The RUBATO Performance Workstation on NEXTSTEP

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Abstract

RUBATO is a software on the NEXTSTEP environment designed to receive score data, to analyze their structure, to shape corresponding performance data and to produce output data for sound production. The central object of RUBATO is the *performance score.* It is responsible for the transformation process from symbolic score data into physical performance data. This process is based upon performance vector fields, a far-reaching generalization of tempo curves to all musical parameters. The modular architecture of RUBATO offers a variety of approaches for theoretical and applied performance research.

1 Performance Theory

Classically, musical performance has been studied from the aestetical [Danuser et al., 1992] and psycho-physiological [Gabrielsson, 1992] point of view. We are, however, lacking a general performance theory dealing with the intrinsic and explicit transformation of the given score data into well-defined physical performance data. Such a theory is concerned with three fundamental problems:

A. Unrestricted symbolic representation of the syntactical and semantic contents of score signs.

B. Unrestricted technological representation of the resulting physical performance output.

C. Explication of the transformation structure: what is being transformed, how it is done, and why.

This makes clear that, without use of computing power and elaborate mathematical models, performance theory is not feasible. In fact, performance and interpretation aesthetics as well as performance psychology are scientific approaches based upon given or imagined performances, whereas performance theory simply has to describe the structures and processes defining a performance. And it should rely on objective veri- resp. falsification of its hypotheses and models. This means that it has to deal with reproducible performance instances. Without the mentioned tools, performance theory would remain what it has been until present: a branch of literature in the spirit of music criticism.

The RUBATO project deals with the above problems A and C. It is not directly concerned with problem B. However, it is essential that the power of a theoretical answer to A and C be paralleled by an equivalent output representation. Otherwise, a detailed description of a violin performance, say, cannot be tested.

This is, why the development of physical modeling is an essential contribution to performance theory. On the other hand, an elaborate sound synthesis should not only be a creative tool for composers, but it has to be backened by a theoretical equivalent capable to describe, what kind of structures the present sound synthesis should convey.

1.1 Previous Research

The present approach differs in several essential points from previous work in this field. Let us mention the pioneering work by Sundberg and his collaborators [Friberg, 1991]. Here are some essential differences:

- Their model does not distinguish between symbolic and physical parameter spaces; only the physical level is considered.

- Their performance rules are deduced from empirical methods ("analysis by synthesis") and not from elaborate analysis of the score .

- No global-local and/or hierarchical structures are used.

- A general method to transform analytical results into performance rules is not evident.

- Continuous curves for tempo, intonation or more general performance vector fields are not considered.

- Parameter-specific rules are not linked to each other in a non-additive way.

2 RUBATO's Architecture

2.1 Development Environment

Apart from the NEXTSTEP® development tools, RUBATO® makes use of Jaffe's Music Kit [Jaffe, 1989], Wolfram's Mathematica® [Wolfram, 1991] and OTI's MathPalette™. This environment is rather restrictive for distribution to other platforms, but the present state of RUBATO is that of a research software. Forthcoming development together with experimental experience will break down these constraints.

2.2 Modularity

RUBATO is composed of a number of modules called RUBETTES®. These modules are grouped according to four domains corresponding to the fundamental tasks of the performance workstation:

- Score predicate representation and predicate calculus
- Musical analysis: Structuring
- Synthesis of performances: Shaping
- Technological output

In this paper, we give a short overview. For a detailed discussion, we refer to the SNSF research report [Mazzola, 1993]. Figure 1 shows the modular structure and the data flow.

It should be stressed that all these Rubettes are by no means normative tools. They are equipped with many controlling parameters and may be joined to other, new Rubettes of different flavours according to the forthcoming research. RUBATO essentially is a non-dogmatic development framework for performance theory.

