EXPLORING THE EFFECT OF MAPPING TRAJECTORIES ON MUSICAL PERFORMANCE

Doug Van Nort
Sound Processing and Control Laboratory
Music Technology Area
McGill University

Marcelo M. Wanderley
Input Devices and Music Interaction Laboratory
Music Technology Area
McGill University

ABSTRACT

The role of mapping as determinant of expressivity is examined. Issues surround the mapping of real-time control parameters to sound synthesis parameters are discussed, including several representations of the problem. Finally a study is presented which examines the effect of mapping on musical expressivity, on the ability to navigate sonic exploration and on visual feedback.

1. INTRODUCTION

In the design of interfaces for expressive musical performance and control there are many factors that need to be taken into account. At a fundamental level, one must consider the musical context within which the performance will be presented, and the expressive goals of performer and composer. This will determine the level of control - whether it be guiding some higher level musical processes or controlling the moment by moment production of sound in response to a performer's gestural input. The former necessitates the consideration of proper metaphors [20] for interaction while the latter can more directly find inspiration in the paradigm of instrumental music performance. These two sit at either end of a spectrum with a *systemic* view of interface design at one end - wherein the interface as well as the compositional process are together taken as the larger system - and an *instrumental* viewpoint at the other. In considering the instrumental perspective, the system in question is the short-term dynamic human input as well as the energy-dependent sound processing that is activated by this. Where along this spectrum the musical context lies will further determine, from a designer's perspective, the role that *mapping* plays. Simply put, and as noted in [10], mapping can be considered as a part of a composition or as part of an instrument. Further, it can be constructed in such a way that it is either

•Explicit: Having an analytic description that is precisely known to the designer.
•Implicit: Based on internal adaptation of a system.

The latter approach is promising and has commonly involved the use of neural networks [1]. The former is interesting in that explicit knowledge allows the designer to systematically fine tune the response of an instrument and develop it over time. This is the approach that we will examine in more depth, and from this point forward it can be understood that the discussion surrounding mapping refers to the explicit sub-type.

[1] See [10] for discussion of relevant work.

2. THE ROLE OF MAPPING

We consider here mapping as a part of the design of a digital musical instrument. In this context, it plays a large role in defining the *feel* of the instrument. This point was explicitly stated in [15] in which a simple one-to-one mapping was shown to limit the expressive potential of a clarinet-like instrument when compared with a more complex many-to-many mapping. The extent of this limitation was systematically examined in [9], wherein a user study was conducted in which the complexity of mapping between a control interface and sound synthesis algorithm was varied through construction of three different interfaces: a one-to-one mapping in which on-screen sliders directly controlled the sound parameters, a bank of physical sliders having the same one-to-one mapping, and finally a "multiparametric" interface in which a set of sliders and a mouse were mapped to the sound parameters in a complex many-to-many fashion. Two interesting results were reported: that the complex mapping was actually better as the tests grew more complex, and further that over time subjects improved significantly with the more difficult interface. This is an interesting result and yet not entirely surprising if we consider that musical performance is an immersive experience in which many things are happening simultaneously.

The authors of [9] articulated the multiparametric and immersive nature of musical performance. They refer to this situation as a *holistic* mode, in contrast to an *analytic* mode that arises from breaking down tasks into subsets and dealing with each as separate objects or entities. This latter mode of thought is aligned with the paradigm of the WIMP interface and most human-computer interaction contexts. In a similar vein, the authors of [12] stress the importance of matching a controller to the perceptual nature of a task in a standard HCI context. They define *integral* and *separable* as fundamental descriptors for the perceptual structure of tasks, where these terms can be seen as parallel to holistic and analytic cognitive modes, respectively. They demonstrated the importance of matching controllers and tasks through a series of user studies informed by the HCI literature [4], [6]. An objective comparison similar to that being done in classic HCI design contexts has been applied to the choice of transducers for musical control in theory [17] and in practice [19]. The use of comparison standards from HCI and the fundamentally different nature of musical interaction (when compared to the WIMP paradigm) raises the question of what defines an appropriate musical task. This issue is addressed in [14], in which the authors put forth suggestions geared at adapting HCI tasks to a musical context.

