

The McGill Digital Orchestra: An Interdisciplinary Project on Digital Musical Instruments

Sean Ferguson¹ and Marcelo M. Wanderley²

¹ DCS, CIRMMT, Schulich School of Music, McGill University

² IDMIL, CIRMMT, Schulich School of Music, McGill University

Background in digital musical instruments. A digital musical instrument (DMI) comprises a control surface that controls the parameters of a digital synthesis algorithm in real time. In the Digital Orchestra Project, a three-year research/creation project, the synthesis engine was hosted on a general-purpose computer, while the gestural control surfaces were new hardware devices created for the project. The mapping between gestural data and synthesis parameters was carried out through the use of custom-written software: The Mapper.

Background in music performance. From a performance perspective, a successful DMI should allow the performer to feel that he or she has accurate control of the musical result of their performance. This sensation results from a number of different factors, including the responsiveness of the instrument (low, consistent latency), haptic feedback, the mapping strategies used, and the reproducibility of musical ideas, among others.

Aims. The aim of the project was to develop and use a number of new DMIs with musical potential comparable to that of existing acoustic musical instruments. An important goal was to foster long-term interdisciplinary collaborations between instrument designers, composers and performers. We also wanted to address the issue of reproducibility in the performance of digital musical instruments by developing appropriate notation methods.

Main contribution. The Digital Orchestra resulted in the development of several new DMIs, from laboratory prototypes to fully-fledged concert instruments. Composers created new works for small ensembles that included these instruments. A musical notation based on dynamic visual elements displayed on a computer screen was developed. The project notably included three years of intensive training on these instruments by performers who had previously already achieved a high level of expertise on acoustic musical instruments.

Implications. The McGill Digital Orchestra presents a number of paradigms for the design, creation and performance of digital musical instruments in the context of a long-term interdisciplinary, collaborative environment. Based on our experience, we propose that one effective measure for the evaluation of a digital musical instrument is its ability to reproduce a performance of a particular piece, either by the same performer or by different performers. This involves the ability to realize a piece based on a notated score, whether on paper or using software-based visual feedback in a graphical environment. We suggest that this may aid in ensuring the viability and longevity of a novel digital musical instrument. The results of this approach to DMI design include instruments that have been used in high-profile professional performances and that are still being actively used by several performers world-wide.

Keywords: Music Technology, Composition, Performance, Digital Musical Instruments.

• *Correspondence:* Marcelo M. Wanderley, Schulich School of Music, McGill University, 555 Sherbrooke Street West, H3A1E3, Montreal, Qc, Canada, e-mail: marcelo.wanderley@mcgill.ca

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Introduction

Digital technologies have revolutionized the way we communicate, interact and learn. Music is another area where such technologies have had a strong impact, most notably the use of computers for music creation and performance. In this domain, the development and musical use of Digital Musical Instruments (DMIs)—musical instruments comprised of a gestural controller (also called a hardware interface or a control surface) used to control the parameters of a digital synthesis algorithm in real time, through pre-defined mapping strategies [Miranda and Wanderley, 2006]—is a burgeoning research field.

The design of novel DMIs has been the focus of much attention in recent years [Cook 2001; 2009] [Wanderley and Depalle, 2004] [Jordà 2005] [Malloch et al. 2006] [Overholt 2009], most notably through the NIME (New Interfaces for Musical Expression) Conferences. NIME started as a workshop during the ACM CHI 2001 Conference in Seattle, becoming a fully-fledged conference in 2002 with NIME02, held in Dublin. Although before NIME a very large body of work had already been developed in this field [Piringer, 2001] (see [Wanderley and Battier, 2000] for a comprehensive review), NIME helped to focus the field as a research community and created an interdisciplinary forum for the showcase of novel DMIs, with several *hundred* designs presented since its inception [Marshall, 2009].

But apart from the technological aspects of device design, a major issue to be studied in this field is the musical use of DMIs. In this aspect, unfortunately, the situation is rather different, with only a reduced number of works that have directly addressed the musical use of DMIs, among others [Machover, 1992][Ryan, 1992][Schloss and Jaffe, 1993][Siegel and Jacobsen 1999][Tanaka, 2000][Burtner 2002; 2003][Oore, 2005][de Laubier and Goudard, 2006][Dobrian and Koppelman, 2006][Butler, 2008][Palacio-Quintin, 2008] and [Stewart, 2010]. For studying the musical potential (composition and performance) of DMIs, a medium to long-term project would be essential where composers and performers can use “stable” or “mature” versions of DMI prototypes as part of their composition and performance practices, ideally in close collaboration with instrument designers.

The McGill Digital Orchestra was proposed as an answer to such need. The Digital Orchestra was a three-year research/creation project that included the development and refinement of a number of novel DMIs and the composition and concert performance of several new musical works written for these instruments. The Project originated from a series of interdisciplinary seminars given at McGill University by Marcelo Wanderley, Sean Ferguson and D’Arcy Philip Gray.

