled flow* and *oppositional vessels*, illustrated with Ligeti's *Atmosphéres* and Saariaho's *Lichtbogen*; fourth, an analysis of Saariaho's *Papillons II*, illustrating an oppositional vessel; and finally, a discussion of *prompted flow*, shown with Grisey's *Partiels*; and a discussion of difference and "pre-audibility," and connections between process philosophy, listener cognition, and aesthetics of nature, with this discussion also engaging audio-visual-tactile analogies and affinities to biological growth.

Preliminaries

Although musical form is typically conceptualized in somewhat architectural terms (structure, sections, and so forth) there exists an alternative conception of musical form from outside spectralist literature that is helpful in understanding spectralism and other music. This concept is called *dynamic form*.

What is dynamic form and how is it analyzed? Tying together and formalizing early twentieth-century holistic energeticist theories with more data-driven contour and form theories of the mid- to late-20th century,[6] I have defined dynamic form as[7]:

The retrospective contour of the flux of a quality

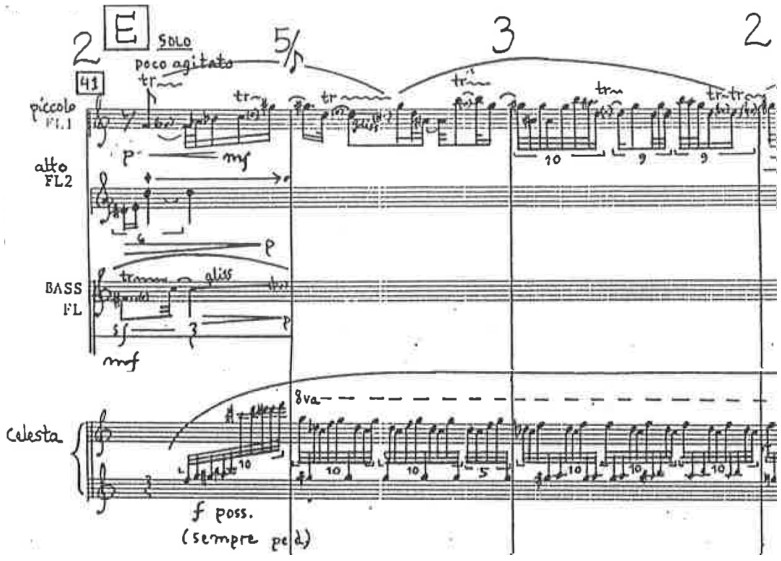
Note that "quality" is left open-ended, needing to be defined or chosen according to what seems appropriate for each piece or passage. This flexibility is purposeful.

To analyze dynamic form is to precisely define (or choose) a scanning procedure (an algorithm of repeatedly doing computations on a stream of input) that produces an appropriate contour of flux when applied to a score (as the stream of input). Thus the procedure serves as a proxy for (or model of) our listening.[8] To be more easily imagined as something through which music flows (like flowing through our listening minds) such scanning procedures are called *vessels*.[9]

A vessel is defined in terms of these parts: *docket*, *gauge*, and *flow system*. Whereas the docket and flow system are more infrastructural and generic, the gauge more often reflects particulars of an analytic-interpretive music situation. A vessel's gauge is a mathematical equation defined in terms of measurable features of a musical score excerpt. It takes score information as input and produces a number as output. The computed number represents the amount (the degree or the intensity) of some heard or hearable quality or property emanating from a given span of music.[10]

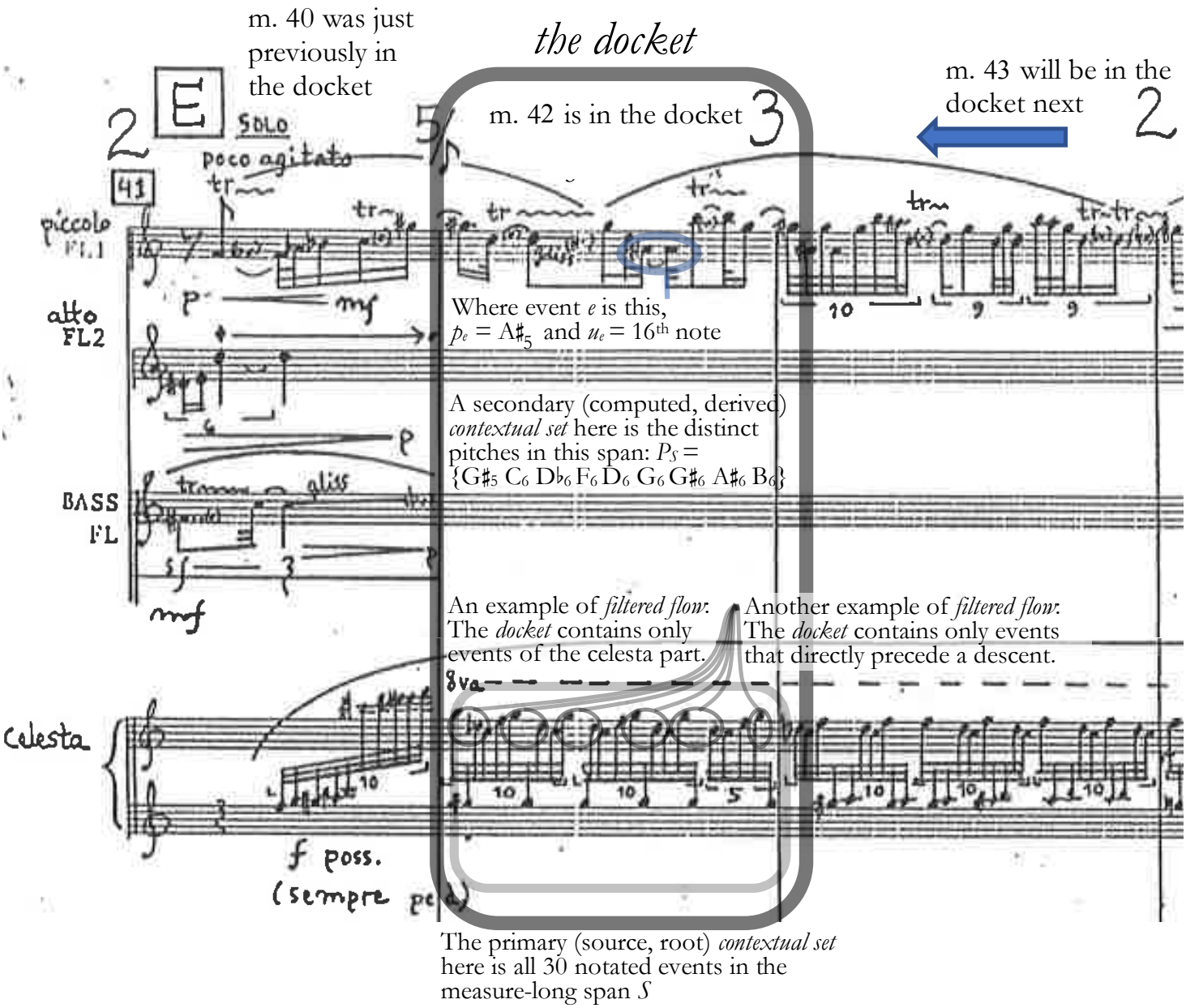
As we hear music flow (elapse in time) we hear various emergent qualities change. For instance, we might hear a gradual increase in syncopation, dissonance, or textural thickness, or intricacy.[11] In Figure 1a, for example, when we hear m. 42, it differs from m. 41 in myriad ways which we might notice: the alto and bass flutes don't present any notes; the piccolo and celesta present higher pitches than in m. 41; the piccolo and celesta contours are now mixed rather than purely ascending; the celesta presents fewer pitches than it did in m. 41; the list goes on. To model our experience of this, the vessel's gauge has to keep performing its computation repeatedly, on successive excerpts (leaving, as a trace, an ever longer series of numbers which can be visualized orthochronically as a contour). To emulate the unstoppable flowing of music into our ears and minds, the vessel moves the gauge along to successive spans (excerpts) of music. So the gauge's input keeps changing, as would be the case if a pressure gauge or thermometer were placed in a pipe or channel of flowing liquid whose pressure or temperature fluctuate. At any instant that one reads the gauge, only a portion of the flowing liquid touches it, and this is the portion being evaluated, such that we could say it is on the gauge's current *docket*. The *docket* is the imagined container holding the score excerpt data from which the gauge calculates its current number—you can imagine this as a chamber or vestibule with a thermometer gauging its content as it keeps flowing through. Score excerpt data keeps flowing through the docket in a strategically decided way; as it does, the flow of score data through the docket triggers the gauge repeatedly, according to strategically decided rules. The strategically decided rules are called the *flow system* of the analysis.

Figure 1a



Excerpt from Saariaho's *Io* (1987), mm. 41–43

Figure 1b



Annotated excerpt from Saariaho's *Io* (1987), mm. 41–43

There are a variety of types of flow system which it can be useful to categorize. For instance a *filltered* flow system might allow only notes from one instrument to flow into the docket. For example, as suggested in Figure 1b, the flow system could filter for only celesta events to go in the docket. Or it could filter for exclusively melodic peaks, notes that directly precede a descent, such as each G6 and D♭6 in the celeste's ostinato; it could also be defined to include peak pitches in all instruments such as the G6 and B6 in the piccolo part. The flow into the docket can also be conditional, for instance being prompted by occurrence of a particular gesture, motive, chord, articulation, and so forth. Upon each increment of flow, the vessel's gauge quantitatively evaluates the current contents of the docket.

To ensure intersubjective transparency, each vessel gauge is defined as a mathematical equation (with an accompanying explanation). A vessel's gauge equation is defined in terms of contextual sets—sets whose content changes over time (the docket's content changing as mentioned above). For instance in Figure 1b the primary (source, root) contextual set is all notated events in the span, which happens to

be thirty distinct events in m. 42; a secondary (computed, derived) contextual set could be the distinct pitches presented in a span, which in m. 42 happens to be the unordered set {G♯5, C6, D♭6, F6, D6, G6, G♯6, A♯6, B6}. The contextual set serves as input to the gauge. It serves as such by specifying the content relative to a point in time (thus making it contextual). For instance the set of distinct pitches of the current span obviously depends on what span is in the docket (m. 41 or some other measure) at the moment.[12] When a new measure flows in, that set's context changes; as time flows, new content flows into the vessel's docket (for practical reasons new content flows in at predetermined increments or according to a prompting rule). That is, the docket is the set's definition; and since this definition makes the set-content time-relative, this content therefore keeps changing at durational increments of a predetermined size, or as prompted by significant occasions in the music's flow.[13] To account for this changing context, a gauge equation specifies its input in terms of the current span *S*, where *S* keeps refreshing itself, each time triggering the gauge to compute a new number, which it appends to the accumulating series of numbers, which upon completion represents the dynamic form.[14] This continuing process of comparing spans of music, as the music flows by, and remembering the overall trajectory of these comparisons, can be considered a model (an idealization) of how dynamic form in music is experienced.[15]

The modeling also assumes properties heard in each span of time *emerge* from basic level details, namely the events notated in the score, where we consider an event to be a basic action of a performer, such as playing a note.[16] In this sense, a conventionally notated span of music has a finite number of events, which are considered to be the elements of that span. For instance we can refer to $\#S$ or $|S|$, denoting the number of elements in *S*, meaning the number of events in that span of music, the size of the set of events.[17]

A gauge equation is defined in terms of the basic properties of each event in a span, such as start time, duration, pitch, or timbre (which I denote with *t*, *u*, *p*, and *i*).[18] The predicate relation "of" is expressed with a subscript, for instance t_e denotes the start time of event *e* and p_e denotes the pitch of event *e*. For instance, considering the third to last piccolo event in Figure 1, its pitch (denoted p_e) is A♯6, thus p_e = A♯6, and its duration (denoted u_e) is a sixteenth note, thus u_e = one sixteenth note (of course, pitches and durations can be further translated into any desired numerical representation). Since these basic properties can be specified in this way, those referring to traditionally distinct domains (pitch versus duration versus timbre and so forth) can freely combine in a gauge equation. Thus we can express interactions between texture, timbre, and pitch, so that, in dynamic form analysis, these need not be held apart as independent domains.[19]

Capital letters denote the set of distinct predicates represented in a span, for instance P_S denotes the set of all pitches in span *S* and I_S denotes the set of all timbres in span *S* (assuming timbral equivalency corresponding to what is notated). A moment in time at which at least one event occurs (an eventful time) is called an *occasion* (thus, two or more events beginning at the same time constitute only one occasion; an occasion is the set of all events that begin at a particular time).[20] T_S denotes the set of occasions (eventful times) in a span *S*. Using this denotational system, together with basic arithmetic I can define computations for many form-bearing qualities, as emerging from basic events notated in a score.

Onward: processes, densities, and varieties

This section discusses form-bearing directed incremental processes (called *processive form*) in Reich's *Drumming* and Murail's *Territoires de L'oubli*. For each analysis an amalgam of two vessels is forged. Although it would be possible to describe, at least vaguely, the relevant processes in plain prose, the purpose of the modeling is to witness how we can partially translate qualitative experiences into quantitative constructs—in some sense reverse-engineering the composer's actions.[21] Therefore, in addition to prose description, we will also consider formal-symbolic denotations.

Modeling processive form in Reich's *Drumming* and Murail's *Territoires de L'oubli*

Consider two well-known classics of their respective styles: Reich's *Drumming* and Murail's *Territoires de L'oubli*. Although motivated through different aesthetic philosophies, their formal processes are comparable. Reich's *Drumming* (1970–71) is easy to follow because it begins by incrementally increasing the attack density. The attack density is of two different kinds: *temporal density* and *eventfulness*. *Temporal density* is defined as a quotient: the size of the set of occasions (eventful times) in the span divided by the duration of the span, which we denote as u_S.[22] The symbol $|T_S|$ denotes the size of the set of occasions and, as already stated, the duration of a span S is denoted u_S.

$$TemporalDensity(S) = \frac{|T_S|}{u_S}$$

To clarify what is meant by a set of occasions, T_S (or equivalently $T_{e \in S}$) denotes the set of occasions of span S—the set of all times in S at which at least one event occurs.[23]

Since I will present similar denotations below, let us pause now to consider what this equation above means. The left side denotes that there is a temporal density quality of a span of music, not an absolute quality but rather a quality of varying degrees. The right side denotes a computation, specifically the size of the set of eventful times (in other words the number of eventful times) divided by the duration of that span. The equals sign asserts that the computation on the right can serve as a model (an illustrative or explanatory proxy) for the qualitative experience denoted on the left.[24]

Yet I propose two caveats. First: One should not fixate on the particular terms on the left. Temporal density, for instance, is merely a somewhat arbitrary placeholder and could be called *attack density*, or be exchanged for yet another word if a better one arises. Second: The benefit of such modeling never reveals itself through its application to a single span. On the contrary the temporal density of a single span is practically meaningless. Rather this computational model becomes meaningful only when one considers the temporal density of one span as compared to that of a previous span. The practical benefit is the model's ability to demonstrate changes of the temporal density. It speaks to Grisey's emphasis on, and concept of, "difference." It sheds light on how concrete details of musical compositions actually prompt a listener's experience of difference.

In contrast to temporal density, which consolidates coincident events before counting, eventfulness counts all events distinctly even if occurring simultaneously.

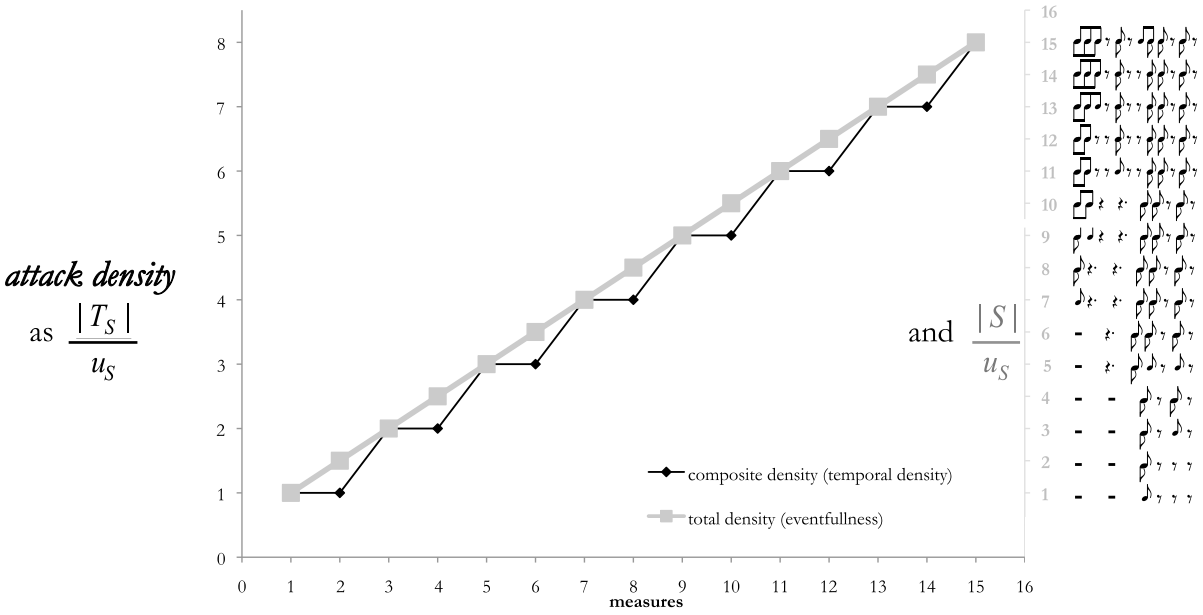
$$Eventfulness(S) = \frac{|S|}{u_S}$$

In measures 1–15 of Reich's *Drumming* as shown in Figure 2a, both temporal density and eventfulness increase incrementally.[25]

Also we easily hear incrementally more drum pitches, thus an incremental increase in pitch variety (graphed in Figure 2b). Pitch variety is the total number of pitches (the size of the set of pitches) in a span, divided by the span's duration. Where P_S is the set of all distinct pitches in span S:

