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New Musical Instrument Design Considerations

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Music is always moving forwards, evolving on all levels including sounds, forms, technique, and audiences. This phenomena is well illustrated by the fact that the popular music of one generation is often completely different from that of the previous generation, sometimes causing tension between parents and children. In modern times, this is also well illustrated by the adaption of other sound tools for musical performance. One outstanding example of this is the turntable, which gave rise to the DJ and the plethora of musical genres that have evolved from that innovation.

Musicians have further explored the recorded artifact as an instrument, adapting CD players by both hacking the electronics and altering the surface of the disk. They have taken the use of microphones to new levels as well and used the amplification microphones make available to create intensities of sounds that were previously impossible while also creating new practices, such as beat boxing, and making these available in large public venues.

Musical evolution is equally evident in the hacker space. When Nintendo's Wii Mote and Microsoft's Kinect were barely released, they were hacked and adapted. The first hacked applications were for musical purposes.

This article discusses the proliferation of new musical instruments/interfaces for computer-based music performance (digital musical instruments). It discusses the notion of a musical instrument schema and how preexisting musical practice can be used to provide design guidelines for this developing field. In so doing, it teases out notions of control and creation and discusses a number of theoretical positions for those notions in musical performance. In addition, I provide a model for musical interface design and discuss it in terms of a large online database of digital musical instruments.

Acoustic Instrument Model

Playing a musical instrument is a complex skill that sits within a network of cultural influences. Musical performance causes the transfer of spatial (pitch) and temporal (duration/rhythm) information from the conscious and subconscious systems of the body to the apparatus that physically produces the sound. Any such information transfer operates from within complex traditions of culture, musical design, and performance technique and is shaped by human cognitive and motor capacities (for example, the event speed and complex polyrhythms in the compositions of Colon Nancarrow[1–3]) as well as personal experiences.[4] Donald Norman[5] refined the term *affordances*[6] to refer to perceived affordances as opposed to objective affordances. This distinction makes the concept dependent not only on the physical capabilities of the actors, but on many contemporaneous influences, including prior experience, expectations, levels of attention, and perceptual ability, which in turn brings enculturation into the frame.

Musicians use gesture both as a means to engage the production of sound on an instrument and as an expression of an inner intentionality. This facet of gesture is intended to convey something of the emotional interpretation the musician wishes to invoke through the nuancing of the musical material. An experienced musician develops a proprioceptive relationship with his or her instrument—that is, a largely unconscious perception of movement and stimuli arising within the body from the relationship between the human body and the instrument during performance. A direct relationship is established between the physical gesture, the nature of the stimuli, and the perceived outcome. The resulting awareness is multifaceted and has been at the core of musical performance for centuries. These levels of engagement extend to distributed cognition—that is, a product of the body as a whole and

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not simply the brain—and as such allow musicians to enjoy an embodied relationship with their instruments (where the instrument and performer may appear to dissolve into one entity), a relationship that is often communicated to the audience through performance gestures.

Computer-based music, however, heralded the dislocation of the excitation, sonification mechanism, dissolving the embodied relationship musicians previously enjoyed with their instruments while simultaneously introducing a range of possibilities that defy the limits of the human body, raising questions about the role of gesture in musical performance and the value of haptics in successful musical instruments.

Acoustic instruments have an idiomatic repertoire—that is, music that focuses on and amplifies the characteristics of the instrument. For instance, the composer Paganinni (1782–1840) is regarded as a master of idiomatic violin music, which is fast, flowing, and virtuosic.

By contrast, the computer is a utilitarian child of science and commerce, a chameleon with no inherent property other than acting as an interface to desired functionality. Friedrich Kittler's notion of construction by process neatly summarizes the computer as having a context generated by its momentary context.[7] Kittler also references the typewriter,[8] pointing out that the letters of the typewriter are dissociated from the communicative act with which it is commonly associated. When we examine the computer, this dissociation is magnified many times over. Each key on a typewriter has a single associated function, whereas a computer keyboard is amorphous, being adapted to the programmer's desire as an interface to a communication framework, a controller for a game, or a function key changing the sound volume or display brightness.

