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Musical Probability and the Music of Claude Debussy

Expectancy and Information in (...Bruyères) *and the String Quartet*

Daniel Shanahan

This article explores the relationship between musical expectancy and information through the use of both hidden Markov models, Bayesian probability and their application to Claude Debussy's Prélude *(…Bruyères)* and his string quartet. *(…Bruyères)*, which is one of the most conservative of the *Préludes*, is an interesting example of the composer's use of »vagrant« sonorities which persist despite a perceived tonal hierarchy. An analysis of the varying levels of information, determined by the levels of expectancy which arise throughout the composition, illustrates an aspect of analysis which has not yet been applied to Debussy's music.
A study of musical information will inevitably lead to the study of probabilty, as a greater degree of information is expressed by events which could be considered to be less probable. Much of the research that has been done thus far in musical probability has used as *a priori* a collection of stylistic precepts, which are referred to as likely events. This article, however, attempts to determine probabilistic events based on »intra-opus« events by using David Temperley's Bayesian approach to determine likely events within a composition. These are classified as events within a hidden Markov model, which examines the interrelationships of variables, some of which are perceived and some which are simply implied. A statistical »extra-opus« methodology is employed and compared to the Bayesian style. In the seond part of the article, melodic probability in a polyphonic context is discussed by examining the several sections from Debussy's string quartet. The probabalistic fluctuations between voices in the quartet are then compared to the single melody of *(…Bruyères)*.

One of the most compelling ideas emanating from recent research in music cognition is the idea that all music is processed and understood in certain universal ways. All music, whether it be an *Intermezzo* by Johannes Brahms or an African dance, is understood syntactically in the Broca's area of the brain as coherent structures consisting of hierarchies and linear transformations. This section of the brain also processes language and speech, and recent research has found that patients afflicted with agrammatic aphasia (rendering them unable to form syntactically coherent sentences) also have difficulty processing standard harmonic progressions.[1] Music, like language, in this context is described as a »particulate« system, which is made up of discrete units that do not have meaning in isolation, but are able to form coherent higher-level structures.[2] Aniruddh Patel notes that the majority of musical scales (including Asian pitch collections) contain somewhere between five and seven

1 Patel et al., *Musical syntactic processing in agrammatic Broca's aphasia*.

2 Aniruddh Patel discusses the nature of particulate systems, and how they are also found in the mating songs of the humpack whale, as well as primates (*Music, Language, and the Brain*, p. 10).

tones[3], and Bruno Nettl states that the majority of cultures employ a similar interval to what we would term a major second.[4] These commonalities lead one to believe that a synchronic, cross-cultural methodology may be applied to the study of musical information, but also that tonal and post-tonal music might share certain common features. This latter aspect will be discussed in this article through analyses of Claude Debussy's music, which contains a certain level of structural coherence despite its rather tenuous approach to tonality.

Many of Debussy's piano works imply somewhat of a paradox. They generate motion, despite instances of stratification and stasis. They emit a sense of cohesion despite a lack of a well-defined tonal hierarchy. Phrases sometimes drift into a state which causes disorientation for the listener. This, in fact, is what Debussy wanted: a pure sonority free of historical or analytical constraints. Any study of Debussy's melodic writing must address this nature of independent succession and continuity as well as the phenomenon of cohesion in the composer's works.

Continuity in Debussy's music has been the subject of a number of analyses. Neela D. Kinariwala[5] discusses stratification in the *Préludes*, while Leonard B. Meyer has noted that in the *Nocturnes* »events come *after* one another, but they cannot readily be understood as following *from* one another«.[6] While this notion of a lack of continuity in Debussy's music persists, it is quite obvious that there is definitely a certain cohesive element at play. Studies of succession, be it musical or not, generally incorporate the use of some sort of Markov process, which analyzes a sequence and the influence imposed on it by the directly preceding state. A »first-order« Markov chain illustrates states which are only influenced by those which directly precede it, while »second-order« chains remember the preceding two, and so forth. Markov processes have been used quite frequently in composition, most notably by Iannis Xenakis.[7]

Hidden Markov Models and Bayesian Probability

The efficacy of Markov chains in analysis, however, has been refuted by some. Eugene Narmour notes that, »[m]usic is not a ›Markov system‹ where no sense of discontinuity and accumulation takes place and where each syntactic event is subject only to a single transition probability.«[8] In fact, a study of musical probability would be incomplete if restricted to a study of the transitional properties of musical events, with no reference to any overreaching system of organisation, however tangential it may be. A study of successive musical elements must therefore also take into account an unobserved element, whether it be an underlying tonal organisation or a certain

3 Ibid.
4 Nettl, *An Ethnomusicologist Contemplates Universals*, p. 468.
5 Kinariwala, *Debussy and Musical Coherence*.
6 Meyer, *Style and Music*, p. 270.
7 The most prominent example of Xenakis's use of Markov chains is *Analogique A+B* (1958–1959). Lejaren Hiller and Leonard Isaacson's *Illiac Suite* (1957) demonstrated Markov chains in a string quartet setting a year before Xenakis.
8 Narmour, *The Analysis and Cognition of Basic Melodic Structures*, p. 318.

thematic element on which the piece is based. This fits almost directly with what is known as a »hidden Markov model«, which not only studies the succession of events and their direct effects on each other, but also addresses certain unobservable parameters. A study of musical probability should therefore include a transitional analysis which is weighted to coincide with this unobserved element.