Certainly one could question an attempt at objective comparison in a field whose raison d'etre is creative expression. However, we should not confound the aesthetic intent of composer/performer with the engineering aspects inherent in the subsequent technologies employed. Thus while computer-based musical performance has undoubtedly benefitted from artistic and idiosyncratic approaches to interface design, a thoughtful consideration of the underlying design methodologies employed can serve to enhance the expressivity and accessibility of the instrument. In the case of mapping, analyzing its effect is not straightforward as the notion of what constitutes a "mapping" is not concrete. The approach taken by the authors of [9] was to change the level of complexity in terms of the correspondence between controller and synthesis parameters. While the results were informative and the chosen task appropriate given the "holistic" nature of musical interaction, it is important to note that the controllers themselves were changed as well. Thus, one must consider that the perceptual nature of these controllers contributed to the perceived difference between the interfaces. This fact was acknowledged in [11] and a new study was briefly mentioned in which the controller was fixed (a bank of sliders) while the association of the position and/or velocity values was mapped to sound parameters in various ways. In the context of the current discussion, this approach examines the effect of *what* is associated. However we maintain that it is equally important to examine the effect of *how* this association takes place. We examine this distinction in more detail in the next section.

2.1. Types of Mapping

The term "mapping" encompasses both the choice of "what to map to where" - that is, the association of control and sound synthesis points themselves - as well as the extension of this to all possible input values. More precisely, a musical instrument can be seen as a collection of discrete and continuous control variables and their sonic effect. Gestures acting on discrete controls are often towards the end of selecting among a set of options (e.g. keys) or states and/or exciting the instrumental system. Continuous control often produces loudness or timbral variations and other such modifications once the system is excited [2]. In the former case the mapping is essentially an assignment of a function to the discrete control. In the latter case, however, the role of mapping is more involved. That is, we can consider a collection of N continuous control variables that are simultaneously accessible as a continuous N-dimensional Euclidean space, in which case mapping refers to both

1. the pointwise association between points in an N-dimensional controller space and an M-dimensional space of sound synthesis parameters. This can be seen as the *what* of the mapping.
2. the rules governing the association of control/sound points not explicitly mapped in a pointwise fashion, but rather the association of entire subregions of the respective parameter spaces. That is, the *how* aspect of mapping strategies.

A trivial example would be scaling a standard midi slider to amplitude in the range 0-1: the MIDI control values 0 and 127 are mapped to the amplitude parameters 0 and 1 respectively (what), and a linear equation governs the association of intermediate MIDI/amplitude values (how). Of course, we are concerned with much more involved mapping strategies in genreal.

These "rules" that map arbitrary values between continuous control and sound spaces can be considered from a functional point of view, and both new and existing work on mapping can be viewed cohesively within this framework. In [2] the authors consider mapping as a linear operator that expresses each point in sound parameter space as a linear combination of the N parameter values of a given control input. This has the geometric interpretation of a hyperplane which represents the control "surface" mapped into the M-dimensional sound space. The exactness is bound to the number of stored presets: if this number is less than or equal to N the plane will pass through the preset sound values exactly, but if it is greater than N the mapping becomes a *multiple linear regression* model and the plane passes somewhere between the preset sound values. The constraint of a linear approach to mapping in this case is traded off with the ability to draw on many results from linear algebra regarding matrix operations.

Thus, taking a functional viewpoint we can consider such a geometric interpretation of the mapping problem. A continuous controller then becomes a surface embedded in some intermediate space of "high level" parameters or in the space of sound synthesis parameters themselves. Considering a mapping's geometric structure provides insight into the types of sonic gestures it can produce as well as it's editability, computational load, etc. and can further suggest new approaches. Where the mappings in [2] result in a single planar surface, others result in a piecewise-linear collection of simplices [3] [3], [8] or

[2] This idea, here in the context of control, can be paralleled with the notion of excitation, selection and modification gestures as discussed in [5]

[3] A simplex (simplices for plural) refers to an N-dimensional triangle.

a globally smooth surface [1], [16]. As discussed in [16], each has advantages depending on the musical context and in particular the perceptual nature of the control as well as that of the resulting sound should be taken into account.

