Designing Professional Instruments for Computer Music Performance

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ABSTRACT

Live performance of computer music is a relatively new phenomenon in the grand scale of music history. While interfaces exist which are explicitly designed for computer music performance, there are relatively few which are to be taken seriously as instruments in themselves. This paper takes a look at the design of such instruments, identifying several desirable characteristics for instrument interfaces, as well as general principles for instrument design. In addition, several notable interfaces are evaluated against these criteria, both to clarify the characteristics and principles and to provide a basic understanding of the ways existing computer music instrument designs are implemented.

Categories and Subject Descriptors

J.5 [**Computer Applications**]: Arts and Humanities—*Performing Arts*; H.5.2 [**Information Systems**]: Information Interfaces and Presentation—*User Interfaces*

Keywords

computer music, musical instruments, music performance, design, virtuosity, expressivity, flexibility

1. INTRODUCTION

Music performance is an art with a long history, but one of the latest chapters finds it exploring an entirely new world. With the advent of computer music, computing has established a presence in the world of music performance and seems likely to stay. Computer music performance, as I will use the term, refers to live performance of computer music by a human performer (as opposed to music composed by a human and then played by the computer). This sort of music performance could be done using a pre-existing interface, such as a mouse, computer keyboard, or touch screen, or it could be performed with a controller intended specifically for music performance, whether that be a MIDI[1] controller or a more specialized instrument.

[1]Musical Instrument Digital Interface - a standardized system for transmitting real time digital music data

Although computer music performance has had a presence in the music world for some time, we have within the last decade or so begun to cross a particularly important boundary: with consumer-grade computers becoming more and more powerful, we are now able to do in software what would have required very specialized hardware twenty years ago [19]. In addition, advancements are being made which open new options for the development of computer music software, such as the use of the Java programming language for real-time sound synthesis [1, 10]. With these advancements, the bar for entry in computer music performance has been significantly lowered, allowing for applications which are both cheaper and easier to produce.

Given these fairly recent developments, it seems now is the time to step into the world of computer music performance. In this paper, I will investigate what it means to create a serious and professional computer music instrument which can exist as a respectable entity within the music world. At the moment, it is rare to find a musician who will identify as a player of a computer music instrument, while many musicians will identify as players of even incredibly obscure traditional instruments. This is a telling indication that computer music instruments are rarely considered to be professional instruments.

I will concern myself here with the characteristics a novel instrument should possess if it is aiming to achieve this professional status (Section 2), and then consider the design paradigms that can be adopted to promote these characteristics (Section 3). I will then utilize these desirable characteristics and design paradigms to analyze several existing computer music instruments (Section 4), both as an illumination of the sort of applications that have been created, and also as further illustration and clarification of the criteria proposed.

It's important to note that I am only considering here instruments that are both novel instruments and direct controllers. By novel instruments, I mean instruments which either build considerably upon a pre-existing interface or utilize a new and unique interface. By direct controllers, I mean the instruments must be used to play music note by note, as opposed to an interface which simply directs the flow or structure of music. Because of this, I will not be considering instruments such as the reacTable [9], as these sorts of interfaces focus primarily on indirect interactions with music.

2. CHARACTERISTICS OF PROFESSIONAL INSTRUMENTS

The primary desirable characteristics for an instrument in computer music performance may not immediately be clear. In the pursuit of a high professional status, novel computer music instruments must address the inherent difficulties and shortcomings of the medium. On the other hand, computer music is already well positioned to excel in certain fashions, so attending to its inherent strengths is no less important. The question then is what these properties are which can stand as overarching criteria for instrument design. Three primary desirable characteristics stand out in the literature: capacity for virtuosity, license for expressivity, and utilization of flexibility. Of these characteristics, virtuosity and expressivity seek to improve intrinsic weaknesses of computer music instruments, and flexibility seeks to capitalize on intrinsic strengths.