The probability of melodic events can be difficult to predict due to the number of variables involved. Melodies may behave differently according to certain harmonic, rhythmic or stylistic precepts. Many studies concerning stylistic probability have focussed primarily on a specific corpus of music, such as folk song collections, which allows for a statistical study of certain behaviours.[9] For an »intra-opus« study of melodic probability to occur, however, one must focus on the various parameters generated from within the composition. In his recent book *Music and Probability*[10] David Temperley constructs a generative model for musical probability through the use of Bayesian probability. Thomas Bayes' rule states that the posterior probability of an event *B*, given a certain underlying assumption *A*, is proportional to the likelihood of that assumption given the event multiplied by the prior probability of the event. More formally:

$$P(A \mid B) = \frac{P(B \mid A) \cdot P(A)}{P(A)}$$

Temperley uses this theory to determine a certain hidden variable, which he calls the *structure*, based on an observed variable, which he terms the *surface*.[11] The equation can therefore be adapted as such:

$$P(structure \mid surface) = \frac{P(surface \mid structure) \cdot P(structure)}{P(surface)}$$

By inferring certain surfaces, such as pitch classes, Temperley is able to create models which determine the likelihood of certain structures, such as keys. The converse is also true: given a certain tonal centre, the likelihood of specific musical events can be extrapolated. This likelihood can then be measured as bits of musical information, which could be used to quantify musical expectation.

Quantification of a Melodic »Surface«

For the analysis of Debussy's prelude *(…Bruyères)* (book 2,5) I have used a »second-order« Markov chain to illustrate probable melodic *transitions*, which in this study were defined as consisting of three notes (two adjacent transitions). Without adher-

9 For a thorough account of such studies, see Huron, *Sweet Anticipation*, pp. 73–89.

10 Temperley, *Music and Probability*.

11 Ibid., p. 11.

ing to a strict »preference-rule« approach, I should explain some of the basic criteria of the transitional weighting scheme that was used for the calculations. For each instance of melodic motion, I weighted the probability of the third note. The expected behaviour or probability of the third note in a melodic transition was defined using specific principles based upon the theories of Meyer and Narmour. An important principle is, for example, that smaller intervals favour continuation, while larger intervals favour reversal. Where triadic processes are implied, such as a major third being followed by a minor third, the process is weighted as highly probable. Additionally, return is weighted as being highly probable, whether it be through neighbour-tone motion or through larger intervals. Octave displacement and duplication have been treated similarly and are both discarded from the equation. The use of these theories for a cognitive study of musical perception is not without objective grounding. Paul von Hippel and David Huron have demonstrated that the tendency to expect reversal or »gap-fills« is a part of a perceptual need for a »regression toward a mean.«[12] They note that because of this inclination, large intervals are in fact likely to reverse, and conversely smaller intervals will continue. It is because of this innateness of melodic motion that I have chosen to study the transitional properties of the music in a Markov-like process, rather than on the basis of a hierarchical system contained within a certain tonal region as explored by Carol L. Krumhansl[13] and more recently by Fred Lerdahl.[14]

To deduce the probability of certain melodic events, it is important to first specify what could be classified as an event. For this study, I have chosen three-note segments, since a two-note event implies a number of possibilities, all of which may be avoided or confirmed at the third note. While generally different segmentations might produce different results, a study revolving around the terminology of Meyer and Narmour would best be split into three-note segments. As the tonality of the melodic motion is incorporated into the structural element of the Bayesian formula, I have calculated the likely intervallic transitions based upon the chromatic scale. Therefore, the referential quantity from which all others are based is 1/12 (or .083). Extremely likely occurrences are given twice this amount (1/6 or .167) while rarer ones are given quantities such as 1/24 (.042) or even 1/48 (.021). The probability matrix below illustrates the weighting of each intervallic transition, with the vertical axis demonstrating the present state, and the horizontal axis showing the likelihood of the intervallic transition. The matrix illustrates, for example, that a rising minor third (+3) is most likely followed by a rising major second (.167) while the intervals +6,+8,+10,+11,-4,-5,-6,-9,-10,-11 are most unlikely (.021). For larger intervals like +8,+9,+10 or +11 a reversing minor second (-1) is most likely (.167) and vice versa (-7,-8,-9,-10,-11 all are attributed a probability of .167 to be followed by +1).

This matrix has been created with Western listeners in mind and as a result has a few obvious biases. For instance, although triadic motion of all sorts is weighted fairly highly, there is an obvious »major key bias«, which Huron notes is common in »Western enculturated listeners« as they »tend to assume that […] music will be in

12 Hippel/Huron, *Why do skips precede reversals?* Also discussed in Huron, *Sweet Anticipation*, p. 5.

13 Krumhansl, *Cognitive Foundations of Musical Pitch*.

14 Lerdahl, *Tonal Pitch Space*.

a major rather than a minor key.«[15] While this bias has been accounted for in the instance of ascending triads, there is less bias in descending, so both descending major and minor triads have been weighted similarly. Similarity is also accounted for, in that a continuation of intervals is weighted fairly highly. While it can lead to chromaticisms (as in two adjacent semitones or a diminished triad), the structural probability governing the overall key (discussed in the following section) counteracts this to some degree, and the ability of a listener to expect a continuation of similar intervals is necessary.

