Almost Tangible Musical Interfaces

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Introduction

Primarily, I see myself as a musician. Certainly I’m a researcher too, but my research is with and for musicians and is inextricably bound up in the practice of performing. Research questions arise through execution, reflection upon and examination of performance. This is because I’d like the findings of my research, and the performance works which are at the core of the work, to be interesting and relevant to other musicians and composers. As someone who put a lot of work into trying to be a good musician for quite some time, this feels like a natural way to operate. I understand how musicians think, I speak the language and I respect their skill and dedication. I don’t for a moment propose that the practice-based research approach I will describe in this chapter is the-one-and-only-way to conduct research in this area. It is, however, an approach that has worked for me. It has enabled me to continue to work creatively, while also engaging in research grounded in an epistemology of practice.

In this chapter I describe a practice based research project centred on the development of a series of virtual musical instruments for use in live performance. My approach to research and practice was informed by action research and design science and I sought evidence about musicians’ experiences with the new instruments I created by way of a series of observational and interview based studies.

The virtual musical instruments that were developed are unusual in several respects. First, they are designed to work in partnership with acoustic instruments, rather than as ‘stand alone’ artefacts. Performances involve at least one acoustic instrument as well as sounds and visuals produced by the virtual instrument. Second, during performance the virtual instruments respond predominantly to the sounds produced on acoustic instruments; in effect the acoustic sounds are used to ‘control’ the computer. (I place the word control in inverted commas here because the relationship between acoustic musician and computer instrument was complex, as will be discussed later). Finally, the virtual instrument software simulates physical objects in order to create a kind of sonic ‘sculpture’ which the musician interacts with.
The creation of the virtual instruments raised a number of questions relating to the nature of musical instruments and creative interaction: How did musicians interact with the virtual instrument? Did they approach it like a traditional instrument? To what degree did they seek to control it? Did it facilitate musical expression? Why, or why not?

To investigate these issues I conducted a study of musicians’ experiences with the virtual instruments. The study, involving a number of highly skilled musicians, focused on approaches to music making and the effect of the software on this process. It resulted in the development of a theory of musical interaction in which three ‘modes of interaction’ were identified representing ways in which the musicians approached music making with the virtual instruments. The modes of interaction describe an attitude, or stance taken, by the musicians towards the instrument, in particular the degree to which they seek control. The three modes are:

**Instrumental** The musician seeks to control the software.

**Ornamental** The musician allows the software to provide an additional audio-visual layer to the performance without seeking to either directly control it or respond to it.

**Conversational** The musician shares control over the musical trajectory of the performance with the software, seizing the initiative for a time to steer the conversation in a particular direction, then relinquishing control and allowing the virtual instrument to talk back.

**Background**

There is a rich history of using electronic and, more recently, digital technologies to create new musical instruments. Instruments and devices such as analog and digital synthesizers, multi-track recorders and vocoders, to name but a few, have had considerable impact. The rapid increase in computer processor performance and development of new interface hardware has led to an explosion of interest in creating novel musical instruments. As evidenced by the growing popularity of the *New Interfaces for Musical Expression* conference, the interface between musician and computer-generated sounds and visuals has been a particular focus.

**Expression**

Musical expression is complex. Traditionally, the term ‘expression’ refers to subtle alterations of dynamic, rhythm and timbre which bring a musical work to life. An
early goal of some researchers was to develop techniques for enabling computers to play notated music in ways that sounded less mechanistic and more human. They sought to do this by uncovering the ‘rules’ which human performers applied to create expressive performances (e.g. Clarke 1985, Canazza et al. 1997). However, this conception of expression is limited and does not accurately reflect contemporary music practice. Of particular concern is the fact that it assumes there is a pre-existing score which is interpreted by a performer. Clearly this is not always the case.

An additional common conception of ‘expression’ involves performers somehow coding extra-musical elements into the music they produce. These extra-musical elements are usually considered to be ‘emotion’ and the implication is that a perfect musical interface will enable the error free ‘transmission’ of emotions from performer to listener. However, expression in contemporary music practice is a complex and ephemeral concept which resists such simplistic characterisation. Performers, including a number who participated in this research, do not always see the purpose of music performance as expressing a pre-existing idea or state. At times the process of music making is a kind of exploratory dialogue with their instrument, other musicians and the broader environment within which the performance takes place. Just what is being expressed is very difficult to pin down.

