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7 From Musical Interfaces to Musical Interactions

Abstract: In this chapter, we review research that was conducted at Ircam in the Real-Time Musical Interactions team on motion-based musical interactions. First, we developed various tangible motion-sensing interfaces and interactive sound synthesis systems. Second, we explored different approaches to design motion-sound relationships, which can be derived from object affordances, metaphors or from embodied listening explorations. Certain scenarios utilize machine-learning techniques we shortly describe. Finally, some examples of collaborative musical interactions are presented, which represents an important area of development with the rapidly increased capabilities of embedded and mobile computing. We argue that the research we report relates to challenges posed by the Human Computer Confluence research agenda.

Keywords: Gesture, Sound, Music, Sensorimotor, Interactive Systems, Sound Synthesis, Sensors

7.1 Introduction

Musical instruments have always made use of the “novel technology” of their time, and the appearance of electronics in the 20th century has stimulated numerous new musical instruments, more than generally acknowledged. Several of them were groundbreaking by introducing novel types of interfaces for music performance, significantly ahead of their time. To cite a few: non-contact sound control by Leon Theremin in the 1920’ (the Thereminvox), sonification of electroencephalography by Avin Lucier in 1965 (Music for Solo Performer), active force feedback interfaces by Claude Cadoz and colleagues starting in the 1970’, bi-manual tangible and motion-based interfaces in the 1984 by Michel Waisvitz (The Hands), full body video capture by David Rokeby starting in the 1980’ (VeryNervousSystem), use of electromyography by Atau Tanaka starting the 1990’. Interestingly, these musical systems can be seen as precursors of several computer interfaces nowadays popularized by the gaming industry (Wiimote, Kinect, Leapmotion, MyndBrain etc...).

Most of these original musical instrument prototypes were played principally by their inventors, who developed simultaneously technology (interfaces, sound processing), artistic works and often idiosyncratic skills to play their instruments. Early prototypes were not always easily sharable with other practitioners. The MIDI standard (Musical Instrument Digital Interface), established in 1983 and rapidly adopted, greatly facilitated then the modular use of different “controllers” (i.e. the physical interfaces) with different “synthesizers”, i.e. sound generation units. This contributed

to foster the representation of digital musical instruments as composed of a “controller/interface” and a “digital sound processor”, both being changeable independently. Unfortunately, the MIDI standard froze the music interaction paradigms to a series of events triggering, using a very basic and limited model of musical events. Any more complex descriptions of gesture and sound are absent from the MIDI format. As a matter of fact, the MIDI piano keyboard, fitting this interaction paradigm, has remained for a long time the primary interface to control sound synthesis.

Nevertheless, a growing community formed of scientists, technologists and artists has explored approaches “beyond the keyboard” and MIDI representations (Miranda & Wanderley, 2006). The international conference NIME (New Interfaces for Musical Expression), started in 2001 as a workshop of the CHI conference (Bevilacqua et al., 2013), contributed to expand this community. A competition of new musical instruments also exists since 2009 held at Georgia Tech³. Nevertheless, the acronym NIME might be misleading, since this community, actually very heterogeneous, is not only focused on “interfaces” but is active on a broader research agenda on “musical instruments” and “interactions” (Tanaka et al., 2010).

The historical perspective we outline on electronic musical instruments should convince the reader that pioneering works in music technology often anticipated or at least offered stimulating applications of emerging technologies. We argue that music applications represent exemplary use cases to explore new challenges stimulated by advances in sciences and technology. In this chapter, we will describe the approach that we developed over ten years in the Real-Time Musical Interactions team⁴ at Ircam concerning musical interfaces and interactions. By explaining both the general approach and specific examples, we aim at illustrating the links between this research and the current topics of the Human Computer Confluence research.

This review will describe design principles and concrete examples of musical interaction that are apprehended through embodied, situated and social interaction paradigms. Musical expression results from complex intertwined relationships between humans (both performing and listening) and machine capabilities. As music playing is in its essence a collective multimodal experience, musical interactions mediated by technologies provoke important research questions that parallels the challenges identified by the HCC agenda, such as “Experience and Sharing”, “Empathy and Emotion”, and “Disappearing computers” (Ferscha, 2013).