	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10	+11	+/-12 /0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11
+1	0.167	0.056	0.021	0.021	0.021	0.021	0.042	0.021	0.021	0.021	0.042	0.083	0.167	0.056	0.042	0.042	0.021	0.021	0.021	0.021	0.042	0.021	0.021
+2	0.056	0.083	0.056	0.042	0.042	0.021	0.021	0.028	0.042	0.042	0.021	0.083	0.042	0.083	0.056	0.056	0.042	0.028	0.042	0.028	0.021	0.021	0.021
+3	0.056	0.167	0.042	0.042	0.042	0.021	0.042	0.021	0.042	0.021	0.021	0.083	0.056	0.056	0.083	0.021	0.021	0.021	0.042	0.042	0.021	0.021	0.021
+4	0.056	0.056	0.083	0.021	0.083	0.021	0.042	0.056	0.021	0.042	0.021	0.083	0.056	0.056	0.042	0.083	0.028	0.021	0.028	0.042	0.021	0.021	0.021
+5	0.028	0.042	0.083	0.083	0.042	0.021	0.056	0.021	0.028	0.021	0.021	0.083	0.083	0.056	0.042	0.042	0.083	0.042	0.021	0.021	0.021	0.021	0.028
+6	0.083	0.056	0.042	0.042	0.028	0.021	0.042	0.021	0.021	0.021	0.021	0.083	0.083	0.083	0.042	0.042	0.028	0.083	0.042	0.021	0.021	0.021	0.028
+7	0.042	0.042	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.083	0.083	0.167	0.056	0.056	0.056	0.028	0.083	0.042	0.028	0.021	0.028
+8	0.083	0.056	0.021	0.042	0.021	0.021	0.021	0.021	0.021	0.021	0.028	0.083	0.167	0.083	0.056	0.042	0.028	0.021	0.021	0.056	0.042	0.028	0.021
+9	0.021	0.021	0.028	0.042	0.021	0.021	0.042	0.028	0.021	0.021	0.021	0.083	0.167	0.167	0.042	0.042	0.042	0.021	0.042	0.021	0.042	0.028	0.021
+10	0.028	0.042	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.028	0.021	0.083	0.167	0.083	0.083	0.056	0.042	0.042	0.042	0.021	0.021	0.083	0.021
+11	0.083	0.042	0.028	0.028	0.028	0.021	0.042	0.021	0.021	0.021	0.021	0.083	0.167	0.083	0.042	0.021	0.021	0.021	0.042	0.021	0.042	0.021	0.083
+/-12 /0	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
-1	0.083	0.042	0.056	0.028	0.042	0.021	0.028	0.021	0.021	0.021	0.042	0.083	0.167	0.083	0.042	0.021	0.021	0.042	0.021	0.021	0.021	0.021	0.042
-2	0.083	0.083	0.056	0.021	0.021	0.021	0.021	0.028	0.021	0.042	0.028	0.083	0.083	0.083	0.083	0.042	0.042	0.038	0.021	0.021	0.021	0.021	0.021
-3	0.056	0.083	0.083	0.021	0.021	0.021	0.042	0.042	0.021	0.021	0.028	0.083	0.056	0.042	0.021	0.083	0.083	0.021	0.042	0.021	0.056	0.042	0.021
-4	0.056	0.056	0.083	0.083	0.042	0.021	0.021	0.021	0.021	0.021	0.028	0.083	0.056	0.042	0.083	0.083	0.083	0.021	0.021	0.042	0.021	0.056	0.021
-5	0.083	0.083	0.056	0.056	0.083	0.056	0.028	0.028	0.028	0.021	0.021	0.083	0.056	0.042	0.028	0.056	0.021	0.021	0.042	0.028	0.021	0.021	0.021
-6	0.083	0.083	0.042	0.021	0.056	0.083	0.056	0.042	0.028	0.021	0.028	0.083	0.056	0.042	0.028	0.056	0.042	0.028	0.028	0.021	0.021	0.021	0.021
-7	0.167	0.083	0.042	0.021	0.028	0.056	0.083	0.042	0.021	0.021	0.021	0.083	0.056	0.042	0.042	0.028	0.028	0.021	0.021	0.021	0.021	0.021	0.021
-8	0.167	0.083	0.056	0.042	0.042	0.021	0.021	0.083	0.028	0.021	0.028	0.083	0.042	0.056	0.042	0.021	0.021	0.021	0.021	0.028	0.021	0.028	0.021
-9	0.167	0.083	0.056	0.042	0.021	0.021	0.028	0.021	0.083	0.042	0.021	0.083	0.042	0.056	0.042	0.021	0.021	0.021	0.028	0.021	0.021	0.021	0.021
-10	0.167	0.167	0.042	0.028	0.028	0.021	0.021	0.021	0.021	0.083	0.021	0.083	0.056	0.042	0.028	0.028	0.021	0.021	0.021	0.021	0.021	0.021	0.021
-11	0.167	0.167	0.042	0.042	0.028	0.021	0.021	0.021	0.021	0.021	0.056	0.083	0.083	0.042	0.028	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021

Figure 1: A probability matrix with weightings for different intervallic transitions.