The Digital Orchestra Project

The goal of the Digital Orchestra Project was to create a number of new digital musical instruments with musical potential comparable to that of existing acoustic musical instruments. Our approach centered on the formation of interdisciplinary

teams of instrument designers, performers and composers. These teams participated in the design, creation and refinement of new instruments, which were then used in the composition and concert performance of a number of original musical works. An important goal was to leverage the expertise of elite performers on traditional orchestral instruments to provide ongoing feedback to the instrument designers. We also wanted to address the issue of reproducibility in the performance of digital musical instruments by developing appropriate notation methods.

Our focus on interdisciplinary collaboration resulted from the desire to create instruments that would remain viable and in use following the tenure of the project. One risk in an approach in which a single person working alone fulfills all the roles of instrument designer, composer and performer is that the resulting instrument – though possibly of interest in various ways – is only ever used by its inventor. The current scene is peppered with unique and fascinating digital instruments with a performer base of one. In the Digital Orchestra, we hoped to develop a methodology for the process of creating DMIs that would increase the likelihood of their being adopted by performers other than the instrument's designer.

The project was planned to take part in three distinct phases. In year one, teams of instrument designers freely experimented with various sensing technologies and together with composers created a large number of prototypes of hardware and software tools. Performers of orchestral instruments carried out testing of these prototypes, as well as practicing on prototypes previously developed for the interdisciplinary seminars briefly mentioned above and described in more detail in the next section. Their impressions of the novel prototypes provided valuable feedback for interactive development of the instruments.

In year two, three teams – each of which included performers, composers, and instrument designers – created new hardware interfaces, synthesis engines and digital signal processing and analysis tools based on the prototypes from year one. At the end of this year, the goal was to finalize the tools of the Digital Orchestra to prepare for concert use in the following year, including documentation. At the end of this year, the composers began preliminary work on new compositions using the resources of the project.

In the third and final year, the composers completed new works for concert performance at the 2008 MusiMarch Festival in Montreal. During this period, the role of the instrument designers shifted from a strictly developmental one, to include support for the technical requirements of each of the works composed for this concert.

While the above planned structure was largely maintained, some alterations did occur. One of the most significant was that the number of concert works that were composed went far beyond the pieces that were performed during the 2008 MusiMarch Festival. The three composers who participated – Sean Ferguson, D. Andrew Stewart and Heather Hindman – composed a total of eight pieces, which received eighteen performances in all during the duration of the project, including performances in Canada, France and Brazil.

Background: The DMI Seminars

In March 2002, the two authors (a composer and a researcher in music technology, respectively) and percussionist D'Arcy Philip Gray first discussed the need for an interdisciplinary seminar that could be taken by students in music technology, composition and performance. The initial impetus came from Wanderley, then recently hired at McGill, who brought the DMI research to McGill's Faculty of Music from his earlier work at IRCAM [Wanderley and Battier, 2000]. The idea was to move from the design of hardware interface prototypes into fully-fledged DMIs, i.e. instruments that could be used in performances anywhere, anytime, not only in controlled research laboratory settings.

The seminar "Digital Musical Instruments: Technology, Performance and Composition" was first given in January 2003. During the course of the seminar, students formed into groups consisting of at least one representative from each of the three areas. In conjunction with lectures given by the professors, students worked on the joint creation of new gestural controllers for digital synthesis engines. This included the design and construction of the new devices (including both hardware and in many cases software for digital synthesis), the development of playing techniques for the instrument and the composition and performance of new works in an end of term class recital.



Figure 1. A typical work session at the DMI Seminar (Winter 2006). From left to right: instrument designer Eileen TenCate, composer Heather Hindman and performer Jonathan Davis are shown discussing the Tralf (lower right corner of the picture), initially developed by composer Geof Holbrook. While TenCate and Hindman discuss the mapping and sound synthesis aspects of the piece, Davis practices with the DMI.

The seminar was repeated on three other occasions, in the Winter sessions of 2004, 2006 and 2010. Such seminars were designed to allow students to actively collaborate during an academic term (13 weeks) on the design, performance and composition of pieces for novel DMIs. Despite the fact that excellent work resulted in the three opportunities when this seminar was offered (for instance, the T-Stick [Malloch and Wanderley, 2006]), we felt that such a limited duration for this exercise did not allow

for a complete, high-level instrument design/composition/performance cycle. In fact, frequently there was not enough time to fully develop novel DMIs. Even when development time was sufficient, many times performance time was minimal, i.e. performers were only able to begin working with the final version of the instrument shortly before the concert.

The main achievement of these seminars was perhaps the forming of a working method for interdisciplinary, collaborative development of new DMIs. Indeed, one of the main goals of the Digital Orchestra project was to apply this methodology on a larger scale by spreading the activities over a longer, more appropriate time span.



