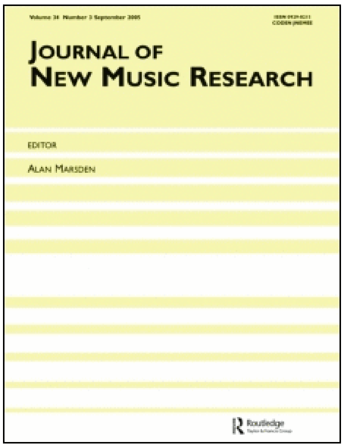

Journal of New Music Research
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713817838

On the Description of Mapping Structures

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Online Publication Date: 01 December 2008

To cite this Article Kvifte, Tellef(2008)'On the Description of Mapping Structures',Journal of New Music Research,37:4,353 — 362
To link to this Article: DOI: 10.1080/09298210902731394
URL: http://dx.doi.org/10.1080/09298210902731394

Journal of New Music Research
2008, Vol. 37, No. 4, pp. 353–362

Routledge
Taylor & Francis Group

On the Description of Mapping Structures

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Abstract

The aim of this paper is to discuss concepts that are useful to describe mappings, the relation between the input and output of musical instruments, in some more detail than is usual in the literature. The design of suitable mappings is of major importance when new instruments – hardware or software – are constructed, and there is a need for more concepts that may be used to describe, discuss and think about mappings. With examples from acoustic instruments, notions of *value* and *set selectors* are developed to specify properties of complex mappings. Further specifications are possible through suggested vocabulary for the description of *set structures*. Also, it is argued that a concept of *input control system* where several control actions are seen as a unit, is better suited to describe mappings across different instruments than studies of single control actions and single couplings in isolation.

1. Introduction

While new electronic instruments in hardware and software open up a vast landscape of possible new expressive sounds, they also raise a fundamental challenge that only to a small extent has been tackled: the new instruments may offer a large number of control possibilities in the form of knobs, sliders, parameters on a screen etc., but the sheer quantity of controls and control possibilities hinders rather than helps expressive musical behaviour. Conventional acoustic instruments have, compared to typical new electronic ones, few controls, but the controls are more complex in the sense that they in many cases affect more than one aspect of the sound – they are *coupled* in various ways.

The challenge is to find ways of controlling the new instruments that do not rely on the detailed manipulation of tens or hundreds of parameters, and one direction to look for ideas is obviously the traditional acoustic instruments. However, while the phenomenon of coupling is well known, there is little literature on the actual structure of couplings as they are found in the many different species of acoustic instruments, and there is also a need for terminology to describe the details of mapping structure. The aim of this article is to discuss a slightly more detailed typology of complex mappings than is usually found in the literature. The challenge is to find ways of description that do not lose too much detail while, at the same time, being sufficiently general to be useful to compare mappings of different instruments, whether they are traditional acoustic instruments or newly constructed electronic ones. The user interfaces of many traditional acoustic instruments are in fact very complex, and this paper makes no attempt to develop an exhaustive descriptive terminology.

The point of departure is the viewpoint that compound or complex mappings between instrument controls and sound parameters seems to be "better" in the sense of being more interesting and rewarding to use, than systems of simple one-to-one mappings. A number of authors have argued in favour of this, see e.g. Goudeseune (2002, p. 85):

> "a compound mapping cross-coupling several controls and synthesis parameters can surprisingly increase the performer's intuitive understanding of the instrument."

This is also indicated in practical experiments where mappings of different types and complexity are compared (see Hunt and Wanderley, 2002, for a description and discussion), and the most complex mapping was found to be the most interesting and effective.

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DOI: 10.1080/09298210902731394

Finally, it may also be argued that it is hard to find more traditional, acoustic instruments dominated by simple one-to-one mappings (see e.g. Kvifte, 1989, pp. 138–145).

The concept of mapping is used in slightly different ways in the literature, depending on where in the total mapping chain (see e.g. Arfib et al., 2002; Kvifte & Jensenius, 2006) the focus is. In the article cited above, Goudeseune sees a musical instrument ''as something into which the performer puts gestures, and which then outputs sound'' (2002, p. 85), but because of the scope of that article, says that ''a mapping is from an instrument's control, to the inputs of a sound synthesizer ('synthesis parameters').'' (ibid). Bielawski (1979), on the other hand, with a very similar definition of ''musical instrument'' has a higher-level perspective, as indicated in his illustration of the connection between gestures of movement and musical gestures (see Figure 1). His perspective is perhaps the more common, to see mapping as the relationship between the input of instrument control and the output *sound* parameters rather than synthesis parameters, and this is also the perspective in the present article. The exact definition of the key concepts (''instrument control'' and ''sound parameters'') is no trivial matter, and may vary considerably in the literature. In this article, the main focus is on general principles of mapping rather than a detailed discussion of input and output parameters.