The melody contained in the opening of *(…Bruyères)* (Fig. 2) is originally assigned the standard probability of .083, since the descending minor third is followed by similar downward motion, which then gives way to a lower neighbour-tone motion, also assigned the standard probability. This, however, is followed by instances of increasing unlikeliness. The ascending G to B^b motion would have a high probability of continuing a triadic motion, but instead it descends a perfect fourth. This perfect fourth is then followed by an equally unlikely leap of a minor 7th. This type of melodic weighting, for better or worse, allows for a certain degree of subjectivity.

15 Huron, *Sweet Anticipation*, p. 360.

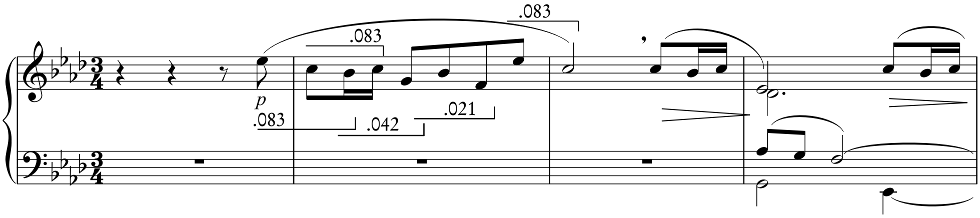

Figure 2: Transitional weightings in the opening of Debussy's prelude *(… Bruyères)*

Quantifying the »Unobserved« Structure

While the surface of a melody may exist within its states of transition, its structure is governed by conditional probabilities relating to the predominant tonal centres. Temperley's polyphonic key-finding model, which is quite similar to a hidden Markov model, addresses many issues pertaining to a structural analysis of this underlying structure. Whereas the surface transitions were calculated based upon a division of the chromatic scale, this should be averaged against the assumption that a melody will in all likelihood be a part of a governing key. Therefore, instead of a division of twelve, a division of seven might seem more apt, which would espouse the notion that each note in a melodic segment has a 1/7 chance of being played. This, however, is not entirely true.

While discussing his polyphonic key-finding model, Temperley notes that an original selection of a key has a 1/24 chance of being chosen, but once it is selected it is 80% likely to remain in that key.[16] While this is arrived at through extra-opus measures, it also holds true mathematically. Similarly to von Hippel and Huron's hypothesis of a regression to an average, it should be noted that if the status quo is given the chance to stay the same, more often than not, it will. Temperley's weighting of .8 was therefore factored into the structural element of the Bayesian equation. The given structure was not allocated a 1/7 probability but rather a 1/7 x 4/5 probability, or 4/35 (.1143). Events which strayed from the »key of the moment« were assigned the remaining .2, which was multiplied by the odds of a specific out of key note, 1/5. This led to a weighting of 1/25 (.04). We will see how a note perceived to be out of key can simultaneously be highly probable, due to the weighting's correlation with the transitional structures discussed earlier.

By using these weightings to determine the underlying structure, Temperley's application of the Bayesian equation are combined with the surface transitions displayed in Figure 1. The probability of certain surface transitions are therefore inferred through an invocation of both surface and structural elements. For example, the probability of Debussy's opening melody (Fig. 2) can be calculated by incorporating the surface weighting (.083) against the structural weighting for a diatonic element (.1143). Using Bayes' theorem, it could be calculated as such (see Figure 7 for a complete analysis of the prelude based on this formula):

16 Temperley, *Music and Probability*, pp. 79–98.

$$P(.083\,|\,.1143) = \frac{P(.083\,|\,.1143) \cdot P(.1143)}{P(.083)}$$

Analysis

(… Bruyères), from Debussy's second book of *Préludes* is one of the composer's most conservative pieces. It has been frequently viewed as a highly tonal piece[17], with little chromatic alteration or shift in tonality. Despite this relative conservatism, however, a probabilistic analysis is able to reveal the varying levels of information conveyed, as well as Debussy's ability to mask certain tonal aberrations with contextual links on the surface. For example, m. 19 contains a chromatic alteration in the left hand (the G^b, Fig. 3), which in most models concerning melodic information, would convey a highly unlikely event, thus generating a high degree of information. By weighting the melodic fragments in the right hand as a fairly consistent 1/24 (.042, as the intervals are consistent, the surface probability is consistent), while also taking into account the descending process of the F-E^b-D^b-C as a diatonic idea (that is weighted as being within the same key), we are given a result which demonstrates consistency with the rest of the composition so far. The overall probability of m. 18 (after the surface weighting is accounted for) is .0117, which returns in the m. 20 after slightly dipping to .0057 in m. 19 as a result of the descending line.

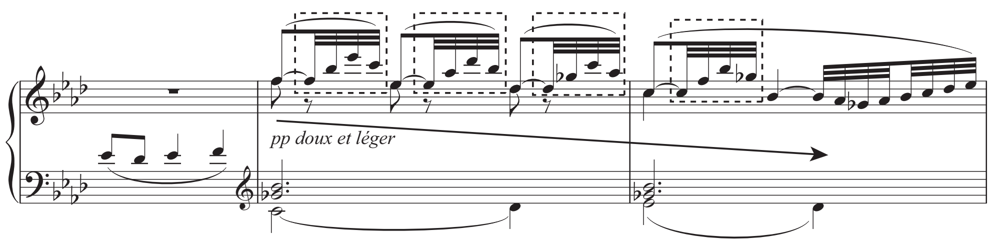

Figure 3: Debussy, *(… Bruyères)*, mm. 18–20. indicating quartal leaps and standard descending process.

