Phase-plane representation and visualization of gestural structure in expressive timing

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1 Background & Introduction

- Considerable scientic interest in expression in music performance (Gabrielsson, 2003).
- A particularly relevant aspect of music performance is expressive Timing (the intentional fluctuations of tempo during a performance)
- The problem of explaining expressive timing in music performances can be regarded as a special case where we want to learn experimentally about the temporal behavior of some dynamical system based on limited observation.
- A common way of studying data in dynamical systems theory is by phase-plane representation.

1 Background & Introduction

This paper argues:

- phase-plane representations of expressive timing provide a useful way of visualizing data, and furthermore, we show that
- such representations are promising in the context of performer characterization and identification.

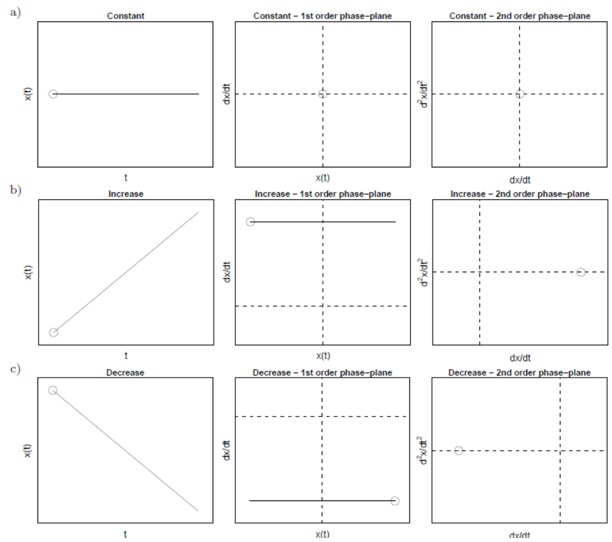
1 Background & Introduction

Choose a different phase-plane method, that exclusively represents tempo information:

- [Section 1] We focus on first-order and second-order phase-planes. The former plots the derivative of tempo versus tempo, whereas the latter plots the second versus the 1^{st} derivative of tempo.
- [Section 2] After introducing the visualization method using schematic examples and describing the procedure for computing phase-plane trajectories from expressive performances
- [Section 3] we review two expressive gestures in performances of Schumann's Traumerei.
- [Section 4] we describe an experiment in which we determine the effects of several parameters of phase-plane representation on tasks like performer identification

2 Phase-plane plots VS time-series plots

2.1 Examples of basic curve types



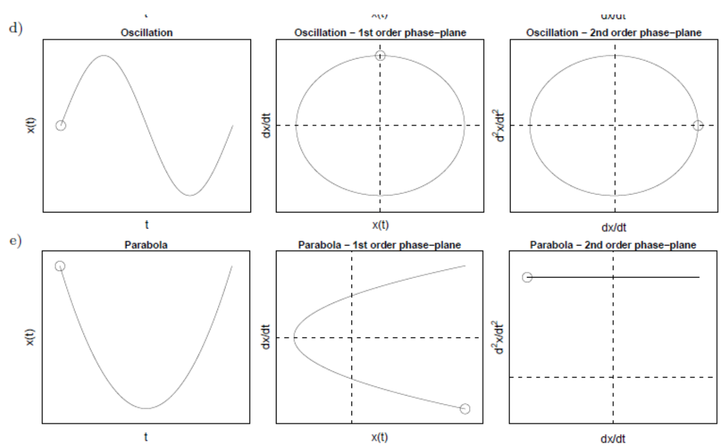


Figure 1: Examples of five basic curve types (first column), and their first and second order phase-plane trajectories (second and third columns respectively); Horizontal and vertical dashed lines represent x and y axes respectively; Circles indicate the beginning of the curves/trajectories; Units are arbitrary

$$\mathbf{y} = x(\mathbf{t}) + \mathbf{e} \quad (1)$$

$$x(\mathbf{t}) = \mathbf{c}'\phi \quad (2)$$

The fitting of the function x to the data y can be done by minimizing the summed squared error:

$$SSE = ||\mathbf{y} - \mathbf{\Phi c}||^2 \quad (3)$$

To take the smoothness constraint into account, a penalty term for roughness is included the quantity that is minimized:

$$PENSSE = SSE^2 + \lambda PEN \quad (4)$$

$$PEN = \int [D^2 x(s)]^2 ds \quad (5)$$

$$S(t) = \sum_{k=1}^{m+L-1} c_k B_k(t, \tau) \quad (6)$$

3 Phase-planes of expressive gestures

- the phase-plane visualization is illustrated for two performances of a melodic gesture (or motif) from Schumann's Traumerei.
- Figure 2 shows the IOI curves (the reciprocals of the tempo curves) and corresponding phase-plane trajectories of two performances of MG2, by Zak (1960) and Horowitz (1947) respectively.