Detailed descriptions of mappings are hard to find. An overview of relevant literature is found in Hunt et al. (2000). But most discussions seem to be of a rather general nature. Typically, we may find descriptions of what may be called the ''mapping chain'' or ''mapping levels'' (see e.g. Wanderley et al., 1998; Kvifte & Jensenius, 2006); as well as distinctions between different types of mapping like one-to-one, one-to-many or many-to-one (Kvifte, 1989, p. 160; Pressing, 1990, p. 14), the last two also referred to as divergent and convergent respectively (Rovan et al., 1997; Hunt & Kirk, 2000). One-to-one mappings are usually referred to as simple, while the two others are seen as complex, especially when combined into a many-to-many relationship.

The term *coupling* is used in e.g. Kvifte (1989) and Rovan et al. (1997) to denote complex mappings. The term *cross-coupling* is also used in the same sense in e.g. Hunt et al. (2003). Here, I will reserve the term cross-coupling for many-to-many mappings, while coupling will be used for many-to-one and one-to-many mappings.

Kvifte (1989) gives examples of couplings for a number of instruments, where control actions are related to the general musical variables pitch, timbre and loudness. There, couplings are visualized in diagrams like that in Figure 2. But there is no discussion of concepts to characterize mappings beyond the simple/complex-terminology mentioned above.

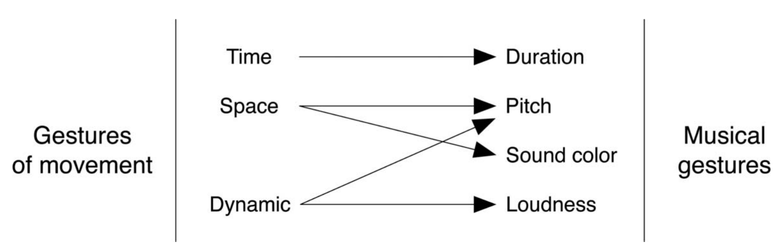

Fig. 1. Bielawski's model.

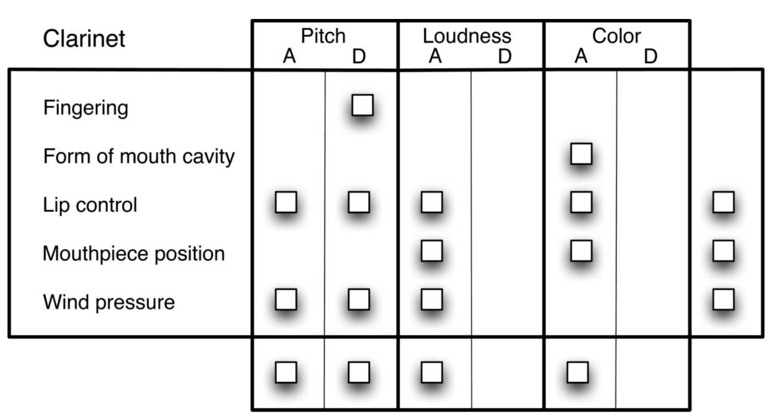

Fig. 2. Couplings for clarinet, after Kvifte (1989). Control actions on the left; sound variables at the top specified as A(nalog) or continuous and D(igital) or discrete. See below for further discussion.

1.1 The subjectivity of mappings and couplings

To describe couplings, one has to make descriptions of the input to and output from the instruments. The input will be described as composed of a number of control actions; the movements that a musician performs to make the instrument produce sounds. The output is musical sound, to be described in very general terms for the purpose of coupling analysis. Here, the description will be mainly in terms of the very general parameters of pitch, loudness and timbre. One example of a coupling described in this way, is shown in Figure 3.

To analyse playing gestures into ‘‘control actions’’, and the result of the actions into general sound parameters, is probably unnatural and irrelevant to most musicians. What might be analytically described as a coupling (e.g. increase in wind force simultaneously affects the two parameters of loudness and pitch) might be experienced as one musical action, where the increase in wind pressure, loudness and pitch, is felt as a unitary musical gesture.

What is aimed at here, however, is not a description from a performer's point of view. Rather, the aim is to contribute to an analytical framework that may be used to describe general properties of instrument control, and, therefore, also to systematize data concerning performers' experiences of playing from different instrument contexts. Such a systematization depends on a set of concepts that are applicable across different instruments, and that may or may not be felt relevant by performers. While performers have a need for good concepts to describe and think about their own instrument, they usually have only a limited need for concepts to describe playing actions of *other* instruments.

