3 Visualizing the Rhythms of Performance

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Traditional staff notation provides a quantized view of musical time: rhythm symbols place each note at a fixed position within a metric framework consisting of integer multiples and fractions of the beat. This familiar representation of rhythm conceals the temporal elasticity of music in performance, including the nuances of *tempo rubato* in Western art music as well as the distinctive rhythmic irregularities in other musical traditions, such as the unequal or "swung" eighth-note subdivisions of jazz and blues and the speech-like rhythms of hip hop and other genres of groove-based music. To promote a clearer understanding of such rhythmic practices, collectively known as *expressive timing* or *microtiming*, several new methods of visualizing rhythm have been proposed over the past century, both in the context of Western art music – the focus of this chapter – and in other contexts.

I begin with some historical background on rhythm notation and a discussion of some pioneering studies of expressive timing from the twentieth century. Next, I turn to scholarly literature published since 2000 that offers novel illustrations of expressive timing alongside sensitive remarks on the motion qualities of Western art music in performance. I conclude by proposing a new visualization strategy for recordings that deviate from the notational meter, with examples from piano recordings by Ignacy Paderewski, Guiomar Novaes, and Claude Debussy.

The figures and examples for this chapter are given on a supplementary webpage: www.rptm.ca/essays/vrp

Beginnings

The idea of showing proportional, integer-related durations through the shapes of the notes on the page can be traced back to the thirteenth-century treatise *Ars cantus mensurabilis* ("The Art of Measured Song") by Franco of Cologne.[1] This was a watershed moment in the history of Western music, because proportional notation freed composers from their former reliance on a limited set of stock rhythmic formulas, the rhythmic modes of the *ars*

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antiqua, and opened new possibilities for rhythmic flexibility, complexity, and innovation. Since the time of Franco, proportional rhythmic symbols have been used in all of the leading systems of music notation in the West, from the mensural notation of the late Middle Ages and Renaissance to the modern notation that emerged in the seventeenth century and remains in common use today.

There is no denying that proportional rhythmic notation presents a simplified image of musical time, because the durations in actual performances rarely form integer relationships with each other. Aware of this limitation, some scholars began seeking new, performance-sensitive representations of rhythm by the early twentieth century.[2] Among these, the most influential was Carl E. Seashore, a pioneering figure in the field of music psychology who assembled a research team at the University of Iowa during the 1920s and 1930s to analyze commercial recordings and live performances. One of the main goals of Seashore's work, summarized in his 1938 textbook on the psychology of music, was to demystify the artistic dimensions of performance, which he equated with "deviation from the fixed and the regular: from rigid pitch, uniform intensity, *fixed rhythm*, pure tone, and perfect harmony."[3] Seashore sought a practical visual representation of these artistic deviations, and his solution is a graphic format that he calls the "performance score."[4] Figure 3.1 is his performance score showing measure-level durations in two renditions of the beginning of Chopin's Polonaise in A Major, Op. 40, No. 1, as performed in the lab by the concert pianist Harold Bauer.[5]

This graph maps the relationship between two aspects of musical time. The horizontal axis shows what we might call "score time"; it divides the performance into discrete increments based on the barlines in the score, a *chain* of units of time that are conceptually equal to each other.[6] The vertical axis shows these units' duration in "clock time," which can be thought of as a continuous timescale, a free-flowing *stream* of musical time. In this type of graph, the changes in vertical position from measure to measure represent expressive timing. Duration is the inverse of tempo, so downward slope means acceleration and upward slope deceleration.

Bauer was asked to play through the entire passage twice with the same expression, and this figure is meant to show that he could do that rather well. The main expressive features here are a "phrase arch" – that is, an acceleration followed by a deceleration – within mm. 1–8, another phrase arch in mm. 9–16, and an acceleration all the way through mm. 17–24.

To give a clearer sense of what the performance score represents, Multimedia example 3.1 includes an excerpt from another recording of the A-major Polonaise from the 1930s, along with my own Seashore-style analysis. The recording is by Artur Rubinstein, who repeats mm. 1–8 as prescribed in the score but does not repeat mm. 9–24.[7] To track Rubinstein's recording, I located measure onsets in Sonic Visualiser, a widely used, open-source performance analysis program.[8] Like Bauer's performance in the lab, Rubinstein's recording has a clear phrase arch in mm. 1–8 as well as a ritardando in m. 16, but in place of Bauer's eight-bar phrase arch in mm. 9–16, Rubinstein gives a pair of four-bar phrase arches that reflect this material's antecedent-consequent design. Another difference is that Rubinstein has a further phrase arch in mm. 17–24 when the opening material returns, in place of Bauer's race-to-the-finish-line accelerando.

Some might object that this performance score misrepresents the musical experience, because our attention may very well be drawn to expressive features in the recording that are not shown in the graph. For example, we might be struck by certain rhythmic details *within* the measure, such as the elongated eighth notes and the compressed sixteenths, as well as certain details of dynamic accentuation, not to mention the wrong notes in the repeat of the opening phrase. Why aren't these features shown in the graph? Seashore would not deny their importance or discourage us from exploring them empirically, but he places a premium on the clarity that can be obtained when variables are isolated. Because the graphs discussed above only show durations at the measure level, they draw our attention to phrase-level patterns that are subtle but nonetheless readily audible and, moreover, musically meaningful given their close correspondence to the phrase structure of the composition and their stability across repeated performances. For these reasons, I find it helpful to avoid thinking of these graphs as representations of the overall effect or "essence" of a performance. Instead, I prefer to think of them as lenses or filters that draw attention to certain expressive features that the analyst considers meaningful.

