A NEW CONCEPTUAL FRAMEWORK FOR DIGITAL MUSICAL INSTRUMENTS

*Joseph Malloch**
Input Devices and Music Interaction Laboratory
McGill University, Montreal
joseph.malloch@mcgill.ca

Elliot Sinyor
Input Devices and Music Interaction Laboratory
McGill University, Montreal
elliot.sinyor@mail.mcgill.ca

David Birnbaum
Input Devices and Music Interaction Laboratory
McGill University, Montreal
david.birnbaum@mail.mcgill.ca

Marcelo M. Wanderley
Input Devices and Music Interaction Laboratory
McGill University, Montreal
marcelo.wanderley@mcgill.ca

ABSTRACT

This paper describes an adaptation of an existing model of human information processing for the categorization of musical contexts and performance behavior. A visualization intended to aid analysis of existing digital musical instruments, and the design of new devices, is presented. Three new DMIs constructed by the authors are examined within this framework to illustrate its utility.

1. INTRODUCTION

It is common when considering and categorizing devices that produce sound to become entangled in the differentiation of instruments, musical toys, and installations. Even within categories, confusion arises; conceptual models of "musical instrument" vary according to historical, cultural, and personal biases. New musical devices have varying degrees of success in penetrating the conceptual boundary between instrument and non-instrument, and frequently their path into the "instrument" domain is unexpected from the perspective of design intentionality. The issue is further confused by a layer of artistic interpretation, exploding the possible definitions of "instrument" into almost any conceivable expressive cultural artifact that can involve sound (including the absence of sound). "Instrument" can thus refer to a controller with no specific mapping, an acoustic device in the classical definition, or can be synonymous with a musical piece itself, in which the interface (including its physical component) is integrated with musical sound output in the composer's expressive intent [20]. However, a systematic investigation of the design space of a musical device (such as dimension space analysis [1]) leads to a categorization of musical devices that considers both design goals and the constraints placed on interaction arising from the possibilities for human behavior and environmental conditions.

For the purposes of this investigation, the definition of "instrument" will be restricted to refer to a sound-producing device that can be controlled by a variety of physical gestures and is reactive to user actions [2]. A digital musical instrument (DMI) implies a musical instrument, with a sound generator that is separable (but not necessarily separate) from its control interface, and with musical and control parameters related by a mapping strategy [22].

* This author received research funds from the Center for Interdisciplinary Research in Music Media and Technology

While any digital system involves computation, the representation of the computer as a symbolic, metaphorical machine generating function-relationships to which we interface sensor and feedback systems does not adequately articulate its role in problem-posing task domains such as music composition and performance.

It has been said that, with respect to computer music, the differentiation between computer and musical instrument is a misconception, and this is a problem that has its solution in interface design [24]. Indeed, a computer may be used to *contain* an instrument, or many instruments, whose limits are only defined in terms of the computer's ability to implement known sound synthesis, signal processing, and interfacing methods. But if the "computer = instrument" paradigm is used, it is likely to leave the impression that digital instruments are also general purpose tools, and that the freedom to change mapping and feedback parameters arbitrarily provides the player with a better musical tool. Instead, the computer can be more aptly viewed as a semiotic, connotative machine that hypothesizes design criteria rather than consisting exclusively of *a priori* cultural and interaction metaphors [11]. Viewing the computer in this way also endows it a constitutive role in performance behaviors that are not directed by explicit intention and evaluation of feedback.

Fields of research that have been applied to interface development range from human-computer interaction [18], theories of design [1] [10], music cognition and perception [14] [17], and organology/ethnomusicology [13], to name only a few. We propose another possible approach, tying together ideas from human-machine interaction and music performance practice by defining the *musical context* of a performance.

2. A HUMAN-MACHINE INTERACTION APPROACH

We have developed a paradigm of interaction and musical context based on Jens Rasmussen's model of human information processing [19], previously used to aid DMI design in [4] and [5]. Rasmussen examines the functions of "man-made systems" and human interaction in terms of the user's perception and the *reasons* (rather than causes) behind system design and human behavior. He develops concepts of human behavior introduced by Fitts [9] and by Whitehead [25], describing interaction behaviors as being *skill-*, *rule-*, or *knowledge-based*. Rasmussen himself suggests that *knowledge-based* might be more appropriately called *model-*

based, and we believe this term more clearly denotes this mode of behavior, particularly during performance of music, as "musical knowledge" can have various conflicting definitions.