The possible value of the descriptions aimed at here is therefore not to be judged from their relevance to performers of single instruments, but from their ability to relate experiences from performers of different instruments to a common framework.

2. Structure of common couplings: set and value selectors

In the following, a small number of couplings will be described to show a number of properties that seem

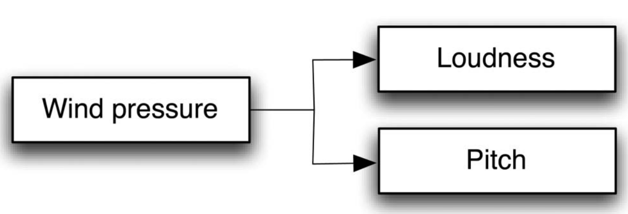

Fig. 3. One-to-many coupling found in many wind instruments.

relevant in a general description of mappings. After a short discussion of the more general concepts of analogue and digital, the discussion moves on to *sets* and *values*, and couplings as organized in set and value *selectors*.

2.1 Terminology

One basic distinction may be made between *discrete* and *continuous* variables (input and output), the discrete variables may only have a number of fixed values, while the continuous variables may take any value in the range they cover. I prefer to use the terms *digital* and *analogue* for this distinction. One reason is that the term ‘‘continuous’’ also may imply a time dimension, in the sense that a variable is controlled continually, and that is another property (that also might be taken into account). Further, it may be pointed out that, for example, the perception of musical pitch[1] may be seen as consisting of (at least) one digital component, concerning discrete scale steps, and one analogue concerning continuous pitch changes like in vibrato, glissandi and ‘‘out-of-tune-ness’’. This perceptual distinction is central to the experience of music, and therefore, also to the study of mappings. But one should also note that there is not a direct one-to-one relationship between signal and perception in this respect – in a signal where the pitch is constantly changing continuously, like in the wide vibrato of an opera singer, we are still able to pick out a digital component, and to agree what (discrete/digital) scale steps are intended.

Another factor is that the analogue/digital concept pair may indicate that there are more differences between these two kinds of variables than just the discrete/continuous-distinction. Following the communication research tradition of scholars like Bateson (1972) and Wilden (1980), one may for example suspect that analogue variables may be more important than digital ones in the communication of expressive content in music. The research tradition on ‘‘expressive timing’’ (see e.g. Kvifte (2004) for references) is one example where analogue variations (in this case of the temporal variable) are taken as indicative of expressive content in music

In the following, the analogue/digital distinction seems to be useful in a number of different situations.

2.2 Wind instruments: an example

One common coupling in wind instruments is illustrated in Figure 3 above. Here wind pressure is shown to affect both pitch and loudness at the same time. Further, we may notice that the wind pressure can be varied continuously, and that the output variables pitch and

[1]Similar considerations may be made for other variables like loudness, timbre and duration.

loudness as a result of this will vary continuously. In Figure 4 this is indicated by an "A" for "analogue" after the names of the control action and the musical variables.

To discuss this control in more detail, we take the tin whistle as example. When wind pressure is increased beyond a certain value, the pitch will no longer be affected only continuously, but will jump to another octave in a discontinuous shift; a digital change, as illustrated in Figure 5 with the addition of the arrow leading to "P(D)".

In this figure, the three arrows do not represent the same kind of control. The analogue control of loudness may be said to represent a *value selection* – through the wind pressure, a certain value of the loudness variable is selected. This is also the case of analogue pitch control. These two controls can therefore be termed *value selectors* (VS). The digital pitch control may be viewed differently: by overblowing, the musician gets access to a new *set* of pitch values, namely the pitch values one octave above the set accessible without overblowing. This control may therefore be termed *set selector* (SS).

The control of analogue pitch can be subdivided further. Viewed as a value selector for analogue pitch, wind pressure is concerned with musical expressions like vibrato and glissandi. But wind pressure may also be used for intonation or the correction of a pitch value selected digitally by a certain fingering. Musically, it makes sense to distinguish these two functions of analogue pitch control, and we might call this second function value *modification*. For our purposes here, however, there is no reason to distinguish these two functions, as long as the mechanism and possible range of the effect is the same in both cases. The effect of wind pressure as described here, is summarized in Figure 6.

We notice that the possible range of both the pitch and loudness variation is also dependent on the length of the air column in use. With a long air column, the amount of possible variation of pitch by variation in the air pressure is relatively small compared to what is possible with a short air column. If the instrument in question is a tin whistle, this length is varied by the pitch control of the fingering.