2.2.1 Score predicate representation and predicate calculus

This domain essentially includes

- a *predicate browser* to edit musical predicates of any relevant type, like notes or rests, all kinds of score-specific predicates such as tempo, dynamics, articulation, time signature, key signature etc.;
- an editor *LoGeoRubette* for definition of logical and geometric combinations of given predicates;
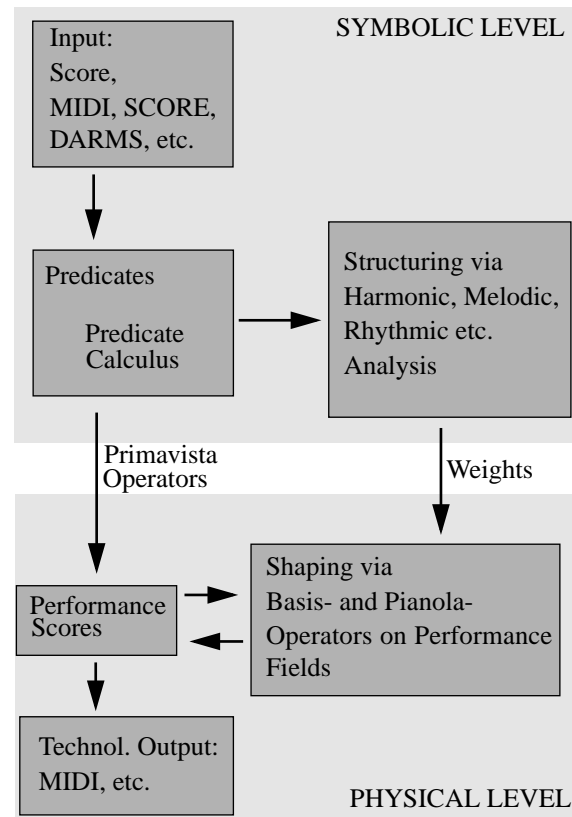- a *predicate view* for visualization of notes and other predicates.

Figure 1: The split architecture of RUBATO is evoked by the dichotomy of symbolic and physical reality. The symbolic representation of music by predicates is analyzed on the structuring module and yields different weight functions. These are the input for the shaping module and act as deformation functions on performance vector fields. The latter determine the performance scores issued from a primavista performance. The output module translates the performance score into a technologically meaningful data output.

2.2.2 Musical analysis: Structuring

Selected predicates from the LoGeoRubette are processed in several analytical contexts. Presently, we dispose of a *MetroRubette* performing a combined rhythmical analysis of selected groups of notes according to local meters [Mazzola, 1990] and metrical levels [Jackendoff & Lerdahl, 1983].

We further dispose of a *HarmoRubette* for doing harmonic analysis in the line of tonal logic of Riemann [Riemann, 1893]. This Rubette consists of three submodules: The first assigns tonal functions (tonic, dominant, subdominant etc.) to given chords, the second calculates harmonic tensors, i.e. functions for tension within the harmonic movement, and the third submodule calculates optimal harmonic progression paths.

The last one is called *MeloRubette*, it performs a melodic analysis of the given score. This depends on

different topological concepts of melodic shape and of similarity among these objects.

As a general principle, analytic Rubettes always produce discrete weight functions on sound events. For instance, a metric analysis produces a metrical weight on the onsets.

This data set is of purely symbolic character, it is up to the shaping module to use such information as guideline to a specific performance.

2.2.3 Synthesis of performances: Shaping

From the initial data stored within the predicate module, a number of *primavista operators* set up a default performance structure, the primavista performance score. Here, only the relatively mechanical score data is realized to yield a first sight reading of the given music.

The primavista performance score is then refined by the shaping operators. These act in function of the given weight functions. We distinguish two types of operators:

- Basis operators and
- Pianola operators.

They relate to the symbolic parameters we presently work on:

Three basis parameters: Onset E, Pitch H and Loudness L;

Three corresponding pianola parameters: Duration D, Glissando G and Crescendo C.

For every symbolic parameter P, we have a corresponding physical parameter p. For example, symbolic onset E, measured in beats, say, is parallelled by the physical onset e, measured in seconds, for example.

Basis operators act on the performance of basis parameters and hence are controlling agogics, intonation and dynamics, whereas pianola operators are responsible for articulation, fine detuning (e.g. violin glissando) and dynamical microstructure (e.g. violin crescendo) of sounds.

The resulting performance score contains all the information to define the effective physical parameter values of the intended performance.

2.2.4 Technological output

Once we are given the performance score, the final process has to transform a priori physical data into realistic technological informations. For example, pitch has to be transformed into key numbers for the MIDI code. At this point, we recognize that a sophisticated technology like physical modeling is essential

for adequate realization of a calculated performance score.