Thus in terms of the perceived quality of the sound and the "musical gestures" that are produced, it is not only important what control parameters are mapped (position, orientation, etc.) to what sound parameters, but also the *trajectory* between presets that the mapping defines is a strong determinant of expressivity. Thus, in mapping through one of an infinite number of paths between two preset sounds, the designer must consider this fact and weight it against the importance of the mapping passing through certain regions in sound space that are not explicitly stored. If this latter requirement is important then a locally editable mapping [8] that allows for insertion of points is beneficial. However in many musical contexts it is the relative response of the instrument that is important, and so the nature of the trajectory (and thus geometric structure) itself may be of greater interest than its ability to map to a given absolute position. We examine this further in the following section.

3. USER STUDY

3.1. Preliminaries

In order to isolate the effect that different mapping geometries can have on an instrument we constructed a user study consisting of a simple interface based on a graphics tablet and FM synthesis. The (X, Y) position of the tablet was mapped to the intermediate FM parameters carrier frequency f_c, harmonicity H and modulation index M. Thus we can think of a two dimensional control surface embedded in a three dimensional intermediate space, with another mapping directly to the lower-level synthesis parameters modulation frequency f_m, modulation depth m and carrier frequency f_c. In this example the synthesis parameter space is of the same dimension as the intermediate space, and the second mapping layer is automatic in that it is defined by the use of FM synthesis. However in general with a geometric approach several such mappings can be used in a multi-layered fashion [18], allowing the geometric structure of control and synthesis space to be considered separately. Even with a single geometry defined, note that the way in which we embed the control surface and in what parameter space defines the complexity of the mapping. The example FM interface is such that moving in one direction along the tablet affects change in all three sound parameters, and thus even this simple example is not simply a one-to-one mapping as is illustrated in figure 1.

Using the same pointwise mapping between tablet and FM synthesis (e.g. X position controls H,M), we constructed two different mapping surfaces - one based on bilinear interpolation and one based on the regularized spline with tension (RST) technique. Both of these are continuous and differentiable, but only the latter has higher-order smoothness while the former is comprised of hyperbolic "patches" that produce more variation between points [16]. This difference is evident in figure 2.

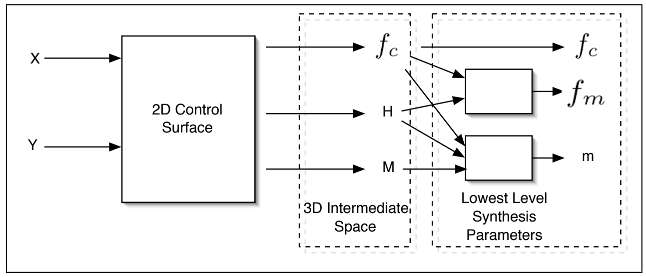


Figure 1. Tablet controller as surface embedded in a three dimensional FM synthesis space

3.2. Qualitative Assessment: Expressivity and Ease-of-Use

Eight subjects were presented with different incarnations of the interface as defined by the two mappings. Every combination of pointwise mapping between controller parameters (X,Y) and synthesis parameters (f_c, H, M) was presented in random order. That is, the two dimensional surface defined by the tablet controller was embedded in a three dimensional space in a fixed way, and the dimensions of this latter space were assigned randomly to the three synthesis parameters. For each set, both the multlinear [4] and RST mappings were used to create the surface passing through (or very near) stored preset points. These too were randomized in terms of inital order of presentation, but once presented they were differentiated by being fixed for a given parameter set and assigned the labels "number 1" and "number 2'.' Thus subjects were presented with a given parameter set defined by a pointwise mapping, and a different mapping function within each set (e.g. interface A-1/A-2, B-1/B-2, etc.). The subjects were told in advance that there were potential differences within and between each set, and were given time to explore each interface. After familiarization they were asked to move the stylus along a constrained path on the tablet surface (again, this was done for each possible association of controller/sound values, and for both mappings). The subjects could move back and forth through this trajectory indefinitely and in any fashion, and could switch between the two choices within a given parameter set at any time. Each subject was asked to give subjective reactions to the two interfaces, citing any differences in general and in particular were asked to comment on the expressivity and ease-of-use. These two terms were further defined to mean "musically interesting" or "instument-like" in the former case, and in the latter case was related to the idea of repeatability and being able to "find" a point in sound space or create a desired musical gesture.