2.1 Virtuosity

For most traditional instruments, it may be said that there are some number of virtuosos, musicians who display a level of skill and technique vastly superior to the average player. This status of virtuosity shows that an instrument has sufficient complexity as to allow for near limitless improvement potential amongst its adopters. Roughly stated, the greater the ceiling for technical play, and the more the instrument demonstrates depth and complexity, the more it shows capacity for virtuosity. It's important to note that raw difficulty is not the same as virtuosity: an extremely obfuscated musical interface does not directly correlate to a highly technical interface. Rather, virtuosity requires that an instrument's difficulty be related to its technical depth, and that relevant difficulty be related somehow to the production of the resulting sound. An interface which requires the player to stand on their head while balancing the instrument on one finger is only comically difficult; it does not automatically allow for virtuosity by merit of being hard to play. Unfortunately, computer music instruments often fail to have this capacity for technical play [4]. Technical play requires creating a technically excellent instrument, which is an art not easily mastered. If an interaction is not fluid and consistent, for example, there is no room for the performer to progress in skill, as there can be no guarantee of a correct response from the instrument. Developing an instrument with capacity for virtuosity is a challenge not only of providing sufficient complexity for potential virtuosos to master, but also a challenge of providing mechanics that are both dependable and coherent. Ultimately, virtuosity is a powerful measure of an instrument's promise. [4]

2.2 Expressivity

Expressivity refers to the musician's ability to finely control the details of the instrument's sound, which is often very challenging in computer music. Common modes of expression on most traditional instruments are dynamics (variation in the softness and loudness of the sound) and articulation (variation in the continuity between notes). Many instruments are also able to produce effects such as vibrato (a rapid and often subtle change in pitch) and tremolo (similar to vibrato, with a change in volume instead of pitch). Almost all traditional instruments have a large number of nuanced ways the performer can precisely modify the sound. These sorts of capabilities provide the musician with a much greater degree of creative freedom, and can be used in ways that are very emotionally evocative. Electronic instruments frequently struggle to provide this license for expression largely because of the difficulty of providing interfaces with the depth that a traditional instrument can have [15]. The mechanics of simply plucking a physical string, for example, are incredibly complex, and provide great expressive potential; the angle, force, and position of the string pluck all can contribute to the sound, as can many other factors. Electronic interfaces, on the other hand, are often much more simplistic, providing only a small number of options to the performer for expression; to model the angle, force and position of a plucked string using electronic sensors would be a difficult task, after all. Difficult as it may be, making a computer music instrument more expressive is a major opportunity to level the playing field with traditional instruments. [16]

2.3 Flexibility

Flexibility is one of the great strengths of computer music, and a very important thing for any novel computer music instrument to capitalize upon. While traditional instruments have many strengths, and provide a wealth of ways in which the musician can play extremely complex and engaging music, they are also very rigid in a sense. A violin, for all its wonderful characteristics, can never sound like anything but a violin. In contrast, the sounds a software-driven instrument can possibly produce are effectively limitless, bounded only by imagination and hardware capabilities. This sort of flexibility is a huge boon to computer music, and is one of the most obvious ways in which it can outpace traditional music performance. [7] The greatest barrier to utilization of this potential for flexibility is simply the interface; it's relatively trivial for software to tune an instrument to a new key on the fly during a performance, but quite another thing to provide a mechanism the musician can use to do this accurately and precisely. An instrument may have dozens of ways to dramatically change the way the sound is produced, but if these changes are not accessible to the player during a performance, the instrument's flexibility is severely limited. The parallels to existing natural instruments start to disappear in the quest for greater flexibility, so the designer must rely increasingly on innovation and creativity, which can be a challenging prospect. [7]

2.4 Summary of Characteristics

These three characteristics, virtuosity, expressivity, and flexibility, while not all-encompassing, should provide a solid basis for evaluation of a particular instrument. Any computer music instrument which expects to function as a respectable instrument in itself should seek to possess all three of these characteristics as much as possible. If an instrument can have no virtuoso, can facilitate no expression, or can demonstrate no flexibility, it is extremely unlikely to succeed as anything other than a toy or a neat bit of technology.

3. DESIGN PRINCIPLES

With these characteristics in mind, we can begin to discuss more general design principles; the principles here are by no means comprehensive, but are the two most prominently mentioned or referenced in the literature.