And of course the very notion of expression is explicitly rejected by some. The composer John Cage, to take a prominent example, made strenuous efforts to try to remove the sense of personal intentionality from his music-making.

“I have found a variety of ways of making music (and I continue to look for others) in which sounds are free of a theory as to their relationships. I do not hear music before making it, my purpose being to hear as beautiful something I have not before heard.” John Cage, cited in Holmes (2002, p. 238)

For Cage, sounds which occur as a result of chance hold a greater fascination than traditionally ‘constructed’ compositions, and his works aim to allow the listener to simply experience sound without attempting to interpret it, decode it or even relate it to past experience. From this perspective the notion of personal ‘musical expression’ is something to be avoided, and certainly not designed for.

The diversity of views on expression and the desirability of facilitating it raise interesting problems for conducting design and research in this area, and this is a point I will consider in more detail later.
Mapping

 Whilst there is a range of views on musical expression, there is clear agreement in the literature that ‘mapping’ is a core issue in electronic instrument design. Performers playing acoustic instruments receive a wide range of feedback directly from the instrument as they physically manipulate it in order to make sounds. Visual and tactile feedback from acoustic instruments is in a sense a by-product of the physical gestures and mechanisms used to produce the sound - it is in-built. Electronic instruments are fundamentally different in this respect. As the energy required in order to produce sound is provided electrically, there is no necessary connection between the amount or quality of physical energy provided by performers’ gestures and the sounds produced by the instrument. Large gestures can map to soft sounds and small gestures to loud ones for example. In addition, any visual or tactile feedback beyond that provided by sensing hardware (mouse, keyboard, etc) is something that needs to be explicitly added by the instrument designer.

 These issues lead to two key areas of practice and research which explore: mappings between gesture and computer generated sounds and visuals; and the design of sonic-visual-haptic feedback which enhances the connection between performer and instrument.

 Mapping in this context is the process of linking the interface to the sounds and visuals generated by the system. A trivial example of a ‘one-to-one’ mapping might be to link the vertical movement of a mouse to the pitch of a generated note—the higher the user moves the mouse pointer, the higher the pitch. This is a one-to-one mapping because one parameter generated by the user (the height of the mouse pointer) is directly linked to one parameter of the synthesis engine that makes sounds: pitch. The designer of a very simple (but not necessarily very satisfying) virtual instrument might therefore map pitch to vertical movement of the mouse and volume to horizontal movement.

 In addition to the simple one-to-one mapping, more sophisticated mappings are possible and probably desirable. ‘One-to-many’ mappings map one user-generated parameter to several synthesis parameters (Hunt et al. 2000). If we took our simple one-to-one mapping strategy instrument and extended it so that moving the mouse to the right simultaneously increased volume and decreased vibrato, then we would be using a one-to-many approach. One user-generated parameter (horizontal mouse position) is mapped to two synthesis parameters (volume and vibrato).
The converse is also possible: a many-to-one strategy in which many user generated parameters are mapped to one synthesis parameter. If we again redesigned our mouse controlled instrument so that moving the mouse vertically resulted in large changes in pitch, but moving it horizontally resulted in finer pitch changes then we would be using a many-to-one mapping. Rovan et al. (1997) call this “convergent” mapping, and claim that although it is harder to master, it facilitates expressive playing more effectively than one-to-one mappings.

In a series of experiments, Hunt et al. (2003) demonstrated that complex mappings such as those built into acoustic instruments appear to result in instruments that, while more difficult to learn initially, are ultimately more controllable and enjoyable to play. The more successful instruments used many-to-many mappings and, in addition, required what might be termed ‘energy injection’ to make sound. Instruments that require energy injection need the player to excite the virtual instrument in some way. In other words, players are required to provide physical energy though the user interface (by continually moving their hands for example) in order for the instrument to continue to make sound.