3 Phase-planes of expressive gestures

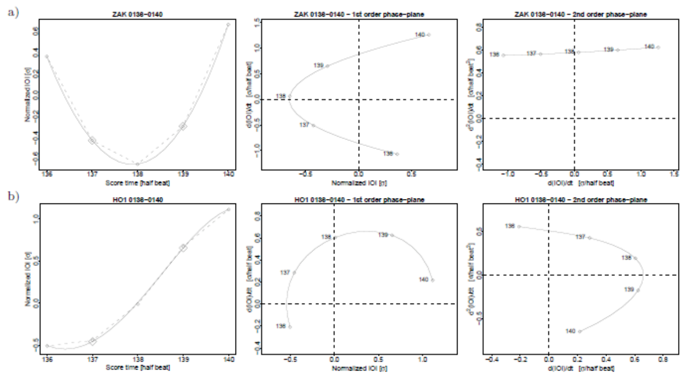


Figure 2: Fitted IOI curves and corresponding phase-plane trajectories for two exemplary performances of a melodic gesture (MG2, fourth instance, half beats 136–140) from Schumann's Träumerei, by Zak (1960) (a), and Horowitz (1947) (b) respectively; In the first column, the circles connected by dashed lines are the measured IOI values (normalized), and the solid line is the fitted spline; Diamonds indicate the breakpoints of the spline; the phase-plane trajectories are annotated with half beat numbers; The units are shown in square brackets in the axis labels; σ denotes the standard deviation of the normalized IOI values

4 An assessment of alternative phase-plane representations

To produce the phase-plane trajectories of S, we use the first and second derivatives of S, D^1 and D^2 respectively, which can be obtained in closed form from S. In principle, any subset of (S, D^1, D^2) can be used to represent the data. In the rest of the paper, we will refer to such subsets as *spaces*. By a trajectory of a musical fragment spanning beats k through l in the space (S, D^1, D^2), we mean a sequence $v_k, \cdots, v_l$, where $v_i = \langle S(t_i), D^1(t_i), D^2(t_i)\rangle$ (and analogous for other spaces). In the current experiment, we compare the six (redundant) spaces S, D^1, D^2, (S, D^1), (D^1, D^2), and (S, D^1, D^2).

4 An assessment of alternative phase-plane representations

Composer, Piece	Fragment name	Fragment start positions (in beats)	Frag. length (in beats)	Cumulative frag. length (% of piece)	No. of performances
Chopin, Op. 10, No. 3	A	3 (repeated at 67, 491)	16	±16%	8
Chopin, Op. 10, No. 3	B	20 (84, 508)	22	±21%	8
Chopin, Op. 28, No. 17	A	14 (62, 206, 434)	35	±26%	10
Schumann, Op. 15, No. 7	MG1/2	3 (35, 67, 99, 131, 163)	9	±28%	28

Table 1: Description of the data used

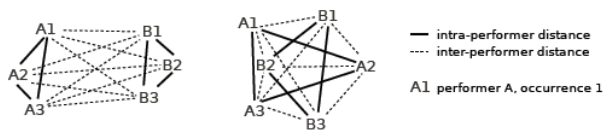


Figure 4: Left: small intra-performer distances and large inter-performer distances (that is, high intra/inter performer gap); Right: intra-performer and inter-performer distances are similar (that is, low intra/inter performer gap)

4.1.3 Evaluation of Clustering

$$IIPG_C(k) = \frac{2}{N(N-1)} \sum_{n=2}^{N} \sum_{m=1}^{n-1} -d_C(\langle k,n\rangle, \langle k,m\rangle) + \frac{1}{K-1} \sum_{l \neq k}^{K} d_C(\langle k,n\rangle, \langle l,m\rangle) \qquad (7)$$

$$IIPG_C = \frac{1}{K} \sum_{k=1}^{K} IIPG_C(k) \qquad (8)$$

$$prec(C) = \frac{k_i}{|C|} \qquad (9)$$

$$rec(C) = \frac{k_i}{K_i} \qquad (10)$$

$$F\text{-}score(C) = \frac{2 \cdot prec(C) \cdot rec(C)}{prec(C) + rec(C)} = \frac{2k_i}{|C| + K_i} \qquad (11)$$

4.1 Data and Procedure

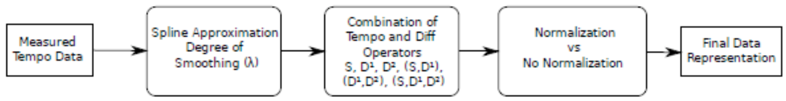


Figure 3: Processing steps from measured data to the data used for clustering

- use data sets containing phase-plane trajectories describing the performances of musical fragments
- select those parts that correspond to the occurrences of a single musical fragment which is repeated multiple times
- then compare a clustering of the data set that was computed from the phase-plane trajectories, to the performer-partitioning of the data set on the one hand, and to the order-of-occurrence-partitioning on the other. This gives us a way to evaluate different representations of the performance data with respect to the partitioning tasks.