3.1 Mapping

Computer music instruments may have complicated interfaces, and indeed may require complicated interfaces to stand up to the ideal characteristics already laid out. It's essential, then, that it be clear to the performer precisely what the result will be for any given action. Mapping is a key tool for achieving this; roughly, mapping refers to the correspondence between action and reaction in an interactive object [8]. In human computer interaction, the disconnect between action and perceived reaction is often called the "gulf of evaluation", and providing strong mapping is an important part of reducing this gulf [12]. Good mapping means an interaction corresponds more or less directly with some change in sound, in a natural manner, such as the mapping of the displacement of a performer's hand to pitch or the high velocity of a struck key to a loud volume.

Bad mapping in some cases may simply mean interactions with the instrument are made more difficult, but in the worst case could directly affect the net potential of the instrument. Mapping done well can facilitate technical play, and thus virtuosity, but questionable mapping could hinder precise control of the instrument, effectively capping its virtuosic potential. If an instrument is poorly mapped, the performer may be limited in their ability to consistently add inflection to the sound, ruining the instrument's expressivity. Bad mapping may cause a unique feature of the instrument, key to its flexibility, to be overlooked or underutilized because it is misunderstood. [4]

3.2 Body and Gesture

One notable similarity between every traditional instrument in existence is the simple fact that interaction is a very physical, tangible event. Although this is really a consequence of the necessity of their construction, this physical nature is often a powerful asset. [15] By incorporating the player's actions more directly into the production of sound, the level of connection the musician has with the music is increased. A simple, stereotypical button press involves the user only minimally. Playing a note on a flute, by comparison, involves the user more dramatically, as the very act of blowing across the instrument is what produces the sound.

Computer music instruments simply cannot reproduce the direct level of interaction found in a traditional instrument, as there can be no actual physical link between the player and the sound. They can, however, recreate the connection to a large degree. By involving the musician's body and facilitating interactions that are of a more physical nature, an interface can utilize this inherent strength of traditional instruments, and develop musical control that is more natural and powerful [13]. This incorporation of the body in musical performance is sometimes referred to as gesture.

Though it is not defined this way, virtuosity is sometimes spoken of as the extent to which the virtuoso's instrument has become an extension of their body; learning and becoming skilled with a traditional instrument nearly always involves a great deal of proprioceptive learning, or learning with respect to the relative position of one's body [17]. A skilled musician internalizes the way their body's positioning and motion affects their instrument. Capitalizing on this internalization can greatly affect an instrument's capacity for virtuosity. Similarly, expressivity, even more so than virtuosity, is increased as the performer is able to intuitively know how to convey their musical intent. [14]

3.3 Summary of Design Principles

These two design principles have important implications for the characteristics we have already determined. An instrument which provides good mapping and a strong body to instrument relationship should increase the degree to which virtuosity, expressivity, and flexibility are provided.

4. ANALYZING EXISTING INSTRUMENTS

Armed with these principles, and the three desirable characteristics for computer music instruments, we can now take a look at some existing instruments of varying age to observe how our criteria behave in the real world. I will consider four such instruments and analyze them against this framework: Lon Theremin's namesake instrument, the theremin, Smule's iPhone ocarina application, McPherson and Kim's augmented grand piano, and Eigenlabs' Eigenharp Alpha.

4.1 Theremin

The theremin [6], created in 1920, is an instrument which bears few similarities to any traditional instrument. The result of research into proximity sensing technology, it is controlled by the movement of the performer's hands, which never touch the instrument itself. Instead, the theremin's pitch and volume are controlled by the distance of the player's hands from two antennae on either side of the instrument. One hand is used to control the pitch of the sound being played, and the other the volume of the sound. The output of the theremin is continuous; starting and ending a note is simply a matter of bringing the volume hand up from the antenna to hold a note, and lowering it back down to release. [20]

Like many instruments, the theremin is both easy to understand and difficult to play precisely. The ease of understanding owes a lot to its straightforward mapping: moving the pitch hand away and toward the pitch antenna causes a direct change in pitch, and the same is true for volume. Literally, there is no input on the theremin which is not directly mapped to output. This mapping allows for a new player to immediately understand how control of the instrument works, although they certainly will not find mastery of the instrument so immediate.