3   The Performance Score

This is the crucial structure bearing all the instructions – as we argue – to convey the details of a performance. To get off ground, we have a look at the local performance situation.

Suppose that we are given the *composition*, a finite set K of sound events in $\mathbf{R}\Pi$, $\Pi = \{E,H,L,D,G,C\}$. Each element $X \in K$ is transformed into a physical sound event $x = \wp(X)$ by means of a performance transformation

$$\wp : \mathbf{R}\Pi \rightarrow \mathbf{R}\pi .$$

Here, we denote by π the set $\{e,h,l,d,g,c\}$ of physical parameters. We now suppose that this transformation is defined on a open neighborhood U of K and is a C^1 diffeomorphism, i.e. an invertible, continuously differentiable map onto an open neighborhood V of $\wp(K)$.

Performance fields are special vector fields which describe performance transformations. They perfectly generalize the situation known for tempo and intonation [Mazzola & Zahorka, 1994]. We consider the diagonal constant vector field Δ on V:

$$\Delta(x) = \Delta = (1, ..., 1) \text{ for all } x \in V.$$

By a general technique of differential geometry, one may consider the so-called inverse image of the Δ-field. This is the C^1 *performance field* $\mathbf{z}$ (hebrew "TSadeh" for German Tempo-Stimmung) on U defined by the formula

$$\mathbf{z}(X) = J(\wp)^{-1}(X)(\Delta) ,$$

where $J(\wp)$ is the Jacobian matrix at X:

$$J(\wp) = \left(\frac{\partial x_i}{\partial X_j} \right) \Bigg|_{X_j = E, H, L, D, G, C}^{x_i = e, h, l, d, g, c} (X)$$

By the fundamental theorem of ordinary differential equations, there is a unique maximal integral curve

$$\int_X \mathbf{z}$$

through every symbolic sound event X in K. This fact enables us to define a physical event x by means of the intersection of this integral curve and a set of "initial points" where one supposes that the physical

value is given. For tempo curves, this simply is the initial value of onset time.

This being, the basic structure defining a performance score is the *performance cell*. It is symbolized by a tetrahedron whose vertices are

- the *performance field*,
- the *initial set*,
- the *initial performance transformation* and
- the *frame* where the performance field is defined.

The performance cell further contains a *kernel*, i.e the set of sound events ruled by the vertices.

This being, a performance score PS is a collection

PS = {LPS1, LPS2,...,LPSn}

of *local performance scores*, each of which is a hierarchy of performance cells. See [Mazzola, 1993] for details.

The essential fact about hierarchies is that, in general, performance cells are interdependent from each other. For example, tempo curves are arranged in a way such that a "mother" tempo may rule over its "daugthers" which, in turn may have "granddaughters" such that every descendent tempo has to fit with its ancestor in determined limit time values, see also [Mazzola & Zahorka, 1994].

The performance score defines a very general structure to be "layed" over the symbolic score in order to define a concrete performance. It is a global, hierarchical structure and it consists of performance cells which are essentially defined by a performance field acting on its local kernel of sound events.

Philosophically, the performance score is the germinal structure of an exact comparative performance theory. It implies that we may ask, which are the differences of a performance by Pollini, compared with one by Ashkenazy. And one may produce mixed performances, 10%Pollini and 90% Ashkenazy, for example.

In what follows, we want to give two relevant illustrations of our approach. The first is concerned with articulation and demonstrates how this phenomenon is visualized via performance fields. The second is a short parcours from metrical analysis to synthesis and shows the far-reaching technique of basis operators.