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Digital Instrument Design

In contrast to the utilitarian view of the computer, when it is considered as a musical instrument, the design requires some serious consideration of musical aesthetics and the relationship between the performer and the audience. The interface and its implementation serve two primary goals:

- to increase performability, allowing the musician to nuance musical outcomes in a way not possible with existing interfaces or using the mouse/keyboard computer interface and
- to increase communication with the audience, displaying something of the energy and intent of the performer, providing a conduit for engagement in the real-time qualities of the performance (the ritual of performance).[9,10]

Any implementation of a new musical interface must therefore consider the ecology of this environment. Michael Gurevich and Jeffrey Treviño have discussed the development of a framework for an ecology of musical action:

> An ecological framework without the assumption of a commodity or a singular creator makes it admittedly difficult to unify or relate the experiences of the individual actors in the system. Donald Norman's formulation of three levels of processing in the human brain and associated modes of experience facilitates a meaningfully descriptive but inclusive consideration of the musical experience from a variety of points of view. The three levels of processing are visceral, automatic and pre-wired reactions to sensory stimuli; behavioral, involved in the subconscious control of learned everyday actions (driving a car, taping, playing a violin); and reflective, the highest-level conscious thought in which we form opinions, plans, and abstractions. Organized in a hierarchy, adjacent levels can inform one another, but control acts downward. The reflective level tries to influence behavior based on conscious thought, and the behavioral level can in turn try to 'enhance and inhibit' the visceral. While Norman argues that good design requires a balanced appeal on all three levels, it is also clear that all three levels are engaged in creating music. Norman describes the skilled performer's ability to play a piece

> unconsciously (behavioral) while simultaneously considering matters of the large-scale form (reflective). The listener reacts viscerally to the sound and may also contemplate meaning.[11]

Gurevich and Treviño point to the difficulty of identifying a unified source for musical creation in a complex system where the interface and the sonification mechanism are separated. Their adaption of the three levels of processing outlined by Donald Norman[12] illustrate some of the cognitive associations brought into play when engaging both as a performer and an audience member during a musical performance.

Visceral and behavioral levels are enshrined in the kinetic gesturing that brings about the musical outcomes, representing a sonification of the performative gesture. The reflective layer is brought to bear by the musician who is actively, but subconsciously planning form, structure, and harmonic progression. The momentary and the future abstract are always coexistent and active.

It is pertinent to this discussion that Gurevich and Treviño state that musicians are working at all three of the levels identified by Norman when improvising and performing dynamic scores. They contextualize Norman's three levels of processing in terms of interface evaluation:

> Norman's three levels of processing offer a new currency for describing the experience of music creation that places the electronic music interface appropriately in context. This framework has three distinct advantages: 1) it admits a broader range of aesthetic concerns; 2) it provides a more meaningful way to "evaluate" an interface; and 3) it expands the scope for the consideration of novel interfaces.[11]

Instrument or Interface

A broad foundational concept of "musical instrument" is embedded in our language and culture. It is useful to unpack that concept to illuminate the influence it has on design and development of a new interface/instrument.

Daniel J. Levitin discussed how perceptual expectations inform musical expectations, establish constraints and limitations in musical practices, and form the basis for idiomatic writing for any instrument.[13] Levitin pointed out how trained and untrained people can sing "Happy Birthday" regardless of the starting pitch. We hold a schema that is isomorphic; it can be applied to any starting point, is widely shared, always retains its integrity, and furthermore, is context sensitive. The notion of a musical instrument might then be defined as a schema as it applies equally to everything from a theremin to a church organ to a tin whistle.

A second primary design consideration is that the objective of a musical instrument is a performance. Stanley Godlovitch's philosophical deconstruction of the notion of musical performance endeavored to address new instruments.[9] Godlovitch put forward the concept of "remote control," saying that

> Computer assisted music, musical quasi-readymades, and experimental music challenge the centrality of immediate agency…. Primary causation involves direct control. Not all causation is primary. Causation is indirect when what the maker does skillfully is at a significant procedural remove from the final effect. Indirect causation is standard in computer art and music. I will call the process remote control.[9]

New musical interfaces and instruments are primarily used/presented, or at least engaged with, by the broader public within an understood performance convention.