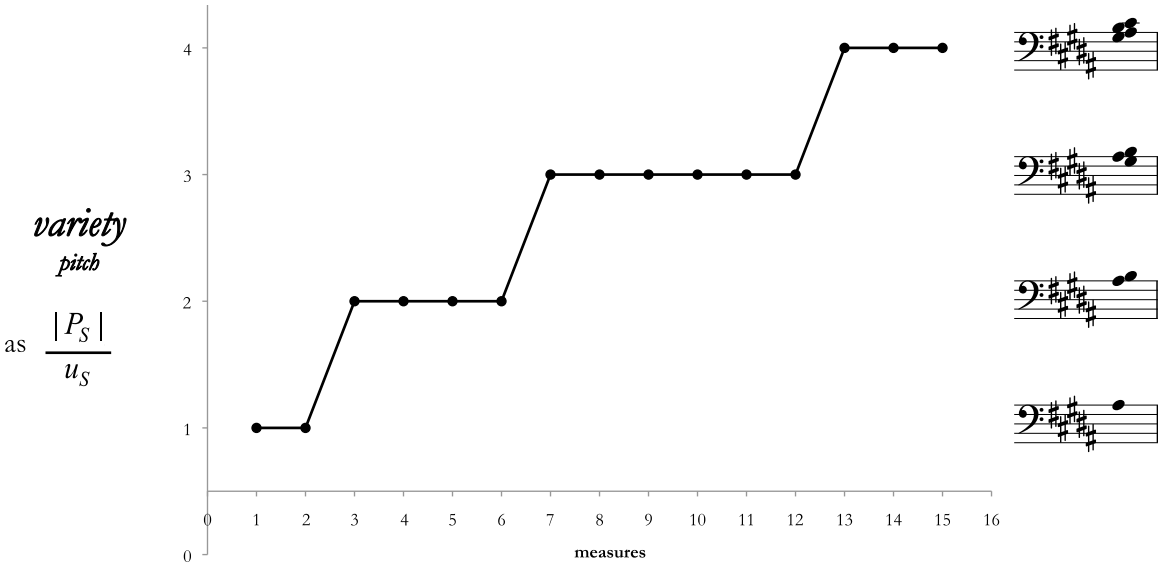
$$PitchVariety(S) = \frac{|P_S|}{u_S}$$

Figure 2a



Increasing temporal density and eventfulness in Reich's *Drumming* mm. 1–15

Figure 2b



Increasing pitch variety in Reich's *Drumming* mm. 1–15

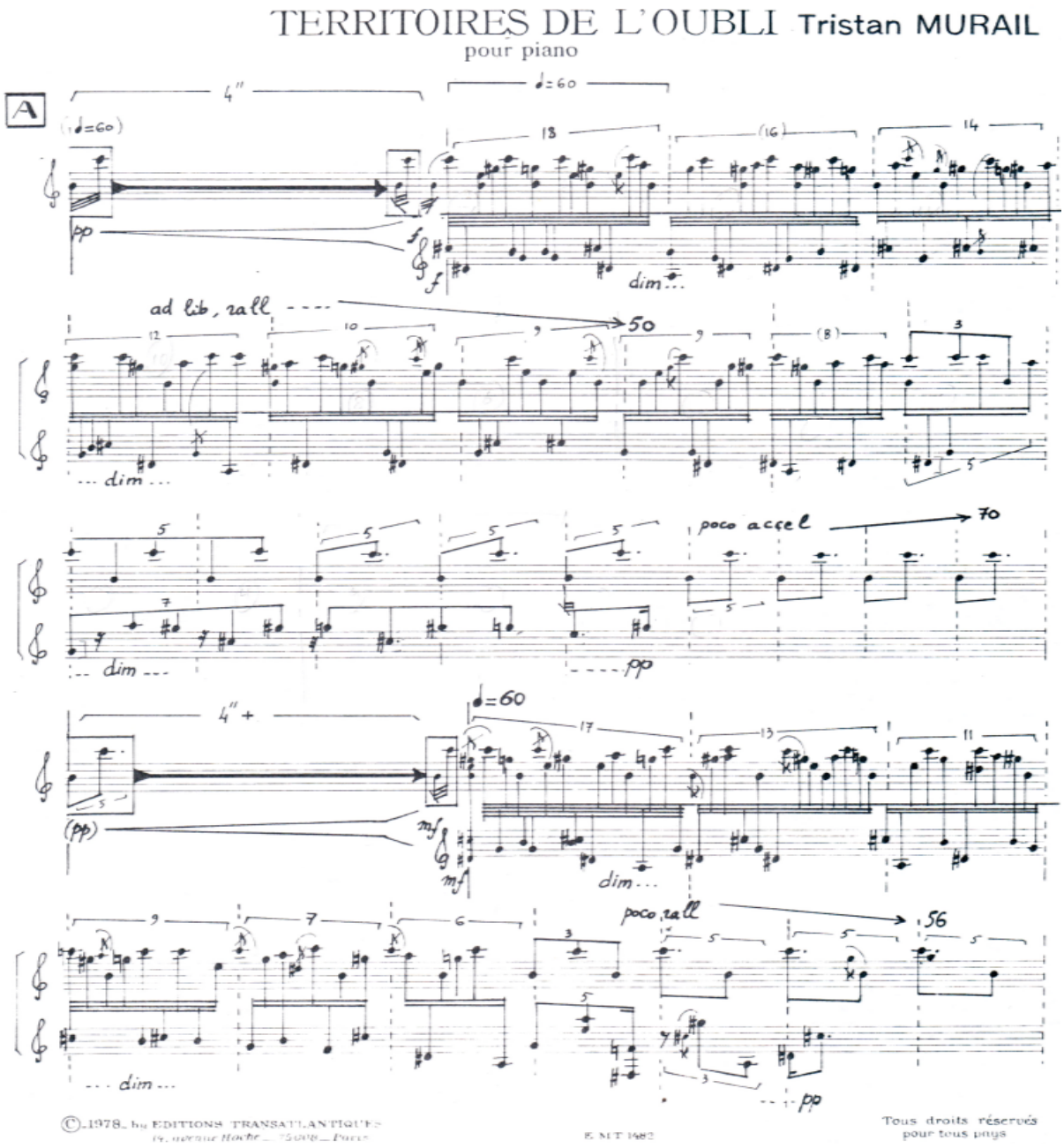
More generally, I am taking "variety" to mean the number of distinct types being presented.

Reich's *Drumming* and Murail's *Territoires de L'oubli* (1978) differ variously. Reich's piece has a steady pulse whereas the pulse of Murail's *Territoires* fluctuates in pliant waves. See Figure 3a. Reich's piece is very repetitive and Murail's only somewhat repetitive. Murail's piece also has a more complex texture and rich harmonies. Nevertheless the first eighteen measures of each piece are strongly shaped by the same two vessels (three vessels if counting both types of attack density), which work in concert with each other in both pieces. The Reich and Murail excerpts both present contexts where it is useful to

conceptually fuse two distinct musical properties—sometimes it is helpful to count apples and oranges together as fruits; and that is the case here.

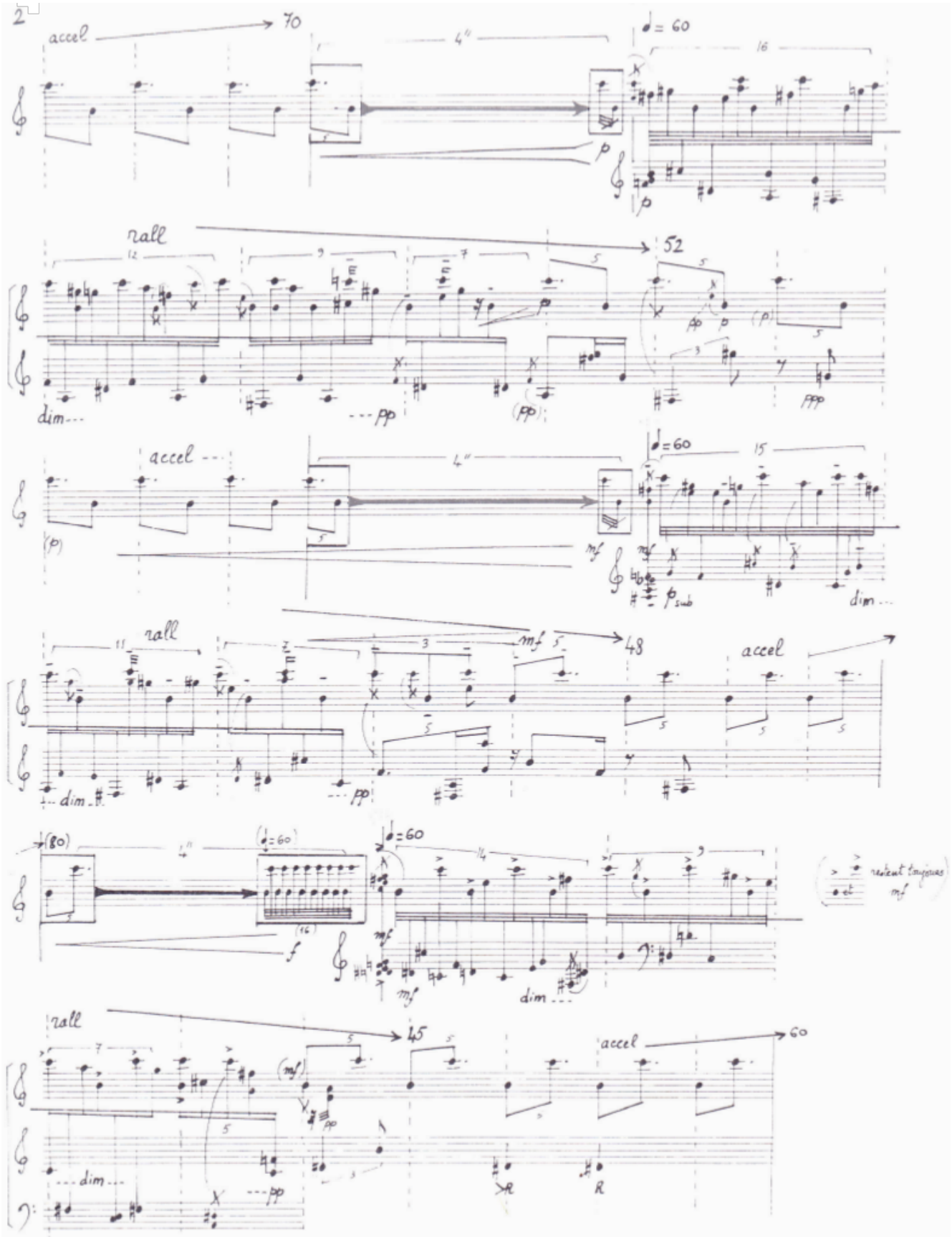
As Figure 3b shows, the attack density of *Territoires de L'oubli* dwindles from nineteen down to two composite attacks per measure; the decreasing tuplets (from quattuordecuplet – to duodecuplet – to decuplet - etc.) and the slowing tempo together help clarify this trend.[26] Loudness also dwindles from *forte* to *pianissimo*. Moreover the number of distinct pitches per measure dwindles from nine to two, as graphed in Figure 3c. Murail achieves this reduction through a gradual high-pass filter, removing one-by-one the lowest pitch (as compared to the Reich excerpt whose pitches expand outward as they enter).[27] In terms of the two qualities *attack density* and *pitch variety*, the Reich excerpt is progressively fortifying these, whereas the Murail excerpt is progressively diluting them.

Figure 3a1



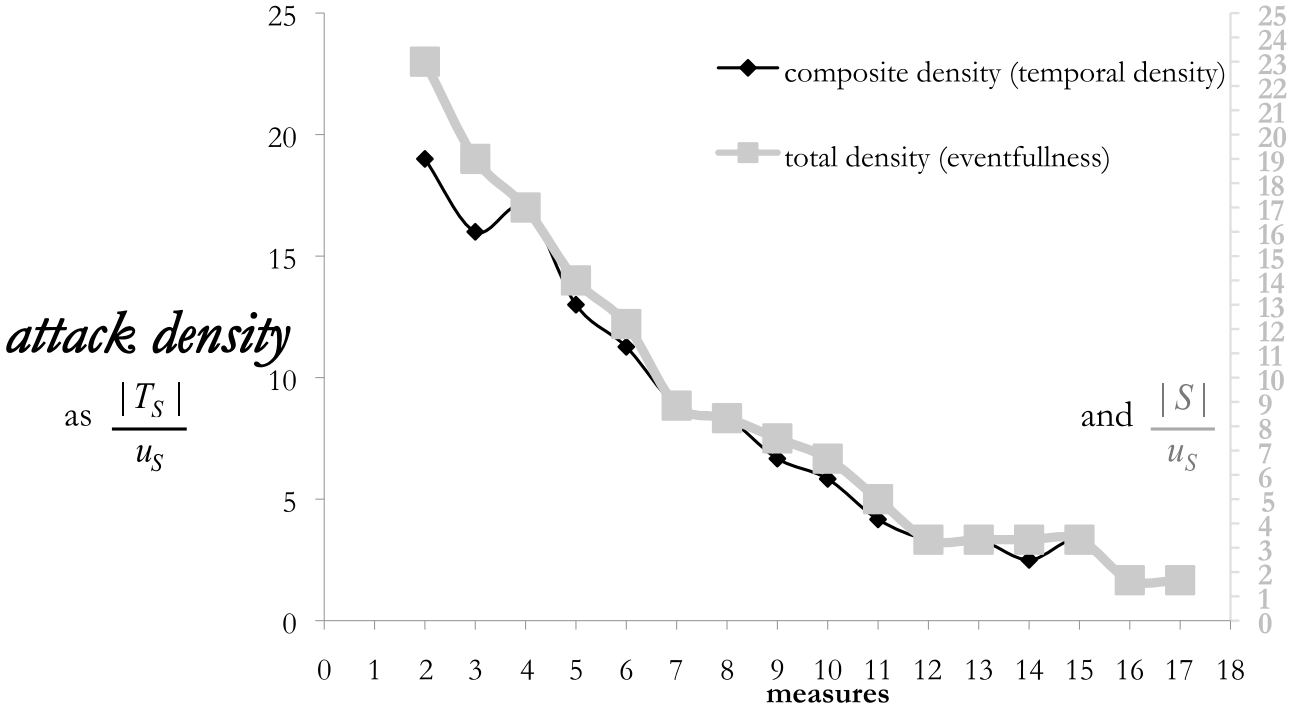
Murail's *Territoire de L'oubli* first page of the score

Figure 3a2



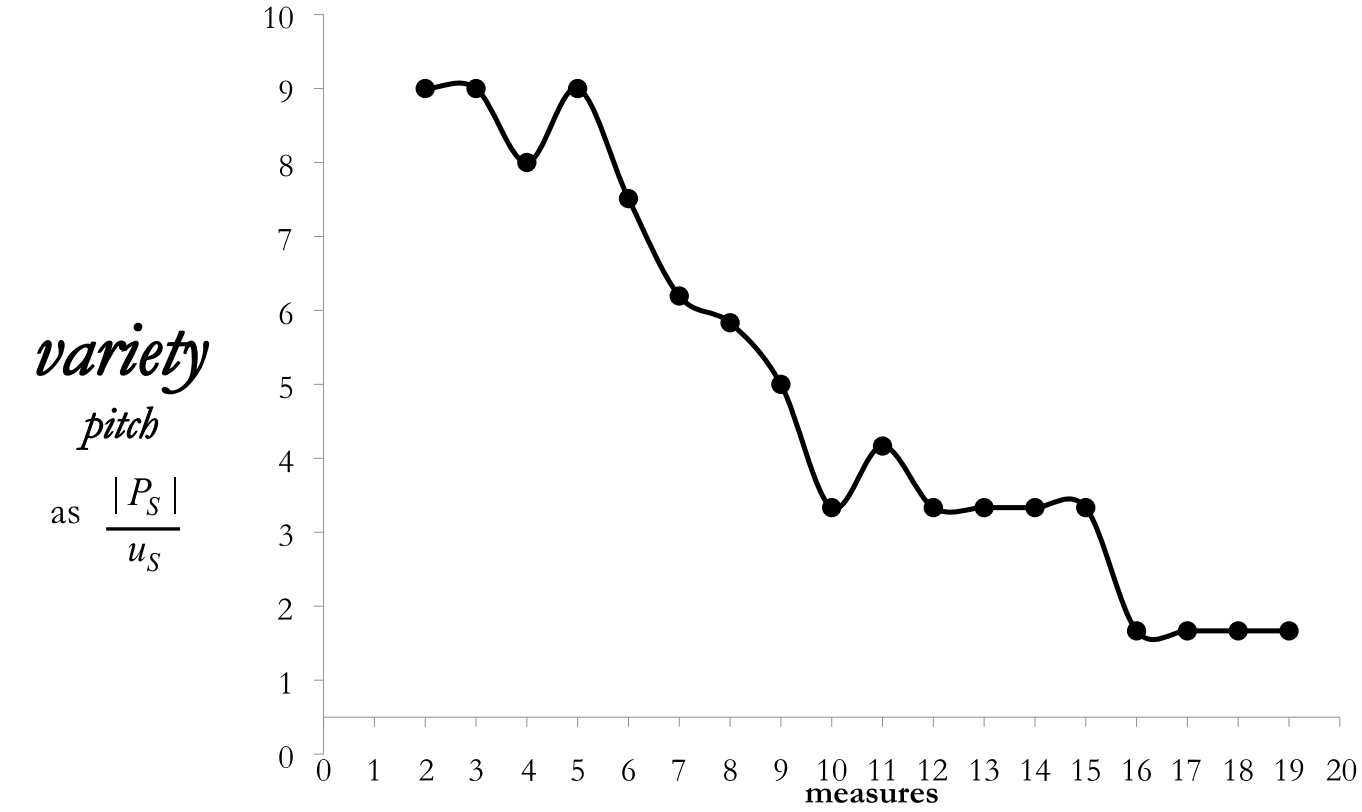
Murail's *Territoires de L'oubli*, second page of score

Figure 3b



Decreasing temporal density and eventfulness in Murail's *Territoire de L'oubli*

Figure 3c



Decreasing pitch variety in *Territoires de L'oubli*

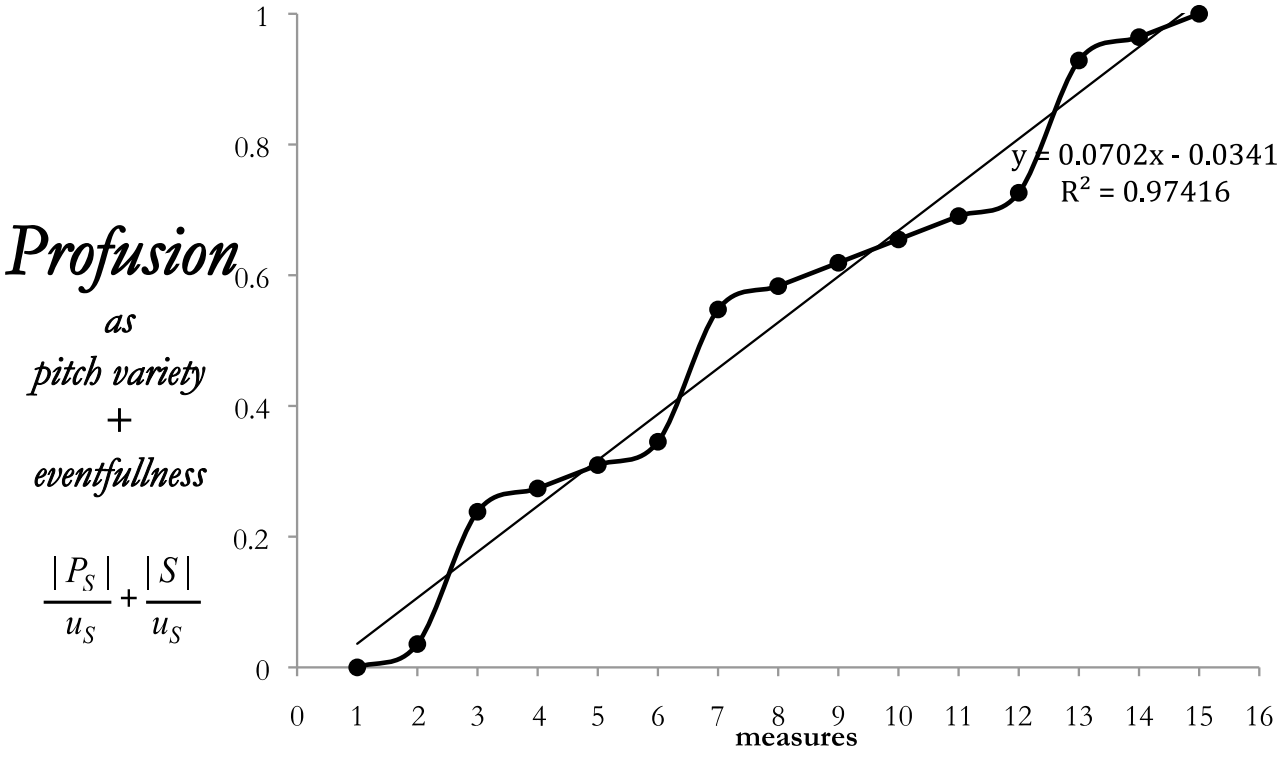
An *amalgam* vessel: *profusion*

Reinforcing this dilution, the Murail excerpt also undergoes a *diminuendo*. Notice that pitch variety and attack density fluctuate together in parallel and they could be conceptualized together under one broader concept—let us call it *profusion*. We can model the situation by amalgamating the two vessels into one. Thus it is an *amalgam* vessel called *profusion*:

$$Profusion(S) = PitchVariety(S) + Eventfulness(S)$$

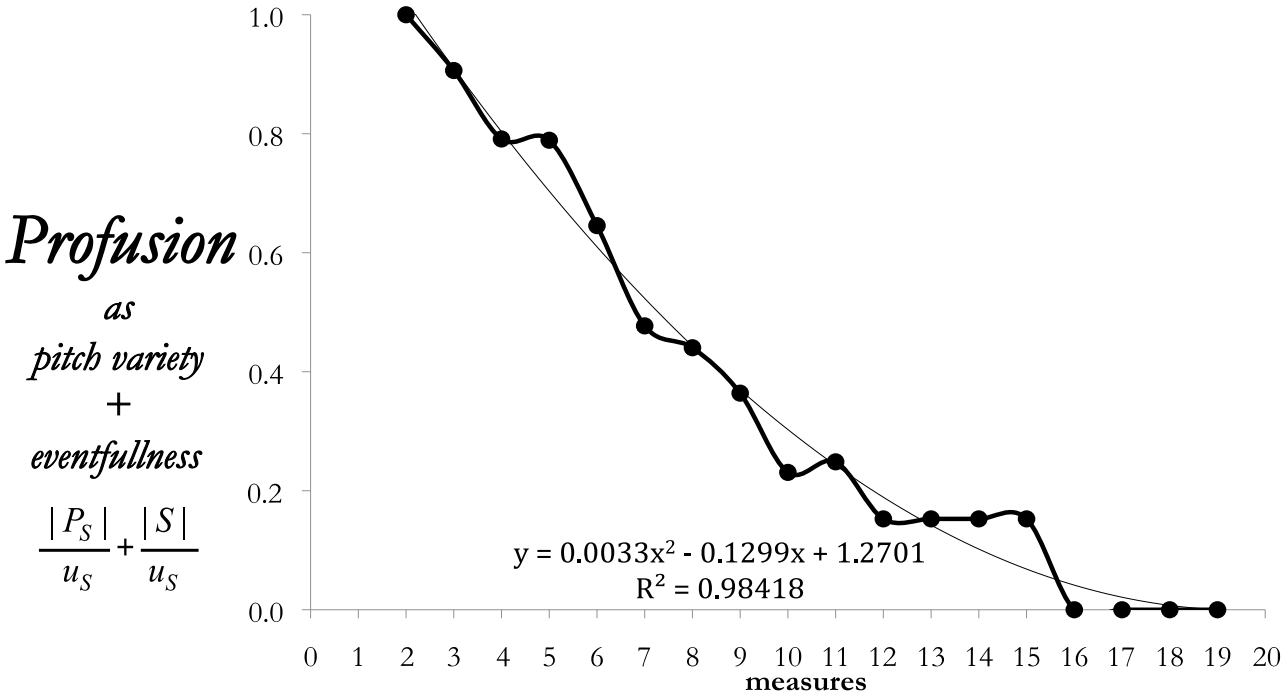
To forge the amalgamation it would be more proper to scale their values to the range from 0 to 1 and take their average, since *pitch variety* and *eventfulness* are entirely different types of magnitudes.[28] This produces the graphs in Figures 4a and 4b. In the Reich excerpt, the profusion increases smoothly. And the decreasing profusion in the Murail excerpt is also strong. As suggested by the smooth curves in Figures 4a and 4b, the computed data very strongly fits mathematical functions (linear and polynomial) which are typically used in psychology, sociology, economics, biology, meteorology, chemistry, physics, and so forth, to model directional change, that is, to empirically demonstrate that collected data has a directional trend.[29]

Figure 4a



Reich's *Drumming*

Figure 4b



Murail's *Territoires de L'oubli*

Up, up, and away: channeling and opposition

This section explains the concepts of *channeled flow* and *oppositional vessels* with excerpts from Ligeti's *Atmosphéres* and Saariaho's *Lichtbogen*.

Channeled flow and fluctuating *prevalence* in Ligeti's *Atmosphéres*

Each vessel discussed so far employs an *open-flow system* (all notes are considered by the gauge). Sometimes a modified approach channels the texture into one or more streams to be gauged separately. Rather than the docket having one chamber through which the entire musical texture flows, it instead has two or more, into which flow different streams of the texture, for instance the woodwinds flowing separately from the strings. This kind of flow is called *channeled flow*.

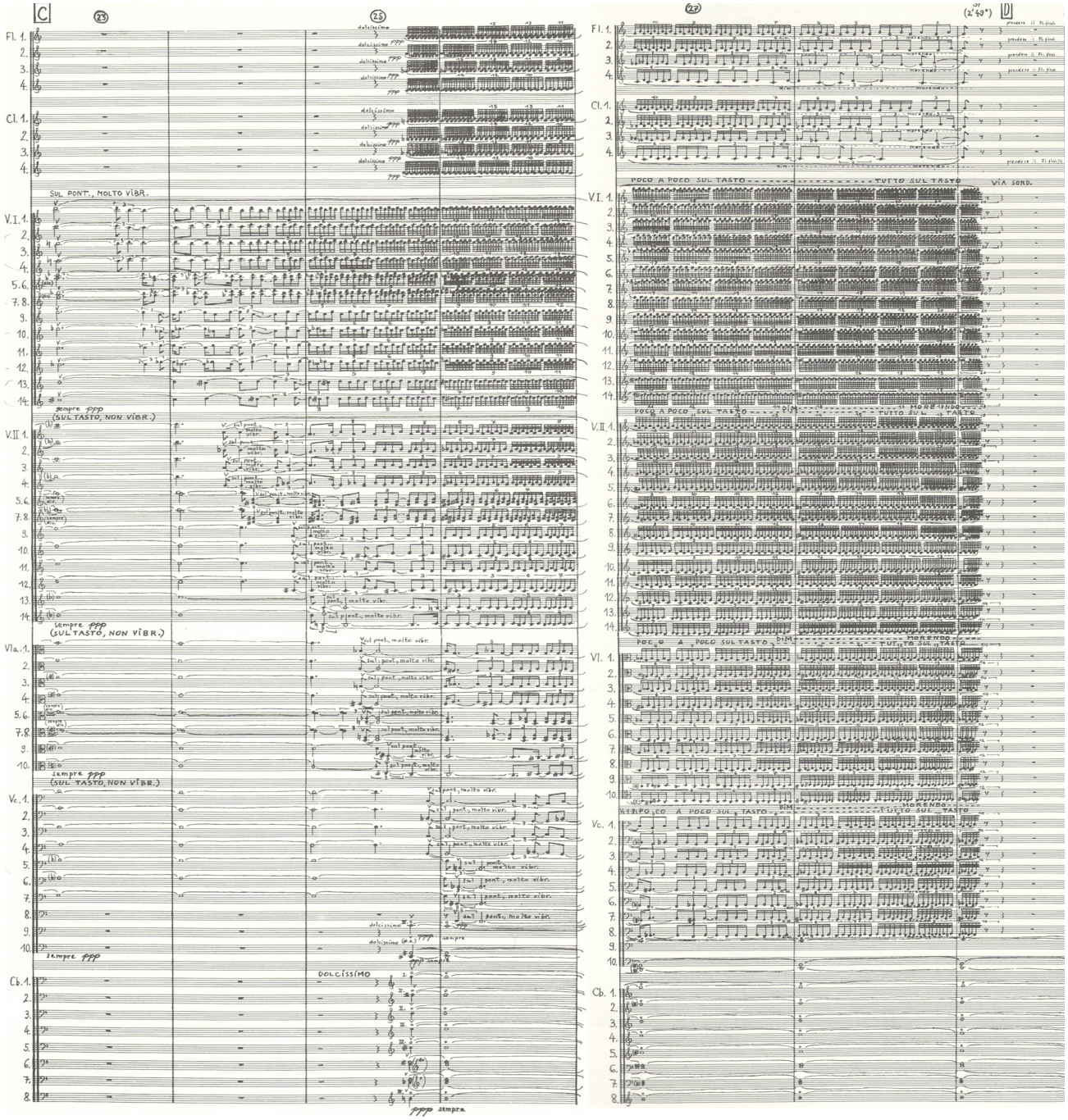
Ligeti's *Atmosphéres* and Saariaho's *Lichtbogen* exemplify appropriate use of a channeled-flow system. In both excerpts the important point is a flux of timbral-textural opposition, a tapered trade-off between densities of distinct timbral-textural streams.

In Figure 5a, the string section at mm. 23–29 of *Atmosphéres* presents a gradual transition from canonic macro-polyphony heard as "molecular" (with distinguishable strands) to a micropolyphony heard as "molar" (Deleuze and Guattari's term for an indistinguishable mass).[30] It might not be clear at first how this transition occurs. Using the terminology and apparatus introduced above, however, we can explain it as an increase in a familiar vessel within a timbral channel. Specifically, the temporal density of the strings increases incrementally. That is, in this context, the transition to a more molar sonic experience comes about through increasing temporal density in the strings channel which has many more participants (via divisi) than the winds and therefore tends more to micropolyphony. In this way, this textural trajectory is modeled with the following vessel, using channeled flow:

$$\underset{strings}{Prevalence}(S) \;=\; \underset{strings}{TemporalDensity}(S) \;=\; \frac{\left|\overbrace{T_S}^{strings}\right|}{u_S}$$

where, as usual, T_S denotes the set of occasions (eventful times) in span S, the upper bracketing $\overbrace{}^{strings}$ denotes the string section being isolated, their combination $\overbrace{T_S}^{strings}$ denotes all the occasions at which the strings play during span S, and $\left|\overbrace{T_S}^{strings}\right|$ is the size of the set of such occasions within span S, that is, the number of string occasions in the span.

Figure 5a



From Ligeti's *Atmosphéres*, mm. 23–29; © Copyright 1963 by Universal Edition A.G., Wien

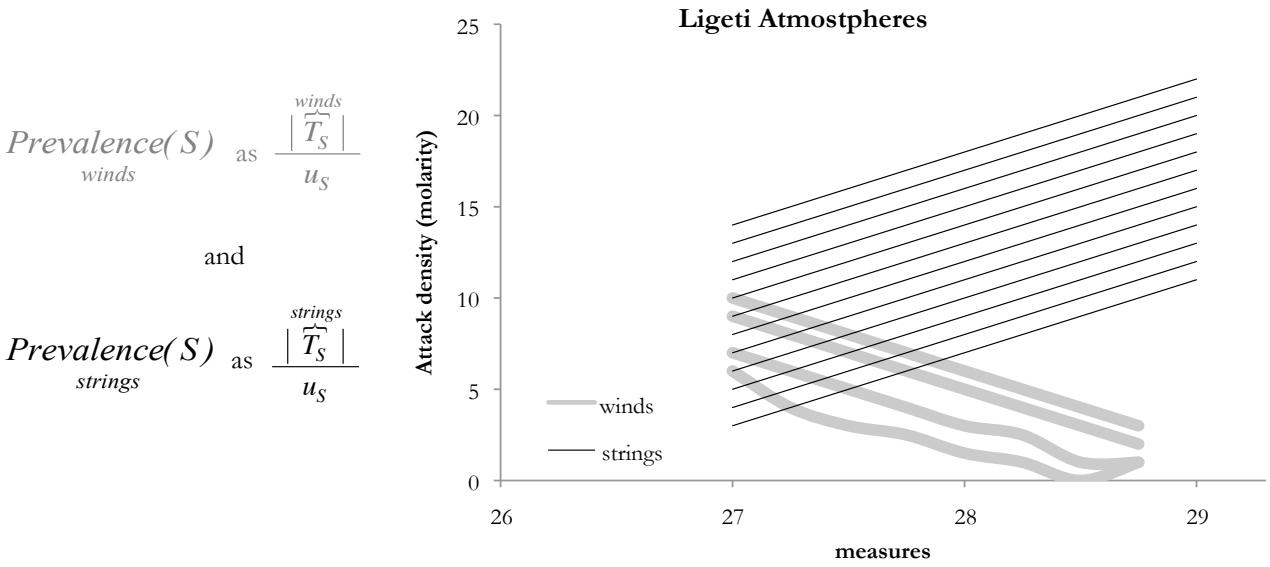
The temporal density of the winds' stream is modeled likewise:

$$\underset{winds}{Prevalence}(S) \;=\; \underset{winds}{TemporalDensity}(S) \;=\; \frac{\left|\overset{winds}{\overbrace{T_S}}\right|}{u_S}$$

I am using the word "prevalence" now because it is the prevalence of the channel that is the point of focus, because it is changing; but I am also invoking "temporal density" because its computation was already explained above (with regard to contexts that did not involve multiple channels). Related definitions are built up similarly below, because we are relating several kinds of musical experiences to each other in terms of more basic quantifiable elements that give rise to them.

Figure 5b shows the flux of both the strings and winds streams. As the strings' temporal density increases, it transforms from molecularity (macropolyphony) to molarity (micropolyphony). The winds stream does the opposite, transforming from molarity (micropolyphony) to molecularity (macropolyphony).

Figure 5b



Flux of temporal density of strings and winds in mm. 23–29 of Ligeti's *Atmosphéres*

Oppositional vessels and waves of timbre densities in Saariaho's *Lichtbogen*

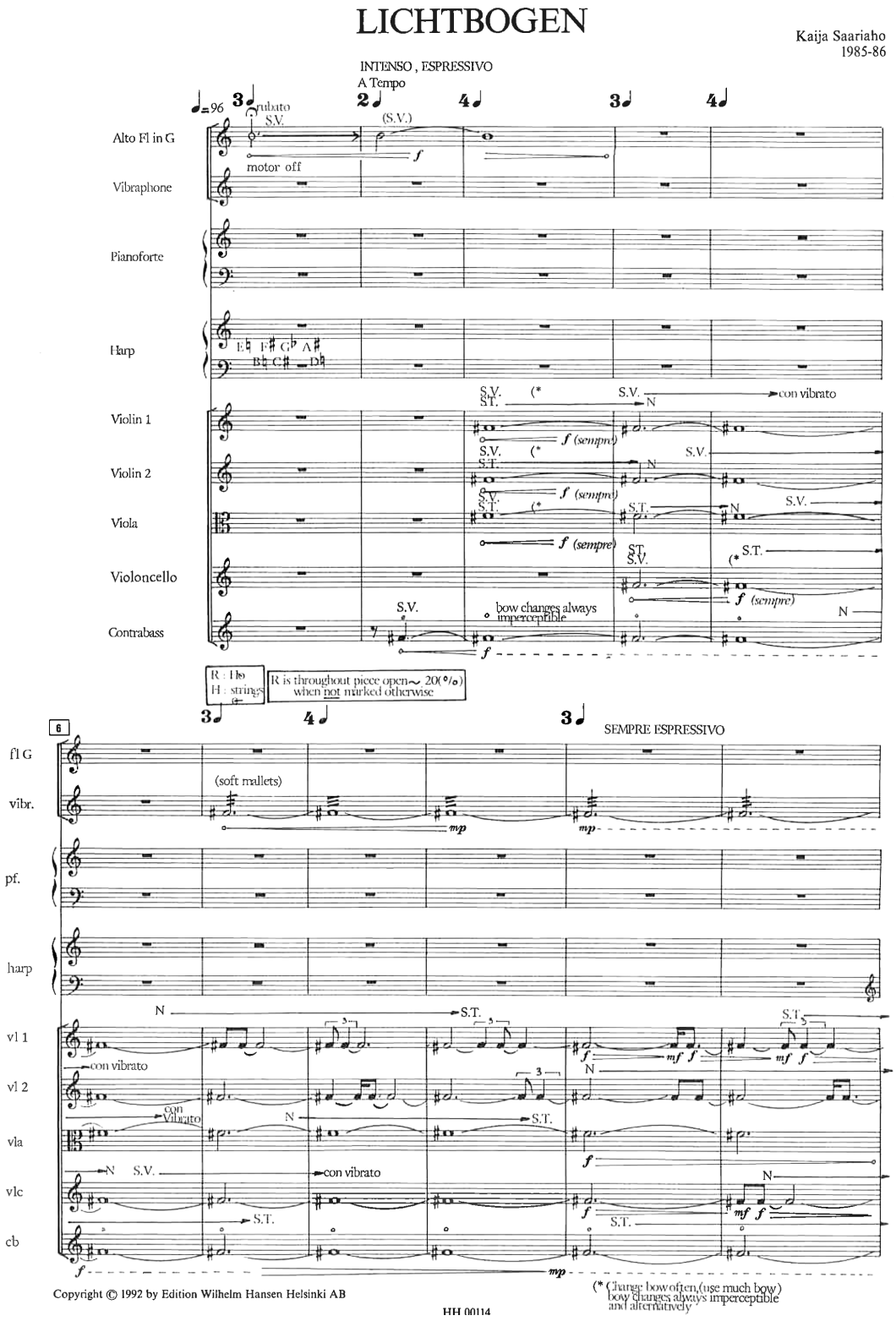
Measures 25–29 of Ligeti's *Atmosphéres* can also be modeled with yet another vessel, which compares the temporal density of the strings against that of the winds, thus tracking the relative molarity of the strings in comparison to the winds. This is a type of *oppositional vessel*, a vessel whose gauge is based on subtraction (or division) between two component vessels:

$$\underset{strings\ vs.\ winds}{RelativePrevalence}(S) \;=\; \underset{strings}{Prevalence}(S) \;-\; \underset{winds}{Prevalence}(S) \;=\; \frac{\left|\overset{strings}{\overbrace{T_S}}\right|}{u_S} \;-\; \frac{\left|\overset{winds}{\overbrace{T_S}}\right|}{u_S}$$

Such gradual textural-timbral flux exemplifes Ligeti's orchestral music. It is easy to glean from mere visual inspection of the score, and even more so with Figure 5b.