We will start by recalling some background and related works in Section 2, followed by our general approach in Section 3. In Section 4, we present examples of tangible interfaces and objects used in musical interactions. In Section 5, we describe the methodologies and tools to design motion-sound relationships. In Section 6, we

³ Margaret Guthman Musical Instrument Competition <http://guthman.gatech.edu/>

⁴ Since 2014, the name has changed to Sound Music Movement Interaction

briefly show how this research is naturally extended to collaborative interactions, before concluding in Section 7.

7.2 Background

We recall in this section important related works on formalizing musical interfaces and gestures. Wanderley and Depalle (Wanderley & Depalle, 2004) described a Digital Musical Instrument (DMI) as composed of an interface or gestural controller unit and a sound generation unit. These two components can be designed independently, in contrast to acoustic instruments. This representation must be completed by the mapping procedure that allows for linking sensor data to sound processor parameters, which is often represented as a dataflow chart. The mapping procedures have been formalized and recognized as a key element in the digital instrument design, with both technical and artistic challenges (Hunt & Kirk, 2000; Hunt et al., 2003). In particular, several studies, methods, and tools have been published (Wanderley & Battier, 2000; Wanderley, 2002.; Kvifte & Jensenius, 2006; Malloch et al., 2006; Malloch et al., 2007).

In parallel to the development of mapping strategies, important research has focused on musician gestures and movements. Following on early works by Gibet and Cadoz (Cadoz, 1988; Gibet, 1987; Cadoz & Wanderley, 2000), several authors formalized and categorized musical gestures (Godøy & Leman, 2009; Jensenius et al., 2009). Different gesture types involved in music playing can be distinguished: sound-producing gestures but also movements less directly involved in the sound production such as communicative gestures, sound-facilitating gestures, and sound-accompanying gestures (Dahl et al., 2009). Different taxonomies have been proposed, revealing that musical gestures cannot be reduced to simple discrete gestural control mechanisms. In particular, continuous movements, with different phases (e.g. preparation, stroke and release) and co-articulation effects must be taken into account (Rasamimanana & Bevilacqua, 2009).

Our research builds on musical gesture research as well as research in human computer interaction. For example, our approach can be related to what Baudouin-Lafon described as "Designing interaction, not interfaces" in a well-known article (Beaudouin-Lafon, 2004). While this article does not discuss music interaction *per se*, his description of "instrumental interaction", "situated interaction" and "interaction as a sensori-motor phenomena" is particularly pertinent for our musical applications as described in the following sections.

7.3 Designing Musical Interactions

We developed over the years a holistic approach to the design of digital musical instruments, that could not be represented solely as a series of technical components chained together. Our approach is based on the concepts described below.

First, our gesture studies performed in the context of acoustic instruments (Rasamimanana & Bevilacqua, 2009; Rasamimanana et al., 2009; Schnell, 2013) and augmented instruments (Bevilacqua et al., 2006; Bevilacqua et al., 2012) helped us to formalize fundamental concepts that remain valid for digital musical instruments. We paid particular attention to the notions of *playing techniques* apprehended at high cognitive level by the performers (Dahl et al., 2009). As formalized by Rasamimanana (Rasamimanana, 2008; Rasamimanana, 2012), these can be described as action-sound units, which are constrained by the instrument acoustics, biomechanics and the musician skills.

Second, we consider the interaction between the musician, the instrument and the sound processes as “embodied” (Dourish, 2004; Leman, 2007), learned through processes described by enactive approaches to cognition (Varela et al., 1991). Playing an instrument indeed involves different types of feedback mechanisms, which can be separated in a primary feedback (visual, auditory and tactile-kinesthetic) and secondary feedback (targeted sound produced by the instrument) (Wanderley & Depalle, 2004). These feedbacks create action-perception loops that are essential to sensorimotor learning, and leads the musicians to master their instruments through practice. We consider thus the musical interaction as a process that implies various degrees of learning and that evolves over time.