In essence, when playing acoustic instruments, “the musician’s energy is physically transformed into the sound energy that is heard by an audience” (Hunt and Wanderley 2002, p.97). This traditional physical connection between musician and music has important implications for the design of expressive instruments.

**Designing Instruments and Examining Performers’ Experiences**

Edmonds and Candy have recently described a range of "trajectories" of practice-based research in interactive arts (Edmonds and Candy 2010). The trajectories are comprised of three main elements: practice, theory and evaluation. How an individual researcher structures the relationships between each of these elements depends on the concerns of the practitioner/researcher and the nature of their practice. One research trajectory involves drawing on theoretical knowledge in order to create new works, which are then evaluated in terms of the theory. A practice-driven trajectory, on the other hand, begins with practice:

"In this case, research questions and design criteria are derived through the creation of Works and this leads to the development of a theoretical Framework which is used in the Evaluation of the results of Practice.”
(Edmonds and Candy 2010)
Any new interface for musical expression has embodied within it theories relating to the nature of interaction and musical expression. The value of the practice-driven trajectory to designers and researchers of new musical instruments is in making these theories visible and therefore open to reflection and, potentially, evaluation or validation. However, the questions that arise are:

• How do we make the theories visible?

• How do we evaluate and refine the theories and the instruments that embody them?

At a high level, my research involves an iterative process of theoretically-informed action and reflection based on action research (Lewin 1946) and design science (Simon 1981, Hevner et al. 2004). The overall process can be seen in figure 1. Theory from the literature and personal aesthetics provide a set of initial criteria for new instruments which are designed in an iterative, user-centred process. The outcomes of the design process are the instruments themselves and a list of the design criteria which I believe they embody. During user studies, the experiences of performers who use the instruments are examined. The user studies aim to both evaluate how well the instruments met the criteria and to use them as provocative prototypes (Mogensen 1992) in order to more broadly examine the performers’ approach to music-making. The contributions of the practice-based research are therefore:

• theories relating the experiences of the musicians to instrument characteristics; and

• refined design criteria informed by practice and research.

The intention is that theoretical and creative development is never ‘done’ and theories, therefore, are considered provisional and open to further refinement. Findings from studies in creative domains are inherently dynamic and culturally specific. Thus, the theories which emerge are of a different nature to theories of the natural sciences. They might best be seen as giving insight into artistic practices of musicians in a particular cultural context rather than revealing universal laws of musical aesthetics that may be applied in any situation.
Figure 1: High-level view of the action research process

The range of possible perspectives on musical expression can present difficulties for those engaged in research in this area. If expression has no ‘nature’ - if it is not an objective thing which exists independent of cultural practices - then how are we to research it? Artists and technicians build new interfaces for musical expression but struggle to meaningfully evaluate their creations because of the difficulty of finding success criteria which are measurable but also meaningful (Wanderley and Orio 2002). Objective evidence such as instrument response time or dynamic range have meaning only in particular artistic contexts. Ultimately, the question - is this instrument expressive? - can only be answered by people trying to use it to make music, and their response will depend on what they are trying to do with it.

To me, this implies that:

• instruments should not be designed in isolation; and

• performers who participate in user studies need to be given latitude to explore the instruments in their own way - not given prescribed tasks.

Perry Cook, observing that the design of a new musical instrument is most effective when driven by specific artistic concerns, advises designers to “make a piece, not an
instrument or controller” (Cook 2001, p.1). Designing a new instrument for a specific work or performer helpfully constrains the design choices and avoids the difficulty of attempting to create a universal instrument capable of supporting widely varying notions of expression.

The instruments I describe in this chapter were developed in collaboration with composer and trombonist Ben Marks. A series of virtual musical instruments were created with Ben, who composed and performed music for them. Broadly speaking, I developed the interactive software and Ben composed the music. Software development and composition proceeded in parallel, with changes in the behaviour of the software leading to changes in the composition and vice versa.