Within this context, the immediate and perceivable agency of the performer is understood to be critical to reception, but the use of computer-based musical instruments often presents a challenge to this paradigm because of a lack of observable primary causation.

Godlovitch's frame of reference for "computer assisted music, musical quasi-readymades" is where a sequence of musical material is predetermined and a performance involves the replay of that material without intervention. Much has changed in the last decade with computing power facilitating real-time software synthesis languages (such as the Supercollider, Max/MSP, Pd, Chuck, Impromptu, and Audiomulch), wherein variables within software synthesizers can be controlled in real time. Such a paradigm is not considered by Godlovitch.

Two distinct approaches to computer-assisted music exist: the replaying of material that contains a fixed morphology (fixed at the time of recording), whereby the momentary detail of the sound is clearly from a source other than the performer, and real-time generation of musical material that may partially redress the causation/agency concerns. We might think of these as a *control state* and a *create state*, indicating that the musician engages in two distinct activities:

- the control of predetermined sequences of sounds (such as the triggering of sound samples in Ableton Live or any other sample based software instruments) and
- the creation of sounds in real time by the manipulation of software synthesis variables, where the sound is synthesized in real time.

These approaches may be differentiated as *control* or *create* and are often interwoven in practice. For instance, a musician may trigger a sample to play in Ableton Live but then use real-time parameter control of an audio effects plug-in (such as filters, delays, or granulation time) to resynthesize the rhythmic presentation of that material or to change the timbre and pitch of the source.

This cohabitation complicates the classification of such performance systems as musical instruments. An examination of NIME/DMI demonstrates that both remote control and primary causation occur simultaneously. It may be agreed that where the act of performance is limited to the triggering of predetermined sequences (remote control) that the interface acts as a controller. A process of control is paramount and most commercially available interfaces designed for this purpose are called controllers, including the Novation Launchpad, Monome, Faderfox, and QuNeo. However, if primary causation is observable, a direct and immediate agency is again central to the performance, and as such, a vestigial reference is made to a definition as musical instrument (a process of creation is paramount).

Instrument/Interface Design

A collective agreement on such definitions is important to the development of common schemas. Returning to Levitin's discussion of musical schemas, a shared model of perceptual and musical expectations and a common understanding of constraints and limitations in musical practices provide the framework for a shared understanding of causation and agency in acoustic music performance. Without such a shared schema for computer-assisted music, which may start with the delineation of the control and creation processes, the general public will always be uncertain about the authenticity of a computer music performance. In an acoustic instrument performance, gesture is central to providing immediate agency and drawing attention to primary causation. Of course, computer music performances have developed their own conventions, and repeated exposure provides a constant updating of any schema associated with such performances.

A study regarding new instrument/interface design examined the practice and application of new interfaces for real-time electronic music performance.

In an effort to begin a discussion regarding collective agreements regarding new instrument/interface design, I undertook a study to analyze how musicians control acoustic instruments[14] and developed a large online database of digital musical instruments as a foundation for the development of a taxonomy for the field.[15]

As part of this work, the online Taxonomy of Interfaces for Electronic Music (TIEM) questionnaire consisted of 72 questions that examine the practice and application of new interfaces for real-time electronic music performance. The questions consisted of a mix of textural and numeric, qualitative and quantitative, arranged into six sections:

1. General description
2. Design objectives
3. Physical design
4. Parameter space
5. Performance practice
6. Classification

The questionnaire was launched in June 2008, and by December 2008, there were more than 800 unique survey views with 70 completed responses.

Figure 1 gives an overview classification derived from the textual qualitative analysis of