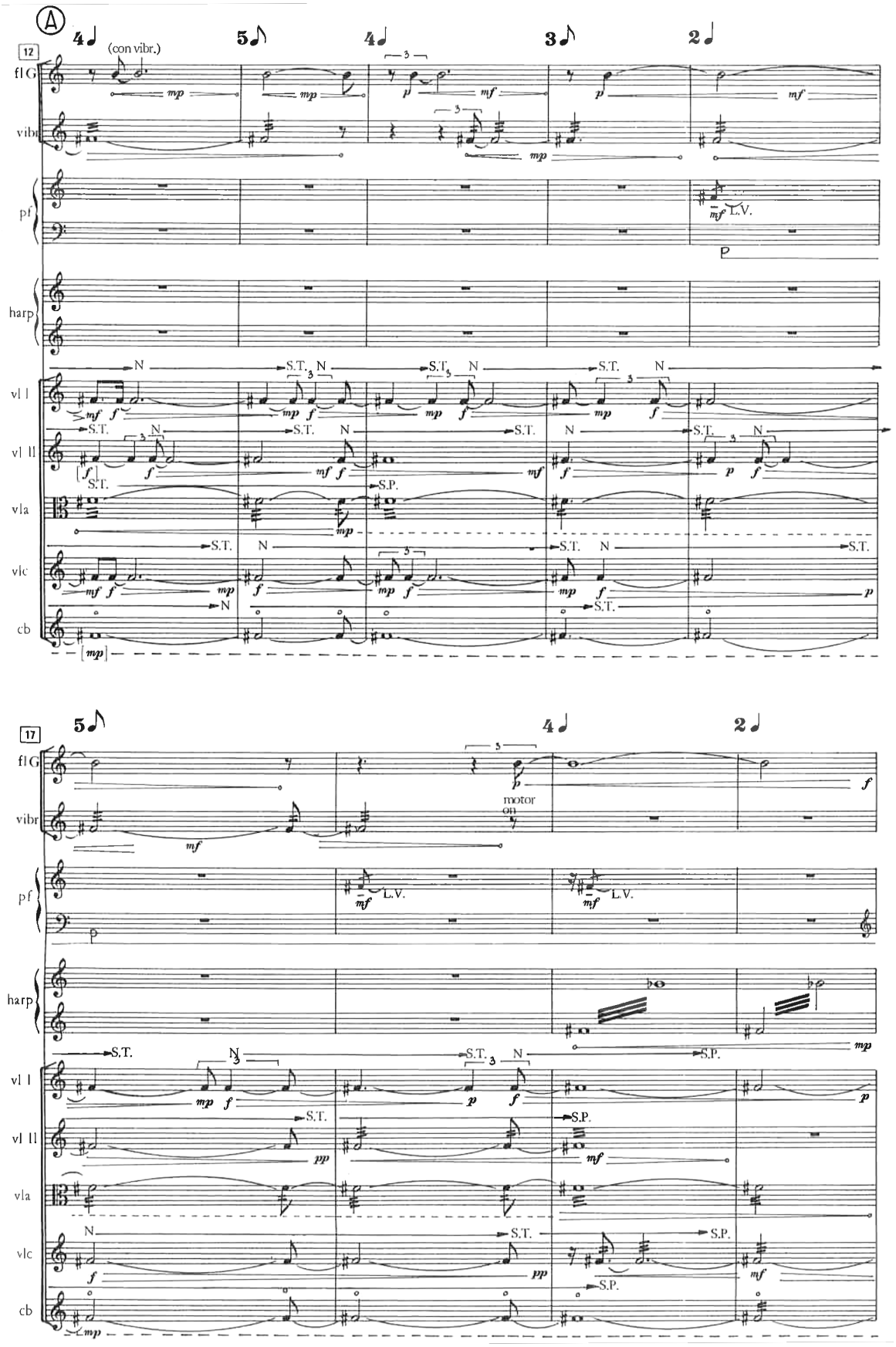
Such is not the case with Saariaho's *Lichtbogen*, whose opening (mm. 1–39, shown partly in Figure 6a) presents a similar tapered textural-timbral flux, but over a longer time range, and involving timbral changes much less easily gleaned from visual inspection of the score. The passage is static in pitch (basically just F♯) so the timbre is the main flux.

Figure 6a1



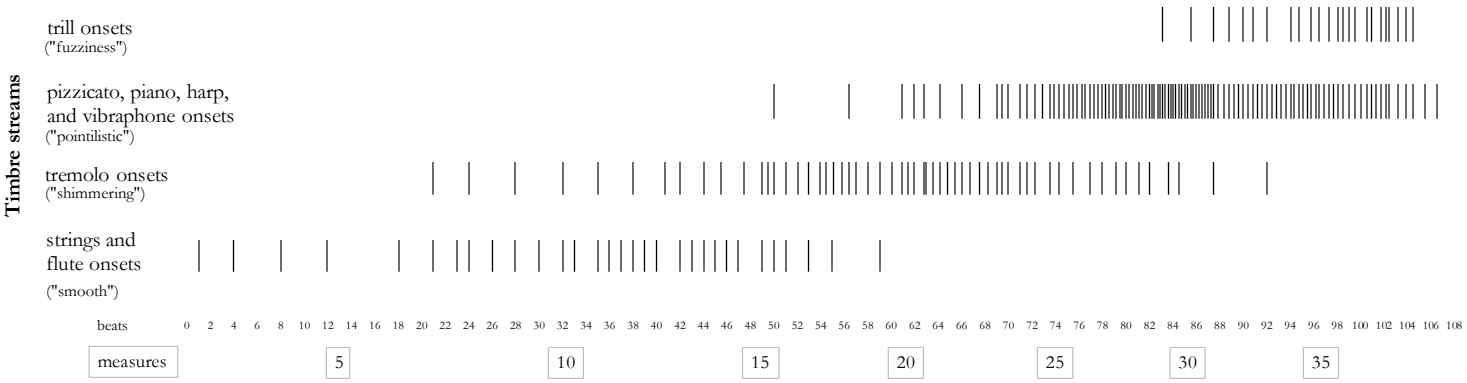
Excerpt from Saariaho's *Lichtbogen* (mm. 1–11)

Figure 6a2



Excerpt from Saariaho's *Lichtbogen* (mm. 12–20)

Figure 6b



Fluctuating timbre densities in the pitch-static intro of Saariaho's *Lichtbogen*

The timbres blend seamlessly yet subtly shift, because the prevalence of each timbre fluctuates. Figure 6b diagrams their onsets. To model this aspect of *Lichtbogen*, I use filltered flow systems targeted to each of the timbres of *Lichtbogen*. Where * denotes onsets that are neither tremolo nor trills, the appropriate timbre-textural vessels are defined thus[31]:

$$Smoothness(S) = \underset{sustainedAttacks}{Prevalence(S)} = \frac{\left| \overbrace{T_S}^{strings\ \&\ flute} \right|}{u_S}$$

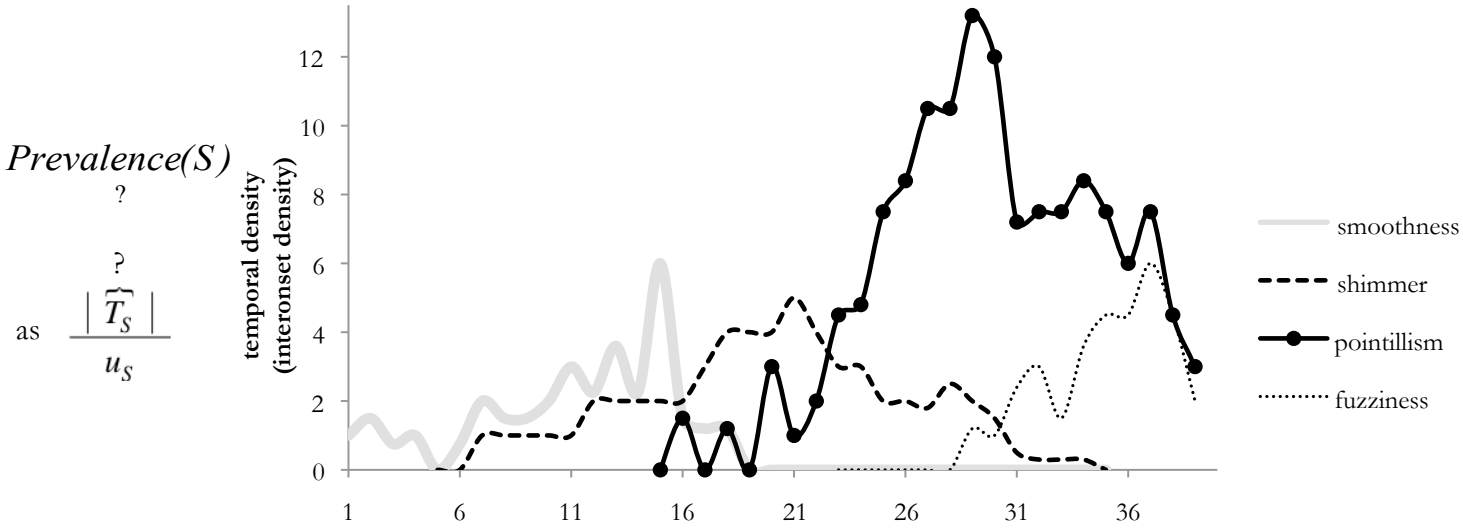
This is saying that, in this interpretive context, the *smoothness* of span S can be defined as the prevalence of sustained attacks in the overall texture; and the prevalence of sustained attacks in the overall texture can be defined as the temporal density in the strings-and-flutes channel (because those are exactly the instruments that have sustained attacks in this context). Analogous logic motivates the following definitions:

$$Shimmer(S) = \underset{tremolos}{Prevalence(S)} = \frac{\left| \overbrace{T_S}^{tremolo} \right|}{u_S}$$

$$Pointallism(S) = \underset{hardAttacks}{Prevalence(S)} = \frac{\left| \overbrace{T_S}^{pizz.,\ piano\ harp,\ \&\ vib*} \right|}{u_S}$$

$$Fuzziness(S) = \underset{trills}{Prevalence(S)} = \frac{\left| \overbrace{T_S}^{trills} \right|}{u_S}$$

Figure 6c



Flux of timbre in Saariaho's *Lichtbogen* pitch-static intro

Figure 6c shows four irregular overlapping arcs of filtered density, one for each of four timbre groups, thereby presenting staggered waves of timbre. Each peaks at a different time: *smoothness* (sustained onsets) at m. 15, *shimmer* (tremolos) at m. 21, *pointillism* (hard onsets) at m. 28, and *fuzziness* (trills) at m. 37. I recommend listening to the first seventy-five seconds of *Lichtbogen* while following the graph (other fluctuations not included, but which could have been, are glissandos and ponticello).

The introduction of *Lichtbogen* presents only one pitch, without obvious rhythmic motive or other repetition; its dynamic form arises through the interacting timbral waves, that is, through the irregular gradual or tapered transitions between the waves of one sound color group and another: from *smoothness* (sustained attack onsets of flute and strings) to *shimmer* (tremolos of vibraphone, flute, and harp), to *pointillism* (hard attack onsets of piano, vibraphone, pizzicato strings, and harp) to *fuzziness* (trills of the strings and flute).

Each transition can also be modeled as an oppositional vessel by subtracting one filtered temporal density from another. Thus Figure 6d shows three successive timbral-textural transitions. Each of them is being modeled as an oppositional vessel, one timbre-texture verses another.

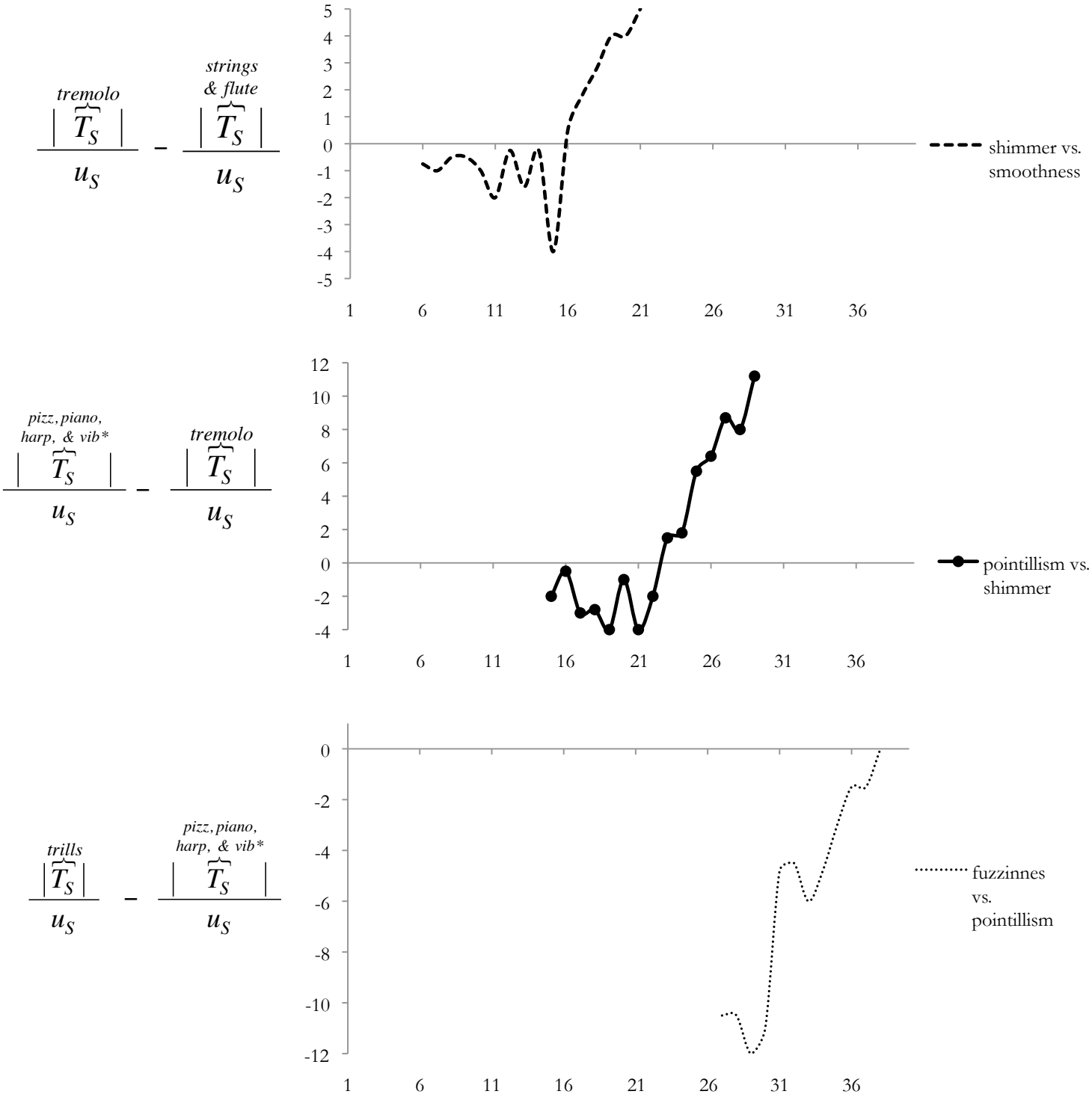
The analysis advances further by considering why the timbre groups flow and ebb in this particular order: sustained notes, tremolos, hard attacks, and then trills. The ordering choice seems driven by the specific kind of energy that events of each timbre emit. They have different emphasis on the excitation of the tone. Within a texture of varied timbres, in some sense sustained tones are the most flow profile, in that they can be smooth. Tremolos don't have any more distinct a beginning but they keep re-energizing, or re-exciting the tone. Hard attacks, such as piano or pizzicato, even harp, put more attention on the note onset than the previous timbre groups do. Finally trills put further emphasis by introducing a minimal change in pitch. Thus, in terms of tone excitation they form a gradated series in which each timbre has greater tone excitation (in the sense just described) than the previous:

$$\text{SUSTAIN} <_{excitation} \text{TREMOLO} <_{excitation} \text{HARD ATTACKS} <_{excitation} \text{TRILLS}$$

Based on this discussion, we can rank these (sustain=1; tremolo=2; hard attacks=3; trills=4) and multiply the prevalence by the ranking as shown in Figure 6e. From this computation arises the ascending curve shown in Figure 6f. That is, the discrete events depicted by four streams of vertical lines (event onsets of each timbral stream) are those from which emerge the sense of continuous

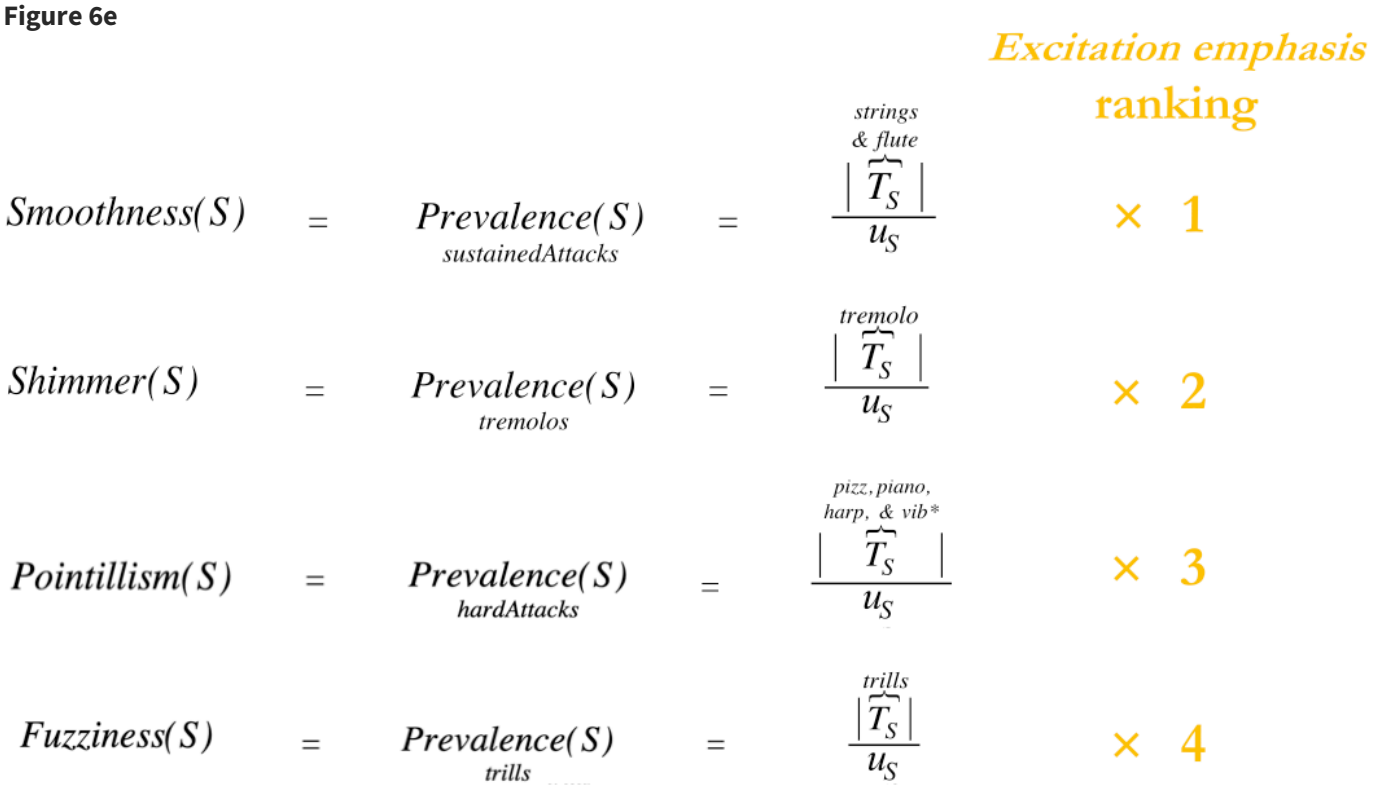
change we experience when listening. Thus, the graph shows how the texture goes from less excitation emphasis to more excitation emphasis, or from a less differentiated (more "molar") to a more differentiated (more "molecular") texture.