Figure 2. Another view of a typical work session of the DMI Seminar (Winter 2004). At the front (right), percussionist Kristi Ibrahim wearing custom gloves with Force-Sensing Resistors practicing a notated score composed by instrument designer Joseph Malloch (an example of a student taking multiple roles in a seminar). In the background, instrument designer David Birnbaum tests a camera-based controller based on the work of Lyons and colleagues [Lyons et al. 2003].

Remarks on DMI Design

During the DMI Seminars as well as during the Digital Orchestra Project we had several opportunities to explore the development of a number of hardware interfaces and DMIs from scratch. Although it may sound straightforward, the process from the original idea to a commercially viable or musically useful realization is indeed a complex one.

Two classic examples of this process in the literature are the Continuum and the Méta-Instrument [Miranda and Wanderley, 2006]. In the case of the Continuum, the initial idea—the development of a continuous sensing surface—yielded three generations of prototypes, each using a different technological solution: from camera-based finger tracking, to conductive rubber and finally to position sensing with Hall-

Effect sensors [Haken et al. 1998]. Only the last solution proved commercially (and musically) viable due to technological limitations of the first two. A similar case is the *Métra*-instrument, which is also currently in its third generation. Although it has not undergone an equivalent amount of technological changes, several improvements were made over the years to allow for performance variations, for instance, the ability to perform the instrument standing up instead of seated [Laubier 1998][Laubier and Goudard, 2006].

One important difference nowadays, if compared to the early developments in the 80's and 90's, is the astonishing ease with which a gestural controller can be built, thanks to the recent wide availability of inexpensive, user-friendly technologies such as the Arduino platform¹. Indeed, the prototyping of a device using a variety of sensors can be completed in just a few minutes, even by inexperienced designers. But although such prototypes can be an acceptable solution for a class project (i.e. a proof-of-concept), they are hardly ever a reliable musical instrument that can be played in concert venues.

Several issues need to be taken into account when improving a prototype to become a musical instrument. For instance, one fairly common surprise when moving a laboratory prototype based on video sensing (e.g. colour tracking) using video cameras, out of a laboratory to a concert venue is the discovery of the high sensitivity of cameras to ambient conditions. Indeed, sensors do not adapt as easily to light variations as the human visual system does. In this case, a setup calibrated in a room with a window will probably not work as initially expected in a concert hall, or even in the same room at different moments of the day. Similarly, infrared sensors that are much less sensitive to ambient conditions can be strongly affected by concert hall lights, that actually also generate infrared light. Unfortunately, these and other annoying situations are only commonly noticed at the actual concert venue, causing major frustration to all involved: performers, instrument designers, composers and, not the least, the audience.

Yet another gap between devices used in controlled environments and DMIs is the choice of sensor technologies used. For instance, as discussed in [Silva et al. 2005], in order to sense the intensity and the direction of the air jet in a transversal flute, very accurate measurement techniques such as Pitot tubes and hot wires that could be used in a research laboratory are not usable in a device to be played in a concert for several reasons, including price, obtrusiveness and complexity of setup. The solution in that case was to use a dual static pressure sensor and obtain an approximation of the intensity and direction values of the air jet from both pressure measurements. Such a solution worked well for a musical instrument, but would probably not be considered for acoustic measurements where accuracy and repeatability requirements are more stringent.

Ergonomics is another crucial factor in DMI design. For example, one gestural controller that we initially thought had a good musical potential in this project was the *Gyrotyre* [Sinyor and Wanderley, 2005]. This interface consists of a moving bicycle wheel held by a performer, whose rotation speed and inclination are sensed by a variety of sensors. Preliminary experiments using this device with a variety of

mappings allowed for a flexible usage as either a solo or accompanying instrument. When tried out by the performers of the project, though, it was not considered as a viable option for the final concert, since the performers thought that its weight was excessive and that it could cause injuries. This situation was not apparent when we were using it for experiments in the laboratory, but was obvious for professional performers who are more aware of their physical condition than are university researchers.

Finally, robustness is important when one considers that musical instruments are played in diverse environments for several years. For a performing musician, it is not normally possible to have a technician available at all times to fix technical problems during the life of an instrument, while this is not necessarily a major problem in a research laboratory.

As can be seen from the above and for many other reasons, the gap between a laboratory prototype and a fully-fledged musical instrument is large and indeed several design iterations and improvements are usually needed to achieve a stable (or mature) version of a DMI.

Examples of DMIs

In this section we will briefly describe three DMIs that were designed and used in the project. They are the T-stick, the T-box (originally named the Tralf) and the Rulers. Many more details on the specific DMI developments during the project can be found in several related publications, for instance [Sinyor and Wanderley, 2005] [Malloch et al. 2006] [Malloch, 2007] [Malloch and Wanderley, 2006] and [Pestova et al. 2009].

T-stick

The T-stick is a tube-like gestural controller equipped with capacitive sensors measuring touch on its surface, accelerometers measuring its inclination as well as its acceleration and deceleration, a piezo crystal measuring deformation and shock applied to the tube, and a pressure sensor that allows the performer to continuously control the pressure of the grip he uses to hold the device. Several T-sticks have been built (roughly 20) with various sizes and features, although all share the common characteristics described above [Malloch, 2007].