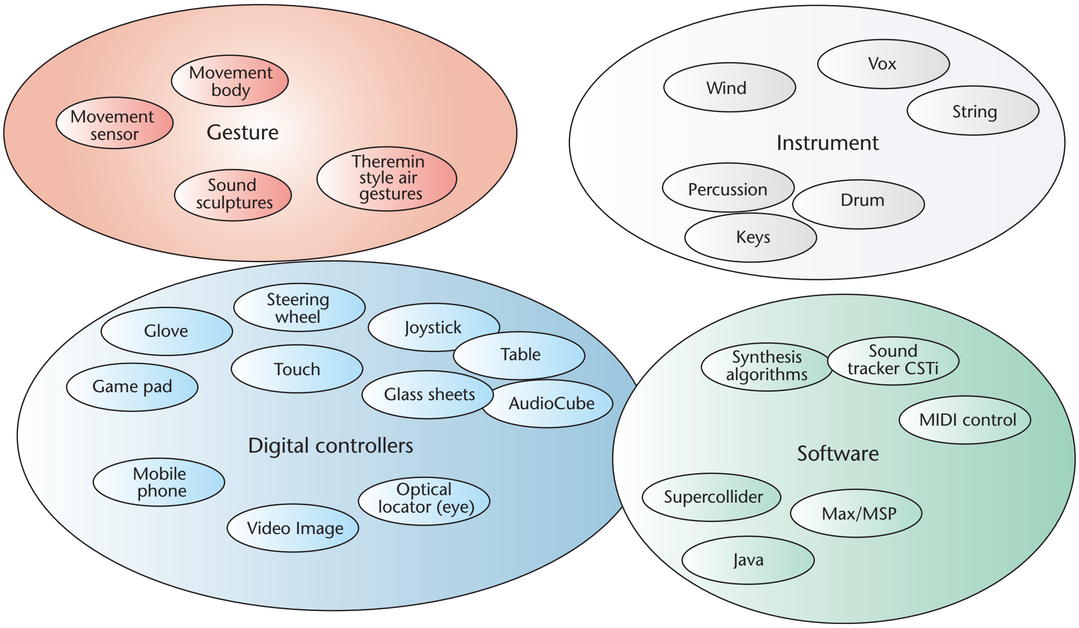

Figure 1. Taxonomy of Interfaces for Electronic Music (TIEM) top-level categories.

Table 1. Summary of responses to some of the quantitative questions in the TIEM survey.

Question	Response (%)
Would you describe your interface/instrument as	
Polyphonic	88.33
Monophonic	11.67
Multitimbral	86.67
Monotimbral	13.33
Do you need to touch it?	
Yes	83.33
No	16.67
Does the interface/instrument provide haptic (tactile/kinaesthetic) feedback to the performer?	
Yes	36.84
No	63.16
Would you describe your interface/instrument as	
Process based (create)	60.71
Event based (control)	39.29

the submissions to the TIEM database and provides a broad concept map containing four principle concepts: gesture, instrument, digital controllers, and software.

Based on trends, the instruments/interfaces discussed in the survey exhibit these traits:

- a moderate learning curve,
- a performer can become an expert with the instrument/interface, and
- increase in practice time results in increase in skill.

There is a clear correlation between the trend for becoming an expert and the trend for practice time/skill. The trend suggests that both very slow and (perhaps) very fast learning curves are undesirable.

Table 1 shows that there is a clear preference for creating polyphonic (88.33 percent), multitimbral (86.67 percent) process-based (create rather than control) (60.71 percent) interfaces/instruments. There is also a strong preference for interfaces that are touched (83.33 percent)—that is, the performer has a physical connection with the interface/instrument. However, despite this preference for tactile interfaces, only 36.84 percent reported providing haptic (tactile/kinaesthetic) feedback to the performer.

The responses clearly show that performers have a strong need for a physical connection with their instrument. A crucial step in the development of new musical interfaces therefore is the design of the relationship between the performer's physical gestures and the parameters that control the generation of the instrument's sound.[16,17] This process, known as control mapping,[18] is understood by the musician as a more homogenous engagement, where agency is decisive.

The survey asked what contributors thought of their system (instrument, interface, composition, or other). There was a slight preference for