The incorporation of body in play of the theremin is also exemplary in some respects, as the player of a theremin almost literally becomes an extension of the instrument itself. Where a violinist's hands produce the music, in a sense the thereminist's hands bear an even stronger connection. However, there is another strong respect with which the theremin does not provide this connection, in that the player literally does not come in contact with the instrument. This lack of contact is something like the antithesis to the body-instrument connection, because there is no physical connection, only a perceived causal connection (however strong). This tension is difficult to resolve, and it becomes difficult to accurately evaluate the body-instrument connection of the theremin; however, one thing is clear: the theremin certainly capitalizes upon the concept of gesture.

Virtuosity also is bred by the theremin. The process of playing and holding a distinct note is a very technical event. Playing a run of notes, such as a scale, becomes exponentially more difficult, as the player must precisely hit each successive note, conceptually located as an unmarked position in the air. This difficulty is not artificial, but is derived from the freedom of sound that the interface provides, and so the ceiling for technical play is extremely high. In fact, the theremin did garner an established virtuosa: Clara Rockmore, a violin virtuosa from a young age, developed extreme technical skill with the instrument, and pioneered a fingering system for use with the pitch hand during theremin play which allows for rapid and precise note changes.

The freedom of pitch that the theremin grants, although it makes basic play more difficult, also allows for many expressive possibilities. Vibrato on the theremin is literally a matter of vibrating the pitch hand, and the effect can be controlled very precisely. Similarly, tremolo can be achieved by vibrating the volume hand. Portamento, a sort of slide between pitches, is produced with a slide of the pitch hand while sounding a note. This total freedom of pitch and volume allows for a great deal of license for expressivity, and ensures that expression on the theremin can be both natural and powerful.

Unfortunately, the theremin has little to offer for flexibility. The instrument is constrained by its two inputs to direct pitch and volume control only. The nature of the interface is such that it would be difficult to add more modes of interaction, as all movement of either hand during performance contributes immediately to the sound of the instrument. The theremin, for all of its ability to produce emotionally engaging and technically difficult music, is unable to facilitate flexible music.

The theremin is a fairly strange instrument, as far as interfaces go, but it is able to deliver in many of the ways in which we expect a professional instrument to perform, and exemplifies musical expression in particular. As an instrument which is considered by many to be a fully professional instrument [2], there are surely lessons to be learned from the theremin's design.

4.2 Smule's Ocarina

Smule's iPhone ocarina application, described in detail in [18], is likely to be one of the more familiar of the instruments discussed here, as it has permeated today's tech-savvy culture more than most computer instruments could dream of; ranked one of Apple's top twenty downloads of all time, the ocarina is popular indeed. The application is based on the real-world ocarina instrument, an ancient egg-shaped flute of sorts. To avoid confusion with the traditional ocarina, when referring to "ocarina" I will mean Smule's iPhone application, unless otherwise stated. The popularity of Smule's ocarina likely owes a lot to its simplicity: the touch-driven interface is comprised simply of four touch zones, representing the traditional ocarina's finger holes, and uses the iPhone microphone to detect when the player 'blows' into the instrument.

Although the design is simple enough, it's not entirely straightforward to understand how playing different notes works. Because the application is based on the actual ocarina instrument, changing notes works similarly. By covering different combinations of the holes with their fingers (and blowing into the microphone), the player can play different notes, but these combinations are not immediately obvious. There is no obvious direct mapping involved, so the new player must learn either by being taught, or through trial and error, how to play a simple scale. Luckily for the new player, there are only sixteen combinations possible between the four holes, so the challenge is not too great.

Since the application is touch-screen based, the connection of body to instrument is not quite as strong as it could be; there is clearly a connection between pressing a "hole" on the ocarina and hearing a sound, but the interaction is fairly flat and not extremely physical. While simple touch screen interactions are, in fact, physical events, they are nondescript. Each interaction feels identical to the last, leaving much to be desired in the way of physical connection. The process of blowing into the microphone to play is a fairly strong connection, and serves the body connection well, but overall, gesture is not one of the ocarina's strong points.