Figure 6d



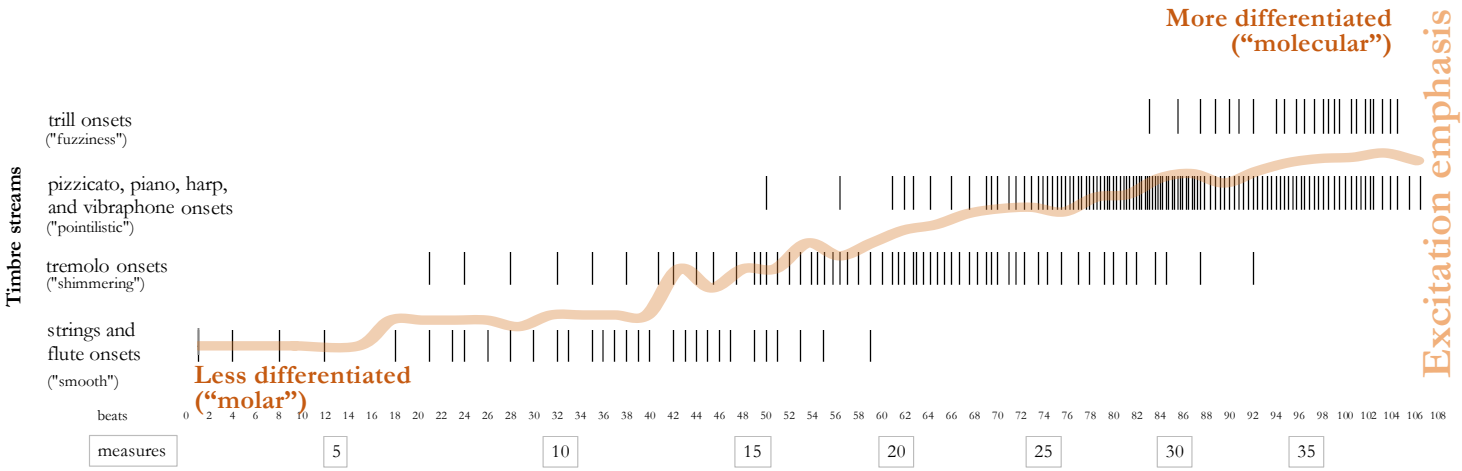
Timbre transitions in Saariaho's *Lichtbogen* intro, modeled with oppositional vessels

Figure 6e



Proportional weighting of timbral streams in the intro of Saariaho's *Lichtbogen*, based on varying emphasis on tone excitation

Figure 6f



Progression of excitation emphasis from less differentiation ("molar") to more differentiated ("molecular"), in Saariaho's *Lichtbogen*

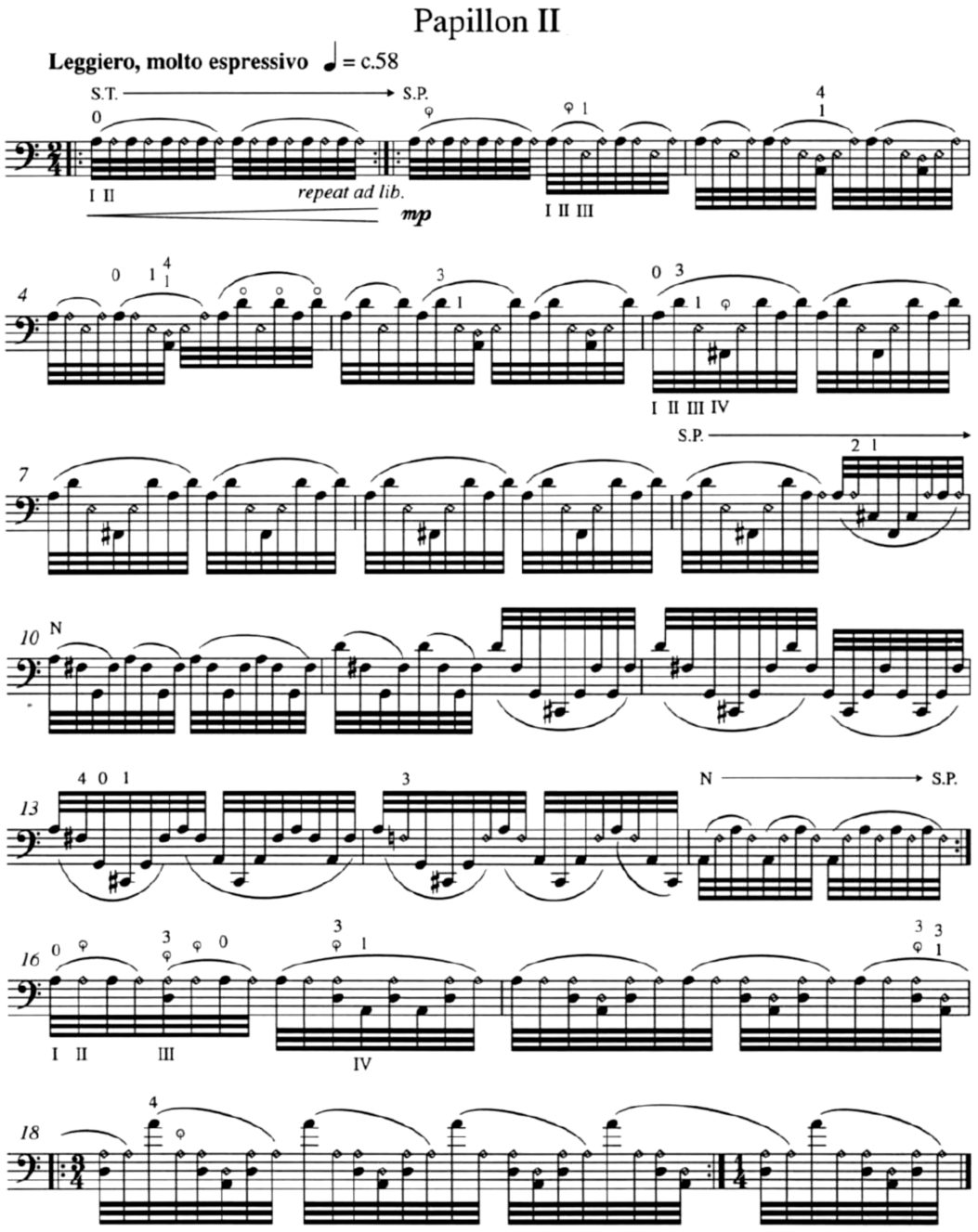
The analysis is meant to show the sense of qualitative change in the introduction emerging through the shifting prevalence of different kinds of discrete events. In this case that qualitative change is itself a shift from more smooth (molar) to more differentiated (molecular). Yet that is only a beginning. This introduction actually serves to launch the remainder of the piece, which is full of plenty of other pitches besides F♯. The introduction's smooth trajectory is from less energy to greater energy. If pitch change trumps all other kinds of tone change (it is some sense the upper limit of timbral change), then the introduction's trajectory of increasing energy continues further beyond the introduction, as other pitches are introduced; and the trend continues beyond the introduction. In this sense the introduction subtly forecasts what follows and the foregoing analysis suggests how it does so.

Metamorphosis

Opposing vessels of variety in Saariaho's *Papillon II*

Holding density constant, Saariaho's *Papillon* II (Figure 7a), projects dynamic form through two types of variety, fluctuating complimentarily. *Papillon II* presents an interesting interaction between texture, timbre, and pitch, which, as mentioned above, in dynamic form analysis are not held apart as independent domains. Also the small scale of *Papillon II* permits showing all of the analysis's computations (in Table 1).

Figure 7a



Papillon II, after a single pitch intro played *sul tasto*, presents a straightforward trajectory of *sul ponticello* to *normale* and back. But that is trivial compared to what else happens. A clear dynamic form arises from the flux of a quality that itself can be reckoned in terms of statistical prevalence of certain event types.[32] Here there are two such qualities, working in opposition. Each of these qualities serves as a vessel of form. Moreover they can be conceptualized as opposite of each other; and in this piece they also fluctuate in opposition to each other. So it is helpful to combine the two vessels into one oppositional vessel.

The dynamic form of *Papillon II* arises from the flux of two types of variety: *pitch variety* and *timbral variety*. The piece starts with one pitch class played two ways: with harmonics (including artificial harmonics) and *normale*. Artificial harmonics seem less uniform in timbre than normally played notes, perhaps because they often have more noise or are more difficult to execute. Thus timbral variety arises from different types of harmonics, each having a distinct timbre, more so than normally played pitches. So more types of harmonics beget greater timbral variety. Therefore, in this analysis, we will assert that different timbre is a different kind of harmonic. Timbral variety, then, can be gauged as the size of the set of timbres in a span, that size being denoted as $|I_S|$, divided by the duration of the span, thus u_S, which in this case is taken to be a one-measure span.[33]

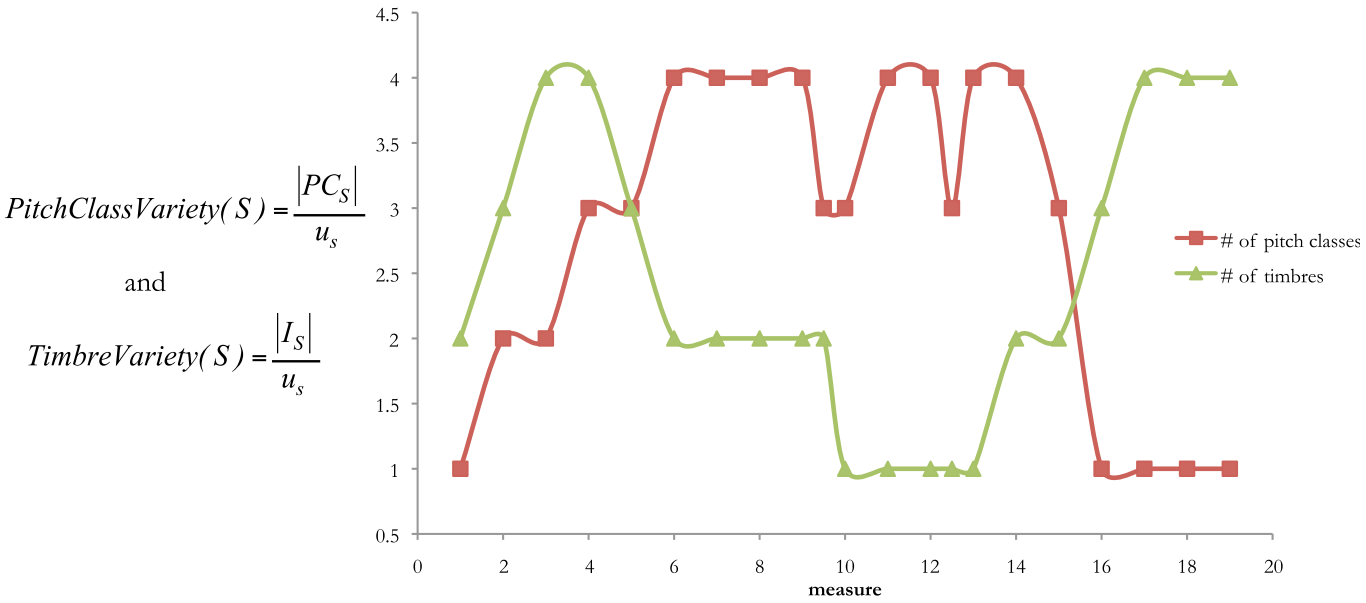
$$TimbreVariety(S) = \frac{|I_S|}{u_S}$$

Figure 7b shows that there is an increase to three different harmonics (plus *normal*e playing), followed by a decrease to just *normale* and then an ascent up to three harmonics (plus *normale*).[34]

The pitch content has virtually the opposite trajectory as the timbre; it increases to a crest of five distinct pitch classes in the middle and then attenuates down to one pc. The gauge is the size of the set of distinct pitch classes $|PC_S|$ divided by the span's duration u_S.

$$PitchClassVariety(S) = \frac{|PC_S|}{u_S}$$

Figure 7b



Fluctuating complementarity between pitch classes and timbres in Saariaho

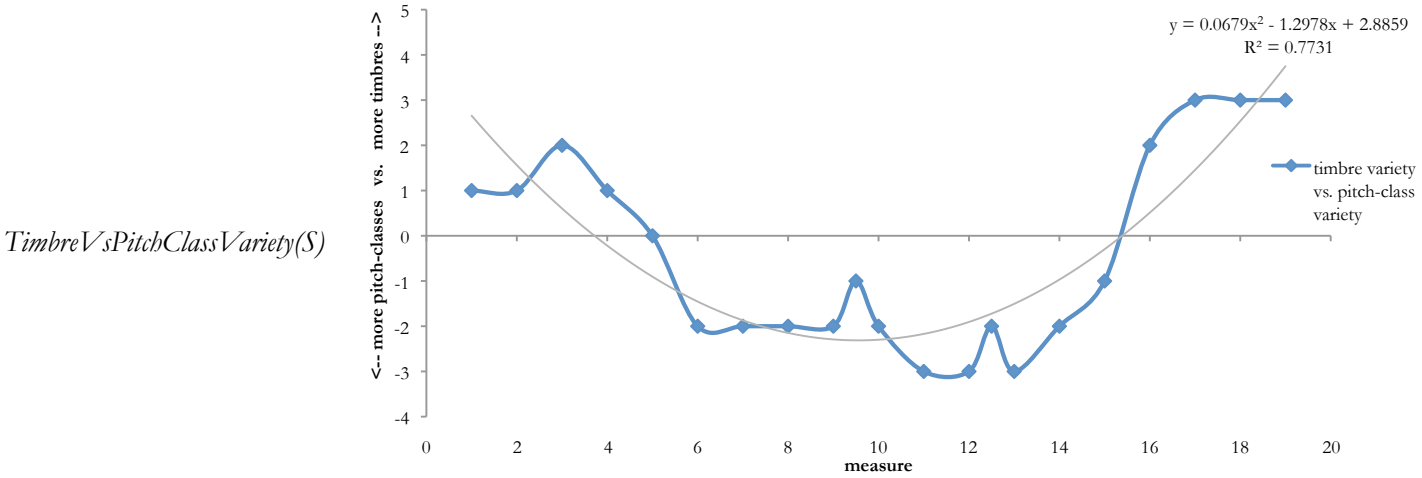
Saariaho (1987) has discussed a so-called "pitch-noise axis," which in this case is clearly traversed by the *ponticello* to *normale* back to *ponticello* trajectory. In *Papillon II*, this axis, or opposition is also paralleled by the two opposed types of variety: variety of noise (timbral variety) versus variety of pitch, which is more forceful and nuanced than simply the pitch vs. noise which Saariaho (1987) describes.

Since these varieties are conceptually opposed and fluctuate in opposition, the dynamic form analysis simplifies by combining them into one oppositional vessel through arithmetic subtraction:

$$TimbreVsPitchClassVariety(S) = TimbreVariety(S) - PitchClassVariety(S) = \frac{|I_S| - |PC_S|}{u_S}$$

Table 1 shows the actual numbers the gauge computes from each successive measure.[35] Figure 7c shows the resulting dynamic form, which I believe clarifies this particular piece and provides insight into Saariaho's composition strategies, beyond what she herself explains.[36]

Figure 7c



Oppositional vessel Timbral Variety vs Pitch-Class Variety in Saariaho's *Papillon II*

Table 1: Input and output data for comparing timbre variety of pitch-class variety in Saariaho's *Papillon II.*

Measure	# of pcs	# of harmonics	# of timbres (= # harmonics + 1)	Opposition: *TimbreVsPitchClassVariety* (= # of timbres − # of pcs)
1	1	1	2	1
2	2	2	3	1
3	2	3	4	2
4	3	3	4	1
5	3	2	2	0
6	4	1	2	-2
7	4	1	2	-2
8	4	1	2	-2
9	4	1	2	-2
9.5	3	1	2	-1
10	3	0	1	-2
11	4	0	1	-3
12	4	0	1	-3
12.5	3	0	1	-2
13	4	0	1	-3
14	4	1	2	-2
15	3	1	2	-1
16	1	2	3	2
17	1	3	4	3
18	1	3	4	3
19	1	3	4	3

Time ruptured and bridged

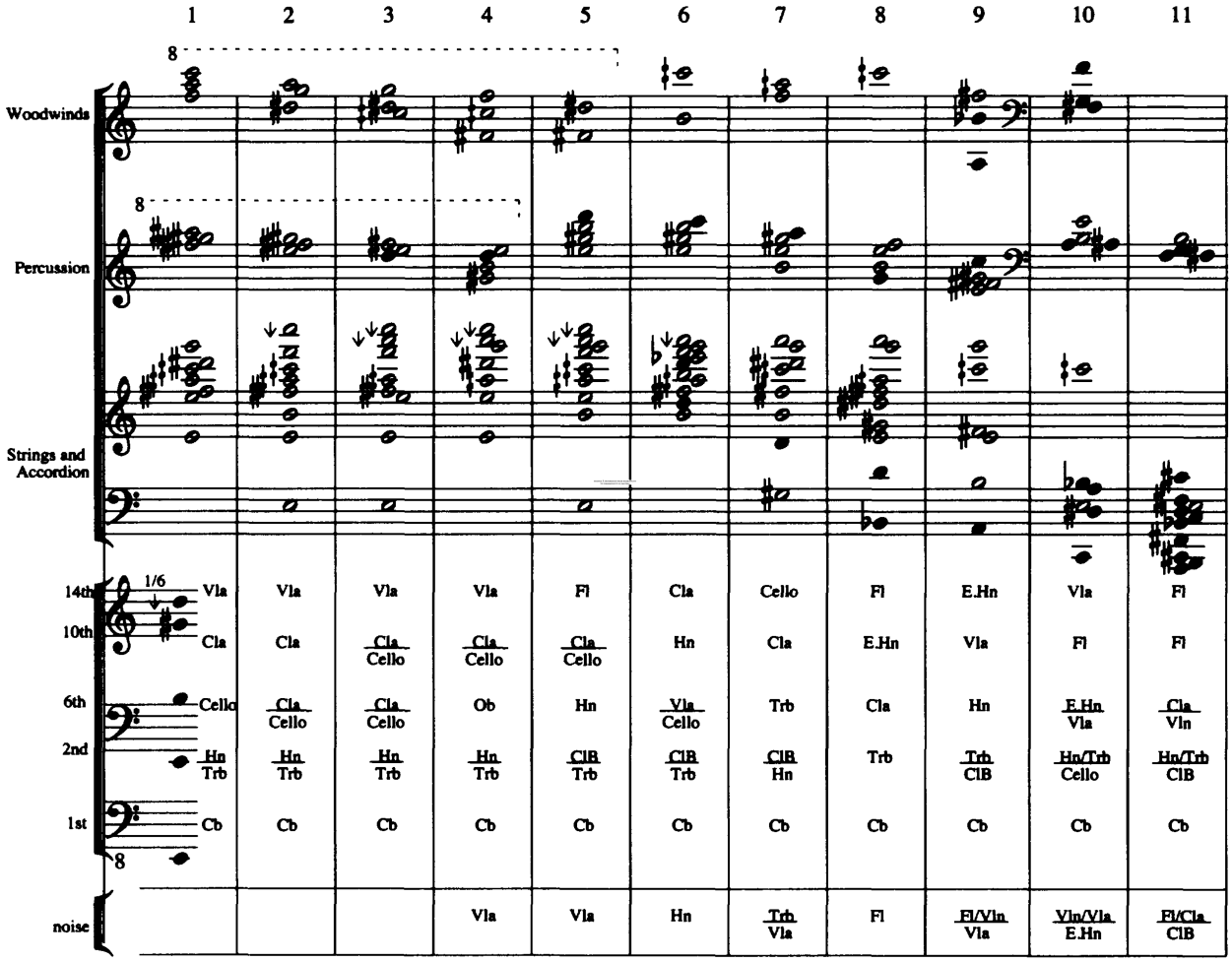
This section explains Grisey's *Partiels* and concepts of "difference" and "pre-audibility" as related to this piece.