Additionally, the social and cultural aspects are to be carefully considered. For example, Schnell and Battier introduced the notion of “composed instrument” (Schnell & Battier, 2002), considering both technical and musicological aspects. As a matter of fact, our research is grounded by collaborations with artists such as composers, performers, choreographers, dancers but also by industrial collaborations. In each case, the different sociocultural contexts influenced important design choices.

Figure 7.1 shows important elements we use in our digital instrument design, which are summarized below as two general guidelines that will be illustrated throughout the end of this chapter:

- Motion-sound relationships is designed from high-level description of motion and sound descriptions, using notions of objects affordances (Gibson, 1986; Tanaka, 2010; Rasamimanana et al., 2011), gestural affordances of sound (Godøy, 2009; Caramiaux et al., 2014), playing techniques (Rasamimanana et al., 2011; Rasamimanana et al., 2006), and metaphors (Wessel & Wright, 2002; Bevilacqua et al., 2013). The performers control sound parameters such as articulation and timbre or global musical parameters. In most cases we abandoned the idea that the performers control musical notes (i.e. pitches) as found in classic MIDI controllers. The motion-sound relationship should favour the building of action-perception

- loops that, after practicing, could be embodied. Therefore, particular attentions must be drawn to the sensori-motor learning processes involved.
- The computerized system is the *mediator* of musical interactions, which encompasses all possibilities from listening to performing. In particular, the mediation can occur between participants: musicians and/or the public. The problem is thus shifted from *human-computer interaction* to *human interactions mediated through digital technologies*.

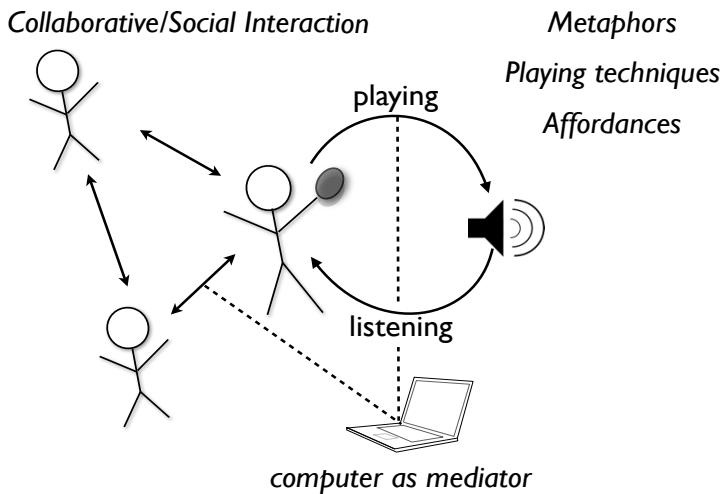


Figure 7.1: Computer-mediated musical interaction: action-perception loops (performing- listening) can be established taking into account notions such as objects affordances, playing techniques and metaphors. The collaborative and social interactions should also be taken into account

7.4 Objects, Sounds and Instruments

Music performance is traditionally associated to the manipulation of an acoustic musical instrument: a physical object that has been cautiously crafted and practiced for several years. On one hand, many digital musical instruments can be viewed in the legacy of this tradition, replacing acoustic elements by digital processes. In some cases, designing and building the controller/interface is part of an artistic endeavour (Oliver, 2010).

On the other hand, digital music practices also challenge the classical role of the instrumental gestures and the instrument in several aspects. In some cases, the performance may be limited to simple actions (e.g. buttons and sliders) that control complex music processes without requiring any particularly virtuosic motor control,

which challenges traditional notions of musical virtuosity. In other case, the interface might be based on non-contact interfaces or physiological sensors that have no equivalent in acoustic instruments⁵.

A great variety of interfaces emerged over the past decade, in parallel to the development of DIY ("Do It Yourself") communities such as the community around the Arduino project⁶. Based on our different collaborations with artists and practitioners, it became evident there is a strong need for customizable motion-sensing interfaces, to support a great variety of artistic approaches.

Based on such premises, we developed the Modular Musical Objects (MO), within the Interlude project⁷ conducted by a consortium composed of academic institutions (Ircam, Grame), designers (No Design), music pedagogues (Atelier des Feuillantines) and industrial partners (Da Fact, Voxler).