If we consider now the system with two inputs – wind pressure and length of air column – the situation is that both inputs have an influence on the effect of the other input: the effect of wind pressure is dependent on the length of the air column. At the same time, the effect of the length of the air column depends on the wind pressure, as indicated above.

This cross-coupling is illustrated in Figure 7. There the influence of wind pressure on the effect of air column length changes, is indicated by an upward arrow labelled "SS" (for "Set Selector"), while the influence of the air column on the effect of wind pressure is indicated by a down arrow labelled "SM" for "Set Modification"). In contrast to a Set Selector, this function does not change the available set of values available completely, but modifies it by expanding or contracting the range of the output variable.

Figure 7 covers common couplings on a number of wind instruments. It is possible to add further details to account for different instruments, but the two main systems *length of air column* and *wind pressure* will remain as central elements. The way the length of the air column is modified will be different between the broad classes of slides, valves and finger-holes, and also each of these classes may be subdivided further.

The length of the air column controlled by fingers on a tin whistle can, for example, be split into two different control actions: one is a set of *fingerings* as shown in a fingering chart; this will be a digital control action, as the

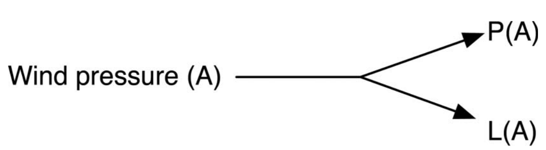

Fig. 4. More detailed diagram.

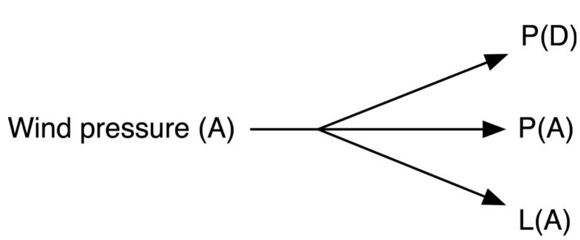

Fig. 5. Digital pitch change added.

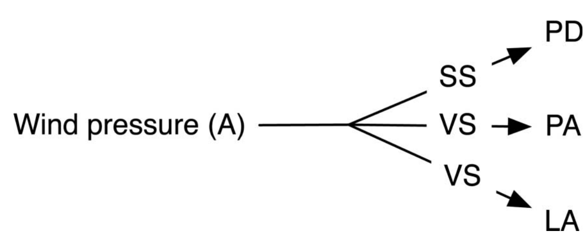

Fig. 6. Effect of wind pressure.

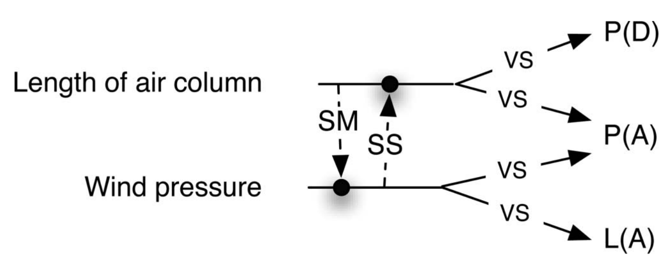

Fig. 7. Interaction of the two input systems in wind instruments.

musician has a limited, well-defined set of discrete possible fingerings, controlling a well-defined set of discrete pitch classes. In addition, each hole on the instrument may be partially covered by a finger. This is an analogue control action, as one may gradually and continuously vary the opening of a hole from completely open to completely closed. This possibility is not available on all finger-hole system instruments, like a traverso with Boehm system closed pads. Such instruments will not have the arrow from Length of air column to P(itch) A(nalog) in Figure 7.

2.3 Input systems: grouping control actions

In the figures above, input control has centred on sets of control actions rather than single actions, like "length of air column" rather than "fingering". In many cases, it is convenient to focus on such *control systems*, or *gestural ensembles* (Kvifte & Jensenius, 2006) rather than on single control actions, as it may be easier to see connections between different instruments in this way. While finger-hole systems and slides have their own distinct problems of playing technique, there are also, as indicated above, some common properties in the principles of control. We will find this notion of input control system convenient also in the following discussion of similarities between fingerboard strings and some button systems.

2.4 String instruments: another example

A more complex coupling is found on string instruments with fingerboards. Common to a large range of instruments found in variants all over the world, is a setup where several differently tuned strings are excited with one hand (with e.g. bow, plectrum, fingers), and where one or more may be shortened by the fingers on the other hand. Many instruments will have some kind of a fingerboard under the part of the strings where fingers are used to shorten them, (but not necessarily, like on the crwth, with no fingerboard).