Figure 2 Ben Marks plays with Partial Reflections II

During development we attempted to document our developing ideas about the virtual instruments and our approach to design using blogs. Through reflection on the process and examination of blog entries we identified a set of applied criteria which guided the design of the instruments. This process of ‘reflection-on-action’ (Schön 1983) helped make some of the tacit ideas guiding our work more concrete and therefore open to examination. Having identified the criteria that guided our work, we were now in a position to consider:
• how well the virtual instruments embodied the criteria; and

• the relationship between the criteria manifest in the virtual instruments and the experiences of musicians who use them.

The specific methods that were applied to consider these issues will be described in the section below entitled “Modes of Interaction”.

**Practice and Research**

In this section I briefly describe the approach to musical interaction that was developed as part of this project, and go on to outline key aspects of the theory which emerged from the design process and user studies.

**Interfaces for Musical Expression**

Drawing on high-level design criteria from the literature as well as personal experience and aesthetics, a series of computer-based musical instruments were developed. Intended for use by experienced acoustic musicians in live performance, these instruments were developed in collaboration with composer/trombonist Ben Marks. Our intention was to develop a unique instrument which responded visually and sonically to acoustic sounds as well as generating sounds of its own. The technique that we developed involved creating software simulations of physical sculptures which the musician could exert force upon by playing their acoustic instruments into a microphone connected to the computer.

To date four instruments have been developed. Each has different characteristics but share the following features:

• Acoustic sounds generated by musicians are the source of ‘gestures’ which act upon the virtual instruments.

• These musical gestures result in force being applied to a software-simulated physical structure (or ‘mass-spring’ model) which responds by moving in physically plausible ways.

• The simulated structure is projected on screen during performance. From the musician and audience’s perspective, this visualisation is the ‘body’ of the virtual instrument.
• The movements of the structure provide parameters for sound synthesis. Thus the sounds that are produced by the virtual instrument appear to be a direct consequence of the movements of the structure.

This approach draws on that described by Momeni and Henry (2006) and Choi (2000). Audio input from the user results in force being exerted on the physical model and in response parts of the model move about, bump into each other, etc. Various measurements of the state of the model, such as speed of individual masses, forces being exerted, acceleration and so on, are then separately mapped to parameters for the audio and visual synthesis engines. The visual synthesis mapping layer maps the X, Y and Z coordinates of masses to the position of geometric shapes on screen and the audio synthesis mapping layer maps characteristics of the masses (speed, force, etc.) to various synthesis parameters (such the individual amplitudes of a set of oscillators for example).

It can be seen that with this approach we end up with three mapping layers. The first maps from user gestures (sound from acoustic instruments in this case) to parameters which change the state of the physical model. The second and third layers map from measurements of the state of the physical model to audio and visual synthesis parameters respectively.

This approach provides a number of advantages. Firstly, because both audio and visual synthesis parameters have the same source (the physical model), sound and vision are clearly linked. While they may be separated if desired (by treating the outputs from the physical model in dramatically different ways), the ‘default’ condition is likely to lead to clearly perceivable correspondences between sound and vision.

Secondly, the dynamic layer provides convenient ways to build instruments based on divergent (one-to-many) mappings. A mass-spring physical model which contains a network of say 10 masses linked together with springs can be set in motion by moving only one of the masses. The movement of this single mass results in multiple movements in the overall structure as the force propagates through the network via the links. Because the model applies the laws of Newtonian physics each of these movements is predictable at a high level and is a direct result of the initial user action. These derived movements provide extra streams of data which may be mapped to audio/visual synthesis parameters.
Third, because the visual display is a representation of the dynamic layer itself (e.g. a display of the actual physical model), the user is more able to understand the state of the system, leading to an improved ability to control the instrument. In addition, such a display can help an audience understand and engage with a live performance, as they are more able to perceive what impact the actions of the instrumentalist have on the virtual instrument.

Finally, the movements of the physical model bring a sense of dynamism to the virtual instrument. As the physical model network reacts to energy supplied by the performer it will often oscillate, providing rhythms the player can respond to. By bringing a sense of unpredictability and a sense of simple agency to the interaction, while still retaining high-level controllability, a physical model mapping layer may help stimulate a more conversational style of musical interaction (Chadabe, 2002). I will return to this point later.