After Seashore's retirement in 1946, a second wave of empirical performance analysis began to emerge in the 1960s and continued into the 1980s and 1990s.[9] New technologies such as MIDI and the personal computer greatly facilitated this type of research. Most empirical studies from this period echo Seashore in equating performance expression with measurable deviations from exact regularity, and they often feature graphs that closely resemble Seashore's performance scores. Innovation during this period lay mostly in the development of new theoretical models that map aspects of musical structure onto patterns gleaned from performance data. Among these *generative* models of performance, as they came to be known, the one cited most often in recent literature is Neil Todd's computational model of phrase arching, the expressive device we observed in the timing graphs discussed above.[10] The model represents phrase arching as sets of nested parabolic curves, and it encompasses both expressive timing and variations in loudness (Figure 3.2).[11] The embedding depth of each curve is proportional to the unit's hierarchical position in the grouping structure, which is itself modeled through the rule system given in Fred Lerdahl and Ray Jackendoff's *Generative Theory of Tonal Music*.[12] The model predicts that the changes in tempo and dynamics at section boundaries will be more extreme than those at phrase boundaries within a section, which will in turn be more extreme than those at subphrase boundaries within a phrase. As supporting evidence, Todd provides graphs of timing and dynamics from performances by professional pianists, with patterns similar to those predicted by the model (see the broken lines in Figure 3.2).

In a thoughtful review of Todd's work, Luke Windsor and Eric Clarke compare human and computer-generated recordings of a Schubert Impromptu and conclude that the model does not provide a complete explanation of how pieces are performed but may nonetheless be useful as a general expressive baseline or norm against which the nuances of a particular performance can be interpreted.[13] This could be described as a deductive (theory-driven) approach to performance analysis. Bruno Repp offers a complementary inductive (data-driven) approach in a series of corpus studies from the 1990s.[14] Here models are extracted from large sets of performance data through statistical methods (mainly averaging and principal components) and are then used as frames of reference for the interpretation and comparison of individual recordings.

In addition to this work by music psychologists, some historical research involving empirical methods of performance analysis began to emerge in the 1990s. One especially noteworthy contribution in this vein is José Bowen's 1996 article on tempo fluctuation in recordings of orchestral music from the Classical and Romantic eras.[15] Bowen tracked the tempo by tapping along on a computer keyboard while listening to recordings, a more efficient but less accurate method than those used by music psychologists.[16] Bowen presents the tempo data in a series of graphs, again mainly in the style of Seashore's performance scores but now at several levels of scale, proceeding from entire movements to individual phrases. He uses this data to support some rather broad interpretive claims about historical trends in performance practice over the course of the twentieth century and about the performing styles of several well-known conductors.

For example, he shows that the tempos within the first movement of Tchaikovsky's Sixth Symphony have become more extreme over time (Figure 3.3),[17] but he also points out that the earlier recordings tend to have wide tempo fluctuations within each section, citing as a prime example the Concertgebouw Orchestra's 1937 recording conducted by Willem Mengelberg (Multimedia example 3.2).[18] Within the latter recording, Bowen highlights a series of three rather extreme phrase arches, beginning in m. 100, as well as a high level of tempo volatility from the beginning of the exposition to the first climax at m. 38.

Another tapping study from the mid 1990s, an essay by Nicholas Cook on Wilhelm Furtwängler's recordings of Beethoven's Ninth Symphony, forged a connection between empirical performance analysis and the discourse of music theory: Cook shows several correspondences between Furtwängler's interpretation and the analysis in Heinrich Schenker's monograph on the Ninth Symphony, which Furtwängler knew well.[19] This sort of disciplinary cross-fertilization was a hallmark of research by scholars associated with the Centre for the History and Analysis of Recorded Music (CHARM), of which Bowen and Cook were founding members. First established at the University of Southampton in 1994, within a decade CHARM grew into a multi-institutional enterprise that hosted a series of international interdisciplinary conferences during the first decade of this century.

Recent Innovations

Over the past twenty years, partly as an outcome of CHARM and other related initiatives, the empirical literature on rhythmic aspects of performance has continued to flourish. During this period, traditional timing graphs have continued to appear routinely in performance analysis contributions, for instance in my own work on prolongational boundaries and metric dissonance in recorded music, and in writings on performing style and expression by Daniel Leech-Wilkinson and Dorrotya Fabian.[20] However, several new types of analytic figures have also been proposed, often in conjunction with observations about subtle qualities of motion that arise from interactions between performing nuances and aspects of grouping and meter. To illustrate this recent trend, I'll now turn to some musical examples from five representative publications, all of which deal with recordings of nineteenth-century music for solo piano. (This repertory has probably been emphasized because piano note onsets are percussive and therefore relatively easy to locate in a sound file, and because *tempo rubato* tends to be more prominent in recordings of music from the nineteenth century as compared to other periods.)