On such instruments, the control of digital pitch may be illustrated by the following Figure 9: here, three distinct control variables may be seen as mutually set selectors. The position of the left hand lengthwise relative to the fingerboard determines the set of pitches available for selection by the fingers of the hand; conversely, choice of a finger determines what pitches are available for the different possible positions of the hand.

This model may be generalized to a wider class of instrument interfaces. There are a number of keyboard systems that are closely analogous to the fingerboard string interface; a common one is found on accordions with button interfaces like in Figure 10.

If we regard the rows as analogous to the strings along a fingerboard, it is easy to see the analogy in the control of digital pitch: hand position, choice of (string) and finger will determine the pitch, and the three parameters will interact in a similar way.

On the (not very common) cecilium (see Figure 11), the analogy is even closer. This free-reed instrument is made to look like a cello, and the buttons, operated by the left hand are laid out like the strings are on a cello (see Figure 12), and the bellows are operated by a handle placed in a way to mimic the bow.

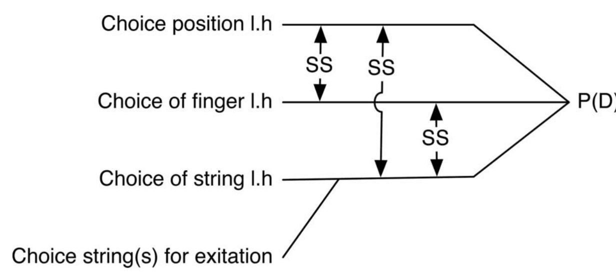

Fig. 9. Many-to-one coupling of digital pitch control.

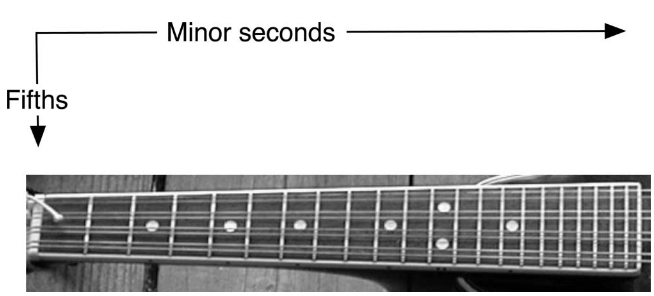

Fig. 8. Organization of pitches on a fingerboard.

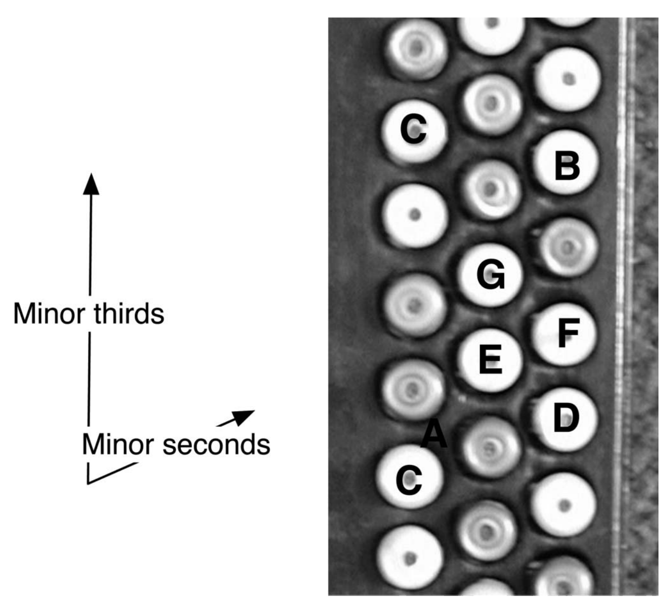

Fig. 10. Organization of pitches on a button accordion.

Fig. 11. Cecilium.