T-box

The T-box uses ultrasound transducers to measure the position of a performer's hands with respect to a fixed reference. Two attachments for the hands each containing an ultrasound transducer (facing the floor) are worn by the performer, who then moves her hands up and down with respect to a wooden box where four ultrasound transducers are placed (facing the ceiling). The amplitude of the signal from the emitting transducer is measured by the receiving one, providing continuous information about the vertical position² of the hands in space. Lateral movements of the hands can create discontinuities in the signal captured by the receivers due to the

narrow directional characteristics of the transducers, therefore also providing a way to control discrete events.

Rulers

The Rulers instrument is a hardware interface composed of several metal rulers (bars) of various lengths, developed by David Birnbaum, [Malloch et al. 2006]. When pressing down or lifting a ruler, as well as when striking them, their positions are sensed by infrared light sensors placed under each bar. The Rulers may be played either with the fingers or the whole arm.

Criteria for the Evaluation of Digital Musical Instruments

Over the years, a number of criteria have emerged to evaluate digital musical instruments from multiple viewpoints.

Reproducibility and Continuous Control

Musical instruments that allow a performer to express herself musically must permit an artist to imagine a musical idea and to reproduce it consistently. If a gesture has an indeterminate musical result, one cannot say that the performer is in control of the instrument. Acoustic musical instruments may be ranked according to their ability to afford the performer with accurate continuous control. For example, according to this definition wind chimes could be said to have less expressive potential than the cello, since the performer has less precise continuous control over the musical result. In digital musical instruments, the equivalent of a wind chime might be the use of a single gesture to trigger a dense sequence of chance events. We avoid designs whose purpose is solely to initiate random sequences. Note that this is not proposed as a means of determining the musical interest of a particular instrumental paradigm, which may nevertheless be high even when it generates unpredictable events. Our goal is to provide the performer with consistent, reliable and continuous control throughout the sonic life of a musical idea in order to ensure that this musical idea will be reproducible over multiple performances.

Our emphasis on reproducibility is intended to contribute to the potential for the adoption of an instrument by other performers. We feel it is important to ensure that a given instrument can allow the same piece to be played by the same performer on different occasions and venues, or by different performers in different locations. We believe that one of the strongest motivations for learning an instrument is the desire to perform a work that one has heard performed previously and to which one has had a positive reaction. Instruments which feature reproducibility as one of their attributes may therefore have a greater chance of adoption.

Reliability

In the presentation of a new instrument in a scientific context, such as a talk during a conference, it is not unusual for unexpected problems to arise. This experience is sometimes referred to as the “demo effect.” In the context of a conference, most members of the audience will be sympathetic, and the instrument can be demonstrated

in other ways, such as a video recording. In the context of a live performance, however, any failure of an instrument to function exactly as expected, no matter how slight, can be catastrophic. Even minute changes can have a devastating effect on the artistic result, whether they are explicitly noticed by the audience or not. If they are aware of any problems, the listeners in a concert setting cannot be relied upon to have similar scientific experience to that of the designers of the instrument, and they may therefore not exhibit the same degree of sympathy to the plight of the performer. If the demo effect can cause embarrassment to a researcher, the failure of an instrument to function properly during concert can cause stress and humiliation for the performer, and existential crisis for the composer.

All instruments – even traditional orchestral ones – have a risk of failure, such as broken strings, dropped mallets and stuck keys. Nevertheless, we attempted to minimize this risk in a number of ways, including: (1) freezing the addition of new features to an instrument well in advance of the concert; (2) giving performers extensive access to the instruments for explorations and rehearsal; and (3) having the composers write small etudes that acted as proving grounds for their musical ideas, means for performers to learn the instruments, and technological test beds.

Expressive Potential

Many definitions exist for musical expression³. An informal explanation from a performance point of view is that an instrument should afford non-conscious control of the musical result. That is, the performer should be able to modify their gestures in an appropriate way without explicit instructions about the details of the gestures, but based on a vivid image that conjures expressive associations. Consider the scenario of an instrumental lesson in which a teacher attempts to influence a student's performance not by providing specific instructions about which gestures to use, but by using an evocative metaphor or image (such as imagining that one is in a flower-filled meadow on a sunny afternoon). An instrument with expressive potential will react to the minute adjustments that this mental image causes in the performance gestures of the student to alter the musical result in the desired fashion. In other words, the system is capable of extracting information about very fine details of the performance gestures.

This expressive relationship between a performer and his or her instrument is a result of both the design of an instrument and of a highly developed performance practice. On any instrument, musical expression is a result of the development of advanced playing technique over a long period of study. One result of this criterion is that the creation of an instrument that could be easily mastered by a performer within a short period of time was not an objective of the Digital Orchestra.