In a 2012 essay on three recordings of the first movement of Beethoven's "Moonlight" Sonata, Elaine Chew superimposes curved arrows on timing graphs to show what she calls "high-level phrase arcs" (Multimedia example 3.3).[21] Chew's conception of the phrase arch phenomenon differs fundamentally from Todd's, because she does not invoke Lerdahl and Jackendoff's rule system, whose input consists of compositional features such as melodic parallelism and cadence.[22] Instead, her conception of the phrase rests entirely on expressive timing: for Chew, a "performed phrase" is simply a segment of the recording that begins and ends with minima in the timing graph.[23] She compares the rhythmic effect of different recordings by considering the relationship between these performed phrases and the metric notation within the first fifteen measures, showing that Daniel Barenboim and Maurizio Pollini slow down at the barlines, whereas Artur Schnabel does so only at formal boundaries marked by cadences. Chew notes that prior to these cadence points, "the consistent ebb and flow across the bar lines creates a sense of continuity, perhaps a clue as to how [Schnabel] creates these long, long lines."[24] The arrow notation in Multimedia example 3.3a highlights the high-level performed phrases in Schnabel's recording. In a follow-up study, Chew considers the formal implications of the high-level phrase arcs in other recordings. For example, she describes the differences between Schnabel's and Pollini's interpretations (Multimedia example 3.3b) in the following way:

> While Schnabel's [recording] draws a long line to the first modulation, to E major, Pollini's long line is reserved for bars 5 through 15. This suggests that Pollini may have heard the first four bars as an introduction, after which the long line begins and stretches to the downbeat of bar 15, which is the cadence in b minor.[25]

Thus Chew's annotated tempo graphs point not only to differences in performing style, but also to different ways of hearing the succession of formal functions in this passage.[26]

Phrasing hierarchy is also the subject of an article on recordings of Chopin's Mazurkas by Mitchell Ohriner, who builds on the traditional timing graph in two ways.[27] As a first approximation, he uses simple annotations to show how different performances resolve a grouping ambiguity in different ways: in Multimedia example 3.4, the third beat of m. 24 in the Mazurka in C Major, Op. 24, No. 2, can be heard either as (a) the ending of a group that begins in m. 21 or (b) the beginning of a group that ends in m. 28.[28] Recordings by Frederic Chiu and Vladimir Ashkenazy tip the balance one way or the other. Furthermore, at the measure level (not shown here), Chiu accelerates in m. 25 but Ashkenazy does not, so there is also a difference in the salience of different levels of the grouping hierarchy in these two performances, as shown through the boldfacing in Multimedia example 3.4c.[29]

The second method involves using an algorithm to describe grouping similarities and differences within a large set of recordings at three levels of scale. As shown in Multimedia example 3.5, the segments of a timing graph are translated into *durational contours*, that is, ordered sets that represent the durations within the segment as integers from 0 (the shortest unit) to *n*–1 (the longest unit), where *n* is the number of units.[30] Next, a contour reduction algorithm checks for *group-final lengthening* (GFL) – that is, a slow ending – at the 2-, 4-, and 8-measure levels, in reference to a hypothetical grouping structure of (2+2)+(2+2) measures.[31] The algorithm omits the midsized duration within a rolling 3-unit window, and this process is repeated recursively until the contour cannot be reduced further. Only contours that reduce to a pattern of decelerating throughout (<01>), or accelerating and then decelerating (<102> or <201>) are considered GFL-reflective. The results are displayed visually as a set of boxes that are either thick or thin, indicating the presence or absence of GFL. Multimedia example 3.6 shows the results for 6 of the 29 recordings of the C-major Mazurka that Ohriner analyzes with this method.[32]

Because the reference structure is the same for all recordings, the second method is less sensitive to fine grouping boundary differences than the first, but it can nonetheless reveal more fundamental differences in the pacing of the recordings. For example, it shows that Brailowsky's recording differs from both Chiu's and Ashkenazy's insofar as it lacks GFL at the four-bar level, giving it a markedly different feel from the other two. (Multimedia example 3.6 includes an excerpt from the Brailowsky recording.) The basic idea here is that the hypothetical (2+2)+(2+2) pattern exists in reality only to the extent that its constituent parts are performed in a GFL-reflective way. In this sense Ohriner's approach (like Chew's) offers a less deterministic representation of grouping than earlier generative approaches grounded in Lerdahl and Jackendoff's rule system.

Meter rather than grouping forms the framework for a new visualization strategy proposed in a paper by Olivier Senn, Lorenz Kilchenmann, and Antoine Camp, who prepared a note-by-note durational analysis of the first four measures in Martha Argerich's recording of Chopin's Prelude in E Minor (Multimedia example 3.7).[33] In this case, units at various levels of the metric hierarchy – measures, half-measures, beats, and beat subdivisions – are represented in both the horizontal and the vertical axis, resulting in a series of nested squares.[34] The left and right hands are tracked separately, and asynchronies at points aligned in the score are shown as positive or negative integers in the middle of the graph, between the two streams of nested squares. Performance expression is multileveled, and it is very helpful to be able to survey several levels of activity at a single glance. This hierarchical representation is thus a significant advance over the traditional timing graph, which tracks durations on only one level of scale at a time, typically the measure or beat level.

Senn et al. point out some recurring patterns in the Argerich recording: the second half-measure is consistently longer than the first, there are consistent "melody leads" (i.e., the melody notes begin a few milliseconds before the chords), and there are beat- and subdivision-level ritardandos into the first three barlines as well as the midpoint of m. 4.[35] The authors describe the overall effect of these patterns as follows: "Argerich seems to make a new effort to gain some speed with each new bar (hence the faster first halves), but this effort is lost [and] as the bar progresses, the tension relaxes and the music seems to stagnate."[36] From the loose fit between Argerich's performed durations and the rhythmic notation, Senn and his co-authors offer this musical narrative-in-miniature as a speculative "inverse interpretation" that is presented "strictly from the listener's point of view."[37] This is a preliminary study of modest scope, limited to four measures from one recording.[38] However, it has the special distinction of having inspired several creative applications, in the form of a series of compositions by the American composer Richard Beaudoin. In these compositions, the durations in the score are derived from various nested-squares performance analyses, including the one in Multimedia example 3.7.[39]