In terms of virtuosity, Smule's ocarina falls somewhat short. The simplicity that the instrument embodies, although it makes for a very accessible instrument, does not lend itself to technical excellence. With only sixteen possible notes available at any given time, and limited options for additional technical content, the skill ceiling simply is not extremely high. Although there is enough depth of skill for some players to demonstrate a basic knack for the instrument, it is unlikely that any virtuosos will appear on the ocarina.

The ocarina allows for expression to a limited degree. Via the iPhone's dual axis accelerometer, the ocarina player can tilt the device to create vibrato: one axis controls the vibrato rate (the rate at which the pitch wavers), and the other controls the vibrato depth (the amount by which the vibrato changes the pitch). Also, by altering the strength with which the player blows into the microphone, small changes in volume can be accomplished. The ocarina is not incapable of expression, but its expressive depth is somewhat restricted.

Finally, flexibility on the ocarina is a situation with a bit of give and take. The instrument can be 'tuned' to different modes (essentially different sets of scales which determine the sixteen notes available); this functionality is not really part of the interface itself, but instead is intended to be set up prior to each performance and not changed during a song. There is little flexibility to be seen in the ocarina application.

Ultimately, Smule's ocarina seems to be intended as a toy application, and not as a professional musical instrument for serious music performance. It is still useful, however, to subject it to these sorts of comparisons to see where exactly it does fall short as a professional instrument. In addition, while it may not deliver on all of the established positive characteristics or design principles, it is interesting to note the areas in which it does demonstrate these things, for the purposes of better understanding how future design of novel instruments might be carried out.

4.3 Augmented Piano

The augmented piano, from [11], is a project by Andrew McPherson and Youngmoo Kim of Drexel University which seeks to enhance a traditional instrument (the grand piano) using modern technology. The project attempts to increase expressivity by increasing the number of ways in which an player can control the sound. It does this by attaching electromagnetic actuators to the strings inside the piano and adding an optical scanner to the keyboard to detect hand and finger positioning and motion. Whereas a standard piano allows only for control of note velocity at the moment a key is struck, the augmented piano allows the pianist to control the sound of each note while it is sustained, and also to play soft, flowing notes without actually striking a key.

One of the explicit goals of the augmented piano project was to create an instrument which had good mapping [11], so it should come as no shock that the mapping on the augmented piano is fairly strong. The keys map downward displacement to note volume: a light touch on a key causes a barely imperceptible hum, while a halfway depressed key causes a soft resonating note. Striking the key as on a standard piano causes the actual piano hammer to hit the string, with the same velocity as should be expected on any other piano.

Of note in McPherson and Kim's research is their realization that pianists' hands and fingers often display motion that has no effect on the sound, but seems to be providing a sort of unvoiced inflection anyway. This demonstrates a strong connection of the pianist's body to the instrument, which on a regular piano goes unnoticed. The augmented piano capitalizes on this untapped expressive information by allowing these sorts of motions to truly influence the sound of the piano, increasing the player's physical connection to the music.

Although much of the technique of play on the augmented piano remains unchanged from the traditional piano, as the interface remains largely the same, the technical depth of the augmented piano is increased by the addition of several new modes of interaction. The traditional piano is an incredibly virtuosic instrument, and the augmented piano inherits this quality simply by merit of being itself a piano. In addition, however, the complexity of the new interactions has the potential to further this virtuosic quality even further.

The potential methods of expression on the augmented piano are numerous. By wavering a finger on a depressed key, vibrato may be added to a note. In addition, the sound of a note can be modulated by the position of the finger on the key while the note is being sustained. By allowing for keys that are not entirely struck to produce sound, a much greater range of sounds can be created using the instrument, also adding to the expressive quality.

The flexibility of the augmented piano is the characteristic most shared with the traditional piano. Because the instrument has such a large number of keys, there is a fair amount of flexibility simply from the sheer range of the piano. Since the sound is entirely generated by vibrating the actual piano strings, there is not much room for improvement of flexibility, as the keys are physically bound to the hammers in the instrument. This prevents most possibilities for reworking the way the input produces the actual sound. Still, the augmented piano is not an inflexible instrument.