Inharmonicity comparison enabled by *prompted flow* in Grisey's *Partiels*

As Francois Rose shows, Grisey's *Partiels* (1975) begins with a series of chords of varying inharmonicity.[37] Figure 8a reproduces Rose's example, with inharmonics as filled noteheads. Each chord is prompted by a loud repeated contrabass low E gesture (Figure 8b). The last two chords comprise only harmonic components, after which inharmonic tones accumulate exponentially. The inharmonicity itself is straightforwardly gauged as the size of the set of inharmonic tones in each span:

$$Inharmonicity(S) \quad = \quad \left| InharmonicTones_S \right|$$

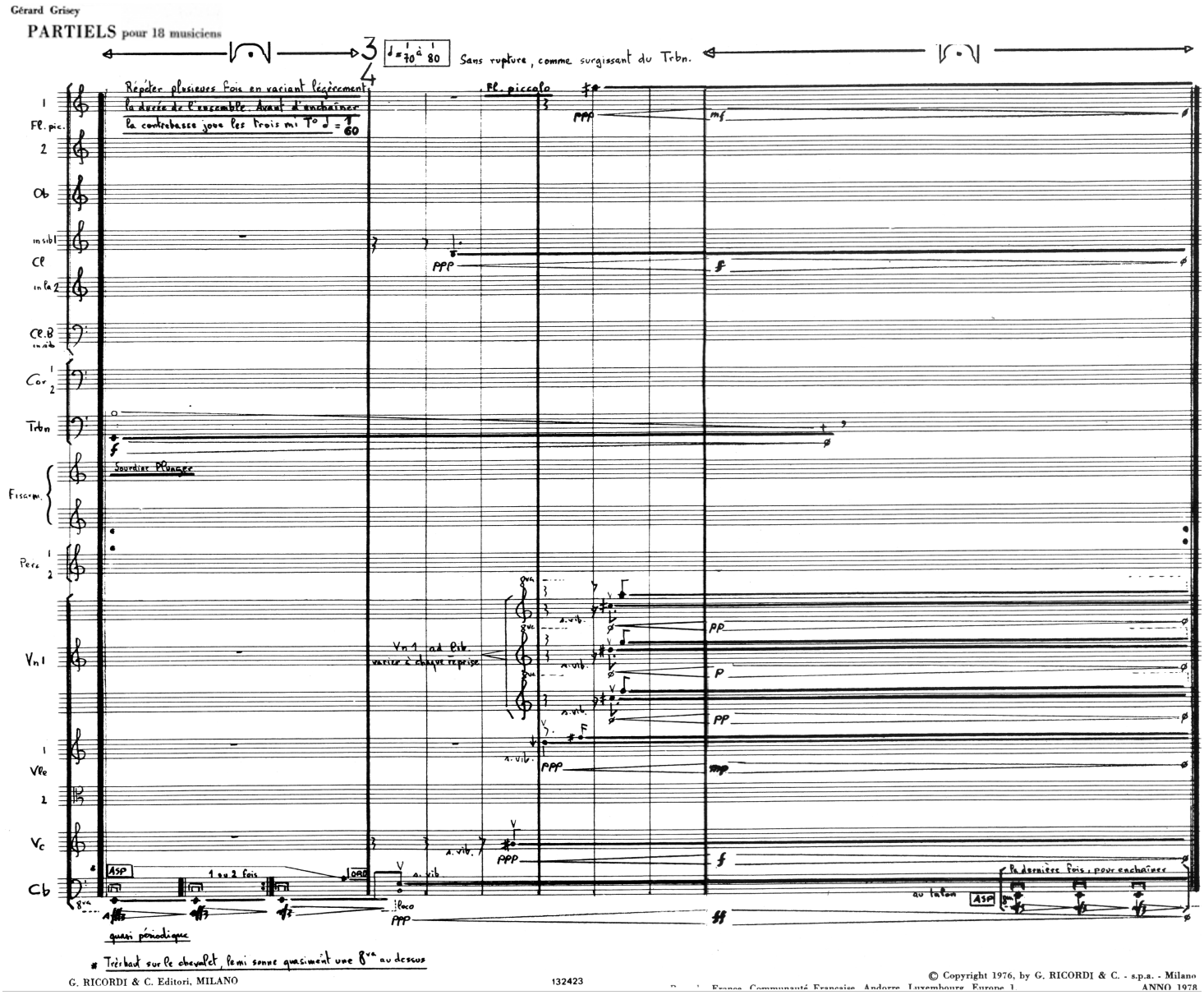
Figure 8a



EXAMPLE 3: PROGRESSION FROM HARMONICITY TO INHARMONICITY IN *PARTIELS*

From Francois Rose's (1996) "Introduction to the Pitch-organization of French Spectral Music," *Perspectives of New Music*, 34, no. 2 (1996): 6–39. Used with permissions from Francois Rose and *Perspectives of New Music*.

Figure 8b1

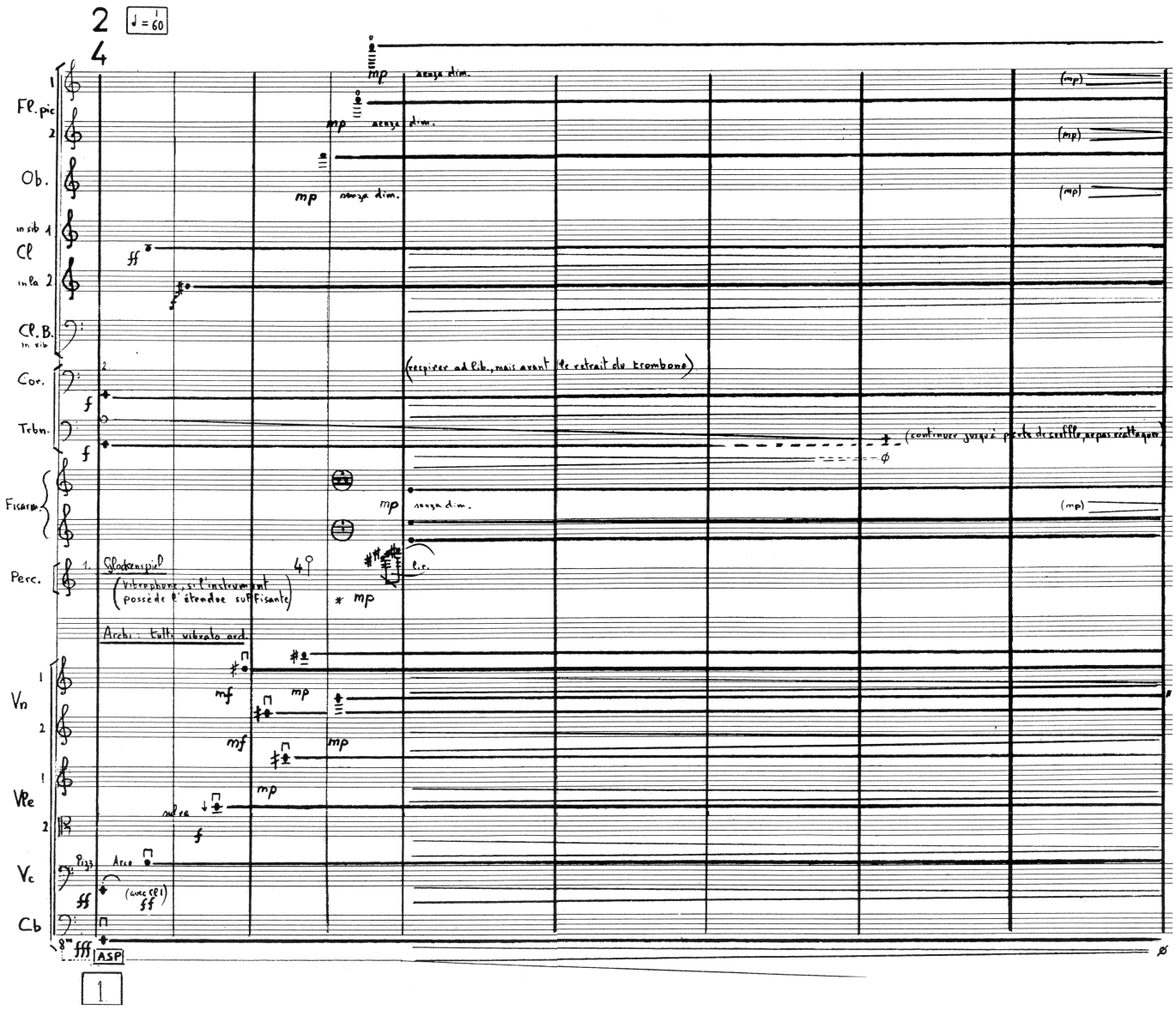


Grisey Partiels score p. 1

The way spans are delineated is not just incidental but rather crucial—without this delineation the form would be much murkier. What was being gauged by previous vessels did not depend on any particular time spans so these could be set somewhat arbitrarily, provided it was consistent (flowing by note or by measure). In *Partiels*, however, the growing chords are conspicuously prompted by each occurrence of the contrabass low E gesture so the analysis more appropriately employs *prompted flow*, which means a flow system regulated by segmental boundaries that arise contextually.

Specifically, in this context each instance of a contrabass low E gesture prompts a new span to flow into the docket, to be gauged for its degree of inharmonicity. This choice corresponds to the fact that a listener does or can experience each instance of a contrabass low E gesture as framing (or marking) the previous wafting pileup of quiet sustained pitches while preparing the way for the next wafting pileup of quiet sustained pitches to be compared to it. This comparison is the basis for experiencing a longer-range trend of increasing inharmonicity.

Figure 8b2



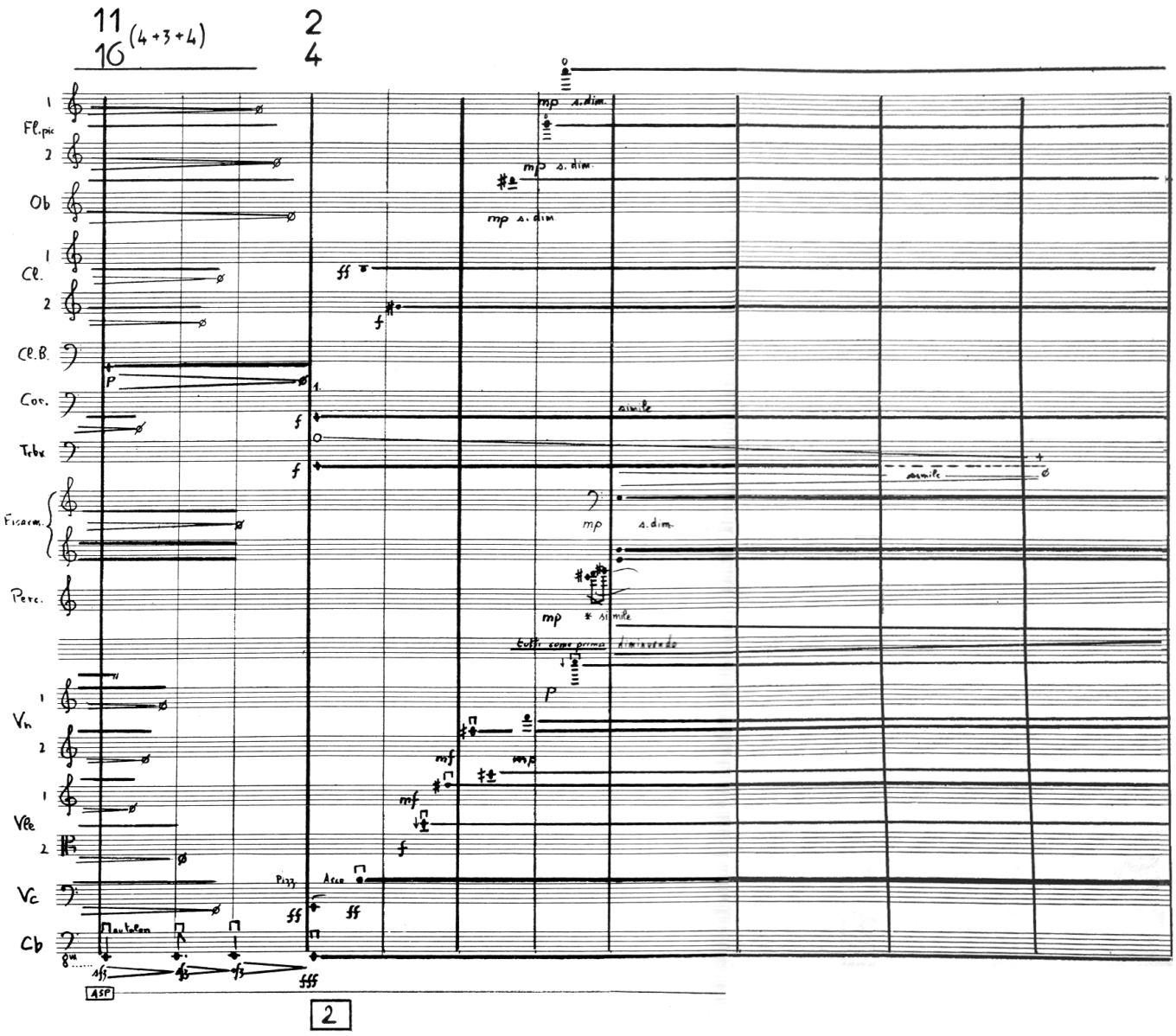
Grisey Partiels score p. 2

The technical formalism for defining a *prompted gauge* (prompted flow)

To generalize the representation of such segmental boundaries I introduce two additional components for formulating vessels. First, a square bracket subscript $_{[n]}$ denotes an occurrence that ends a span and prompts the vessel's gauge. Thus $S_{[n]}$ denotes a span ended by occurrence n and $t_{[n]}$ denotes the time at which occurrence n happens. Second, the nabla symbol ∇ (like an upside-down Greek delta) denotes a *backward difference*, which is the difference between the present item and the preceding one. It is defined thus: $\nabla f_n = f_n - f_{n-1}$. [38]

Whether in music or outside of music, sometimes unpredictable things beyond our control often prompt us to compare the present to some moment or moments in the past. So when comparing the present to the past, we do not typically do it at regular intervals, nor is the past being compared typically the same distance back in time as a previous comparison was, especially if, say, some

Figure 8b3



Grisey *Partiels* score p. 3

noticeable phenomenon recurs at an accelerating rate. Only in some circumstances do such comparisons obey a stable timing (comparing one morning to the next or one beat to the next in metrically stable music). So, on the one hand listeners can experience differences (accelerations or decelerations) of timing when comparing one particular present to some moment in its past than they would when comparing some other present to a moment in its past. Yet on the other hand when timing remains stable, listeners may experience other kinds of difference. (The sun is brighter this morning than it was yesterday morning; the chord heard on this beat is louder than the one heard on the previous beat.) This important flexibility in how we experience difference in music is strategically mirrored by flexibilities in our use of the backward difference operator in dynamic form modeling. We use this backward difference operator in a flexible way whereby it denotes an arithmetic difference (numerical subtraction) if it precedes a numerical designation (like time t); or it can denote a difference between sets (the elements of one set but excluding the elements of another set) if it precedes a set symbol (like a span S). Either way, it occurs in tandem with the square bracketed prompt designation; in this way it denotes the difference between the most recent occurrence and the previous one. Thus $\nabla S_{[n]}$ denotes the span of music starting from the previous occurrence of n up until the most recent

instance of n. By contrast, $\nabla t_{[n]}$ denotes the amount of time elapsed since the previous occurrence of n. This way the notation is versatile, enabling the representation of numerous vessels. Potentially anything can serve as a prompt. For instance if we are interested in the amount of time between switches of melodic contour direction (up vs. down), we would use this prompted gauge:

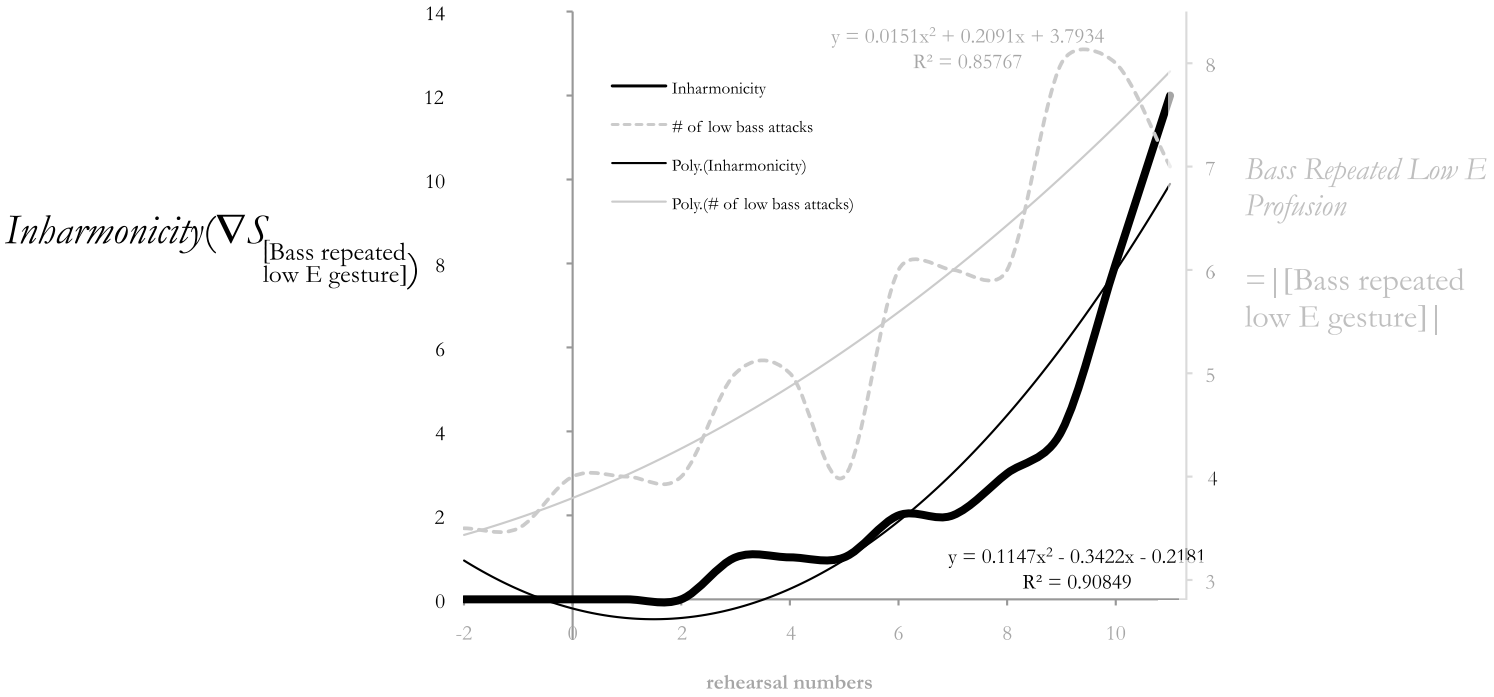
$$\nabla t_{[\text{SWITCH: direction}]}$$

Gauging inharmonicity, profusion, and prompt intervals in Grisey's *Partiels*

The gauge for Grisey's *Partiels* should be prompted by the contrabass repeated low E gesture; so rather than arbitrary spans S, we are instead interested in each span lasting from the previous occurrence of the bass low E gesture up to its most recent occurrence, denoted like so: $\nabla S_{[\text{Bass repeated low E gesture}]}$. Each occurrence prompts the gauge to tally the number of inharmonic tones contained in the elapsed span.[39] Thus the dynamic form shown in Figure 8c arises from this: $\mathit{Inharmonicity}(\nabla S_{[\text{Bass repeated low E gesture}]})$

A 2nd degree polynomial closely fits, showing a smooth trajectory that a listener who is attentive to this feature might glean in retrospect.[40]

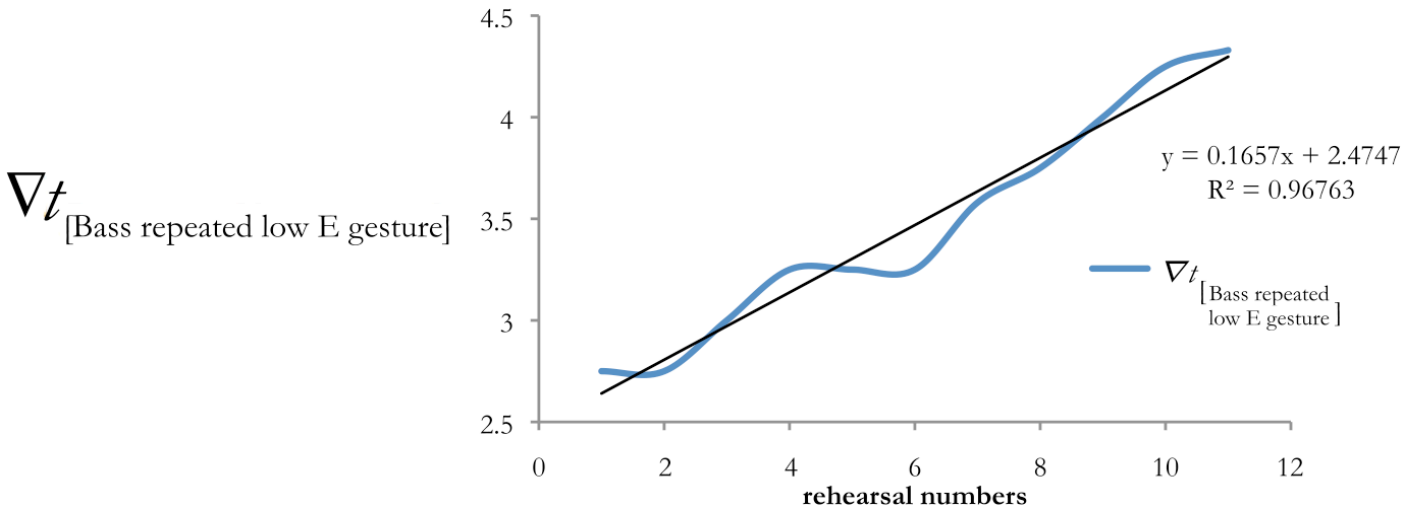
Figure 8c



Flux of Inharmonicity and Low bass E profusion in Grisey's *Partiels*

Yet the ascending dynamic form also arises through another vessel embedded in the prompt itself, that is, in the bass's low E gesture, which increases irregularly from three (or four *ad libitum*) up to ultimately eight attacks (before descending to seven attacks) as shown (partly) in Figure 8b. Thus also the number of events within the prompt serves as a vessel of form, whose gauge is represented as |[Bass repeated low E gesture]|, meaning the size of the set of events within the prompt gesture, with the size computation prompted by each completed occurrence of this gesture. We can call this the *profusion* of the low E gesture, whose flux Figure 8c shows as an irregularly rising grey dotted curve. Additionally, from rehearsal [1] onward, the time between the low E gestures steadily increases. Thus this vessel $\nabla t_{[\text{Bass repeated low E gesture}]}$ also produces a rising form (Figure 8d).