Briefly, skill-based behavior is defined as a real-time, continuous response to a continuous signal, whereas rule-based behavior consists of the selection and execution of stored procedures in response to cues extracted from the system. Model-based behavior refers to a level yet more abstract, in which performance is directed towards a conceptual goal, and active reasoning must be used before an appropriate action (rule- or skill-based) is taken. Each of these behaviors is linked to a category of human information processing, differentiated by their human interpretation; that is to say, during the differentiable modes of behavior, environmental conditions are perceived as playing various roles, which can be categorized as *signals*, *signs*, and *symbols*. Figure 1 demonstrates our adaptation of Rasmussen's model, in which both performance behaviors and musical contexts are characterized as belonging to model/symbol, rule/sign, or skill/signal domains.

2.1. Skill-, Rule-, and Model-based Musical Performance

Skill-based behavior is identified by [4] as the mode most descriptive of musical interaction, in that it is typified by rapid, coordinated movements in response to continuous signals. Rasmussen's own definition and usage is somewhat broader, noting that in many situations a person depends on the experience of previous attempts rather than real-time signal input, and that human behavior is very seldom restricted to the skill-based category. Usually an activity mixes rule- and skill-based behavior, and performance thus becomes a sequence of automated (skill-based) sensorimotor patterns. Instruments that belong to this mode of interaction have been compared more closely in several ways. The "entry-fee" of the device [24], allowance of continuous excitation of sound after an onset [14], and the number of musical parameters available for expressive nuance [6] may all be considered.

It is important to note that comparing these qualities does not determine the "expressivity" of an instrument. "Expressivity" is a word commonly used to discuss the virtue of an interaction design in the language of artistic criticism. It wrongly defines expression, a concept that is unquantifiable and dynamically subjective, as an aspectual property of an interaction. Clarke, for example, is careful not to state that musical expressiveness is heightened by the possession of a maximum or minimum number of expressive parameters; instead, he states that the range of choices available to a performer will affect performance practice [6]. The musician can still perform expressively, but must transfer her expressive nuance into different structural parameters. This relates to the HCI principle that an interface is not improved by simply adding more degrees of freedom (DOF); rather, at issue is the tight matching of control parameters with the requirements of the task [12].

During rule-based performance the performer's attention is focused on controlling a process rather than a signal, responding to extracted cues and internal or external instructions. Behaviors that are considered to be quintessentially rule-based are typified by the control of higher-level processes and by situations in which the performer acts by selecting and ordering previously determined procedures, such as live sequencing, or using "dipping" or "drag and drop" metaphors [24]. Rasmussen describes rule-based behavior as *goal-oriented*, but observes that the performer may not be explicitly aware of the goal. Similar to the skill-based domain, interactions and interfaces in the rule-based area can be further distinguished by the rate at which a performer can effect change, and by the number of task parameters available as control variables. Additionally, they can be differentiated according to whether or not the performer is aware of the goals inherent in the interaction.

The model domain occupies the left side of the visualization, where the amount of control available to the performer, and its rate, is determined to be low. Although this area also accounts for goal-oriented behavior, it differs from the rule-based domain in its reliance on an internal representation of the task. Rather than responding with selections among previously stored routines, a performer exhibiting model-based behavior possesses only goals and a conceptual model of how to proceed. The performer must rationally formulate a useful plan to reach his goal, using active problem-solving to determine a correct course of action. This type of behavior is thus often used in unfamiliar situations, when a repertoire of rule-based responses does not already exist.

2.2. Signals, Signs and Symbols

By considering their relationship with the types of information described by Rasmussen, musical contexts for performance can also be distributed among the interaction domains. The signal domain relates to most traditional instrumental performance, whether improvised or pre-composed, since its output is used at the signal-level for performance feedback. The sign domain relates to sequenced music, in which pre-recorded or pre-determined sections are chosen and ordered during performance. Lastly, the symbol domain relates to conceptual music, which is not characterized by its literal presentation but rather the musical context in which it is perceived. In this case, problem-solving and planning are required of the performer — for example, the performance of conceptual scores, which may lack specific "micro-level" musical instructions but instead consist of a series of broader instructions or concepts that must be actively interpreted by the performer [3].