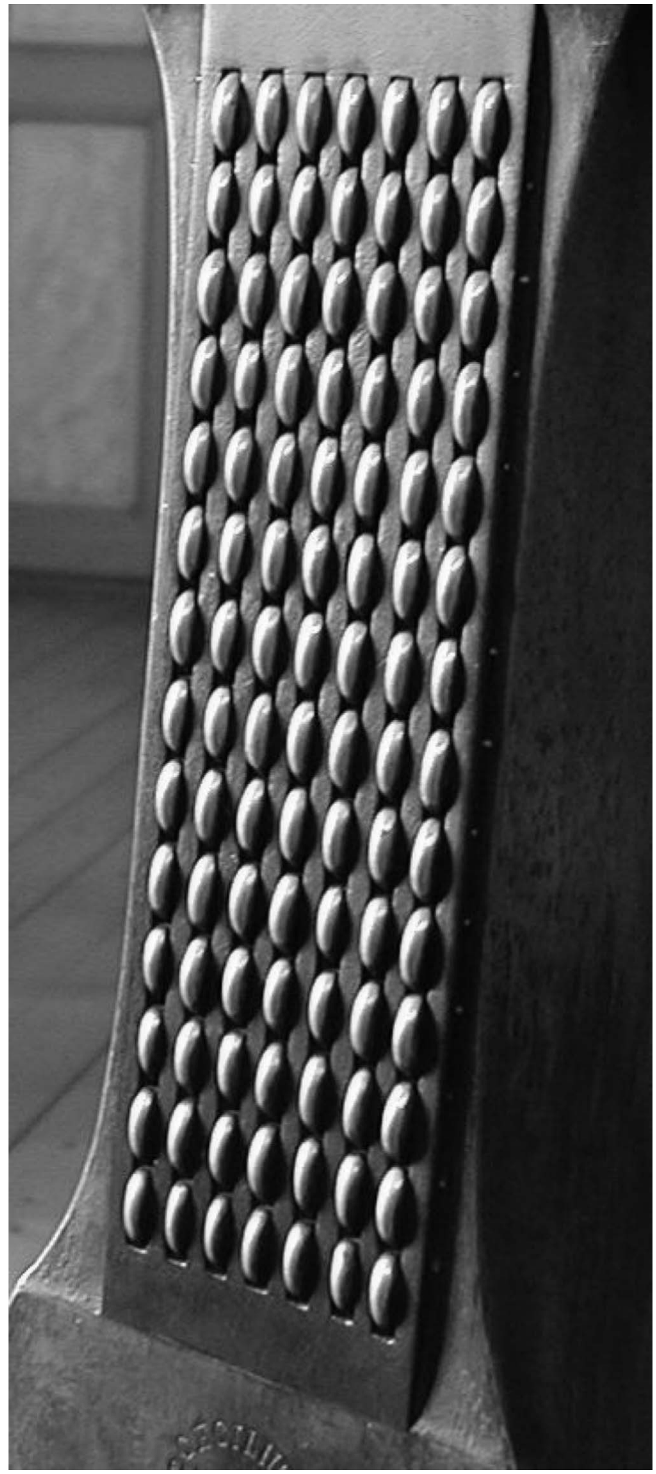

Fig. 12. Buttons on the cecilium neck.

2.5 Multidimensional input

The defining characteristics of the input control system described in the previous section are:

- the pitch values are laid out in two dimensions;
- the pitch values are not tied to specific fingers.

And in some cases also:

- pitch values can be found in several places.

The accordion example with three rows of buttons does not offer the last option, however, a common variety of this interface is to add two more rows, for example, to the left of the rows in the figure, with the same relationship as the existing rows. In this way, two of the existing rows are in effect duplicated, and pitch values can be found in more places.

The great popularity of such systems should be attributed not only to the fact that they afford several fingering options for given sequences of tones, but also because the performer has several different options to make models of pitch relationships. Different models may be useful in different situations; e.g. thinking harmonically or melodically may call for different approaches. For use in contexts where it is relevant to be able to transpose chords and melodic patterns to different keys, there is also the added benefit of more or less equal fingering patterns in different keys.

3. Independence of parameters

The description of wind instruments in Figure 7, shows two one-to-many couplings (length of air column to PD and PA; wind pressure to PA and LA). There is also the many-to-one coupling of the air column and wind pressure controlling analogue pitch. As noted by e.g. Hunt and Wanderley (2002), this may be viewed as an example of a many-to-many or *complex mapping*. There is an additional point to consider in this connection. The one-to-many coupling of wind pressure means that a change in analogue loudness implies a change also in analogue pitch, a change that may or may not be wanted. To be able to control loudness and pitch independently of each other, one needs an additional control of either parameter. In Figure 7, PA is also controlled by length of air column, so it is in principle possible to compensate for pitch changes that are a result of changes in air pressure. On the tin whistle, this is not very practical, as one has to use partial covering of holes to accomplish this, almost impossible to do even with moderately fast melodies. On other wind instruments, like reeds, lips provide an alternative control of analogue pitch that is more convenient. The general rule is: if a parameter in a one-to-many coupling is to be controlled independently of the other parameters in the coupling, the parameter also has to be part of a many-to-one-coupling; in other words, the system has to be a complex coupling.