We have described our instruments in detail elsewhere and will therefore not go into further detail here. Interested readers are referred to Johnston (2009), Johnston et al. (2009, 2008), Johnston and Marks (2007), Johnston et al. (2007). Photographs of the instruments in action can be seen in figures 2 and 4. Video can be found online at: http://www.andrewjohnston.net/

**Modes of Interaction**

Having constructed our instruments and used them in performances, we conducted a series of user studies in order to improve our understanding of how musicians approached using instruments of this kind. During the user studies seven highly experienced, professional musicians from a range of backgrounds used the instruments and were asked about their experiences. Each session lasted around two hours. Musicians were asked to think aloud as much as possible during this time and in addition a semi-structured interview was conducted. Each session was video taped.

The fourteen hours of video that were gathered were then transcribed and grounded theory methods (Glaser and Strauss 1967, Glaser 1978) used to build theoretical understanding of the musicians’ experiences and how these related to the instruments’ design. During grounded theory analysis it is expected that open coding will lead to the discovery of a ‘core’ category, a key issue which appears to have particular relevance to the situation under study (Glaser and Strauss 1967). The core category emerges during analysis as the researcher continually compares incidents in the data and attempts to identify relationships between them.
During analysis of the data gathered during this study, it became apparent that the musicians did not always approach the virtual instruments in the same way. Sometimes a musician would express frustration because they felt they did not have enough control over the virtual instruments, but then at other times the same musician would complain that the virtual instruments were not autonomous enough, and that they wanted their behaviour to be less predictable. It seemed that the qualities the musicians sought in a virtual instrument would change during their interactions and that they interacted with the virtual instruments in different modes. Thus, the core issue which emerged during analysis, was that of the use of different modes of interaction.

We found that the musicians’ interactions with the virtual instruments could be classified into three modes: instrumental, ornamental and conversational.

When approaching a virtual instrument ‘instrumentally’, musicians sought detailed control over all aspects of its operation. They wanted the response of the virtual instrument to be consistent and reliable so that they could guarantee that they could produce particular musical effects on demand. When interacting in this mode, musicians seemed to see the virtual instruments as extensions of their acoustic instruments. For these extensions to be effective, the link between acoustic and virtual instruments had to be clear and consistent.

When musicians used a virtual instrument as an ‘ornament’, they surrendered detailed control of the generated sound and visuals to the computer, allowing it to create audio-visual layers or effects that were added to their sound. A characteristic of ornamental mode is that the musicians did not actively seek to alter the behaviour or sound of the virtual instrument. Rather, they expected that it would do something that complemented or augmented their sound without requiring direction from them.

While it was not always the case, it was observed that the ornamental mode of interaction was sometimes a ‘fall back’ position when instrumental and conversational modes were unsuccessful. While some musicians were happy to sit back and allow the virtual instrument to provide a kind of background ‘audiovisual wallpaper’ that they could play counterpoint to, others found this frustrating, ending up in an ornamental mode of interaction only because their attempts at controlling or conversing with the virtual instrument failed.

In the conversational mode of interaction, musicians engaged in a kind of musical conversation with the virtual instrument as if it were another musician. This mode is
in a sense a state where the musician rapidly shifts between instrumental and ornamental modes, seizing the initiative for a time to steer the conversation in a particular direction, then relinquishing control and allowing the virtual instrument to talk back and alter the musical trajectory in its own way. Thus, each of the three modes of interaction can be seen as points on a balance-of-power continuum (figure 3), with instrumental mode at one end (musician in control), ornamental mode at the other (virtual instrument in control) and conversational mode occupying a moving middle ground between the two.

![Diagram](image)

**Figure 3: Instruments which support conversational interaction facilitate a shifting balance of power between musician and virtual instrument**

The implication is that virtual instruments which seek to support conversational interaction, need also to support instrumental and ornamental modes.

**Some Comments on the Grounded Theory Method**

The grounded theory method is an approach to gathering and analysing qualitative data (Glaser and Strauss 1967, Glaser 1978). There is insufficient space here to describe the method in detail, but for this project it involved the following:

- ‘data’ which was analysed were the video recordings of musicians using the virtual instruments and talking about their experiences.

- video recordings were transcribed.