The reactions of the participants were quite consistent. While it was true that each mapping was constructed in

[4] Multilinear refers to the general N-dimensional case. Bilinear simply refers to the two dimensional realization. We will refer to the mapping as multilinear from this point forward.

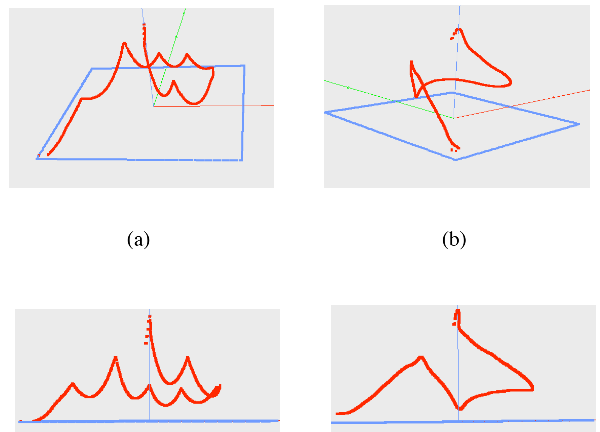
such a way that varying one parameter affected several synthesis parameters, the perception of this was not equal in all cases. Regardless of the order of presentation or the orientation of control surface in sound synthesis space, people consistently found the multilinear mapping scheme to be more interesting from a musical standpoint. In fact, the majority of those interviewed stated that this mapping “added another dimension” to the interface (though this was not actually the case). Other comments ranged from “it is more non-linear” to “this one sounds more gestural.” Thus, in this musical context where absolute position (e.g. specific pitches) was not important, the relative motion of trajectories through sound space characterized by patches of smooth and sharp transitions between points was favored over the highly smooth surface. In other words we found that *the dynamic quality associated with the transition between sound synthesis parameters - as determined by the mapping - can contribute to the perceived expressiveness of the interface.*

There was a different reaction when subjects were asked about the ease-of-use, defined in terms of one’s ability to “find” a sound and repeat this. The majority of users found the RST mapping better in this regard, saying that it was “more direct” and was, for example, “easier to find a specific pitch”. Thus there existed a conflict in terms of the mapping preference: the multilinear technique was deemed more expressive and musically interesting while the RST mapping was deemed easier to navigate the sound space with. This shows that in choosing such a mapping strategy *a tradeoff exists between the expressive potential and its ease-of-use and repeatability.*

3.3. Quantitative Analysis of the Effect of Visual Feedback

When used with a two or three dimensional controller, both the multilinear and RST mapping strategies have an inherent visual representation by their construction. Thus in the case of navigating through an abstract sound space, visualizing the mapping itself might help one to know precisely where they are in some appropriately-defined intermediate space. On the other hand, the perceptual nature of control might be different than the perceptual nature of the sound space, in which case perhaps the visualization surface should reflect this control structure while a second surface can map points from this control space into sound synthesis space. This latter approach was taken in [7], in which the mapping from control to sound synthesis space was achieved by a piecewise-linear interpolation over triangularized regions, but the visualized mapping surface was based on a spline interpolation. In this case movement of a cursor over a smooth rubber sheet-like surface resulted in a potentially jagged movement across piecewise simplices in sound synthesis space. It seems that there is no a priori reason why these two mapping would cognitively work together, and that this should be explored further.