Some other recent studies have explored phrase-level patterns of dynamics as well as expressive timing. Jörg Langner and Werner Goebl explore interaction between these two domains of performance expression through innovative "performance worm" animations involving a string of overlapping discs in a space defined by tempo on the horizontal axis and loudness on the vertical.[40] Multimedia example 3.8 demonstrates this approach through an analysis of a recording of Chopin's Etude in E Major, Op. 10, No. 3, by the pianist Mauricio Pollini.[41] As noted above, Todd's generative model suggests that both tempo and dynamics tend to increase and decrease in arch-shaped patterns over the course of a phrase. If the dynamic and tempo arches were congruent, then one would expect the performance worm to move diagonally most of the time, first to the northeast and then to the southwest. However, Langner and Goebl observe that in many recordings, such as the Pollini recording in Multimedia example 3.8, the tempo tends to increase before the dynamic level in the approach to a phrase's climax, and counterclockwise patterns are prevalent overall.[42] Though based on a relatively small sample of recordings, this observation suggests a possible refinement of our understanding of phrase arching. Follow-up studies have sought further recurring patterns of motion in the tempo-loudness space, including performer-specific patterns as well as generic patterns, through artificial intelligence models.[43]

Dynamic and temporal aspects of phrase arching are explored in a different way by Nicholas Cook in the chapter on recordings of Chopin's Mazurkas that forms the centerpiece of his broad-ranging book on performance analysis, *Beyond the Score: Music as Performance*.[44] Cook presents the data in the form of "scape plots" in which beat-level data are represented at the base of a triangle and adjacent beats' values are averaged recursively at higher levels, as shown schematically in Figure 3.4.[45] The loudness triangle is inverted and aligned with the timing triangle along the base, creating a diamond shape overall, and the numerical information is color-coded in such a way that flame-like patterns emerge at the loudest and slowest points in an excerpt. Multimedia example 3.9a is Cook's analysis of a recording that he describes as a textbook example of phrase arching, namely Heinrich Neuhaus's recording of Chopin's Mazurka in C-sharp Minor, Op. 63, No. 3.[46] Through graphs of several other recordings of this piece, Cook demonstrates that the technique of phrase arching, though prevalent since the Second World War (especially among Russian-trained pianists), was less widely used in the first half of the twentieth century, when a more rhetorical and improvisatory style of performance prevailed. In Ignaz Friedman's recording (Multimedia example 3.9b), for instance, Cook hears a "focus on moment-to-moment expression" arising from features such as the unusually long opening upbeat and abrupt changes of tempo and articulation later in the excerpt.[47] Thus Cook uses his flaming diamond graphs to support the argument that phrase arching is a historically and culturally specific practice, not a universal or "hard-wired" psychomotor phenomenon, as Todd's model and other generative models seem to imply.

Despite their sharp differences in design, all of the recent examples I have surveyed help bring into focus musically meaningful patterns that might otherwise escape our notice, as well as the qualitative effects that these patterns help to generate. Like Seashore's performance scores, then, these new types of graphs can be thought of as analytic lenses or filters that help us reach a clearer understanding of the music we are actually hearing, as distinct from the music we read on the page. Another way in which these new graphs resemble Seashore's performance scores is that they use the notational meter – the beats and measures shown in the score – as a frame of reference: durations are tracked at the level of the notated beats, and measure numbers are shown either on the horizontal axis (Chew, Ohriner, Cook), at the top of the nested squares (Senn et al.), or on the face of the performance worm (Langner and Goebl). In my view, this is not problematic in the particular examples surveyed above, because these beats and measures can easily be heard and felt in these recordings. However, reliance on the metric notation limits the generalizability of these analytic approaches, because many other recordings do not conform to that notation – especially those by performers trained at the beginning of the twentieth century, a period when many musicians and critics railed against the "tyranny of the barline."[48] I consider the variations in meter within such non-literalist recordings to be a distinct type of "artistic deviation from the regular" – in other words, a special type of performance expression.

Visualizing Metric Variation in Performance

Let's consider two versions the opening of Chopin's Mazurka in A Minor, Op. 17, No. 4, one recorded by Ignacy Paderewski in 1923 and the other by Guiomar Novaes in 1954.[49] According to the score (Multimedia example 3.10a), this excerpt consists of eight bars in triple meter, grouped as 4+4.[50] Timing graphs of the two recordings are very similar (Multimedia example 3.10b), and the corresponding timescape graphs are nearly identical (Multimedia example 3.10c).[51] However, these illustrations conceal some fundamental differences between the recordings in the domain of *experiential meter*, by which I mean the meter felt by the listener, as opposed to the meter represented in the score.[52] To get at these differences, I will borrow some concepts and analytic symbols from Christopher Hasty's *Meter as Rhythm*, which casts meter not as a structure or schematic framework but instead as a dynamic, emergent aspect of the listening experience.[53] Hasty represents experiential meter through static images, but I will instead use animations in an effort to represent more directly the temporal qualities that the theory describes, an approach suggested in John Roeder's review of

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Meter as Rhythm.[54] I created Multimedia example 3.11–3.15 using Adobe Animate, a multimedia computer animation program.