The evaluation of the expressive potential of an instrument seems to us to be best done by the performer of that instrument, by comparing it to their prior experience with their own musical instruments. Over the course of the three years of the project, feedback from the performers indicated that this aspect of the instrument designs improved constantly, largely due to the performers' input during the design process. For example, the scaling used in a mapping might be adjusted a great deal over the

course of the development of an instrument if the performers felt that changes to the sound were too great or too small for the gestures that engendered them. By the time that they were performed in concert at the end of the project, performers indeed felt that they had expressive control of the instruments.

Interdisciplinary perspectives

In this section we discuss the contributions of each of the disciplines to the overall goals of the project.

Music Technology

DMI design was at the core of the Digital Orchestra Project, and music technologists at McGill performed several tasks in this direction: the study and development of novel pressure and position sensors based on paper [Koehly et al 2006], the use of a variety of sensors available for commercial applications [Wanderley et al. 2006 – SensorWiki] and the evaluation of the choice of sensors that best fit a musical application [Marshall 2009]. The design of novel devices was also carried out by technologists, but with the indispensable help of composers and performers, e.g. the T-Stick, [Malloch and Wanderley 2006], the Gyrotyre [Sinyor and Wanderley, 2005] and the Rulers [Malloch et al. 2006]. Another use of sensors and technology in the project was the development of tools for gestural control of sound spatialization [Marshall, Malloch and Wanderley, 2009], using both existing devices for capturing gestures as well as novel designs.

Apart from the extensive evaluation and testing of a variety of sensors and their use in the design of novel DMIs, instrument designers also developed tools for mapping the sensor outputs to sound synthesis control inputs. This was an interesting, initially unexpected, outcome of the project. In fact, in practice, the development of mapping strategies by an interdisciplinary group of people is not an obvious task for the following reasons: 1) people do not all have the same technical knowledge to approach mapping strategies (i.e. good programming experience with Max/MSP in this case), and 2) in a group, the opportunity to easily create and destroy mappings on the fly simultaneously by different people playing versions of the same controller is essential (contrary to the case of a single instrument designer). The solution to this issue is called the Mapper [Malloch, Sinclair and Wanderley, 2008].

The Digital Orchestra Mapper was designed as a decentralized network for the management of peer-to-peer data connections using the Open Sound Control communication protocol.

An intuitive graphical user interface was developed for dynamically creating, modifying, and destroying mapping connections between control data streams and synthesis parameters (cf. figure 3).

Another software tool that proved essential in the project was the *Digital Orchestra Toolbox* [Malloch et al. 2010], a large collection of Max/MSP objects that help the design of novel DMIs by providing tools for data conditioning and processing⁴.