We constructed a quantitative “target acquisition” task [4] as a way to examine the effect of using a single mapping surface for both parameter mapping and visual feedback. The same tablet controller/FM synthesis interface from the previous test was employed. For this experiment, a box was presented on screen containing an ‘x’ placed at one of two locations. The presentation order of location 1 vs. 2 as well as the given mapping were randomized. When the stylus was moved across the screen, a “trace” was left of the trajectory as in figure 2. For the test, the subject’s view of the controller was obstructed, so that the only visual feedback they were relying on was screen-based (in conjunction with proprioceptive and sonic feedback). The participants were instructed to “acquire” the target x by using the visual feedback in the form of the trajectory, and were informed that this would be timed. The timer began when the subject pressed a button on the stylus and stopped as soon as the target was reached - at which point an on-screen button flashed and a distinct bell sound could be heard indicating the successful acquisition. For each test the stylus began in the lower left corner of the tablet controller. The time to target acquisition was recorded for each subject across all tests, with the results shown in figure 3.



(a) (b) (c) (d)

Figure 2. Visualization of trajectory across a mapping surface (a) Multilinear 3D trajectory and (c) 2D Projection. (b) RST 3D trajectory and (d) 2D Projection.

The graph of figure 3 displays the mean and standard deviation for acquisition time in ms for the multilinear and RST based mappings at both locations of the target point (Note that the range is slightly different for the two graphs). In both instances, the RST mapping took less time to acquire the target. This difference was exceptionally large for location 1, and was considerable for location 2 as well. We attribute added difficulty of acquiring location 1 with the multilinear based mapping to the fact that its position was at a global maxima on the mapping surface, whereas location 2 was situated at a local maxima. This further seemed to affect the variance, as this was quite large for multilinear location 1. Overall, the variance was considerably lower for the RST based mapping surface. Thus, from this test we see that the RST

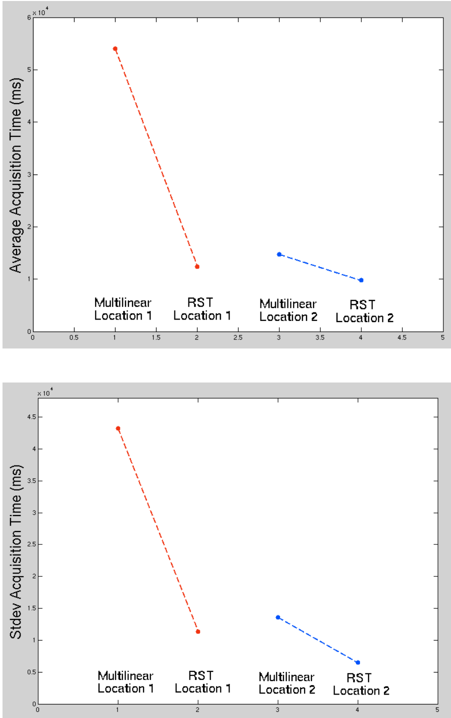


Figure 3. Mean (top) and standard deviation (bottom) for acquisition times from test 2, for locations 1 (red) and 2 (blue).

mapping was more intuitive and consistent as visual feedback in comparison with the multilinear scheme. These two experiments lead us to conclude the following:

•The perceived complexity of an interface is linked to the dynamic quality of the mapping - its effect on transitions between regions in control and sound synthesis space.

•A mapping that produces musically interesting trajectories may not allow for easy and intuitive control.

•This tradeoff between expressivity and ease-of-use extends to the use of the mapping for visual feedback.

4. CONCLUSIONS

The role that mapping plays in determining the "feel" of the instrument has been discussed. In highlighting previous work, we have articulated a point that often goes overlooked: that a mapping strategy consists of both a pointwise association between certain control and synthesis parameters - the *what* element - but it also consists of the mapping of entire regions of control and sound synthesis space. This *how* component of mapping determines the trajectories and thus influences the musical gestures that are possible with an instrument. We isolated the effect of this latter aspect of mapping by varying interpolation strategies while keeping controller, synthesis algorithm and pointwise mapping fixed. The results indicate that the dynamic quality of the mapping surface - related to the geometric structure of the mapping function - does alter perceived expressiveness. However, a tradeoff was found between the increased musicality afforded by a mapping and the ease with which one can explore the sonic terrain of the instrument. This tradeoff extended to the use of the mapping for visual feedback as well. Therefore, a multi-layered mapping approach may prove beneficial when the perceptual nature of control and sound synthesis space are treated separately and a mapping with appropriate geometric structure is constructed for each.

5. ACKNOWLEDGMENTS

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