4   First Example: Articulation

This problem relates to the parameter space of onset E and duration D. In the following, rather academic example, suppose that we are given a slight tempo variation of sinoidal character, i.e.

$$T[E] := 1+0.1Sin[E] .$$

In the first instance, we show the performance field for a strong staccato, in fact a shortening by 50% of the nominal durations. In the second instance, we show this articulation field for a legato of 150% of the nominal durations. Observe that the onsets are by no means altered!
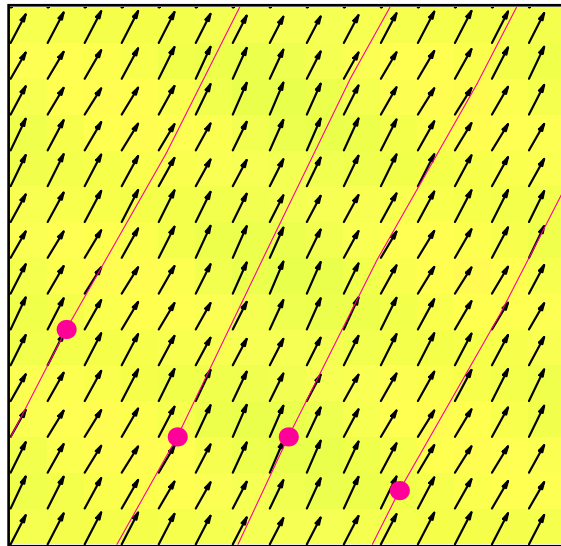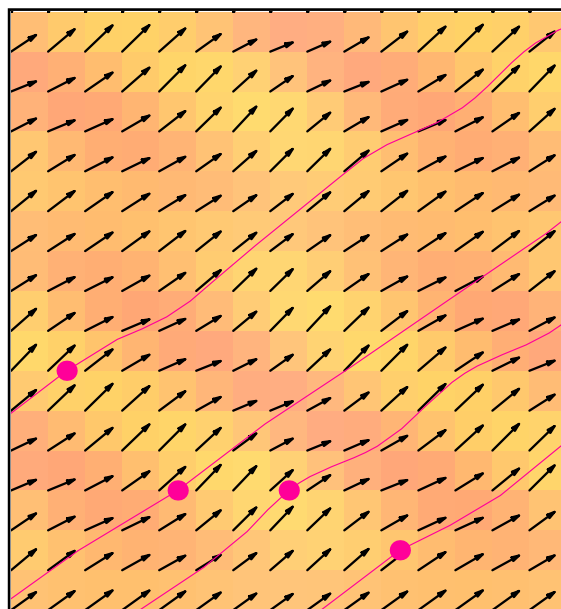

Figure2: Above: The articulation field for 50% staccato, together with four sound events and their integral curves. Visualization of the vector field is supported by Hue and saturation color code (here only in gray levels). Below: The articulation field for 150% legato.
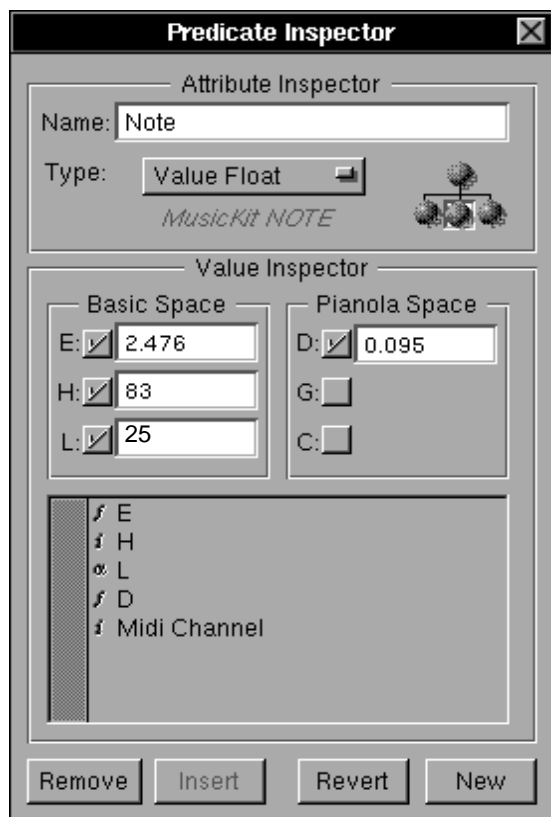
Figure3: *The predicate inspector shows each note of the sound material in its parametric structure. Here, we are dealing with piano sounds from a* MIDI *file. The parameters are E, H, L and D. The* MIDI *channel is indicated as fifth coordinate.*

5   Second Example:Metrical Analysis

This example starts from a metrical analysis of the melody line of the first eight bars of Schumann's "Hasche-Mann", the third composition of the famous "Kinderszenen" op. 15.