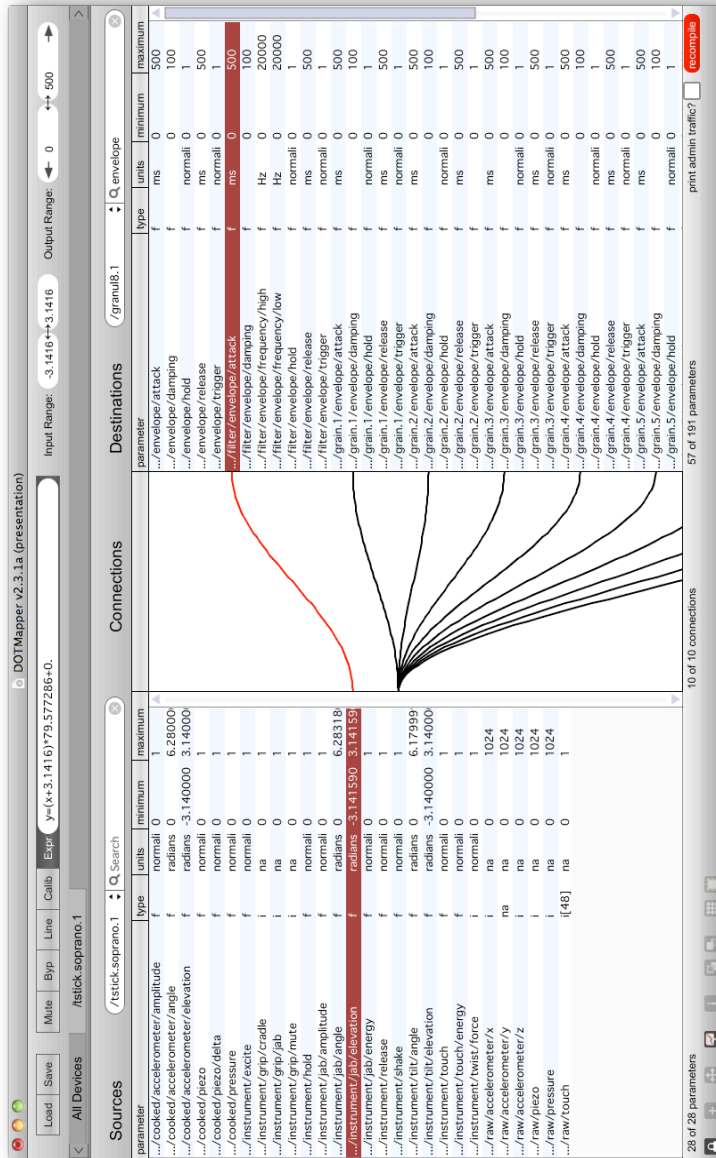


Figure 3. The current graphical interface for the Mapper, developed in Max/MSP. On the left side (Sources), controller parameters are displayed. Raw sensor outputs – in the case of the Soprano T-Stick used in this figure, the values of accelerometer x, y and z axes, the piezo crystal, the pressure sensor and the capacitive sensors – and higher-level parameters are available, such as information about the grip or the amount of energy used by the performer. On the right side (Destinations), the inputs of the synthesis algorithm are displayed, in this case, granular synthesis inputs. The middle part of the figure allows the designer to create connections between both sides, effectively establishing mappings between controller and synthesis variables. Furthermore, as seen in the top part of the figure, designers can condition the mappings defining an expression describing the behaviour one wants to achieve, limiting input and output ranges, etc. A full description of the functionalities of the Mapper is presented in [Malloch et al. 2008].

Composition

An important requirement for the longevity of an instrument is the existence of a compelling repertoire of works that serves to motivate future performances. One of the principal goals of including composers in the development process and including performances in a professional context was to attempt to create viable works of art with value beyond simply demonstrating the capabilities of the instruments.

In order to create a corpus of music, it became apparent that the development of an appropriate system of notation was crucial. In our experience, three different approaches are used: (1) a metaphorical representation of the resulting sound; (2) a graphic representation of the type of gesture desired; or, (3) a symbolic system with no obvious links to either gesture or sonic result. In practice, the type of notation that we have used includes a combination of traditional musical notation with the addition of new graphical elements representing any or all of the above three approaches.

In Figure 4, for example, small circles of various types in the part for the FM Gloves [Marshall, 2010] (indicated on the middle staff as “gl.”) act as a metaphorical representation of short sounds created by tapping gestures of the fingers against the thumbs. Note that the same notation of sonic result is used in the cello part on the top staff, which uses different gestures to create the same result. The small curved arrow in the first measure of the glove part, on the other hand, graphically represents the desired gesture—a rotation of the hand—but does not indicate the sounding result.

Figure 4. An excerpt of the score for *The Long and the Short of It*, for cello and two digital musical instruments, by Heather Hindman.

In Figure 5, the length of the vertical bars on the three-line staff is a graphical indication of the gesture of gripping the t-stick instrument. The bars represent the body of the instrument and the length of the bars indicate the grip to be used. In this case the vertical bars are at their longest, indicating that the entire instrument should be gripped by both hands. The figure in the circle above the barline indicates, among other things, the physical orientation of the instrument; in this case it is to be held vertically. The square grids above the staff are a kind of tablature notation that

indicate two separate instances of a synthesis algorithm that are combined to create the voice of the instrument. The position of each icon in the two-dimensional space of the grid indicates the variation of two control parameters for the algorithm. The performer is to interpolate between the instances of this notation using whatever gestures will create the desired result. The change of the star between the first two grids in this example indicates that only one of these parameters is to change, while the lack of change to the circle indicates that the control parameters of the second instance are not to change. Note that these indications are symbolic and do not correspond directly either to the gesture to be used nor the type of sound that is created. In performance, the user is able to confirm that he or she is accurately producing the desired effect by referring to a matching graphical interface. Composer D. Andrew Stewart developed this dynamic interface to be displayed on a computer screen and used by the performer to provide visual feedback during the rehearsals and performance of a piece: see Figure 6.

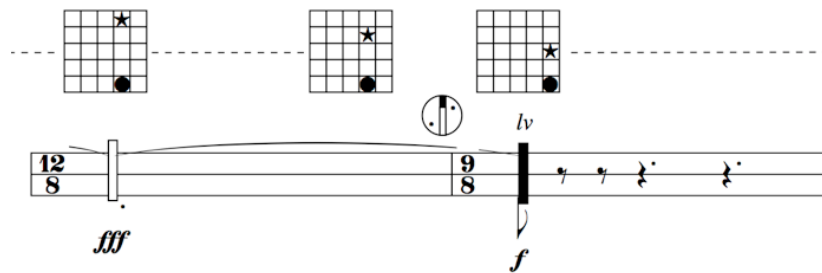


Figure 5. Notation of the t-stick part for *Catching Air and the Superman*.