For Hasty, the basis of the experience of meter is *projection*, the feeling that once a duration has been articulated, it will immediately be reproduced: after hearing two sounds, we expect a third sound at a specific future moment (Multimedia example 3.11a).[55] A *complex projection* occurs when a long projection is coordinated with two or more shorter projections (Multimedia example 3.11b),[56] and within a complex projection, the *dominant beginning* (|) launches a projection that remains active for more than one beat, while a *continuation* (\) initiates a shorter projection between two dominant beginnings.[57]

One of the benefits of Hasty's analytic notation, as compared to traditional metric symbols like time signatures and barlines, is that it allows for more subtlety and flexibility in tracking changes of meter. Hasty defines three types of metric change relevant to the excerpts discussed below: *denial* occurs when a timespan does not fulfill its projected duration and instead launches a new projection that is considerably shorter or longer than the one before it (Multimedia example 3.12a),[58] *deferral* happens when an extra continuation postpones a dominant beginning and therefore alters the metric type, for instance by shifting from duple to triple meter (Multimedia example 3.12b),[59] and *interruption* occurs when the ending of a projected duration is pre-empted by a new, early beginning (Multimedia example 3.12c).[60]

Hasty's own analyses center on *compositional* applications of these processes of metric change, mainly in music from the twentieth century, and he uses scores rather than recordings as his objects of analysis. I often hear these same metric processes when listening to recordings of earlier, common-practice repertoire, including the Paderewski and Novaes excerpts discussed above, to which I now return.[61]

Multimedia example 3.13a shows the variations in meter that I hear in the Paderewski excerpt.[62] Up to the boundary of the introduction and theme, I hear a projection of triple meter without anacrusis. This triple meter is so well established that I feel a fifth downbeat during the sustained chord that begins in the fourth experiential measure, but the mazurka theme enters before this fifth measure is completed – a clear case of interruption. A further complication occurs during the first three beats of the theme, which Paderewski plays as weak–strong–weak. This can be heard either as a syncopation or an anacrusis in its local context, but once the theme's second downbeat is articulated the ambiguity resolves in favor of syncopation. From that point on, I hear an unambiguous triple meter until the end of the excerpt.

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Multimedia example 3.13b maps the hypermeter in Paderewski's recording, which is equally flexible. Although a potential for duple hypermeter can be sensed throughout the excerpt, this potential is fully realized only toward the end.[63] Duple hypermeter is ubiquitous in Romantic piano music, so we might reasonably expect it at the outset of the recording. Instead, the second hyperdownbeat is deferred until the sustained chord at the end of the introduction, which gives the fourth experiential measure a much stronger sense of "beginning" than the third, and suggests that the recording begins with *triple* hypermeter. This effect is enhanced by the increased tempo and rhythmic activity leading up to the sustained chord, which bring a sense of anacrusis, of into-the-beginning. However, the projection of this triple hypermeter is interrupted by the entry of the mazurka theme, which itself projects the duple hypermeter expected from the outset.

In Novaes's recording, I hear a fundamentally different metric process involving a shift from duple to triple meter at the surface level (Multimedia example 3.14a). Duple meter is projected throughout the introduction, and the triplet figure near the end of the introduction sounds like a *quarter-note* triplet, not an eighth-note triplet as in Paderewski's recording and in the score. This quarter-note triplet foreshadows a shift from duple to triple meter at the beginning of the theme, and the ritardando that surrounds the triplet helps smooth out this metric transition. In conjunction with this ritardando, a shift from duple to triple hypermeter can also be discerned in the introduction (Multimedia example 3.14b). The accents on the first and fifth chords of the introduction project duple hypermeter, and the triplet figure defers the next hyperdownbeat until the sustained chord. Then, as in Paderewski's recording, this triple hypermeter is interrupted by the entry of the mazurka theme, which itself projects duple hypermeter throughout.

The Paderewski and Novaes example show some ways in which an investigation of experiential meter may shed light on distinctive and meaningful patterns that would be obscured in an analysis framed by the notational meter. To demonstrate this approach further, I will now turn to a more metrically intricate passage from Debussy's 1913 piano roll recording of his piece *D'un cahier d'esquisses* ("From a Sketchbook") as reissued on CD.[64] The passage includes a cadenza that features two gong-like bass notes, each of which is followed by a rapid ascending passage and a short melodic fragment. The cadenza is preceded by a short transition and followed by a coda.[65] Multimedia example 3.15a maps the metric fluctuations that I hear in this excerpt.

A clear and continuous tactus can be felt throughout the excerpt, but the underlying (measure-level) projections are considerably less clear and continuous: a slow duple meter is established at the outset, but two processes of metric change, namely, denial and deferral, can be traced within the cadenza. Because of the slow tempo, these processes do not bring as much tension as the interruptions and deferrals in the Paderewski and Novaes recordings. Instead, they bring a subtle ebb and flow of metric determinacy over the course of the excerpt.

The melodic fragment after the cadenza's initial gong stroke includes an extra continuation ("weak beat") that defers the next downbeat until the second gong stroke. This establishes a potential *triple* meter, but when the melodic fragment returns soon after the second gong stroke, its rhythm is altered in such a way that the gesture now encompasses four beats instead of three. The result is that the tentative triple meter recedes from our field of awareness,[66] and the referential duple meter is restored.

By the end of the excerpt, the tempo has become slow enough to undermine the duple meter, which seems to dissipate shortly after the coda begins. However, there is a feeling of rhythmic continuity between the tactus pulses of the cadenza and the triple measures of the coda. In other words, there seems to be a transition from a slow duple to a moderate triple meter toward the end of the excerpt, similar to what happens in the Novaes excerpt discussed above.