The general goal was to empower users to create their own "musical objects", which necessitates the customization of both tangible interfaces and software (Rasamimanana, et al., 2011). The project included the development of various scenarios based on object and sound affordances and metaphors (Schnell et al., 2011; Bevilacqua et al., 2013).

The first part of the project consisted in the design of an ensemble of hardware modules for wireless motion and touch sensing. These interfaces can be used alone or combined with existing objects or instruments. The exploration with different combinations, in particular with every-day objects, enable for the experimentation of movement-sound relationships.

From a technical point of view, the MO interfaces are based on a central unit containing an inertial measurement unit (3D accelerometer and 3 axis gyroscope). The central unit is connected wirelessly to a computer (Fléty & Maestracci, 2011). This central unit can be combined with various active accessories bridging to other sensors, passive accessories or objects. For example, a dedicated accessory connects piezo sensors to the MO (see Figure 7.2). These piezo sensors, when put on a object, allows for sensing different touch modalities (tap, scratching, etc) by directly measuring the sound wave transmitted at the surface object.

The second part consisted in creating scenarios with software modules for motion analysis and sound synthesis mostly based on recorded sounds (Schnell et al., 2011; Schnell, et al., 2009). The general design approach and scenarios have been described in several publications (Rasamimanana et al., 2011; Schnell et al., 2011; Bevilacqua et al., 2013; Schnell et al., 2011). We recall here some examples.

⁵ however one might argue that the role of the conductor could be similar to some non-contact interfaces

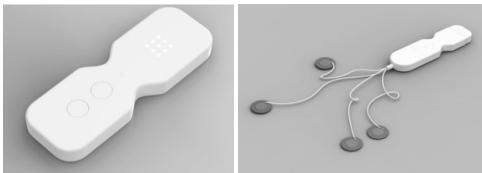
⁶ <http://www.arduino.cc>

⁷ <http://interlude.ircam.fr>, 2008–2011

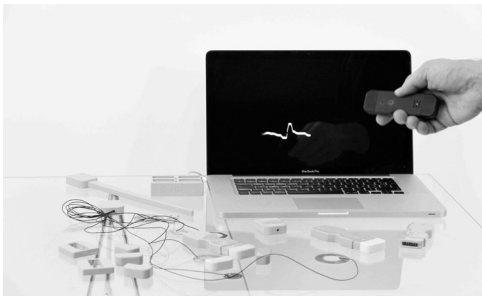
A first case is the MO-Kitchen as illustrated in Figure 7.2. Here, several kitchen appliances were transformed into “musical objects”. For example a whisk with a MO attached to its top was used to control various guitar riffs, performing either small oscillatory motion or energetic strokes.

It is interesting to observe that the original affordance of the object is extended or shifted by the musical interaction. Introducing a feedback loop between the action and the perception modifies the original affordance towards an “action-sound” affordance. Similarly, associating an action to a particular sound will also modify its perception. Therefore, designing musical interactions is achieved by experimenting iteratively with objects, sounds and actions, until consistent action-sound relationships emerge.

Modular Musical Objects: from concepts to scenarios



simulation: a sensor unit with different passive and active accessories



prototypes



MO-Kitchen: scenario with kitchen appliances

Figure 7.2: Modular Musical Interfaces by the Interlude Consortium. Top: 3D simulation of the central motion unit (top-left) that can be modified with passive or active accessories (design: NoDesign.net, Jean-Louis Frechin, Uros Petrevski). Middle: Prototypes of the Modular Musical Objects. Bottom: MO-Kitchen scenario, illustrating the case where the MO are associated with everyday objects (Rasamimanana, Bloit & Schnell)

In another application, metaphors were used to illustrate action-sound relationships. For example, the *rainstick* metaphor was used to represent the relationship between titling an object and the simulation of “sound grains” (i.e. small sound segments) sliding virtually inside the object⁸, the *shaker* metaphor was used to represent the relationship between moving energetically an object with various rhythmic patterns.

Other actions such as tracing in the air or scratching a surface were also used to control different sounds, establishing relationships between various motion characteristics (e.g. velocity and/or shape) and sound descriptors. The next section describes different strategies and tools that were developed to formalize, model and implement these cases.