At mm. 21 and 23 (Fig. 4), however, the result is slightly different. While the ascending fourths of m. 21 are highly probable (they were weighted at .042), the addition of chromatic alteration to begin the modulatory sequence creates an instance of very low probability. This dip can be seen in the probability graph below (Fig. 7), which demonstrates the fluctuations of the entire composition. M. 23 (Fig. 5) generates a lesser dip compared to measure 21. In it, the melodic transitions alternate between stepwise process and return through neighbour-tone motion (indicated by the arrow in Fig. 5), both of which are weighted as the standard 1/12 (.083). The arrival at the new key, however, and the occurrence of certain pitch classes which had thus far been avoided (such as the D natural) generate a low probability rating in the model. Temperley's model achieves similar results in

17 The most notable analysis arguing along these lines would probably be from Felix Salzer's *Structural Hearing*.

analyses of Robert Schumann's *Papillons* op. 2 (no. 1) and Frédéric Chopin's Mazurka op. 6,1.[18]

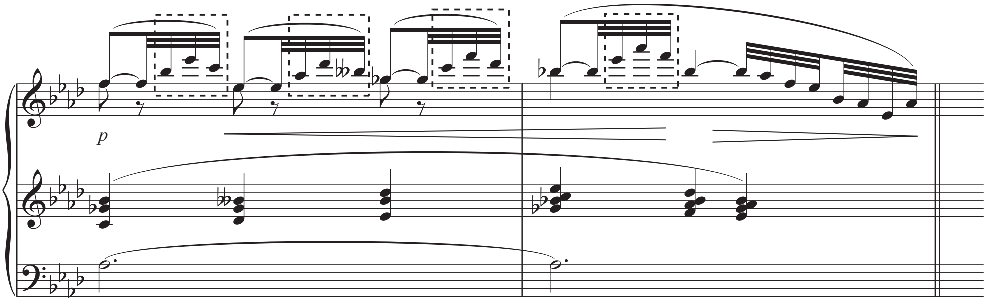

Figure 4: Debussy, *(… Bruyères)*, mm. 21–22.

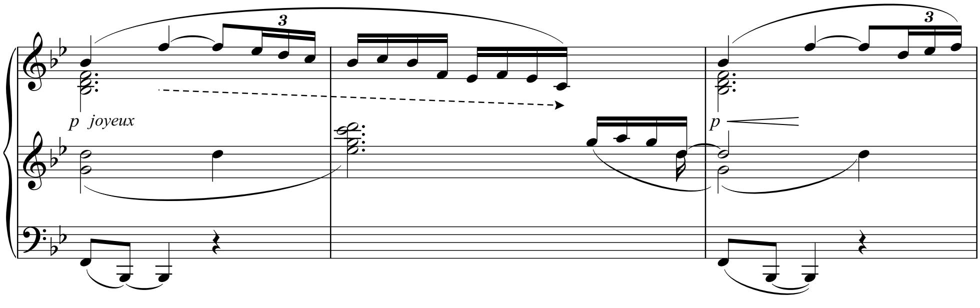

Figure 5: Debussy, *(… Bruyères)*, mm. 23–25.

The next occurrence of a highly unlikely event comes at m. 29 (Fig. 6). Again the change in tonal centre has been given the structural weighting of .2, which was then offset by the large leap in the right hand. This result, however, is somewhat misleading. If the leap was ignored in favour of the process occurring between D in the top stave and the E and G in the middle, it would have been clear that the unlikely tonal transition was counterbalanced by a somewhat hidden likely process. The nature of the transition, however, creates high levels of information in this section. The most frequent process was an ascending minor third followed by stepwise motion, and this was weighted as such, which explains the peaks at either side of the graph in Figure 7. The probability chart of the entire composition in Figure 7 illustrates Debussy's tendency to bookend the composition with familiar melodic transitions on either side of less expected occurrences generating higher levels of information. While Debussy's fondness for ternary structure has been discussed at length by a number of theorists, the similarity to an ABA structure with the graphic probability levels should be noted.

18 Temperley, *Music and Probability*, p. 112.

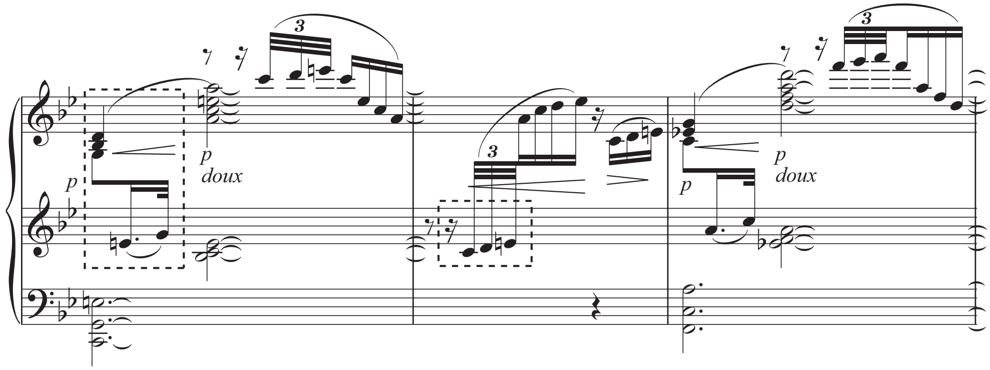

Figure 6: Debussy, *(… Bruyères)*, mm. 29–31.