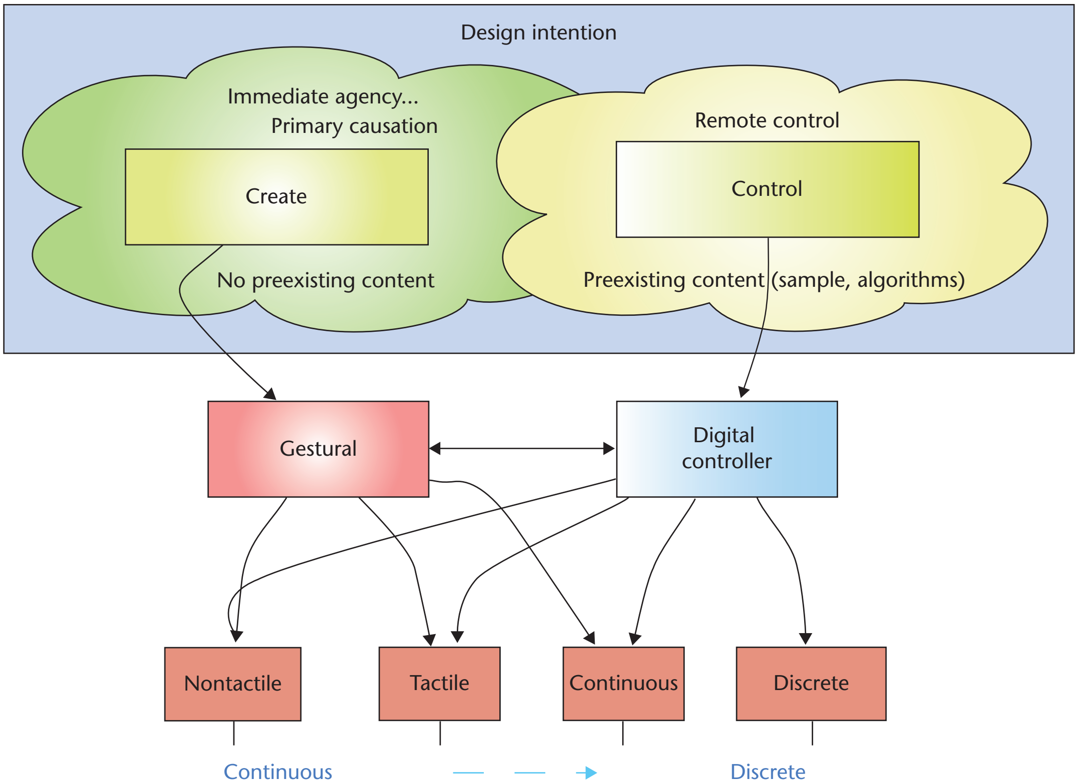

Figure 2. TIEM proposed taxonomy that maps the transition from create to control.

describing the systems as an instrument (67.16 percent) versus interface (55.22 percent), but some also think about their systems in terms of a composition (16.42 percent). Responses under the "other" category included the following: all the above, composition tool, holistic approach to sound, installation, interactive environment, interface and composition, performance device, performance environment, rhythm generation system, and semiautomatic improviser.

The range of responses indicates how complex the challenge of classification is in this field. The musical instrument schema I discussed earlier would not cover all the categories self-identified by TIEM contributors.

It should be noted that this notion of an interface/instrument being represented also in terms of a musical composition, while familiar to those working in the area, is of course radically different from the concept of a traditional acoustic instrument. This difference is well represented by Margaret Kartomi's assertion that musical instruments are fixed, static objects that cannot grow or adapt in themselves.[19]

Figure 2 shows a preliminary proposal taxonomy that illustrates a sliding scale from continuous data to discrete data. It maps the transition from create to control, consistent with our discussion about these ideas. It seeks to distinguish between a digital controller and a system, where primary causality can be identified through observing the musicians gestures, and it distinguishes between primary design intentions and execution.

The many interconnections illustrate that in practice no digital musical instrument is limited to a single category. They often enable a mix of continuous and discrete events demonstrating a crossover of the create/control paradigms.

The ThuMP Project

The ThuMP project, which I established in 2006 at the University of Western Sydney with industry partner Thumtronics P/L, sought to use an acoustic instrument to model musical control. It asked questions about how professional musicians controlled musical instruments to produce high-level outcomes and sought to discover the extent to which those parameters where discrete or interdependent.

Acoustic instruments form an important historical reference point for musical instrument design and are supported by instrumental technique literature. (For instance, the flute literature includes several such examples.[20–23]).