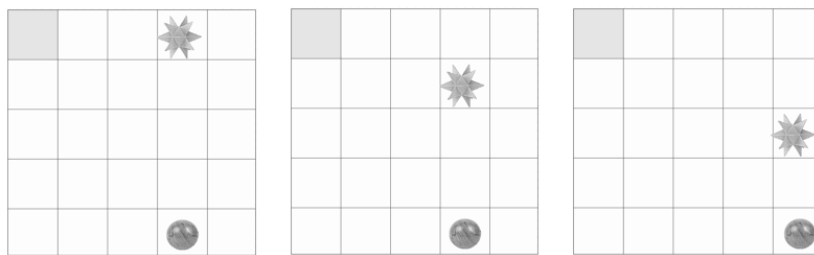


Figure 6. Examples of the dynamic graphical user interface for t-stick notation developed by D. Andrew Stewart for his work *Catching Air and the Superman*. The three grids indicate the state of the display at each of the three points notated in the score in Figure 5. Only one grid is visible on the screen.

One unexpected development that took place during the Digital Orchestra Project was the role taken by composers in collaborating in the development of the mapping of gestures to the parameters of the digital synthesis algorithms that served as the voices of the instruments. In our original conception, mapping was placed within the domain

of the instrument designers. In practice, however, the designers created powerful tools for mapping (e.g. The Mapper, the Digital Orchestra Toolbox), but the responsibility for the actual implementation was shared with the composers. We thus came to see mapping ultimately as being as much an artistic as a technological activity.

As indicated by its title, an important compositional goal of the Digital Orchestra Project was the integration of digital musical instruments into both large and small ensemble settings. This included the combination of different digital musical instruments into a chamber ensemble, as in D. Andrew Stewart's *Sounds Between Our Minds* for three DMIs, or into an ensemble including both digital and traditional acoustic musical instruments, as in Heather Hindman's *The Long and Short of It*, for an ensemble of two digital instruments and cello, or in Sean Ferguson's *Ex Asperis*, for two gestural controllers and large chamber ensemble. One of the greatest challenges of this approach was the blending of the voices of the different instruments in a coherent manner. Different techniques were used to accomplish this. For example, in D. Andrew Stewart's large ensemble work *Catching Air and the Superman* – for two new digital musical instruments, keyboard MIDI controller and a chamber ensemble of 13 instrumentalists – the composer first created the synthesized voices of the two DMIs and then performed spectral analyses on these sounds, using the most prominent partials to derive the microtonal pitches that formed the harmony of the chamber ensemble. In this way, the composer was able to successfully integrate the harmony of the traditional instruments into the timbral world of the DMIs. Other techniques included, for instance, ensuring that the voices of the digital instruments occupied different registers and had different timbres and attacks. In order to create a sense of ensemble, composers often chose to isolate each instrument's voice in a single loudspeaker placed close to the performer, rather than, say, mixing all of the instruments into a single stereo or surround audio environment. In this way it was hoped that listeners would be able to use spatial cues to associate a particular voice with a physical instrument on stage.

Performance

In order to evaluate DMIs for their musical potential, it was crucial to have input from advanced artists who had already experienced a degree of artistic symbiosis with their own instruments, whether it be cello, piano, percussion or any other instrument. The performers involved in the Digital Orchestra provided constant feedback to the instrument designers and composers throughout the entire three-year period. Since the instruments were not designed to be based on existing acoustic instruments, many different types of performers were involved (e.g. piano, percussion, cello, etc.). Furthermore, performers were not necessarily required to have had previous experience with gestural controllers.

Their contributions took a number of different forms. They evaluated the physical aspects of the instruments, such as size and weight. At one point, for example, concern over possible injury to performers due to the heavy weight of one instrument caused it to be rejected for future use in the Digital Orchestra, as described above. They also evaluated the “feel” of the materials of the instruments and helped in the fine-tuning of the tactile feedback that the instruments provided. The performers were

particularly vociferous in their demands for low and consistent latency between gestures and their sonic results.

The composers also benefitted from the performers' expertise. The instrumentalists worked closely on the development of the notation for the instruments and of idiomatic playing techniques. Another important area of collaboration was the appropriateness of physical gestures to musical material.