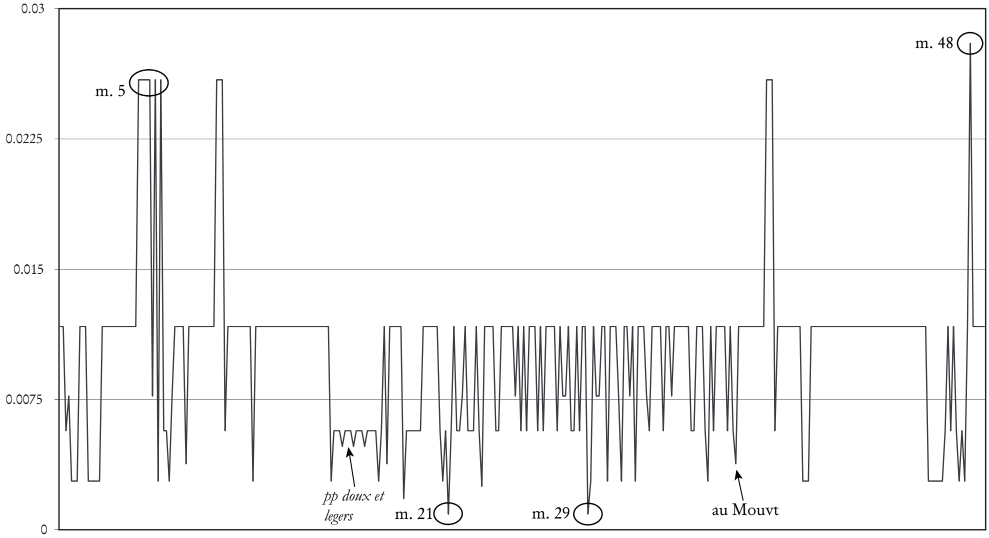

Figure 7: Probability graph of *(… Bruyères)*.

The probability graph demonstrates the various rates of probability throughout the piece, while the inverse graph (Fig. 8) illustrates the levels of original information conveyed. In Figure 7, the probabilities show the likelihood of the melodic occurrence that has taken place. Typically, we see that the most unlikely events take place in the middle-section, and are »bookended« by highly probable elements. As can be seen in Figure 8, the least probable occurrences have conveyed the most amount of information. In addition to highest and lowest points in these graphs, it should be noted that the majority of the composition is in a state of flux. I would argue that this is not only a result of the changing surface calculations or the structural shifts between centres, but a combination of both. At times, Debussy would use the structure to offset the surface and vice versa. This constant fluctuation leads to motion within a composition. Debussy's music, more so than others, emits a sense of stasis throughout, while simultaneously containing a certain degree of what

Edward Lippman terms »progressive temporality«.[19] This constant fluctuation also further reinforces the strength of a hidden Markov process when discussing musical probability. This suggests a common principle with what Karlheinz Stockhausen has described as the essence of his »Moment form«: »Each moment, whether a static state or a process, is individual and self-regulated, and able to sustain an independent existence«.[20] This independence is demonstrated through these fluctuations, as is their overall dependence on a larger formal structure.

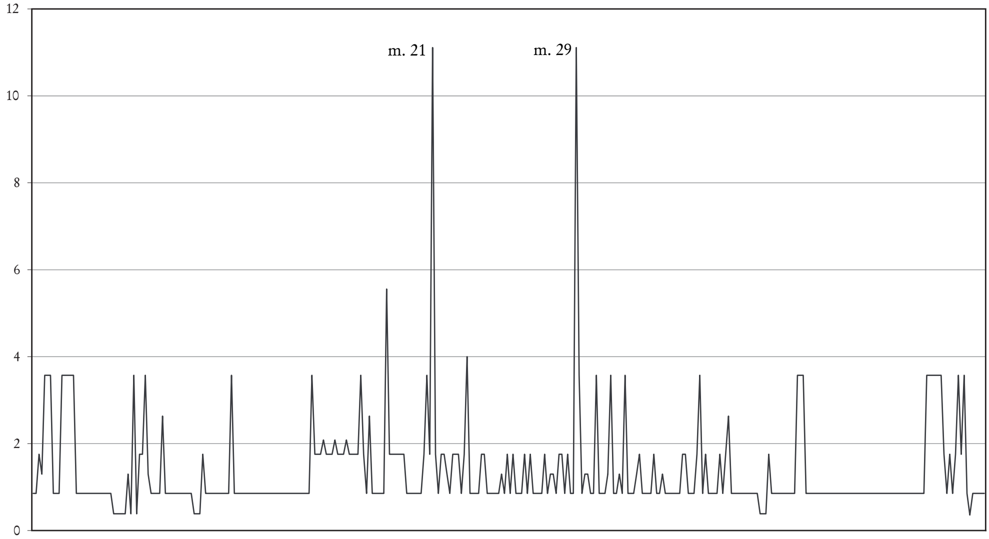

Figure 8: Information processed in *(… Bruyères)* (inverse of probability scores in Figure 7).