The score and recording are again quite remote from each other in this case. The cadenza is mostly unmeasured in the score (Multimedia example 3.15b), and one of its main focal points in the recording, the second gong stroke, is altogether absent.[67] A few beats later, at the beginning of the coda, the score indicates a change from $\substack{6\\8}$ to $\substack{6\\4}$ meter, as well as a tactus shift (dotted quarter = quarter), indicating that the coda should proceed at only one-third the tempo of the previous $\substack{6\\8}$ measures – a dramatic discontinuity in comparison to the seamless connection heard in the recording.

These animations provide a new way to visualize and interpret the nuances of rhythm and timing in recordings that lack a consistent metric framework. As such, they fill a gap in the literature surveyed in Parts I and II of this chapter. Further applications might explore recordings of Gregorian chant and other types of monophonic singing in free rhythm, as well as free-flowing instrumental music like the unmeasured keyboard preludes of the French baroque. These are just a few of seemingly endless possibilities for research in performance analysis, a field that will surely continue to grow and develop as new technologies become available in the years ahead – thereby helping to further expand our appreciation and understanding of the rhythms of performance.

Figures and Multimedia examples for Chapter 3

These figures appear on the website www.rptm.ca/essays/vrp

3.1 Timing in the opening of Chopin's Polonaise in A Major, Op. 40, No. 1, performed by Harold Bauer (Seashore, *Psychology of Music*)

3.2 Graphs of human and computer-generated performance expression:
   - (a) Timing in an excerpt from Haydn's Sonata in E-flat Major, Hob. XVI/49 (Todd, "A Computational Model of Rubato")
   - (b) Loudness in an excerpt from Chopin's Prelude in F-sharp Minor, Op. 28, No. 8 (Todd, "The Dynamics of Dynamics")

3.3 Average tempos in various recordings of the first movement of Tchaikovsky's Symphony No. 6 in B Minor, Op. 74 (Bowen, "Tempo, Duration, and Flexibility")

3.4 Generalized scape plot design (Sapp, "Computational Methods")

These multimedia examples appear on the website www.rptm.ca/essays/vrp

3.1 Timing in the opening of Chopin's Polonaise in A Major, Op. 40, No. 1, performed by Artur Rubinstein

3.2 Timing in the first movement of Tchaikovsky's Symphony No. 6 in B Minor, Op. 74, performed by the Concertgebouw Orchestra conducted by Willem Mengelberg (Bowen, "Tempo, Duration, and Flexibility")

3.3 Timing and high-level phrase arcs in the opening of Beethoven's "Moonlight" Sonata, Op. 27, No. 2
   - (a) performed by Artur Schnabel (Chew, "About Time")
   - (b) performed by Artur Schnabel (top half) and Maurizio Pollini (bottom half) (Chew, "From Sound to Structure")

3.4 Timing and grouping in an excerpt from Chopin's Mazurka in C Major, Op. 24, No. 2 (Ohriner, "Grouping Hierarchy and Trajectories of Pacing")
   - (a) performed by Frederic Chiu
   - (b) performed by Vladimir Ashkenazy
   - (c) effects of performance strategies upon grouping structure

3.5 Durational contour in Chopin's Mazurka in C-sharp Minor, Op. 63, No. 3, performed by Stanislav Bunin (Ohriner, "Grouping Hierarchy and Trajectories of Pacing")

3.6 Group-final lengthening in six recordings of Chopin's Mazurka in C Major, Op. 24, No. 2 (Ohriner, "Grouping Hierarchy and Trajectories of Pacing")

Endnotes

1 This innovation and its cultural significance are discussed in A. W. Crosby, *The Measure of Reality: Quantification and Western Society, 1250–1660* (Cambridge University Press, 1997), 151–63.

2 These newer representations are based on the measurement of musical durations in "clock time," a practice whose origins in the eighteenth and early nineteenth centuries are discussed in M. R. Grant, *Beating Time and Measuring Music in the Early Modern Era* (Oxford University Press, 2014), 127–34 and 183–208.

3 C. E. Seashore, *Psychology of Music* (New York: McGraw-Hill, 1938), 29, emphasis added. For further details on Seashore's contributions, see A. Gabrielsson, "The Performance of Music," in D. Deutsch (ed.), *The Psychology of Music*, 2nd ed. (San Diego: Academic Press, 1999), 527–32.

4 Seashore, *Psychology of Music*, 21–2.

5 Ibid., 246.

6 The "chain" and "stream" analogies are borrowed from C. Seeger, "Prescriptive and Descriptive Music-Writing," *The Musical Quarterly*, 44 (1958), 185.

7 A. Rubinstein, *Fryderyk Chopin: Polonaises (Selections) [and] Andante spianato and Grande polonaise brilliant*, Naxos 8.110661, 2000, track 5 (recorded December 1934). Unfortunately, recordings of Bauer's performances in the lab are not available.

8 C. Cannam, C. Landone, and M. Sandler, "Sonic Visualiser: An Open Source Application for Viewing, Analysing, and Annotating Music Audio Files," in *Proceedings of the ACM Multimedia 2010 International Conference* (New York: ACM Publications, 2010), 1467–8. See also N. Cook and D. Leech-Wilkinson, *A Musicologist's Guide to Sonic Visualiser* (https://charm.rhul.ac.uk/analysing/p9_1.html), accessed September 26, 2019.

9 Gabrielsson, "Performance of Music," 532–79; Gabrielsson, "Music Performance Research at the Millennium," *Psychology of Music*, 31 (2003), 225–37.