3. USING THE VISUALIZATION

Our visualization is intended to clarify some of the confusion surrounding music interface design at several levels. Firstly, it may be used to analyze, compare, and contrast interfaces and instruments which have already been built, in order to facilitate an understanding of their relationships to each other. Additionally, the design of new interfaces can benefit from this approach, whether the designer intends to start with a particular interface concept, or he wishes to work within a specific musical context. Finally, the visualization may be informative to those who already have an interface which they believe to be lacking in some respect, and wish to adapt it to different types of musics, or to increase its potential for performance within a specific musical context.

Consider the drum machine, for instance the Roland TR-808. To create a rhythm, the user selects a drum type using a knob, and then places the drum in a 16-note sequence by pressing the corresponding button(s). When the "start" button is pressed, the sequence is played automatically at the selected tempo. Using the diagram, this is clearly a rule-based way to perform a rhythm. A skill-based example in a similar vein would be using a drum machine with trigger pads that require the performer to hit the pads in real-time. Of course, a drum kit would be another obvious skill-based example. In the same musical context but on the opposite end of the chart we can consider using the live coding tool Chuck [23] to create the same rhythm. Here the performer would take

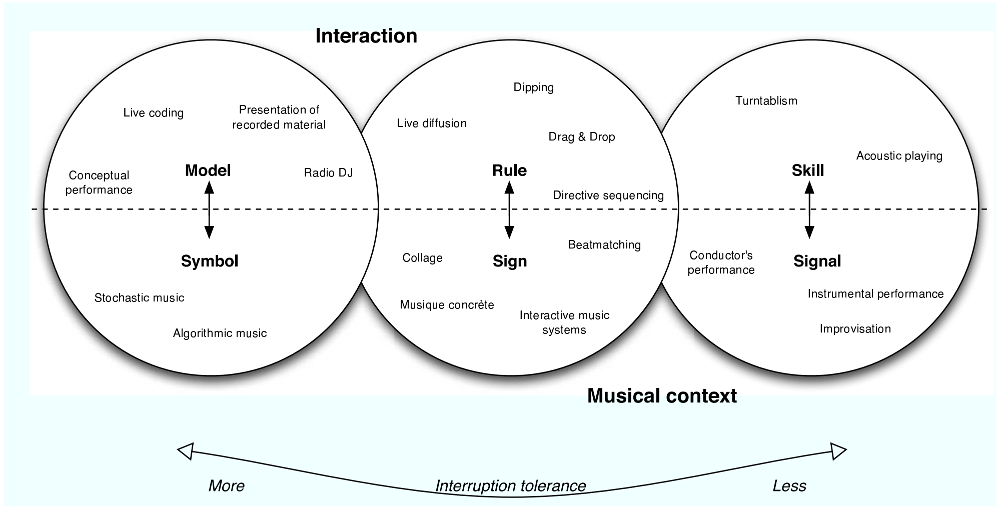

Figure 1: A visualization of the framework.

a model-based approach. Playing a beat would require breaking the task into sub-tasks, namely creating a loop and deciding on an appropriate rest interval based on the desired tempo.

4. APPLICATIONS AND IMPLICATIONS

4.1. The Rulers

The *Rulers*, an interface developed by one of the authors[1], was designed to evoke the gesture of plucking or striking a ruler (or "tine") that is fixed at one end, such as when pressed against the edge of a table. An infrared reflect sensor under each of the seven tines transduces its motion to electrical signal which is then digitized and sent to a computer, where mapping and synthesis take place in Max/MSP. Each of the tines play one of seven percussive samples, slices extracted from the Amen breakbeat [8]. Each sample consists of either a single drum or cymbal, or a sequence of drums comprising a short rhythm. Because the samples contain sub-rhythms, the instrument must be played in the context of a global tempo set in the Max/MSP patch that remains fixed during the course of the performance. Naturally, each tine oscillates for a different amount of time when plucked, as they are of different lengths. The playback samples have been selected and assigned to each of the tines strategically, so that the length of the sample played back correlates to the length of time each tine vibrates. This provides an element of visual and passive haptic feedback to the player, as information about the sound each tine produces is tightly coupled to the physical construction of the interface. Output amplitude is determined by the amplitude of the tine's oscillation, leading to control over the amplitude of initial excitation and damping — characteristics that classify it as an instrument that outputs musical events with a "non-excited middle" [14].