7.5 Motion-Sound Relationships

Two distinct problems need to be solved to implement motion-sound interaction following the guidelines we proposed. In the first case, we wish to design movement and playing technique that match particular sounds. We describe below an approach based on what we refer to as *embodied listening*. In the second case, we aim at building interactive systems, which require programming the gesture-sound mapping procedures. We present a short overview of systems we built, using machine learning techniques.

7.5.1 From Sound to Motion

Listening to sound and music induces body movements, consciously or unconsciously. An increasing number of neuroscience studies describe the interaction occurring between listening and motor functions. For example, neurons in monkey premotor cortex were found to discharge when the animal hears a sound related to a specific action (Kohler et al., 2002). Fadiga showed that listening to specific words can produce an activation of speech motor centres (Fadiga et al., 2002). Lahav found activation in motor-related brain regions (fronto-parietal) occurring when non-musician listen to music they learned to play by ear (Lahav et al., 2007).

In the music research field, Godoy and collaborators explored different types of movement that can be performed consciously while listening, such as “mimicking” instrumental playing (Godøy et al., 2006b), or “sound tracing” that corresponds to moving analogously to some sound characteristics (Godøy et al., 2006a). Leman et al.

⁸ a first version was developed in collaboration with the composer Pierre Jodlowski in the European project SAME and called the Grainstick

explores embodied listening by seeking correlation between musician and audience movements (Leman et al., 2009).

We found that exploring the movements induced by listening represents a fruitful approach to design movements-sound interaction. We perform experiments where subjects were asked to perform movement while listening to various sounds and short music excerpts. Different strategies are typically opted by the subjects, depending on the sound type and their cultural references. In some cases, it is possible to find a correlation between specific motion and sound parameters (Caramiaux et al., 2010). In a second study, we compared movement strategies that occur when “mimicking” sound, obtained from every day objects or obtained through digital sound processing (Caramiaux et al., 2014). We found that the users tend to mimic the action that produced the sound when they can recognize it (typically linked to every day objects), otherwise they tend to perform movement that follows acoustic sound descriptors (e.g. energy, pitch, timbral descriptors) in the case of abstract sound that cannot be associated to any every-day action.

From these experiments, we learned that, across participants, different movement strategies exist that often directly reveal which sound features the participants perceive (Tuuri & Eerola, 2012). Interestingly, a subject tends to converge after several trials to idiosyncratic movements associated to a given sound, while remaining very consistent and repeatable over time. This fact offers a very promising methodology to create user-centred approaches to specify movements-sound relationships (Caramiaux et al., 2014b).

7.5.2 From Motion to Sound

Generally two approaches for motion-to-sound mapping are generally proposed: explicit or implicit mapping. Explicit mapping refers to using mathematical relationships where all parameters are set manually. Implicit mapping procedures refer to setting relationships through implicit rules or learning procedures, typically using machine learning techniques (Caramiaux & Tanaka, 2013). Both strategies are actually complementary and can coexist in a single application (Bevilacqua, et al. 2011).

We have developed different implicit methods and an ensemble of tools (mostly in the programming environment Max/MSP⁹). First, regression techniques or dimensionality reduction (e.g. principal component analysis) (Bevilacqua, Muller, & Schnell, 2005) were implemented to allow for relationships that map, frame by frame, n input to m output. Recent works make use of Gaussian Mixture Regression (François et al., 2014).

⁹ <http://www.cycling74.com>

Second, time series modelling were also implemented to take into account temporal relationships. In particular, we developed the *gesture follower* that allows for motion synchronization and recognition. It makes use of a hybrid approach between dynamic time warping and Hidden Markov Models (Bevilacqua et al. 2007; Bevilacqua et al., 2010). Working with any type of data stream input, the *gesture follower* allows for aligning in real-time a live performance with a recorded template. Thus, this allows for the synchronization of different temporal profiles. In this case, the motion-sound relationship is expressed in the time domain, which we denote as *temporal mapping* (Rasamimanana et al., 2009; Bevilacqua et al., 2011).