The melody is given as a MIDI file and then traced in RUBATO's predicate browser as shown in figure 3 above. The metrical analysis only considers the onsets of these events. It then calculates all the maximal local meters containing a determined onset E. A local meter is a succession of equidistant onsets *within* the given melody. This relates to the concept of metrical level of [Jackendoff & Lerdahl, 1983]. Form this information, we deduce a weight m(E) of onset E. for each E. Figure 4 shows such a metrical weight function, together with order 2 interpolation and other selections of control parameters.

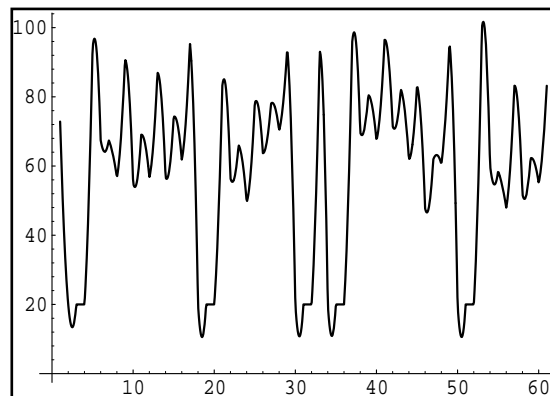Observe that, though nothing is said about the bar limits, we get a surprisingly good "accent curve"!

Figure4: *The metrical weight of the first eight bars of Schumann's "Hasche-Mann" melody from the analysis by local meters. Here, we show the order two interpolation. Observe the strong bar accent though no information about bar limits is given. Only the onsets or the melody sounds are known to the metrical analysis.*

This analysis is used to deform the primavista performance field in the parameter space of onset E (horizontal axis) and loudness L (vertical axis).

We show two deformations: The first only acts upon the loudness component: it is a vertical deformation field. Its auditive effect is surprisingly similar to what one would expect from a human performer. The second simultaneously acts on loudness and onset (i.e. tempo). The operation of the metrical weight relies on the mathematical formalism of Lie derivatives used in mathematical physics, see [Mazzola, 1993] for details.
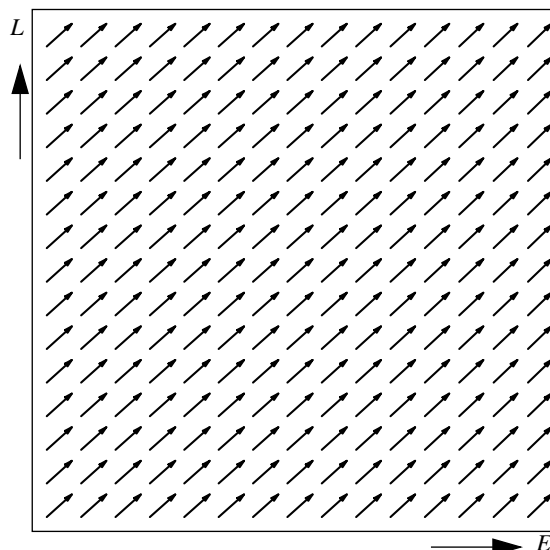