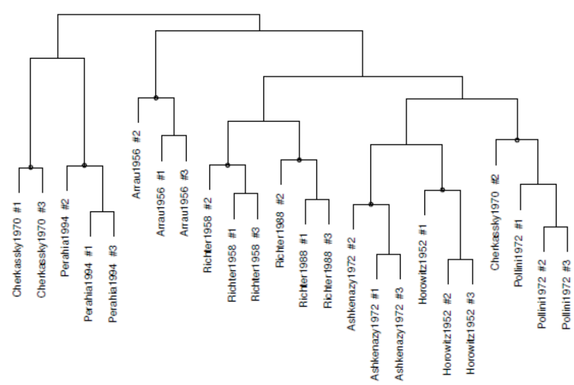


Figure 5: Dendrogram obtained from hierarchically clustering the Chopin, Op. 10, No. 3 (fragment B) performance data set. The clustering is obtained by considering trajectories in the space D^2, the second derivative of tempo. The parameter λ for controlling the roughness penalty is optimized for performer identification ($\lambda = 10^{-4}$); The labels show performer/year and order-of-occurrence; The circled nodes jointly form the clustering with maximal average cluster F-score, given the performer/year labels

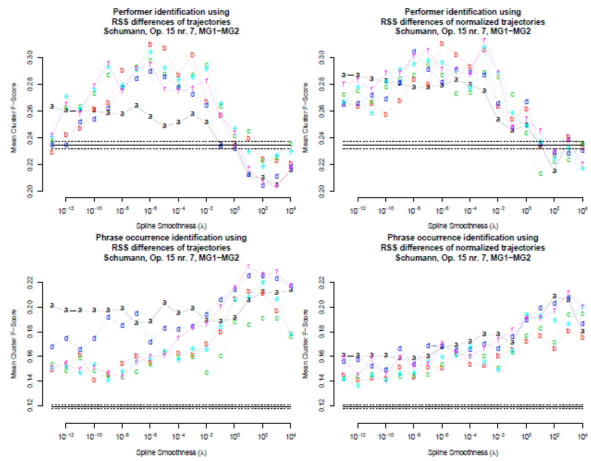


Figure 6: Mean cluster F-scores as a function of spline smoothness, for different combinations of tempo and derivatives. Legend: **a**: tempo (S); **b**: first derivative of tempo (D^1); **c**: second derivative of tempo (D^2); **d**: (S,D^1); **e**: (D^1,D^2); **f**: (S,D^1,D^2); Horizontal lines indicate estimated baseline F-score (solid) with standard error (dashed); Left column: non-normalized trajectories; Right column: normalized trajectories; Top row: performer identification; Bottom row: phrase-occurrence identification

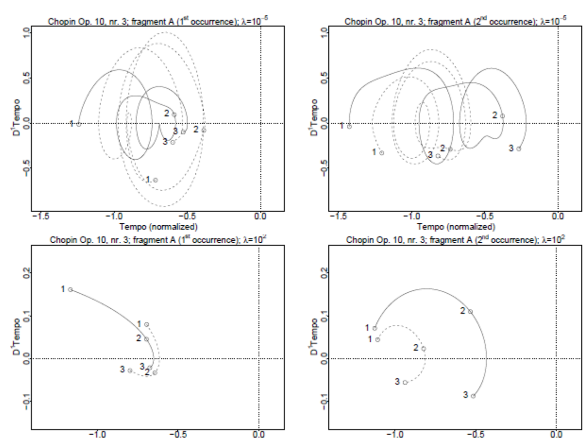


Figure 7: First-order phase-plane trajectories for Ashkenazy 1972 (solid curves), and Richter 1988 (dashed curves) recordings of Chopin, Op. 10, No. 3, fragment A. The numbers along the trajectories indicate the starting of consecutive bars; Left column: first occurrence of fragment; Right column second occurrence; Top: unsmoothed trajectories, bottom: smoothed trajectories

Conclusion

- Phase-plane trajectories may suggest a particular class of functions that could fit a particular tempo curve. This can be a benet in the modeling of expressive timing
- In addition, different representations of phase-plane trajectories were compared experimentally.
- Results indicate that phase-plane trajectories are most performer specific when moderate degrees of smoothing are used, and normalization is applied. Highly smoothed and non-normalized trajectories on the other hand, are more indicative of the order of occurrence of the fragment in the musical piece.
- The experiment also showed that considering tempo derivatives in addition to tempo in general facilitates the distinction between performers based on their performances.
- In conclusion, we argue that phase-plane representations of expressive timing are an interesting alternative to conventional time-series plots of expressive timing information. Not only do they allow for intuitive visualizations of expressive gestures, but they also seem relevant for the characterization of the timing of individual performers.

Thank you!