10 N. Todd, "A Model of Expressive Timing in Tonal Music," *Music Perception*, 3 (1985), 33–58; Todd, "A Computational Model of Rubato," *Contemporary Music Review*, 3 (1989), 69–88; Todd, "The Dynamics of Dynamics: A Model of Musical Expression," *Journal of the Acoustical Society of America*, 91 (1992), 3540–50.

11 Todd, "Computational Model," 77; Todd, "Dynamics of Dynamics," 3549.

12 F. Lerdahl and R. Jackendoff, *A Generative Theory of Tonal Music* (MIT Press, 1983), 345–52.

13 L. Windsor and E. Clarke, "Expressive Timing and Dynamics in Real and Artificial Musical Performances: Using an Algorithm as an Analytical Tool," *Music Perception*, 15 (1997), 127–52. The human and computer-generated recordings discussed in this article are available in N. Cook, *Beyond the Score: Music as Performance* (Oxford University Press, 2013), companion website (www.oup.com/us/beyondthescore), media examples 3.08 and 6.02, accessed September 26, 2019.

14 Among his many publications in this vein, the most widely cited is B. H. Repp, "Diversity and Commonality in Music Performance: An Analysis of Timing Microstructure in Schumann's 'Träumerei,'" *Journal of the Acoustical Society of*

America, 92 (1992), 2546–68. See also C. E. Cancino-Chacón, M. Grachten, W. Goebl, and G. Widmer, "Computational Models of Expressive Music Performance: A Comprehensive and Critical Review," *Frontiers in Digital Humanities*, 5, No. 25 (2018), 1–23.

15 J. A. Bowen, "Tempo, Duration, and Flexibility: Techniques in the Analysis of Performance," *Journal of Musicological Research*, 16 (1996), 111–56.

16 Ibid., 130. Bowen estimates his method's margin of error at 60 ms, as compared to 10 ms for Seashore's and Repp's methods. Of these authors, only Repp provides data to justify his estimate (Repp, "Diversity and Commonality," 2551).

17 Bowen, "Tempo, Duration, and Flexibility," 137.

18 Ibid., 140 (graph) and 142 (discussion).

19 N. Cook, "The Conductor and the Theorist: Furtwängler, Schenker and the First Movement of Beethoven's Ninth Symphony," in J. Rink (ed.), *The Practice of Performance: Studies in Musical Interpretation* (Cambridge University Press, 1995), 105–25.

20 A. Dodson, "Performance, Grouping, and Schenkerian Alternative Readings in Some Passages from Beethoven's 'Lebewohl' Sonata, Op. 81a," *Music Analysis*, 27 (2008), 107–34; Dodson, "Metrical Dissonance and Directed Motion in Paderewski's Recordings of Chopin's Mazurkas," *Journal of Music Theory*, 53 (2009), 57–94; D. Leech-Wilkinson, *The Changing Sound of Music: Approaches to Studying Recorded Musical Performance* (London: CHARM, 2009), https://charm.rhul.ac.uk/studies/chapters/intro.html, accessed September 27, 2019; D. Fabian, "Commercial Sound Recordings and Trends in Expressive Music Performance: Why Should Experimental Researchers Pay Attention?" in D. Fabian, R. Timmers, and E. Schubert (eds.), *Expressiveness in Music Performance: Empirical Approaches Across Styles and Cultures* (Oxford University Press, 2019), 58–75; D. Fabian, *A Musicology of Performance: Theory and Method Based on Bach's Solos for Violin* (Cambridge: Open Book Publishers, 2015), https://openbookpublishers.com/htmlreader/978-1-78374-152-6/main.html, accessed September 27, 2019.

21 E. Chew, "About Time: Strategies of Performance Revealed in Graphs," *Visions of Research in Music Education*, 20 (2012), 13.

22 See note 13. Chew's performance-centered definition of phrase also diverges sharply from the two prevailing views of phrase in music theory today, which remain grounded entirely in compositional features: W. Rothstein, *Phrase Rhythm in Tonal Music* (New York: Schirmer, 1989), 3–15; W. Caplin, *Classical Form: A Theory of Formal Functions for the Instrumental Music of Haydn, Mozart, and Beethoven* (Oxford University Press, 1999), 260, note 5.

23 Chew, "About Time," 8.

24 Ibid., 9.

25 E. Chew, "From Sound to Structure: Synchronising Prosodic and Structural Information to Reveal the Thinking behind Performance Decisions," in C. MacKie (ed.), *New Thoughts on Piano Performance: Research at the Interface*

between Science and the Art of Piano Performance (London: London International Piano Symposium Publications, 2016), 143–4.

26 The relationship between performance and alternative readings of formal function is discussed more fully, though without performance analysis graphs or data, in J. Schmalfeldt, *In the Process of Becoming: Analytical Perspectives on Form in the Early Nineteenth Century* (Oxford University Press, 2011), 118–21.

27 M. S. Ohriner, "Grouping Hierarchy and Trajectories of Pacing in Performances of Chopin's Mazurkas," *Music Theory Online*, *18.1* (2012).

28 Ibid., ¶ 7.

29 Ibid., ¶ 8.

30 Ibid., ¶ 16.

31 Ibid., ¶ 15 and ¶ 22. When successive durations are too close to be differentiated aurally, the second iteration is pruned, so mm. 37–38 in Figure 3.8 will reduce to <102>, making it GFL-reflective. Ohriner admits that the algorithm is not able to recognize the contour in mm. 33–34 as GFL-reflective because it has a sawtooth pattern. This is a limitation of the methodology.