Figure5: *This is the E-L-performance filed before the deformation from the metrical analysis is added. The tempo is the above sinoidal function, the L-field is constant.*
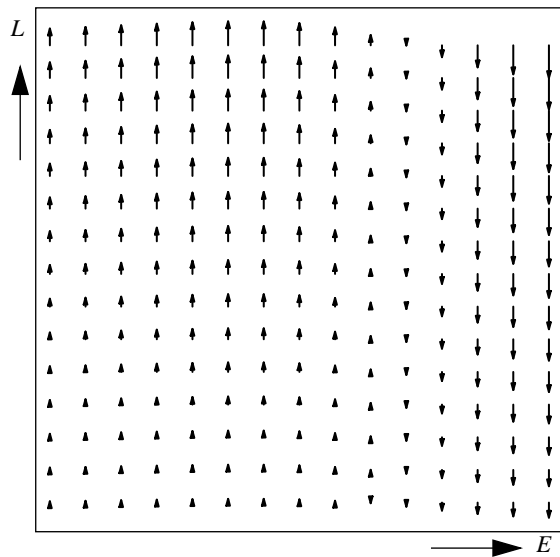
Figure6: Above, we see the deformation field for a purely vertical effect. Hence, the resulting tempo curve is the same as before, only loudness is affected, see the resulting field below. This is seen in the fact that the horizontal component of vectors is independent of their vertical coordinates. – We should stress that these effects are quantitatively exaggerated for the sake of visual evidence! Only the relative length of the vectors is shown.
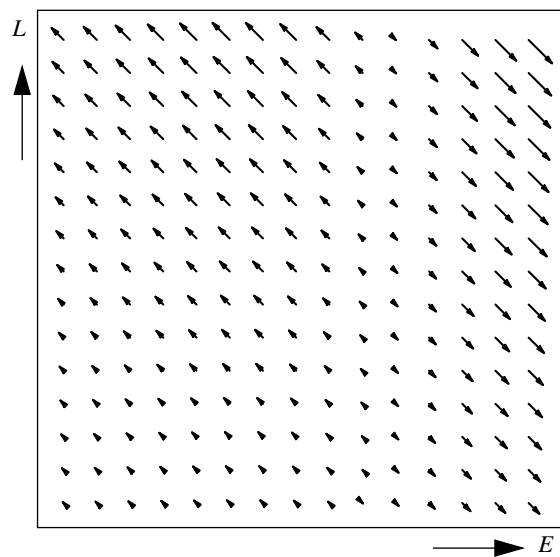

Figure7: Above, we see the deformation field for a mixed, diagonal effect. The resulting tempo is altered as well as the resulting loudness deformation. For each angle of this deformation field, we get another mixture of agogics and dynamics deformation. The fundamental difference to the preceding deformation is, that now, tempo is a function of loudness too, and not merely of onset!
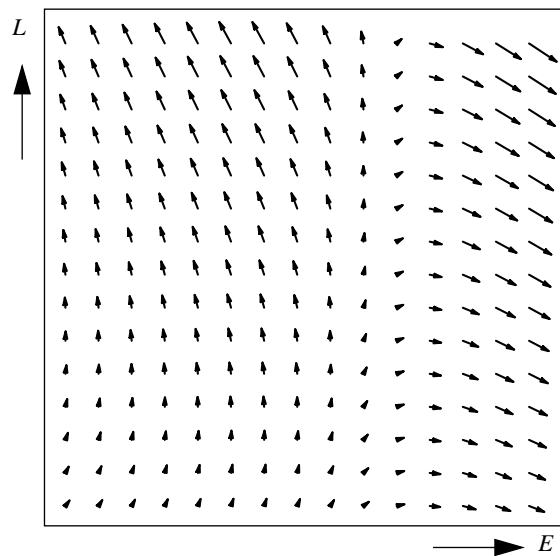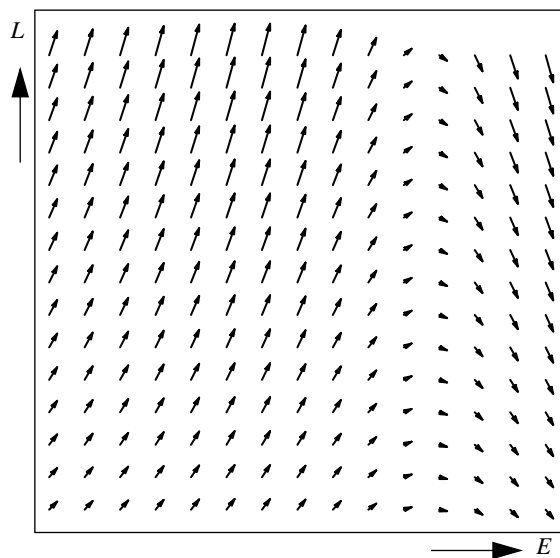
6   Conclusion

The preceding examples illustrate that the interactions of parameters in performances are highly non-trivial. The RUBATO workstation may offer a tool for musicologists and working musicians to access and manipulate these parameters. Performance fields, which are classical structures to the study of dynamical systems, open a window to the delicate connection between structure and emotion.

7   Acknowledgement

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