Although a considerable body of literature exists discussing models of mapping (one-to-many and many-to-many[24–26]), the literature is

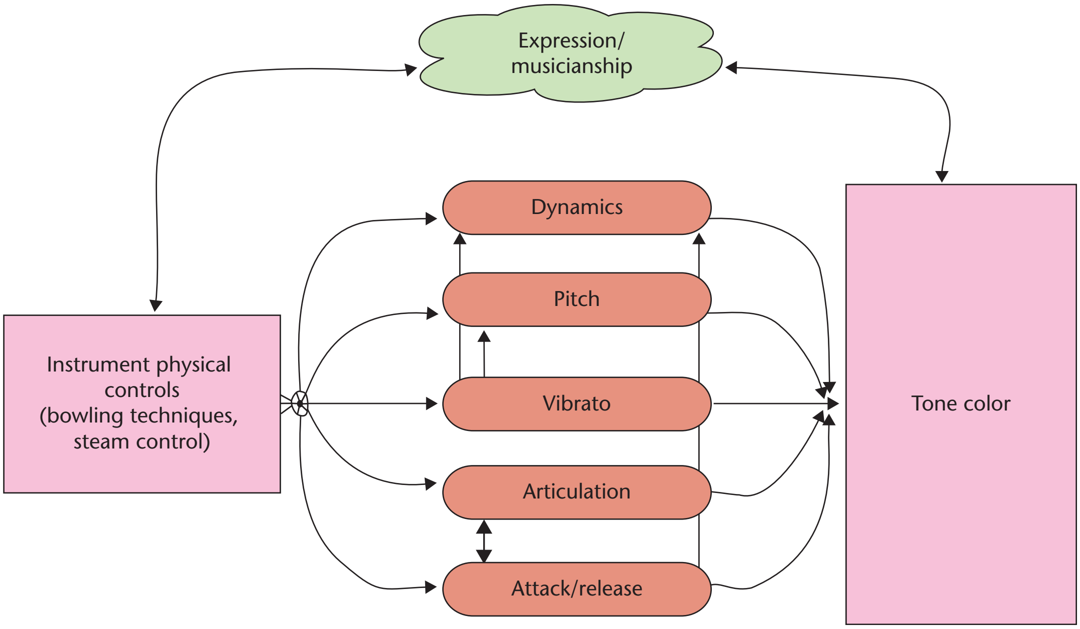

Figure 3. Musical parameter overview from the ThuMP project.

largely devoid of discussion as to the underlying musical intentionality associated with the control mechanisms being outlined. Acoustic instruments offset this issue because their inherent design intention is for the performance of music.

Rather than analyzing the mapping strategies displayed in the existing electronic music interface paradigms, the ThuMP project sought to develop a generic model of successful and enduring acoustic musical instruments, with the selection constrained by the specification that all instruments should be able to produce a continuous tone that could be varied throughout.

The ThuMP project interviewed wind, brass, string, and piano accordion performers, asking them about the control parameters they brought to bear in playing their instrument. We sought to prioritize the parameters and understand their inherent interrelationships.

The musical parameters each interviewee discussed included pitch, dynamics, articulation (attack, release, sustain), and vibrato, with physical controls (speed, direction, force, and so on) also being noted. In addition, the interconnections between these controls and the overall effect on the sound of the instrument were distinguished. The analysis was then represented diagrammatically, noting the connections and interrelatedness of the physical controls, the control parameters, and their effect on the overall sound of the instrument (see Figure 3)

These models of instrument control were broken into two stages:

- Musical parameters (such as dynamics, pitch, vibrato, articulation, and attack/release) are identified as the musical characteristics musicians were seeking to control. A good command of these parameters was also identified as key to achieving a well-developed instrumental tone, something that was of principle concern for all interviewed musicians.

- Four predominant physical parameters were identified that were commonly aggregated to bring about the musical attributes: pressure, speed, angle, and position (see Figure 4).

The model represented in Figure 3 also indicates the role musical expression or musicianship plays in aesthetic decisions and the manner in which these notions act as an overall metric for the musical sensibility that underlies all Western instrumental training and musical decision making and are probably central to the definition of a musical instrument schema.

I use this model to establish principles of design for new musical interfaces/instruments, from biosensors on dancers to individual musical performance devices. The model is also being applied to the analysis of the TIEM database of new musical interfaces/instruments that I developed (see http://vipre.uws.edu.au/dmi).