32 Ibid., ¶ 22.

33 O. Senn, L. Kilchenmann, and A. Camp, "Expressive Timing: Martha Argerich Plays Chopin's Prelude Op. 28/4 in E Minor," in A. Williamon, S. Pretty, and R. Buck (eds.), *Proceedings of the International Symposium on Performance Science 2009* (Utrecht: European Association of Conservatoires, 2009), 110.

34 A similar graphic format was used several years earlier in a study of piano roll recordings: H. Gottschewski, "Graphic Analysis of Recorded Interpretations," *Computing in Musicology*, 8 (1992), 95.

35 Senn et al., "Expressive Timing," 110.

36 Ibid., 111.

37 Ibid., 108.

38 A further four measures are analyzed in a follow-up study: O. Senn, L. Kilchenmann, and A. Camp, "A Turbulent Acceleration into the Stretto: Martha Argerich Plays Chopin's Prelude Op. 28/4 in E Minor," *Dissonance*, 120 (2012), 31–5.

39 This compositional approach is discussed more fully in R. Beaudoin and A. Kania, "A Musical Photograph?" *Journal of Aesthetics and Art Criticism*, 70 (2012), 115–27. The "microtiming" page on Beaudoin's website (www.richardbeaudoin.com/microtiming) includes a complete list of works for which nested-squares analyses served as a compositional resource.

40 J. Langner and W. Goebl, "Visualizing Expressive Performance in Tempo-Loudness Space," *Computer Music Journal*, 27 (2003), 69–83.

41 https://iwk.mdw.ac.at/goebl/animations.html, accessed September 22, 2019.

42 Langner and Goebl, "Visualizing Expressive Performance," 72.

43 Summarized in G. Widmer and W. Goebl, "Computational Models of Expressive Music Performance: The State of the Art," *Journal of New Music Research*, 33 (2004), 210–12.

44 Cook, *Beyond the Score*, 126–223.

45 C. Sapp, "Computational Methods for the Analysis of Musical Structure" (Ph. D. dissertation, Stanford University, 2011), 96. (Sapp, a CHARM Research Fellow, collaborated with Cook on the Mazurka project discussed in *Beyond the Score*.)

46 Cook, *Beyond the Score*, 198 (color version from online supplement).

47 Ibid., 189 (graph, color version from online supplement) and 190 (quotation).

48 See, for example, D. G. Mason, "The Tyranny of the Bar-Line," *The New Music Review and Church Music Review*, 9 (1909–10), 31–3.

49 J. I. Paderewski, *Paderewski Plays Chopin, Volume II*, Pearl GEMM CD9397, 1990, track 10 (recorded May 1923); G. Novaes, *Guiomar Novaes: Chopin Mazurkas*, Vox PL7920, 1954, track 4.

50 *Friedrich Chopins Werke* (Leipzig: Breitkopf and Härtel [1879]), vol. 3, 22.

51 I created Figure 3.14c using an online scape plot tool (www.mazurka.org.uk/software/online/scape/) after tracking the recordings at the beat level in Sonic Visualiser.

52 This term was coined in R. S. Parks, "Structure and Performance: Metric and Phrase Ambiguities in the Three Chamber Sonatas," in J. R. Briscoe (ed.), *Debussy in Performance* (Yale University Press, 1999), 280.

53 C. Hasty, *Meter as Rhythm* (Oxford University Press, 1997).

54 J. Roeder, Review of *Meter as Rhythm* by C. Hasty, *Music Theory Online*, 4.4 (1998), paragraph 2.4.

55 Hasty, *Meter as Rhythm*, 84–86.

56 Ibid., 106.

57 Ibid., 104.

58 Ibid., 88–89.

59 Ibid., 133–35.

60 Ibid., 87–88.

61 Others have drawn extensively on Hasty's work in analyses of jazz, popular music, and world music recordings. Two recent examples: N. Murphy, " 'The Times They Are A-Changin' ': Flexible Meter and Text Expression in 1960s and 70s Singer-Songwriter Music" (Ph.D. dissertation, University of British Columbia, 2015), esp. 40–49 and 121–201; J. Roeder, "Formative Process of Durational Projection in 'Free Rhythm' World Music," in R. Wolf, S. Blum, and C. Hasty (eds.), *Thought and Play in Musical Rhythm* (Oxford University Press, 2019).

62 This analysis builds on some observations in Dodson, "Metrical Dissonance and Directed Motion," 65–66.

63 I attribute this feeling of a potential hypermeter mainly to the fast tempo and repetitive rhythm in the recording. My expectation of *duple* hypermeter is surely conditioned by the stylistic norms of Romantic piano music in general, and of Chopin's Mazurkas in particular.

64 C. Debussy, *Claude Debussy: The Composer as Pianist*, Pierian 001, 2000, track 14 (recorded November 1913). This recording is explored more fully in A. Dodson, "'So Free as to Seem Improvised': Rhythmic Revisions and Kinetic Form in Debussy's Recording of *D'un cahier d'esquisses*," in T. Popovic (ed.), *Claude Debussys Aufnahmen eigener Klavierwerke* (Stuttgart: Steiner Verlag, forthcoming).

65 For an overview of the form, see R. Howat, *Debussy in Proportion: A Musical Analysis* (Cambridge University Press, 1983), 138–9.

66 Hasty describes this type of attenuation process to be a weak form of denial because in such cases "it is not at all clear 'when' the projected potential . . . becomes exhausted." Hasty, *Meter as Rhythm*, 89.

67 C. Debussy, *D'un cahier d'esquisses*, first edition (Brussels: Schott, 1904).