4. Details of mapping: set structure

4.1 The structure of input and output variables

There may be significant differences in concepts needed for the different types of output variables. Pitch is a relatively well-ordered variable, with a well-defined set of possible digital values ordered in scale systems, while timbre is a far more untidy variable, as is evident from, for example, the large number of different controls affecting timbre found on different synthesizers, and the absence of a generally accepted set of descriptors for timbral qualities.

On acoustic instruments, however, it may seem that controls for timbre typically have less structure than controls for pitch, though such a statement is problematic as long as timbre as a musical variable is quite elusive, and often a matter of dispute. To what extent are, for example, chord voicings, relative loudness and timing of the different notes in a chord, and "touch" important factors in timbral qualities of piano playing? What kind of vocabulary and common understanding do we have for this?

In the following, I will focus on the control of pitch, and introduce a few concepts that seem relevant in this connection. A detailed discussion of other output variables is left for a later occasion, but the concepts introduced here are quite general in nature, and will be relevant for any variable that is at least on an ordinal level, i.e. that values on the variable can be ordered along some dimension in a meaningful way. On such a general level, the discussion may also be relevant to the control of certain dimensions of timbre, e.g. brightness, as well as any other ordered dimension.

Take three different wind instruments as examples: the tin whistle, the willow flute, and the trombone. In all three instruments we find couplings with set selectors, but with different organization of the sets.

In the tin whistle, the range of available pitches is split into two distinct or disjunct sets. The advantage of the set selector mechanism here, is that it effectively doubles the number of available controllable pitches, as each of the fingerings can be used in both sets, as shown in Figure 13.

However, it is also possible to view the organization in another way. If we regard fingerings as set selectors, and air pressure as value selector, the sets will be organized as in Figure 14. The pitch sets may now be described as gapped and interlocking.

As a general rule: in a many-to-one coupling, it is a matter of analytical choice, which control to call set selector and which to call value selector. It is implied that a musician may benefit from being able to shift perspective in different situations. It will also be evident that sequences of values located within a set (regardless of the perspective chosen) will be easier to perform than

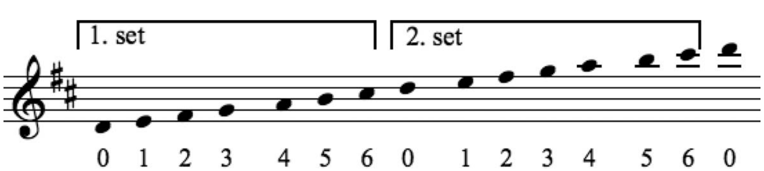

Fig. 13. Set organization on tin whistle. Number indicates numbers of open holes.

sequences that require change of sets. The latter case implies that both a set selector action and a value selector action must be performed, while an intra-set sequence only requires a value-selector action.

On the willow flute, the pitches are controlled by a combination of wind pressure and right hand index finger that can open or close the tube. The pitch series may be seen as a combination of two different harmonic series; when the tube is closed, the fundamental is one octave below that of the open tube. The closed tube will give only odd partials, while the open tube gives also the even partials. A typical willow flute will be made so that a comfortable playing range is found for the partials 4–8 for the open tube. The closed tube's odd partials in the range 7–15, from a fundamental one octave of the open tube, will then fit between the open tube tones to form an almost diatonic scale, as shown in Figure 15, left.

One possibility is to regard the index finger (used to close or open the end hole of the flute) as a set selector, selecting between the two sets of pitches from open and closed tube respectively, as indicated above the staff in Figure 15, left. Alternatively, wind pressure may be seen as a set selector, selecting between the five tone pairs indicated below the staff in Figure 15.

On the trombone, digital pitch is controlled by a combination of lip control/air pressure and slide position. Each slide position affords a number of pitches in the harmonic series, with a fundamental dependent on the slide position (Figure 16). Given seven recognized positions, and eight available pitches on each position – the number may vary with the skill of the musician – the available pitches can be ordered in two different ways. As an analogy to the willow flute, there are a number of gapped sets, here one for each slide position, instead of the two for open/closed on the willow flute; alternatively one may regard the organization as eight analogue, continuous and overlapping sets following the number in the harmonic series (Figure 17).

The situation is similar in fingerboard strings and button accordions. As the following figure of sets on the button accordion indicates, the pitch control can also here be viewed in different ways, as ordered either in a number of continuous, adjacent sets (Figure 18, below the system), or in a number of gapped sets (above the system). The quite common extension of this interface with the introduction of two extra rows changes the adjacent sets into overlapping, thereby providing the performer with more fingering options for a given combination of pitches.