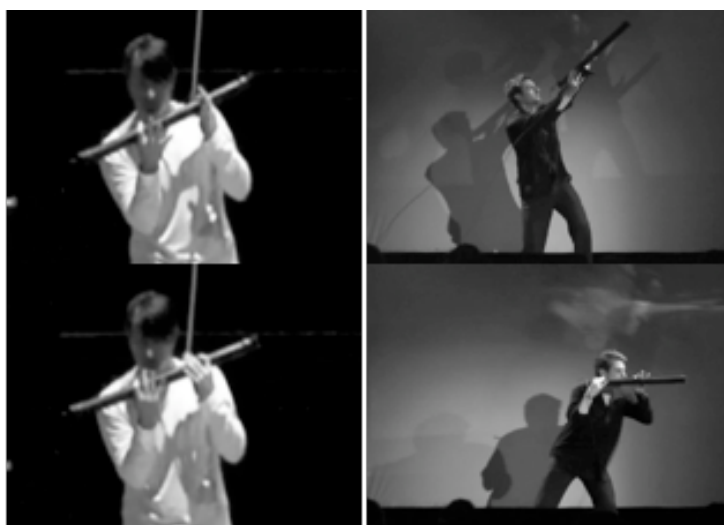


Figure 7. D. Andrew Stewart demonstrating two different playing techniques on the T-stick: tapping (left) and jabbing. In tapping, arms remain stationary, while the sensing of the finger impacts, as well as the orientation of the T-stick, provide control variables. The top image shows the hands in position just before a multi-finger tapping gesture, while the bottom image shows the moment of contact. In jabbing, large amplitude gestures are produced by thrusts of the instrument so that the orientation and the acceleration of the device are the main control variables, as well as hand positioning. The top image is the end point of an upwards jab and the bottom image is the preparation for a horizontal jab.

Since our goal was to design instruments that had the potential to be performed by many different artists, we felt it would be valuable to observe the process of the adoption of a new instrument by a performer who had not participated in its development. At the end of the second year of the project, cellist Erika Donald joined the Digital Orchestra to perform the soprano t-stick in Heather Hindman's piece *The Long and the Short of It*. Ms. Donald was asked to document her experience in learning this new instrument. Her contributions were particularly valuable, since they gave the point of view of a performer approaching a new DMI for the first time. She was given approximately a year to develop expertise on the instrument before performing in concert.

Given our stated desire to create instruments with expressive potential, as described earlier, a fair question would be to what extent were we successful? If the goal was to achieve the same degree of refinement as a traditional orchestral instrument such as the cello within the confines of a three-year research project, then we did not succeed. But if the goal was to use an interdisciplinary approach to move in the proper direction so that the performers felt that they were able to reliably express their musical ideas without undue interference from the instrument, then we believe that the project has been a success. Furthermore, we feel that continuing to work in this way will allow us to move closer to this goal by incorporating feedback from experienced performers into the process of designing and refining DMIs. Ultimately, as in any musical endeavor, the success or failure of the Digital Orchestra Project should be judged by its artistic results. We feel that the enthusiastic response we received to the performances by the Digital Orchestra, both from the general public and from those familiar with the domain of digital musical instruments, is a good indication that we were able to achieve our goals to a large degree.

Conclusion

The McGill Digital Orchestra presents a number of paradigms for the design, creation and performance of digital musical instruments in the context of a long-term interdisciplinary, collaborative environment. Issues related to mapping strategies, notation, the relationship of physical and musical gestures, robustness, responsiveness, and arose during the course of the project. Furthermore, the Mapper software and Digital Orchestra Toolbox continue to be used in other contexts.

Based on our experience, we propose that one effective measure for the evaluation of a digital musical instrument is its ability to reproduce a performance of a particular piece, either by the same performer or by different performers. This involves the ability to realize a piece based on a notated score, whether on paper or using software-based visual feedback in a graphical environment. We suggest that this may aid in ensuring the viability and longevity of a novel digital musical instrument.

The results of this long-term, multidisciplinary approach to digital musical instrument design include interfaces that have been proven in high-profile professional performance contexts and that are still being used actively by several performers world-wide.

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¹ www.arduino.cc

² as well as the orientation of the hands.

³ See, for example, the discussion of "expressivity" in [Malloch et al. 2006]

⁴ Both software tools are freely available from the IDMIL website at www.idmil.org/software

Biographies

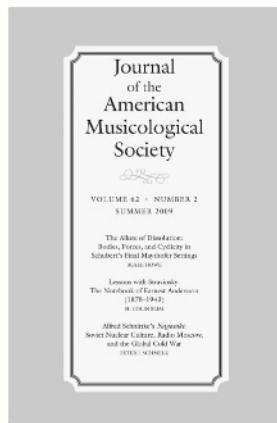
Sean Ferguson is Associate Professor of Composition at the Schulich School of Music of McGill University, in Montreal, Canada, where he directs the Digital Composition Studios. Since 2009 he has also been the Director of the Centre for Interdisciplinary Research in Music Media and Technology. His music has been performed by ensembles such as the Montreal Symphony Orchestra, the *Orchestre Philharmonique de Radio-France*, the *Ensemble contemporain de Montréal* and the *Société de musique contemporaine de Montréal*. In 2009 he served as the Music Chair of the ICMC. His research interests include computer-assisted composition, live electronics and digital musical instruments.

Marcelo Mortensen Wanderley holds a Ph.D. degree from the Université Pierre et Marie Curie (Paris VI), France, on acoustics, signal processing, and computer science applied to music. His main research interests include gestural control of sound synthesis, input device design and evaluation, and human-computer interaction. In 2003 Dr. Wanderley was the Chair of the International Conference on New Interfaces for Musical Expression (NIME03). In 2006, he co-authored the textbook "New Digital Musical Instruments: Control and Interaction Beyond the Keyboard", A-R Editions. He is currently Associate Professor of Music Technology at the Schulich School of Music, McGill University, Montreal, Canada.



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