Playing the Rulers is principally a skill-based behavior, requiring constant performer input to sustain musical output. While it does not allow for continuous excitation, it does allow continuous modification after an onset, as the tines may be damped to affect the decay rate of musical events. Nonetheless, because the musical output contains fixed elements of rhythm over which the performer has no real-time control, the interaction is also directing short-time musical processes that do not originate from the player but are hard-wired into the instrument/system. Thus it incorporates elements of both the signal and sign domains.

Figure 2: The Rulers, by David Birnbaum.

4.2. The Celloboard

Another new interface, the *Celloboard*, was designed to tie sound output with continuous energy input from the performer. Using contact microphones and accelerometers to sense the amplitude, direction and pressure of bowing gestures, this controller allows the continuous excitation, as well as modification, of its sound. Sensor data is sampled by a microcontroller configured to act as a Human Interface Device (HID) [15]. Mapping and sound-synthesis are implemented in Max/MSP, using scanned synthesis [16][7]. Pitch and some timbral elements of the sound are controlled by sensors on the controller's neck, sensing position and pressure of touch on two channels, and also strain of the neck itself on one axis.

With its many continuously-controlled parameters and integral mapping, the Celloboard controller easily fits into the skill/signal domain. Also, any interruption in performance will immediately

[1] Developed at the Center for Computer Research in Music and Acoustics 2004 Summer Workshop.

be audible since sound output requires constant bowing of the interface. It possesses a high "entry-fee" for both sound excitation and modification, and does not easily allow higher-level control of musical processes. Adaptations suggested by the visualization might be to map the physical controls to a synthesis technique even less process-based than the present scanned synthesis implementation, or to allow the selection of discrete pitches (effectively lowering the modification entry-fee), in order to make the instrument more quickly mastered if a larger user-base is desired.

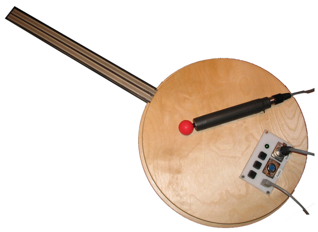

Figure 3: The Celloboard, by Joseph Malloch.

4.3. The Gyrotyre

The Gyrotyre [21] is a handheld bicycle wheel-based controller that uses several motion-related sensors, namely a gyroscope sensor and a two-axis accelerometer, to provide information about the rotation and orientation of the wheel. It was designed as a controller around a small group of mappings that would make use of the continuous motion data as well as the discrete events of the emitter passing the phototransistors. Mapping and synthesis are accomplished with Max/MSP. We will look at two Gyrotyre mappings in order to place them within the framework. The mappings offered consist of an audio scrubber, a drum trigger patch, and an arpeggiator.

Figure 4: The Gyrotyre, by Elliot Sinyor [21].

In the first mapping, the interface controls playback of a sound file, scrubbed backwards and forwards by spinning the wheel, evoking the behavior of a turntable. The wheel may be spun very fast and then damped to achieve a descending glissando effect (depending on the audio sample), or it may be kept spinning at a constant speed. This "instrument" (i.e. this particular mapping of the Gyrotyre controller) would then fit in the skill-based domain of the framework.

With the arpeggiator mapping, spinning the wheel while pressing one of the keys on the handle repeatedly cycles through a three-note arpeggio. The arpeggio's playback speed is directly correlated to the speed of the wheel, and the performer can change the root note and the octave by tilting the Gyrotyre. In this case, the performance behavior is predominantly rule-based. The performer reacts to specific signs, such as the current root note and the speed of the playback. The skill-based aspect of performance is the sustaining of a constant speed of rotation, while holding a steady root-note position. Ostensibly, a performer could practice to develop these skills, but this would offer little advantage, as the instrument outputs discrete pitches. Considering the musical context could lead to two changes: the mapping could be somehow altered to reflect the required skill in the musical output, and/or the root-note selection method could be mapped to a gesture more appropriate for a rule-based behavior.