Probability Between Voices: Interaction in Debussy's String Quartet

This fluctuation in informational properties is also present throughout Debussy's String Quartet. The process of a descending major second followed by a descending minor third in the beginning (violin 1, Fig. 9) is similar enough to generate a high degree of probability. The diminished triad of the first violin in the first measure, however, is weighted as a tonal deviation and therefore generates a high degree of information, as the first high peak in the graph shows. Interestingly, this is in stark contrast with the information generated by the cello, which begins with a chromatic motion to A^b, but then continues with highly likely stepwise motion. Information is also generated in the opening bars by the descending fourth followed by an ascending minor sixth in the first violin and the tonal deviations in the viola in the third and fourth measures.

19 Lippman, *The Philosophy and Aesthetics of Music*, p. 44.

20 »Jeder Moment, ob Zustand oder Prozeß, ist ein Persönliches, Zentriertes, das für sich bestehen kann.« (Stockhausen, *Kontakte*, programme note; quoted after Wörner, *Stockhausen*, p. 110f.)

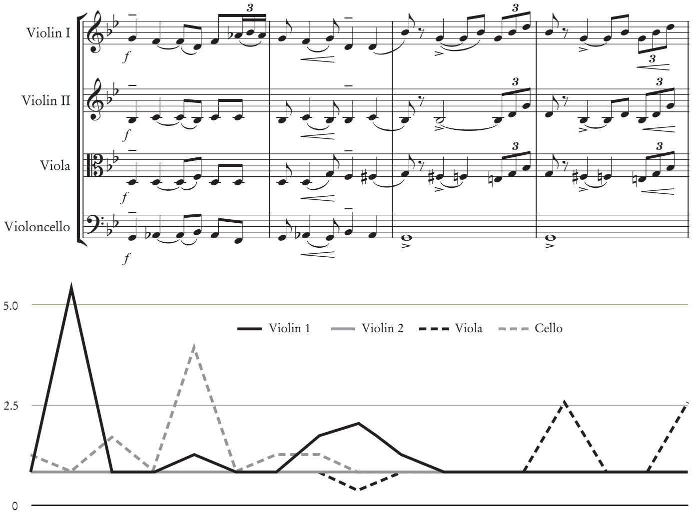

Figure 9: Debussy, String Quartet in G Minor, 1st movement, mm. 1–4, score and information graph.

When this statement returns at m. 26 (Fig. 10), it contains much more fluctuation between voices than at the beginning. While the three lower voices each present some sort of chromatic alteration, this is undermined by their intervallic motion. Both the second violin and the viola move stepwise, while the cello strives for closure after a leap of a perfect fourth. In a rare instance in the first movement, m. 28 generates information in all four voices. The cello part contains a shift in tonality which is subverted by the somewhat cadential melodic motion, and the viola's is undermined by the »gap-fill« motion after a leap of a minor seventh.

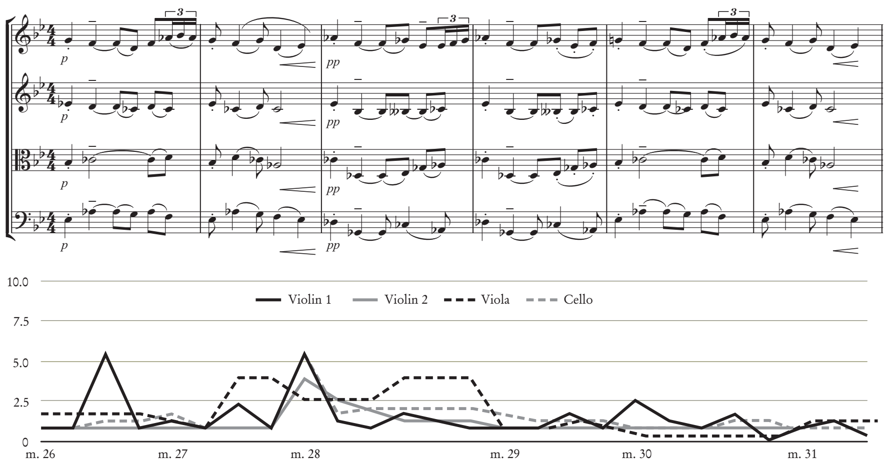

Figure 10: Debussy, String Quartet in G Minor; 1st movement, mm. 26–31, score and information graph.

Debussy is less subtle later in the movement, as both the violins and the viola play heavily chromatic passages with less than predictable intervallic motion. For example, at m. 134 (Fig. 11) a leap of an augmented fourth (F# to C) in the viola is followed by another leap of a perfect fifth (C to G), which is then followed by an expansion (with a leap from A^{b} to C and B down to C. All other voices also show unexpected leaps at this point. This peak is followed by a comparatively conservative motion in all voices, each containing intervallic duplication, which provides a contrast to the peaks in information previously encountered by the listener. In addition, the E^{b} in the second violin (m. 135.3) is no longer as improbable as it has just appeared in the viola.

Figure 11: Debussy: String Quartet in G Minor; 1st movement, mm. 132–137, score and information graph.