Figure 8d



Increasing time between occurrences of the Bass Repeated Low E Gesture

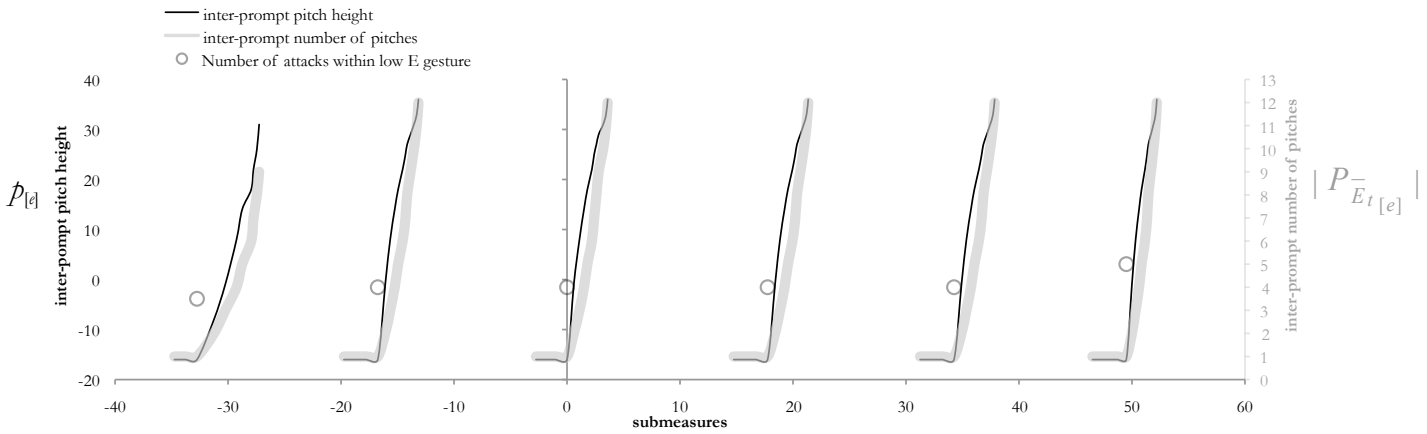
The three vessels of form demonstrated in *Partiels* suggest a signature facet of form in spectral music: distinct layers of subtlety, coordinated with each other. For instance if one hears an increasing number of low E bass attacks (increasing profusion), then one experiences almost the same rising dynamic form as if one were to hear the increasing number of inharmonic tones. Both are predominantly rising. The two vessels are mutually reinforcing, infusing a kind of redundancy that makes processive form in spectral music unusually forceful and clear without ever being trivial. This tendency to strategically use redundancy is something spectral music shares with common practice music and with biological entities (which inspired Grisey), and differentiates it from compositional practices, such serialism, that are able to offer sometimes more opulent varieties of detail and intricacy because they are willing to compromise audible clarity of form as an intrinsic value in favor of other experiential values. I do not intend this as a value judgment, but rather as a neutral differentiator which dynamic form analysis helps illustrate, especially through this introductory section of Grisey's *Partiels* taken as an example.

Gauging inter-prompt dynamic forms in Grisey's *Partiels*

Not only does the first section of *Partiels* present a rising form, but so too is there one within each prompted span. Following each repeated low E bass gesture, there is a clearly audible accumulation of sustained pitches. To represent this vessel, consider that E_t denotes the occasion of time t, that is, the set of events that commence at time t. A horizontal line above can represent unelapsed events. Using this convention, we can let the symbol $\overline{E_t}$ denote the set of events active (not yet elapsed) at time t. Let the vessel be prompted by each event e, indicated with the prompt symbol $[e]$. Thus the vessel gauge for *textural thickness* computes the size of the set of events still active (unelapsed) at time $t_{[e]}$, which all together is designated as $\left|\overline{E}_{t[e]}\right|$ which can be verbalized from outside inward and left to right thus: the size of the set of still active (unelapsed) events at the time the prompting event e begins. A graph is not shown but it is obvious from the score that more and more sustained notes accumulate approaching each occurrence of the repeated low E prompt.

Clarifying each rising form is that the events present an accumulation of new pitches, whose computation we can represent thus: $\left|P_{\overline{E}_{t[e]}}\right|$ (the set of pitches of all events that are unelapsed at the time of event e.) In grey curves (keyed to the right axis) Figure 8e shows the rising dynamic forms for the repeated rehearsal 0 and the next three spans. These are partials in ascending order. To indicate

Figure 8e



Rising dynamic forms after each repeated low E bass gesture

pitch height also increasing, the gauge is represented as $p_{[e]}$ and is also shown in Figure 8e (left axis); we are defining the vessel such that each event *e* is prompting its gauge and we are taking the pitch (or pitch height) of each event.[41] Since the tones sustain, *AvgPitch*($\overline{E}_{t[e]}$) and *MaxPitch*($\overline{E}_{t[e]}$) would also present the same rising form. It is hard to avoid hearing some increase in that aspect of form. Besides the increasing inharmonicity already analyzed, there are these three additional notable features that are increasing; the number of low E bass attacks (their profusion) is mostly increasing over the entire 60-submeasure span, and two more features are increasing within each inter-prompt span: the height of pitches increases, and, entailed by this, the number of distinct pitches increases. Following each low E prompt, there is no other competing activity; so hearing an ascending form (in this case articulated as simply ascending pitch) between prompts is unavoidable, and this conceptually—and maybe even viscerally—jibes with the mostly ascending profusion and ascending inharmonicity experienced over the course of the whole intro section.

Of course counting notes or measuring pitch (pitch height) would be trivial and unremarkable under other circumstances. Yet here their stark rising patterns resonate with longer-range patterns of increasing inharmonicity and increasing profusion within the repeated low E gesture. This analysis suggests how mutual reinforcement is at play in Grisey's strategy. The fact that something basic (like pitch) is so conspicuously rising primes the listener to seek other vessels presenting a similar pattern more subtly, which perhaps references our similar experience of seemingly coordinated processes in natural phenomena, which have been an inspiration to Spectralist composers, especially Grisey.

Grisey's concepts of difference and pre-audibility as related to prompted flow

Gilles Deleuze, inspired by Bergson and others, developed an alternative to Western philosophy's traditional Platonist emphasis on identity and negation, promoting instead an emphasis on difference.[42] Deleuze interrogates the concept of "difference" by discussing it in relation to "repetition" as a kind of foil. Writers such as Dufourt and Pustijanac remark on Grisey's debt to this facet of Deleuze's and Bergson's thinking and Grisey has explained his interest in difference, difference rendered in terms of repetition, if we take repetition to include predictability with some degree of difference.[43] Repetition that includes difference is not purely repetition, but rather mere resemblance, echo, or resonance; it is a mode of conduct, which in terms of the process philosophies of Heraclitus, Bergson, James, Whitehead, and Deleuze, is the closest to pure repetition there can be. All repetition is impure, as every instant is unique, since it has a unique history of prior instants.[44]

The emphasis on difference, in terms of change or dynamism, is the central project of this chapter. But the way Grisey foregrounds difference in his compositions arises from his insights into listener

"protension" or "pre-audibility," which are bound in the concept of prompted flow, which I have demonstrated above, and whose connection to protension, pre-audibility, and Deleuze's "difference in repetition" are explained below.

Grisey's *Partiels* focuses its progressive inharmonicity through a distinctive presentational strategy, allowing the listener to repeatedly anticipate and verify the next change (Grisey's "pre-audibility"), thereby encouraging the listener's self-confidence. Predictability arising from cognitive retention of past events modifes our perception of upcoming or present events, a process Edmund Husserl calls "protension" (the anticipation of the next moment),[45] also evident in Christopher Hasty's projection-based theory of meter as rhythm.

Any resemblance to some past event could be enough to spawn a protension as to how it might continue or recur. Therefore a noteworthy context for difference in Grisey's music is difference noticed through such resemblances, echoes, or resonances: repetition that paradoxically prompts a listener's awareness of its own non-repetition: imperfect duplication. Chris Arrell quoting David Bündler's Grisey interview, explains: "'Difference' is Grisey's term for the perceptual distance between successive events."[46] Grisey asserts that "difference or lack of difference between compared objects defines the essence of perception."[47]

Therefore, Grisey, being "constantly concerned with how to make it as clear as possible and not get lost in the complex world of sounds,"[48]

> provides points of reference which the listener will notice and remember ... He employ[s] various means to make [the temporal constructs within his compositions] more obvious, more distinct for the listener, such as recurring ideas or frequent repetitions... These relations oblige the listener to keep thinking "forwards and back," in order to grasp the mutual influence of the musical material and the process of shaping the dynamic form of the music. The individuality of a sound event can be grasped thanks to the contexts which expose it,

as explained by Humiecka-Jakubowska, citing Grisey's 1978 lecture.[49] Thus, in active listening we become aware of some object of perception, to which we keep comparing subsequent sonic events, as conditioned by that music previously heard.

The contextuality of our auditory perception is paramount. Further quoting Grisey:[50]

> By including not only the sound but, moreover, the differences perceived between sounds, the real material of the composer becomes the degree of predictability, or better, the degree of "pre- audibility." So, to influence the degree of pre-audibility we come back to composing musical time directly—that is to say perceptible time

As Grisey remarks, it is not so much the characteristics of the sound itself that matter "but rather the difference or lack of difference between one sound and its neighbor...[It is] the transition from the known to the unknown and the amount of information that each sound event introduces."[51]

Thus, as Grisey explains to Bundler, pre-audibility enables him to "trigger a surprise to the listener."[52] According to Grisey, what gives life to musical time is "this game between predictability and unpredictability, expectation and [surprise]." And bringing forth this liveliness outside of common practice norms requires careful attention.

> My personal answer is that I am always trying to first establish the rules of the game—the process of the form—for the listener rather clearly—very often too clearly—in order later on to be able to distort it or to change directions.[53]

It is the setting up of a pattern, a quasi-repetition, that enables or primes a listener to forecast future events, prompts the listener to compare events to those of the recent past, and sharpens the accuracy of such comparisons, thereby boosting the listener's sensitivity to subtle differences.

The occurrence of a prompt—for instance a [bass low E gesture] or [accented chord]—is actually a kind of repetition (a parallelism), one inducing some degree of rupture; the vessel's gauge is invoked upon encountering each occurrence of the defined type. And it is by virtue of this rupture that we are prompted to notice a difference compared to the past. It could be a difference of time, ∇t (the time since the previous prompt), or a differing intensity of some property of ∇S (the span elapsed since the previous prompt). Either way, a comparison to the past is induced. Prompted gauge vessels can show identity (or reminiscence) being subordinated to difference, thus exemplifying Deleuze's project.

Spectral music can sound unconventional while being accessible because it emphasizes directed incremental change, which can induce a forecast of the next change, which Stefano Lombardi Valluri calls "vectoriality." It is a meta-repetition: a repetition of a change. In Grisey's *Partiels* (and spectralism generally) repetition of a change links to repetition of an event configuration that prompts comparisons based on a backward difference (∇), from which springs yet further anticipation (protension) of the future, thus enticing the listener.

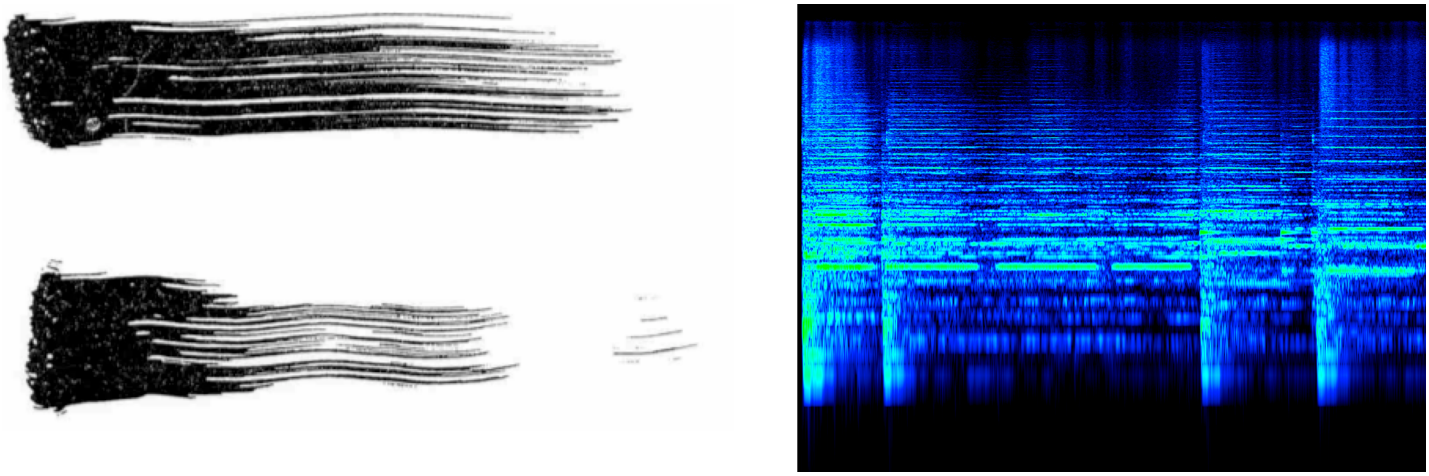
Conclusion

To listeners familiar with spectralist compositions already, it is obvious they exhibit audible formal processes. One might be inclined to probe further into pre-compositional architectures, rather than grappling with a formalism, presented in this chapter, that has, strictly speaking, evolved outside the historical lineage of spectralism. The analytical approach taken in this chapter (dynamic form), however, reveals insights of its own. The purpose of doing dynamic form analysis is twofold. First, we develop a pictorial-numerical representation of a composition's form, useful as a listening aid, and without privileging any particular architectonic-structural sectionalizing, that is, without referencing static metaphors for form. Rather, it is conceived as arising through dynamism (flux). Second, by defining the vessel needed to produce a dynamic-form graph, we gain a realistic sense of what a listener actually has to do to hear, or experience, the dynamic form: if a listener must subliminally or consciously monitor the changing prevalence of a certain event type within the music's flow, this will emerge through the modeling. If a listener must subliminally or consciously monitor timing between events, this will emerge. If a listener must filter streams from one another to trace a certain kind of flux, this will emerge. If the listener must subliminally or consciously compare overlapping spans of time to sense a long-range trend, this will emerge, and so forth. Moreover, details of the written score and a listener's overall formal experience of the score's performance, which are potentially remote from each other, are thereby connected.

Three features of spectral music have been brought into focus by the preceding analyses: incremental processes (inducing "vectoriality") in spectral music as well as related music by Ligeti and Reich; prompts (ruptures of time, which induce retrospective comparisons); and "difference and repetition." Related but not yet discussed is self-similarity (recursion, fractals), which plays a distinctive role in spectralist poetics by emulating natural processes. Spectralist form often entails a resonance not only between time frames (differentiated repetition) but also between time scales: smaller time spans embedded within similar larger ones: wave after wave as well as waves within waves. A micro to meso to macro scale analogy from timbre to texture to form plays out: each prompt-to-prompt span in *Partiels*' intro constitutes a time-dilation of the attack-decay-sustain-release of a performed pitch. Each prompt analogizes to an attack. Each built-up harmonic/inharmonic chord between prompts analogizes to the subtle timbral shifting of a sustained pitch. Grisey's "skeleton-," "flesh-," and "skin-of-time" are thus exemplified.

Saariaho also exploits a visual analogy to acoustic decay in the brushstroke inspiring her *Verblendungen* (Figure 9). The sudden onset and gradual thinning are as audible to the listener as they are visible to the viewer of the brushstroke. Both have an abrupt beginning (to the left) and a tapered continuation (moving rightward). Her *Papillon II* magnifies a dynamized complementarity between variety of pitch (periodicity) and variety of timbre (noise), as a long wave of shifting complementarity that poetically emulates the potential timbral flux of a cello's bow stroke.[55]

Figure 9



Saariaho's *Verblendungen* shape and its spectrograph

Spectralist emphasis on incremental change not only induces a sense of "vectoriality" (protension toward the future) but also jibes with humans' experience of space and growth: of, in physical space, passing through intermediate points to reach a distant one, and likewise, of biological growth proceeding through intermediate stages. It is a familiar but versatile, highly adaptable, mode of comprehension for space-inhabiting living creatures such as we are.

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Notes

1 By “styles” I am referring to historically situated creative movements (usually examplfied by a handful of composers). Other examples are Wagner’s form from literary-dramatic narrative, Steve Reich’s form from gradual physical processes, and twelfth century Ars Nova isorhythms and formes fixe. But this exhaustive comparison to other styles is not as laborious as it might seem; for various reasons few styles of music— mostly only Western and Indian classical musics — are tightly entangled enough with their own tradition of prose discourse or written pedagogy to warrant that its creators ever bother to explain, promote, or emphasize their approach to form.