The initial *gesture follower* architecture was further developed into a hierarchical model (François et al. 2012). For example, different movement phases such as preparation, attack, sustain, release can be taken into account. Second he extended the concept of temporal mapping using a Multimodal Hidden Markov Model (MHMM) (François et al. 2013b, 2013a). In this case, both gestural and sound data are used simultaneously for training the probabilistic model. Then, the statistical model can be used to generate sound parameters based on the movement parameters.

The important point is that these machine-learning techniques allow us to build mapping *by demonstration* (similarly to some methods proposed in robotics) (François et al., 2013a). Thus, these techniques can be used in the scenarios we described in the previous section, where the user's motions are recorded while listening to sound examples. These recordings are used to train the parameters that describe the motion-sound relationships. Once this is achieved, the user can explore the multimodal space that is created. Such as methodology is currently experimented and validated.

7.6 Towards Computer-Mediated Collaborative Musical Interactions

Music playing is most of the time a collaborative and social experience (Schnell, 2013). Computer-mediated communication is nowadays fully integrated in our cultural habits. Music technology started to integrate collaborative aspects in several applications, with new tools to jam, mix or annotate media collaboratively. Nevertheless, computer-mediated performance remains mainly concerned with either a single performer, or performers with their individual digital instruments. There are notable exceptions of course, such as the *reactable*, a tabletop tangible user interface that can be played collaboratively (Jordà et al 2007) , or also some examples found in laptop and mobile orchestras (Oh et al. 2010).

The different concepts and systems we described previously have been extended to collaborative playing. Figure 7.2-bottom illustrates an example where several MOs interfaces are used simultaneously. Other scenarios were explored with sport balls, inserting a miniaturized MO inside the ball. Games and sport using balls represents interesting cases that be used as starting points to invent new paradigms of music playing.

In the project Urban Musical Game¹⁰, different scenarios were implemented. The first one was to collaboratively play music, the balls being used as instruments. Different playing-techniques (roll, throw, spin etc) were automatically linked to different digital sound processes (N. Rasamimanana et al., 2012). The second one was to focus on a game inspired by existing sports (volleyball, basketball). In this case, the sound produced by the ball motion was perceived as accompanying the game. A third class of scenarios corresponded to games driven by the interactive sound environment. In this case, the game depends on specific sound cues given to the users (see Figure 7.3).



Figure 7.3: Example of one scenario of the Urban Musical Game. Participants must continuously pass the ball to the others. The person loses if she/he holds the ball when an explosive sound is heard. This moment can be anticipated by the participants by listening to evolution of the music : from the tempo acceleration and the pitch increase. Moreover, the participants can also influence the timing of the sonic cues by performing specific moves (e.g. spinning the ball)

In summary, the Urban Musical Game project allowed us to explore different roles for the sound and music in collaborative scenarios. We have just scratched the surface of important research that are necessary to develop further computer mediated collaborative interaction that will profit from the rapid growing of connected objects.

¹⁰ by Ircam-NoDesign-Phonotonic

7.7 Concluding Remarks

We presented here concepts that guided us for the development of motion-based musical interactions. While the controller/interface plays a significant role in such interactions, we argue that the important part of the design should be devoted to motion-sounds relationships. These relationships can be developed using concepts such as affordances, playing techniques and metaphors. Importantly, concepts from embodied cognition, applied in both listening and performing situation, reveal to be fruitful for designing and modelling musical interactions.

We briefly described some techniques based on machine learning to implement the musical interaction scenario, which allows designed to handle notion of movement phrases and playing techniques that can be defined by demonstration. We believe this represents a promising area of research which should eventually allow non-specialists to author complex scenarios.

We stress that the musical interactions we described can be seen as interaction *mediated* by technology. Even if tangible objects often play a central role in the presented interactions, the presence of the computer itself disappears – or at least us not perceived as such. In most of our musical applications, the computer screen is not part of the interface and hidden from the users. This allows the players to fully focus their attention on mutual interaction and collaboration keeping the designed mediation technologies in the role of supporting playing and listening.

Musical interactions can thus represent fruitful and complex use cases related to HCC research. This implies cross disciplinary projects, between scientist, technologist but also artists and designers, contributing essential elements of research and helping to shape innovative approaches.

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