The Governance of Tonality

While melodic expectancy in *(… Bruyères)* can be seen as being dictated by transitional elements, it would be a mistake to disregard the effects of a unifying key in this, the most tonal of the *Préludes*. As previously mentioned, Temperley's external calculations of modulation have been included in the calculation of the surface probability. Within a chosen key, however, the hierarchy of tonal elements might be able to be viewed as a type of control element. There are a number of studies concerned with the calculation of such an order, the most notable being the Krumhansl-Kessler key profiles[21], which were perhaps the first to illustrate such levels of tonal perception. Carol L. Krumhansl and Edward J. Kessler calculated their key-profiles by playing certain melodies to listeners followed by an isolated probe tone, and then asked the subjects to describe the »goodness of fit«[22] of this tone. The methodology takes a statistical reading of the occurrences of the pitch classes, and stresses the perception

21 Krumhansl / Kessler, *Tracing the Dynamic Changes in Perceived Tonal Organization*.
22 Ibid., p. 336.

of the root and fifth first, followed by the third, second, fourth, sixth and seventh degrees. With the exception of the relatively low importance of the perfect fourth for the key-profile, this also correlates with the natural overtone series.

A more statistical model was studied by Bret Aarden[23], who took a series of melodies and calculated the statistical importance of each scale degree, coming to similar conclusions as the Krumhansl-Kessler method. In his recent book *Sweet Anticipation: Music and the Psychology of Expectation*, David Huron draws on this research by calculating the probabilities of scale-degree transitions in a large sample of several thousand German folk songs. Huron's matrix of these transitions can be seen below, with the antecedent state constituting the y-axis and the consequent the x-axis.[24]

	1	2	3	4	5	6	7	rest
1	0.03416	0.02806	0.01974	0.0021	0.01321	0.00839	0.02321	0.03678
#1	0	0.00042	0.00004	0	0	0.00003	0.00002	0.00002
b2	0.0004	0	0.00001	0	0	0	0	0
2	0.0419	0.02632	0.03282	0.00678	0.00825	0.00201	0.00586	0.01521
#2	0	0	0.00018	0	0	0	0	0
b3	0.0003	0.00108	0.00001	0.00071	0.0001	0	0	0.00017
3	0.01555	0.04865	0.03142	0.02644	0.02365	0.00281	0.00029	0.02357
#3	0	0	0	0	0	0	0	0
4	0.00054	0.0126	0.04127	0.01506	0.01712	0.00441	0.00125	0.00537
#4	0.00003	0.00016	0.00037	0.0001	0.00257	0.0004	0.00003	0.00013
5	0.02557	0.0053	0.02854	0.03653	0.04835	0.02076	0.00369	0.02284
#5	0	0	0.00001	0.00001	0	0.00027	0.00003	0.00002
b6	0.00001	0	0.00001	0.00003	0.00021	0	0	0.00002
6	0.00238	0.00168	/00065	0.00342	0.03642	0.01261	0.00854	0.0041
b7	0.00062	0.00003	0.00001	0.00003	0.00043	0.00119	0	0.00025
7	0.02025	0.0051	0.00035	0.00029	0.00323	0.01327	0.00448	0.00275
rest	0.01974	0.01096	0.01644	0.00706	0.03082	0.00487	0.00241	n/a

Figure 12: Huron's scale-degree probabilities with diatonic continuations (Huron, *Sweet Anticipation*, p. 158).

By combining the probabilistic levels of the scale-degree transition in *(... Bruyères)* with the probability chart derived from the Bayesian methodology discussed earlier, the differences as compared to a solely external representation of the melodic transitions become apparent. While the external assessment will undoubtedly shed less light on the composition, it will nevertheless add a needed level of stability which a study of intervallic transitions alone would not be able to accomplish. As the following discussion aims to demonstrate, the addition of the transitional probabilities for the scale degrees illustrates the fluctuating nature of *(... Bruyères)* more vividly. Certain melodic movements, such as the third scale degree moving to the seventh in the second measure, are seen as relatively likely processes intervallically, but generate a high level of information tonally. Similarly, the modulation to B flat

23 Aarden, *Dynamic Melodic Expectancy*.

24 Huron, *Sweet Anticipation*, p. 158.

major in m. 23 generates very little information intervallically, as it is arrived at through a transitional motif. The intervallic transition, however, allows the level of ductility necessary in Debussy's music. It therefore seems necessary to use both external and internal systems when calculating melodic probability. Listeners don't experience music in a vacuum, and it is generally understood that most listeners would perceive Debussy's music as being a descendant of the Western tradition, despite his attempts to erode the governing rules of tonality.

Further Research and Conclusion

Any thorough analysis should investigate multiple musical parameters and their interaction with one another. Although the analyses above were focussed on the melodic level alone, they allow some conclusions about the substructure of Debussy's musical style: We find Debussy obfuscating seemingly unlikely events by placing them within highly probable contexts. When rhythm and harmony are included, this is even more so. The composer subverts harmonic predictability through the use of unlikely rhythmic and harmonic structures. Future research would incorporate the effects of form. Upon the reappearance of a segment previously encountered, the information levels change significantly, producing a sort of »diminishing returns« aspect in formal probability, which should be explored with more depth.

The melodic analysis, however, provides a certain understanding of quantified expectation in Debussy's music. By treating the melodic elements as events independent from each other, we have illustrated how melodic continuity may take place despite an overwhelming series of discrete successive elements. This cohesion born out of differentiation will hopefully be a step towards analyzing and quantifying the paradoxes at play in a study of the cognitive aspects of Debussy's compositions.

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