As the augmented piano is, at its roots, a traditional piano, in most senses it does inherit all of the positive characteristics and design of its extremely successful and powerful predecessor; few would challenge the piano's status as an expressive and virtuosic instrument. It also appears to succeed in its goal of improving expressivity, although its flexibility largely remains the same. Few computer music instruments so literally attempt to add to the history of the traditional instrument, and the augmented piano's status in that regard makes it a very interesting case to consider.

4.4 Eigenharp Alpha

The Eigenharp Alpha [3], is a large instrument, similar in appearance and size to a bassoon, with an array of many small button-like keys on the front, a mouthpiece wind controller at the top, and two touch sensitive control strips along each side. Each key is built to pivot both horizontally and vertically, and also to measure to what degree the key is pressed. The keys are set up somewhat similarly to the frets on a guitar; there are five vertical rows of keys, ascending in pitch along each row. Unlike a guitar, where strings are held at frets and then plucked, strummed, or made to vibrate in some other manner, on the Eigenharp a note is typically sounded simply by pressing a key. Additionally, the wind controller can be used to control the volume of held notes, or the control strips on the side of the instrument can be used to 'bow' the notes, in a manner similar to a cello.

Mapping is fairly straightforward on the Eigenharp: the downward displacement of each key is typically mapped directly to volume, and the tilt in each direction is mapped to pitch shift or some sort of modulation. The strip controllers are often mapped to a global effect on the sound or the overall volume of the instrument. The wind controller is usually mapped to volume, but could also be mapped to an effect, or used to produce tremolo. Each mapping is by default direct, so it's clear what an input will do in any given circumstance, but this mapping can be changed by the user if desired.

The involvement of the body in playing the Eigenharp is very strong, largely due to the many ways in which physical input can affect the sound. Practically every facet of the finger's interaction with a key controls some nature of the way the note is played, and in addition, the way the hand moves along the side of the instrument can also change the way the music is produced. The Eigenharp has a well defined physical connection with the player, and closely mimics the nuanced ways in which a traditional instrument interacts with the musician.

Virtuosity is well accounted for, as the interactions available provide for significant technical depth. The keys offer a precise and consistent method of control, with sufficient complexity to assure a high skill ceiling. Although the instrument is still very young, it seems likely that the Eigenharp can allow for virtuosic play.

Because of the detail involved in each key press, the expression available to the Eigenharp player is vast. Fine manipulation of the keys while playing notes allows for a sophisticated level of control over the emotional content of the music. The wind controller can add more depth to the expression by allowing another layer of input to the way the sound is created. Eigenlabs touts the Eigenharp Alpha as "the most expressive electronic musical instrument ever made" [5]. This probably contains a significant amount of hyperbole, but certainly a more modest claim is merited: the Eigenharp is an extremely expressive instrument.

The greatest strength of the Eigenharp, however, is its flexibility. Integrated into the instrument is a method for rapidly changing the instrument's functionality, which operates using a language called Belcanto. Belcanto is input using a set of note phrases which correspond to a particular command. A particular phrase, when input into Belcanto, could set the Eigenharp to retune to a different key, for example. Because Belcanto is played using a small subset of the keys, a performer can continue to play with one hand, while quickly playing a short Belcanto phrase with the other. This capability for on-the-fly adjustment greatly increases the instrument's flexibility for performance.

The Eigenharp is a unique instrument, and fulfills each of the positive characteristics and design principles nicely. It is a good working example of a completely novel device which fits the criteria outlined here for a legitimate computer music performance instrument.

5. CONCLUSIONS

These four evaluations should provide a basic understanding of the way existing computer music instruments embody the goals for design presented here. The five criteria outlined in this paper can be applied to any instrument designed for computer music performance, and are potentially useful tools in the design of such instruments.

In the grand scale, computer music has only just begun to establish its presence in music, and it's unclear where it will go next. New interfaces for computer music performance are being created every year, and this rate is certainly showing no signs of slowing. With this set of principles, which seek to improve the success and legitimacy of such instruments, the design process can be more directed and fruitful.

If we can continue to improve the way we design computer music instruments, the future of computer music performance will be an exciting one indeed. Hopefully, as time goes on, we will be better able to identify exactly what it is that instruments should strive to provide for musicians. Between this greater understanding of instrument design, and ever increasing technological possibilities, it seems great things could be in store for computer music performance in the years to come.

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