Conclusion

The two research projects discussed here have sought to assist the developing area of digital

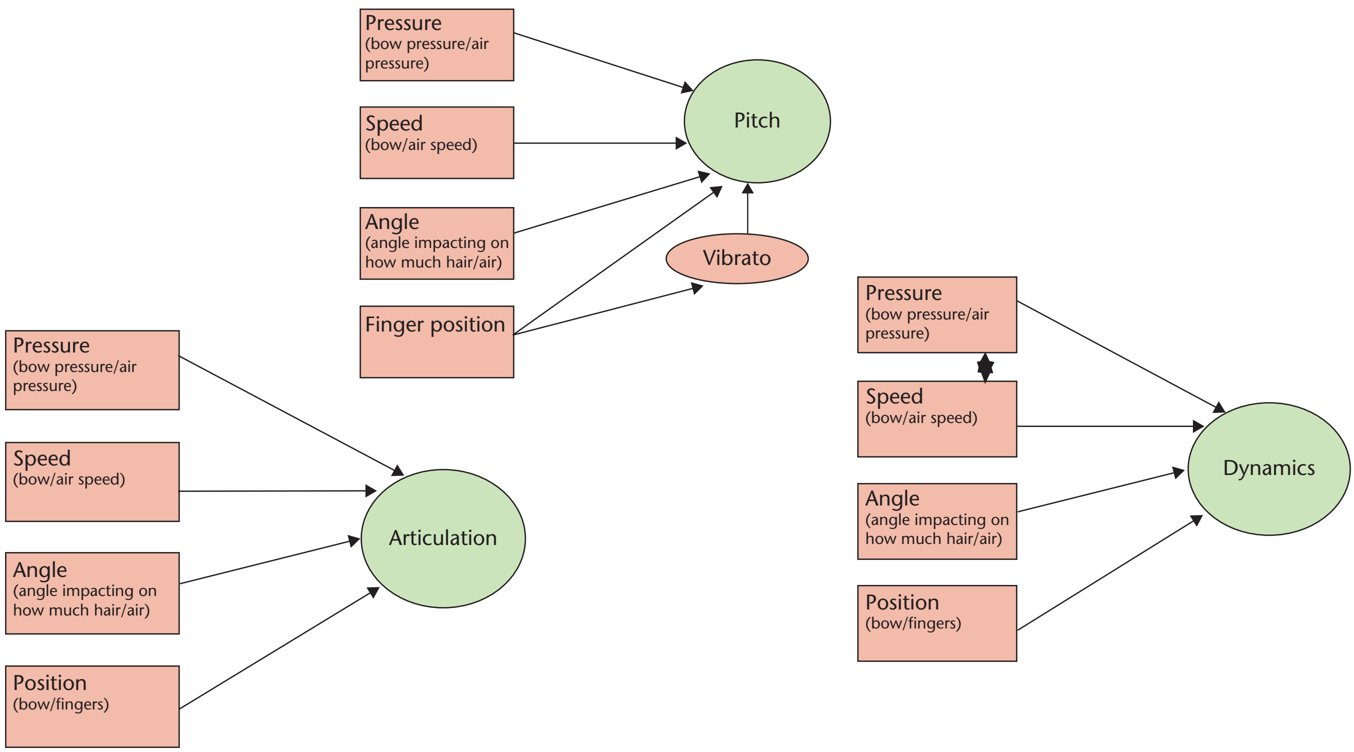

Figure 4. Control parameters model.

musical instruments and establish foundational design guidelines for successful instrument/interfaces as well as a taxonomy that could act as a metric for comparative studies. This article illustrates the complexity of such propositions, discussing the fact that no control parameter in a music instrument exists in isolation, and proposes a sliding scale from continuous to discrete data input.

My hope is that a discussion might develop around the need for design guidelines and a metric that provides a basis for comparative studies of the effectiveness of instruments/interfaces for musical performance. I propose the need for such tools so that the field of digital music instruments can evolve in sophistication and success in terms of mass market uptake. It is striking to note that although many attempts at designing new digital instruments have occurred over the last decade or so, none are prevalent in the performance arena. The need to work out why previous attempts have not had commercial success is critical to the long-term viability of this field of enquiry. **MM**

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