5. CONCLUSIONS

In summary, there is no way to judge the validity of a design approach unless goals are considered. The authors have presented a framework that correlates performance behaviors and musical contexts, intended for aiding design regardless of the chosen approach. Rather than viewing various design approaches as competing, this framework should promote a dialogue that encourages musical device designers to explore creatively and enjoy a rewarding musical experience.

6. ACKNOWLEDGMENTS

The authors would like to thank Ian Knopke, Doug Van Nort, and Bill Verplank.

7. REFERENCES

[1] D. Birnbaum, R. Fiebrink, J. Malloch, and M. Wanderley. Towards a dimension space for musical devices. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2005.

[2] B. Bongers. Physical interaction in the electronic arts: Interaction theory and interfacing techniques for real-time performance, 2000.

[3] J. Cage. *Silence: Lectures and Writings*. Wesleyan University Press, Middletown, 1961.

[4] B. Cariou. Design of an alternative controller from an industrial design perspective. In *Proceedings of the International Computer Music Conference*, 1992.

[5] B. Cariou. The aXiO midi controller. In *Proceedings of the International Computer Music Conference*, 1994.

[6] E. F. Clarke. Generative principles in music performance. In *Generative Processes in Music, J. A. Sloboda ed*, pages 1–26. Clarendon Press, Oxford, 1988.

[7] J. Couturier. Contrôle gestuel de la synthèse scannée, 2003. [Online]. Available: `http://www.lma.cnrs-mrs.fr/~IM/Projets/scansynth.htm`

[8] E. Davis. Raízes e fios - ciberespaço polirrítimico e eletrônica negra. In *Rizoma Afrofuturismo*, 2001.

[9] P. Fitts and M. Posner. *Human Performance*. Brooks/Cole Publishing Co., Monterey, CA, USA, 1962.

[10] T. C. N. Graham, L. A. Watts, G. Calvary, J. Coutaz, E. Dubois, and L. Nigay. A dimension space for the design of interactive systems within their physical environments. In *Proceedings of the Conference Designing Interactive Systems*, 2000.

[11] M. Hamman. From symbol to semiotic: Representation, signification, and the composition of music interaction. *Journal of New Music Research*, 28:90-104, 1999.

[12] R. J. K. Jacob, L. E. Sibert, D. C. McFarlane, and M. P. M. Jr. Integrality and separability of input devices. *ACM Trans. Human Computer Interaction*, 1(1):3–26, 1994.

[13] S. Jordà. Instruments and players: Some thoughts on digital lutherie. *Journal of New Music Research*, 33(3):321–341, 2004.

[14] D. Levitin, S. McAdams, and R. L. Adams. Control parameters for musical instruments: a foundation for new mappings of gesture to sound. *Organized Sound*, 7(2):171–189, 2002.

[15] M. Marshall. Building a usb sensor interface, 2005. [Online]. Available: `http://www.sensorwiki.org/index.php/Building_a_USB_sensor_interface`

[16] M. Mathews and B. Verplank. Scanned synthesis, 2000. [Online]. Available: `http://www.csounds.com/scanned/`

[17] J. Mishra. A model of musical memory. In *Proceedings of the 8th International Conference on Music Perception and Cognition*, 2004.

[18] N. Orio, N. Schnell, and M. M. Wanderley. Input devices for musical expression: Borrowing tools from hci. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2001.

[19] J. Rasmussen. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. Elsevier Science Inc., New York, NY, USA, 1986.

[20] N. Schnell and M. Battier. Introducing composed instruments, technical and musicological implications. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2002.

[21] E. Sinyor and M. M. Wanderley. Gyrotyre: A dynamic hand-held computer-music controller based on a spinning wheel. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2005.

[22] M. M. Wanderley. Gestural control of music. Presented at the *International Workshop on Human Supervision and Control in Engineering and Music, Kassel, Germany*, 2001.

[23] G. Wang and P. Cook. On-the-fly programming: Using code as an expressive musical instrument. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2004.

[24] D. Wessel and M. Wright. Problems and prospects for intimate musical control of computers. In *Proceedings of the Conference on New Instruments for Musical Expression*, 2001.

[25] A. Whitehead. *Symbolism, Its Meaning and Effect*. Macmillan, New York, NY, USA, 1927.