2 For instance in the most basic sense the opening canon of Josquin’s *Ave Maria* presents a repeated process of voice entrances in ascending registers and the ascending and descending 5–6 sequences later in the same stanza (depicting the filling of first heaven and then earth) are another common incremental process. And Handel’s “Harmonious Blacksmith” variations, like many other Baroque variation sets, present an incremental process of increasing diminution (called doubles technique) also used comically by Mozart (in the “Pa-pa-pa” duet from the *Magic Flute*). In Joshua Mailman “Agency, Determinism, Focal Time Frames, and Processive Minimalist Music,” in *Music and Narrative since 1900*, ed. Michael Klein and Nicholas Reyland, 125–44 (Bloomington, Indiana: Indiana University Press, 2013), I discuss another kind of rhythmic incremental process, one of increasing echo-rate, in the coda of Beethoven’s *Lebewohl* sonata Op. 81a, and in “Pragmatist

Ironist Analysis and Embodied Interactivity: Experimental Approaches to Sensor-Based Interactive Music Systems Inspired by Music Analysis," in *Music, Analysis, and the Body: Experiments, Explorations and Embodiments*, ed. Reyland and Thumpston, Analysis in Context, Peeters/Leuven Studies in Musicology, 2018, I present an incremental chordal process in Liszt's *Mephisto Waltz* No. 1 (and a similar one in Reich's *Music for 18 Musicians*). In Joshua Mailman, "Temporal Dynamic Form in Music: Atonal, Tonal, and Other" (PhD diss., Eastman School of Music, University of Rochester, 2010) I show yet other kinds of gradual and incremental processes, ones that are pitch-textural, in Isaac's and Josquin's hexachord motets (*O Decus Ecclesiae Virgo* and *Ut Phoebi radiis*) as well as an incremental rhythmic-textural process in the theme and variations of Haydn's Sonata No. 30 in A.

3 Examples of incremental processes in 20th century music abound. In Mailman, "Temporal Dynamic Form," I show particularly salient examples in Ives's *Hallow'en*, the fourth movement of Ruth Crawford Seeger's *Quartet 1931*, and each phase transition in Reich's *Piano Phase*. In Joshua Mailman, "Renewing the Riverbed: Critical Aesthetic and Epistemological Purposes for Analysis, Fueled by Performative Theory," in *Musiques électroacoustiques / Analyses <-> Ecoutes*, ed. Nicolas Marty, trans. as "Pour un renouvellement à la source: visées critique-esthétique et épistémologique de l'analyse, fondées sur la théorie performative," 33–57 (Delatour France, 2015), I demonstrate, in the coda of the first movement of Bartok's Fourth Quartet, a particularly salient incremental textural process emerging from the interaction of pitch, rhythm, and dynamics.

4 See Gérard Grisey, "Zur Entstehung des Klanges," *Darmstädter Beiträge zur Neuen Musik* 17 (1978): 73–79; Grisey, "Tempus ex machina," trans., rev., and completed in *Contemporary Music Review* 2, no. 1 (1987): 239–75; Hugues Dufourt, "Gérard Grisey: La fonction constituante du temps," *Musicae Scientiae*: Discussion Forum 3 (2004): 47–70; and Dimitris Exarchos, "The Skin of Spectral Time in Grisey's Le Noir de l'Étoile," *Twentieth Century Music* 15, no. 1 (2018): 31–55.

5 For instance, to the extent spectral music is represented in visual form it is either a reproduction of Grisey's or Saariaho's own published or unpublished (sketched) diagrams, annotations of scores, or sonograms of audio recordings. Or the visual representations are newly made diagrams that depict pre-compositional structure. For examples see Kaija Saariaho, "Timbre and Harmony: Interpolations of Timbral Structures," trans. by S. Welbourn, *Contemporary Music Review* 2, no. 1 (1987): 93–133; Manfred Stahnke, "Die Schwelle des Hörens: 'Liminales' Denken in 'Vortex Temporum' von Gérard Grisey," *Österreichische Musikzeitschrift* 54, no. 6 (1999): 21–30; Jean-Luc Hervé, Dans le Vertige de La Durée: Vortex Temporum de Gérard Grisey (Paris: L'Harmattan / L'Itinéraire, 2001); François-Xavier Féron, "Gérard Grisey: première section de *Partiels* (1975)," *Genesis* (2010), http://genesis.revues.org/352; Ching-Yi Wang, "Spectral Music and Gérard Grisey's 'Vortex Temporum I and II'" (PhD diss., University of California–Davis, 2012); Ingrid Pustijanac, "Time's Arrow in Spectral Music," *Nuove Musiche* 1 (2016): 145–60. There do exist some isolated or fleeting examples of a new score-data-derived computation being visualized (for instance in Orjan Sandred, "Temporal Structures and Time Perception in the Music of Gerard Grisey," 1994, accessed October 16, 2019, http://www.sandred.com/texts/Temporal_Structures.pdf ; Jon Forshee, "Surveying the Topography of Tristan Murail's *Territoires de l'Oubli*" (Master's thesis, Eastman School of Music, University of Rochester, 2004); Rhonda Taylor, "Gérard Grisey's *Anubis Et Nout*: A Historical and Analytical Perspective" (DMA diss., University of Arizona, 2005); Je□rey Hennessy, "Beneath the Skin of Time: Alternative Temporalities in Grisey's 'Prologue for Solo Viola,'" *Perspectives of New Music* 47, no. 2 (2009): 36–58. Nevertheless, what is generally lacking in literature on spectral music is a thorough generalizable attempt to demonstrate from score data how a listener can sense processes when hearing a composition, that is, how the sense of an incremental or gradual progression can arise from hearing the notes in the score performed.

6 For works from earlier in the century, see Ernst Kurth, "Die Voraussetzungen der theoretischen Harmonik und der tonalen Darstellungssysteme" (*Habilitationsschrft*, Berne: University of Berne, 1913) and Hans Mersmann, "Versuch enier Phänomenologie der Musik," *Zeitschrft für Musikwissenschaft* 5 (1922–23): 226–69. For works from later in the century see Charles Seeger, "On the Moods of Musical Logic," *Journal of the American Musicological Society* 13 (1960): 224–61; Wallace Berry, *Structural Functions in* Music (Englewood Cliffs, NJ: Prentice-Hall, 1976); David Lewin, "Some Investigations into Foreground Rhythmic and Metric Patterning," in *Music Theory Special Topics*, ed. Richmond Browne (New York: Academic Press, 1981); Robert D. Morris, "New Directions in the Theory and Analysis of Musical Contour," Music Theory Spectrum 15 (1993): 205–28; and John Roeder, "A Calculus of Accent," *Journal of Music Theory* 39, no. 1 (1995): 1–46. One of several examples of my own work on dynamic form analysis can be found in my article on Robert Morris's String Quartet *Arc* (Joshua Banks Mailman, "Trajectory, Material, Process, and Flow in Robert Morris's String Quartet *Arc*," *Perspectives of New Music* 52, no. 2 (2014): 249–83). Numerous others are shown in my PhD dissertation (Mailman, "Temporal Dynamic Form") and subsequent articles. For discussion of Kurth's theory of *Kraftwelle* (force waves) and *Wellendynamik* (wave dynamics)

see Lee Rothfarb, "Energetics," in *The Cambridge History of Western Music Theory*, ed. Thomas Christensen, 927–55 (Cambridge, U.K. and New York: Cambridge University Press, 2002).

7 This definition of dynamic form was first presented in Mailman, "Temporal Dynamic Form."

8 "Model" should be taken in a broad sense. It may be descriptive or suggestive (uncoercively prescriptive) or, more likely, some mixture of the these. Thus "our listening" refers to what some of us hear some of the time whether aware of it or not, or what we choose to focus on, with perhaps varying success, and is therefore both an attestation as well as an invitation. No kind of prior training covers all the possibilities, so the listener's prior training is often besides the point.

9 The term "vessel" is chosen since it flexibly denotes both something through which fluid flows, as well as an object that advances over or though some medium (a ship moving in water).

10 Two familiar examples of such computed properties are dissonance and syncopation, though the properties need not be familiar or even have pre-existing names such as these. Whether familiar or not, a form-bearing property is usually emergent rather than basic; thus it is usually computed in terms of the configuration of basic properties such as pitch, duration, loudness, and timbre. Besides this, properties that are basic with respect to a score (and composers' usual level of prescription) are of course emergent with respect to physical phenomena (different kinds of vibrations); but generally in analysis (score-based analysis) we are not dealing with that level of granularity, which is why we can consider properties such as pitch and loudness as basic in the context of dynamic form analysis.

11 At this point, I am not speaking of conscious awareness. I am merely pointing out that if a person is hearing music being performed from a score and that music contains dissonance or syncopation, he or she is experiencing those in some fashion, and those are emergent with respect to the basic elements (notes) written in the score.

12 Dockets do not necessarily always contain exactly a measure; rather they could contain any size span of music; it depends on how the flow system is defined, specifically its prompting rule. In this example being discussed in the main text, the flow system is bringing in spans of the same length (one measure).

13 Of course time flows continuously; but for pragmatic reasons a flow system is configured to only trigger an inflow/outflow to/from the docket in a manner that is needed for capturing and conveying the relevant fluctuations that, in retrospect, create the dynamic form.

14 For instance *S* at one time may contain a greater variety of note values than at another time, and this may affect what number is computed by the vessel's gauge at the one time versus the other.

15 A model of listening is a way of thinking through one's listening in retrospect as well as a way of influencing one's future listenings. That is, it may be informed by prior listening and may influence future listening. Thus such models underwritefeedback processes of evolving listening practices.

16 Although "playing a note" could broken down into smaller constituent events—and indeed each crest of a sound wave could be considered an event in some sense—we are choosing to instead align our ontology of eventhood with that which composers most typically control directly when they compose a notated score.

17 Readers might be familiar with the flanking pipe to denote the absolute value of a number, such as |-3] = 3. But my use of the flanking pipe symbol here is not that, but rather is instead the standard mathematical representation of the number of elements (the cardinality) of a set: |{a, b, c}| =3, so if S ={a, b, c} then |S|=3.

18 The letter *u* designates duration because d could be confused with dynamics, docket, or the pitch D. Likewise i, the second letter of the word timbre, is used to designate it because *t* and *T* are used to designate time.

19 Although texture, timbre, and pitch are treated as independent inputs, as *t*, *u*, etc, they are, or can be, combined into a single number as output, representing their joint emergent affect, and in that sense are no longer independent domains.

20 From this point of view, each eventful "moment of time" in a musical composition, (a moment which at least one event begins) is considered coextensive (identical with) with the set of these events. Since one of the properties of events is their start-time, the occasion which they constitute inherits this property from them. Thus we are not defining occasions

chronometrically but rather in terms of what happens (what begins) at a particular time; the chronometric time itself is rather a secondary property of the occasion.

21 I say "reverse engineering" because the composer has presumably had in mind a particular qualitative e□ect which he or she forges through music notation which is quantifiable.

22 The symbol u_s can be unpacked as: the end time $_{\rightarrow S}t$ minus the start time t_S of the span, thus $_{\rightarrow S}t - t_S$.

23 The capital letter *T* denotes the set of all distinct times in a span, by analogy with the other uses of other capital letters; for instance P_S is the set of all pitches with span *S*. Thus capitalization represents a kind of aggregation of distinct values represented by corresponding lowercase designations. Such sets can always be stipulated in set-builder notation, for instance:

T_S = (or $T_{e \in S}$)	$\{t \mid \exists e \in S \text{ such that } t_e = t\}$	All the times at which begin events in span S. Such times (eventful times) are called occasions.

24 An analogy that might be helpful here is the quality of heat: It is a subjective qualitative feeling which can vary in degree and yet corresponds to a computation, namely the average kinetic energy of molecules.

25 For "eventfulness" there is a separate vertical axis (in grey) on the right.

26 This examination of Murail's *Territoires* is greatly inspired by a more limited one by Forshee, "Surveying the Topography."

27 An example of a spectral excerpt that tapers down to a more central pitch is the keyboard part of Saariaho's *Solar* (1993) at mm. 282–93; formally in terms of pitch dynamism it is exactly the reverse of the Reich excerpt.

28 A simple scaling formula is: scaled(x) = (x − min(x)) / (max(x) − min(x)), where the maximum and minimum are identified in relation to the whole analytical context. I hasten to add, however, that in cases where amalgamating is most appropriate, scaling does not appreciably change the result, because we have already established, as our prerequisite for amalgamating, that the properties being scaled exhibit the same trend.

29 The strength or closeness of the fit is indicated by the squared correlation coe□icient (also called R-squared) whose valuecan range from −1 to 1, with 0 indicating no correlation (no trend, no fit), −1 indicating perfect inverse correlation, and 1 indicating a perfect correlation (a perfect fit). Values close to 1 indicate a tight fit, in other words data that is predominantly a directional trend. In Figure 3, the R^2 values of 0.97416 for the excerpt of Reich's Drumming and 0.98418 for the excerpt of Murail's *Territoires* indicate that the Profusion computation very strongly models (empirically demonstrates) a directional trend in the score data.

30 Gilles Deleuze, and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. Brian Massumi (Minneapolis: University of Minnesota Press, 1987), sections 4 and 5.

31 Although the words "smoothness," "shimmer," "pointillism," and "fuzziness" are descriptive, they are being used as evocative labels (names) for computations. These computations are relevant to hearing this music and must be verbally referenced somehow. I do not claim they account for all the subjective meanings that these words might elicit. The four words are merely pragmatic.

32 Prevalence can be modeled equivalently as rate or as density depending on the situation. For density, you choose a time interval and count how many eventful times occur within it. Whereas for rate, you are choosing an eventful time, measuring the time interval since the previous eventful time, and dividing 1 by that number. These are quantitatively equivalent but useful in different situations, mainly depending on whether it's advantageous to compare averages gauged at regular intervals (attacks per measure) or compare only when something noteworthy happens (a chord change or timpani entrance for instance). In the latter case, you are usually attending to an individual noteworthy occasion and sensing the rate at which comparable occasions have occurred so far, by sensing the time since the previous comparable occasion occurred. Either way: 7 dinners per week is quantitatively equivalent to 1/7 of a week from the previous dinner to

the current one. Thus density and rate can be different perspectives on the same quantity, each useful in different situations. The section later in this essay on *prompted flow* illustrates situations where rate is more appropriate than density.

33 Although technically variety should be gauged as the number of types minus one (only one timbre would be an absence of variety) it's simpler to count level 1 as minimal variety. It makes no significant difference to the dynamic form analysis.

34 To provide more detail in the graph, the computation switches to half measures in m. 9 and m. 12, where the arpeggiation pattern changes within the measure.

35 Numerical tables for other dynamic form analyses in this essay are omitted.

36 *Papillons* IV and VII are and can be analyzed similarly. An analysis of *Papillons* VII by Michael Tavani (in my University of Alabama graduate seminar) finds a "tone-noise gradient" based on prescribed "finger placement" and "bow technique";see Michael Tavani, "Saariaho Papillons IV Analysis," paper presented for the seminar on Analysis of Carter, Berio, Reich, and Saariaho, University of Alabama, Spring 2016.

37 Francois Rose, "Introduction to the Pitch Organization in French Spectral Music," *Perspectives of New Music* 34, no. 2 (1996): 6–39.

38 I thank Steven Reale, whose use of the backward difference operator to model metrical dissonance in "The Calculus of Finite (Metric) Dissonances," (*Music Theory Spectrum* 41:1 (2019): 146–71) inspired my own expanded use of it for situations such as this one. Reale may be the first to employ the backward difference operator to music. I learned of his work on this in 2017, through a prepublication dra of his article, which he shared with me at that time.

39 The pair of percussion dyads bookending each span could instead serve as a prompt.

40 Such direct use of inharmonicity to sculpt form in spectral music has strong resonances with Hindemith's chord fluctuation theory (see *The Craft of Musical Composition* (London: Schott, 1937), trans. Arthur Mendel, 1945), which influenced Grisey, according to Julian Anderson, "A Provisional History of Spectral Music," *Contemporary Music Review* 19, no. 2 (2000): 7–22.

41 I am using the convention whereby middle C4=0, C#4=1, C5=12, C3=−12, and so forth.

42 Gilles Deleuze, "La Conception de la différence chez Bergson," *Etudes bergsoniennes* 4 (1956): 77–112, translated by Melissa McMahon as "Bergson's Conception of Difference," in *The New Bergson*, ed. John Mullarkey (Manchester: Manchester University Press, 1999).

43 Hugues Dufourt, "Gérard Grisey: La fonction constituante du temps," *Musicae Scientiae: Discussion Forum* 3 (2004): 47–70; and Pustijanac, "Time's Arrow in Spectral Music," 145–60. In regard to difference see Grisey, "Tempus ex machina," pp. 239–40, 247, 249, 253, 258, 269; Grisey "Zur Entstehung des Klanges," pp. 73–79; and David Bündler, "Interview with Gérard Grisey, January 18, 1996, Los Angeles" (January 18, 1996), accessed August 10, 2017, www.angelfire.com/music2/davidbundler/grisey.html. Additionally Grisey articulates this idea again in liner notes: "No longer composing with notes but with sounds; no longer composing only sounds, but the difference that separates them …. Acting on these di erences … controlling the evolution (or non-evolution) of the sound and the speed of its evolution" (Grisey, liner notes to *Les Espaces Acoustiques*, trans. John Tyler Tuttle, Musidisc France 2001, Una corda 465 387-2; quoted in John Young, *Sound in Structure: Applying Spectromorphological Concepts* (Montreal, 2005), 2).

44 Henri Bergson, *Creative Evolution*, trans. Mitchell (New York: Random House, 1911); Heraclitus, 1962. *The Cosmic Fragments*, trans., ed. Geoffrey Stephen Kirk. Cambridge: Cambridge University Press, 1997; William James, A Pluralistic Universe. New York: Longmans, Green, and Co., 1909; Alfred North Whitehead, *Process and Reality*. New York: The Free Press, 1978. First published 1929.

45 For Husserl, see: Edmund Husserl, *The Phenomenology of Internal Time-Consciousness* (Bloomington: Indiana University Press, 1964; first published 1928); for pretension (and absence of it) in Reich's music, see Giacomo Albert, "Vectoriality and

Protension vs Symmetries and Endless Processes in Minimalist Music: Some Reactions Stemming from the Analysis of the Sketches of Steve Reich's It's Gonna Rain," *Nuove Musiche* 1 (2016): 127–28; for Hasty, see Christopher Hasty, *Meter as Rhythm* (New York: Oxford University Press).

46 Chris Arrell, "The Music of Sound: An Analysis of Partiels by Gérard Grisey," in *Spectral World Musics: Proceedings of the Instanbul Spectral Music Conference*, ed. Robert Reigle and Paul Whitehead (2013); Bündler "Interview with Gérard Grisey."

47 Justyna Humiecka-Jakubowska, "The Spectralism of Gérard Grisey: From the Nature of the Sound to the Nature of Listening," trans. John Comber, *Interdisciplinary Studies in Musicology* 8 (2009): 227–51, citing Grisey, "Zur Entstehung des Klanges."

48 Bündler "Interview with Gérard Grisey."

49 Humiecka-Jakubowska, "The Spectralism of Gérard Grisey," citing Grisey, "Zur Entstehung des Klanges."

50 Grisey, "Zur Entstehung des Klanges."

51 Grisey "Tempus ex machina," 258.

52 Bündler "Interview with Gérard Grisey."

53 Murail (2004, 57) evades over-predictability by including variation, ornamentation, aleatoricism, and other devices.

54 Stefano Lombardi Vallauri, "Vectoriality/Protension in Post-Tonal Music: Introduction," *Nuove Musiche* 1 (2016): 11–33.

55 The purity–noise–purity arc also resonates with the tonal-textural arc of sonata forms and common practice binary forms generally.