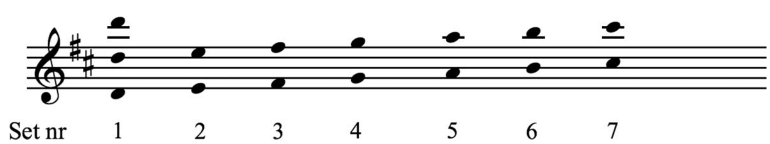

Fig. 14. Alternative view of set organization on tin whistle.

Fig. 15. Set organization on willow flute, shown in two alternative views.

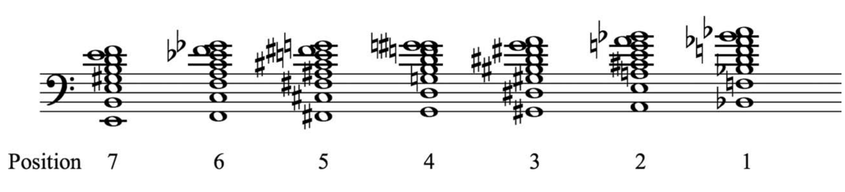

Fig. 16. Available pitches on each slide position on trombone.

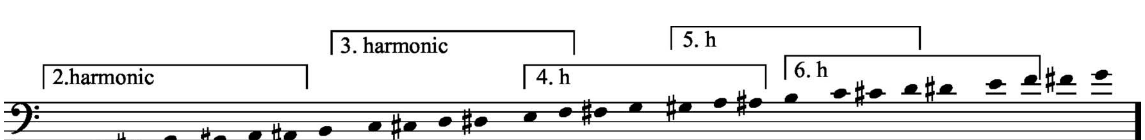

Fig. 17. Alternative set organization on trombone.

Fig. 18. Adjacent (below staff), alternatively interlocking (above staff) sets on the button accordion.

The point here is not to decide which of these interpretations is the "right" or "best". Both interpretations may have their use, both from a technical and from a musical point of view. For a performer the different possible interpretations of sets and selectors may be of use in different situations, as is perhaps more evident in cases like fingerboard string instruments and brass.

4.2 A typology of sets

The sets described above have some fundamental differences. First of all, there is the distinction between *analogue* and *digital* sets – whether the values in a set are confined to a small set of discrete values, or can take on any intermediate values between the minimum and maximum values. The trombone has both kinds; the set of a given harmonic over the full range of the slide is a continuous analogue set, while the set of a harmonic series on one single slide position is a digital, gapped set.

Sets may contain all possible values the instrument can yield, and thus be a *complete* set. None of the pitch sets on the wind instruments discussed are complete in this sense. A normal piano keyboard may be seen as a complete set, when regarding all keys together as a chromatic sequence, or as two incomplete, gapped sets of white and black keys respectively. Strings on a diatonic harp may be another example.

It is also possible to distinguish between *continuous* and *gapped* sets. The two pitch sets described for the tin whistle (seven scale steps in each of two octaves) are continuous in the sense that they contain all relevant values within the range of the sets (assuming the whistle is used for diatonic music). The alternative view in Figure 14 shows seven gapped sets. The two sets of pitches on the willow flute associated with open and closed tube respectively are also gapped.

There are also different ways sets may be related to each other. The two continuous pitch sets of the tin whistle are, as mentioned above, *disjunct*. This may be seen as a special case of degree of *overlap*, that may range from total overlap (identical set of possible values) through partial overlap, to disjunct and contiguous, and disjunct and non-contiguous. A special case of disjunct sets is the interlocking set, as shown in Figures 14, 15 and 18.

5. Concluding remarks

The design of mappings is an important aspect of the construction of new instruments. It may seem a good idea to use simple or one-to-one mappings, to make an interface easy to understand, and the complexity of some interfaces of traditional acoustic instruments are sometimes seen as a hindrance. As mentioned in the introduction to this paper, however, complex couplings seem to be preferred over simple ones, and the challenge for constructors of new instruments should therefore rather be to make sensible complex interfaces. Through a study of existing instruments, one might get some ideas on the degree and kind of complexity that is preferable.

The set of concepts discussed here represents no exhaustive set necessary to describe details in mappings between input and output variables of musical instruments, but may be useful in the process of constructing more complex mappings than simple one-to-one relations between input and output parameters. The approach used here also ties together some instruments that have some similarities in user interface, but that usually will be rather distant in traditional instrument classification systems. This also indicates that an approach based on mapping might be an alternative to traditional instrument classification systems.

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