- videos and transcriptions were examined minutely (line-by-line) and ‘coded’. A ‘code’ in the grounded theory terminology is simply a label attached to the transcript. If a musician made a comment about the degree to which they felt in control of the virtual instrument, then that comment might be labelled with the ‘control’ code, for example. Codes were created as needed. The open-source software *Transana* (Woods and Fassnacht 2007) was used to facilitate this process.
Coding facilitated a process of constant comparison, in which incidents in the videos were examined in relation to one another. This led to the identification of the ‘modes of interaction’.

In this project, the grounded theory method was indispensable, but also very time consuming. The process of transcribing the many hours of video, labelling incidents and linking these together into a unifying theory was necessary - at least in this case. I see this process as essentially being about really taking account of what went on during the user studies - what was said and how, how the musicians behaved and how they responded to the virtual instruments. The grounded theory methods were useful in improving my awareness of the video material and my sensitivity to the experiences of the musicians. I don’t think I could have achieved the necessary degree of familiarity with this material with less labour-intensive methods. When this degree of immersion is required, such as for PhD level practice-based research, I don’t see a better approach.

That said, the fact that so much time is given over to transcription and analysis could be a disincentive for many practitioners, as time spent on these tasks reduces time that can be spent on creating new work. Ultimately, the decision of whether to pursue practice-based research of this type will depend on the degree to which the individual artist feels they already understand the contexts within which their works are experienced. For me, the results have been worth the effort, but starting down this path will always be a leap of faith to a large degree.

**New Work**

The process of practice and research outlined in previous sections led my creative practice in new directions. I have been particularly motivated to further explore conversational interaction through extending the complexity and richness of the instruments I create, and providing additional channels through which musical conversations can occur.

The work *Touching Dialogue* (figure 4), presented at the 2010 New Interfaces for Musical Expression conference with Phil Slater (trumpet) and Jason Noble (clarinet), illustrates the evolution of these ideas. First, the physical model at the core of the *Touching Dialogue* instrument is considerably more complex than those described above. It is comprised of 48 individual masses, as opposed to the 12 masses of earlier instruments, and uses more sophisticated physical modelling techniques that provide a higher degree of realism.
Second, two performers interact with this instrument at the same time. Each performer has a microphone, which allows them to poke and prod the virtual instrument using the sounds of their acoustic instruments. I see this as providing an additional channel for conversational interaction as the musicians interact with one another through the virtual instrument, as well as their acoustic sounds.

Third, and perhaps most significantly, I change the physical structure of the instrument over time. A limitation of the instruments described previously is that their physical construction and response to sound remains constant throughout a performance. This is primarily because my initial idea was that the instruments would predominantly be used in instrumental mode, that musicians would want to master the instrument in order to be able to achieve detailed control over its behaviour in performance. If the behaviour and response of the instrument was inconsistent, I felt that this would be unlikely to occur. However, while consistency of response is important, the user studies revealed that musicians were generally more engaged when instruments exhibited a degree of autonomy and unpredictability. What is needed is a balance between controllability and complexity of response.

To achieve this, I’m changing my approach. For Partial Reflections, I was essentially a technician: I set up the virtual instrument and during performance monitored its behaviour and made any adjustments that were required in order to keep in running as it should. With Touching Dialogue I take a much more active role, making changes
to the physical properties of the instrument as the work progresses. I adjust the
tension in the springs holding the model together, break and reconnect springs and
adjust damping and other parameters in order to give the virtual instrument a wider
expressive range.

I have found that it is possible to alter characteristics of the model in this way without
compromising the controllability or legibility of the instrument at a high level. I
believe this is a technique which can help sustain conversational interaction over
longer periods by allowing the virtual instrument to exhibit a wider range of
behaviours. The fact that the virtual instrument changes over time also provides
additional material for composition/improvisation, providing greater scope for more
sophisticated works. The challenge in future work lies in developing techniques
(musical and computational) for altering structures in this way while retaining
transparency and providing sufficient support for instrumental interactions.

Conclusions

In this chapter I have described the creation of a series of virtual musical instruments
and an examination of the experiences of musicians who use them. I’ve presented an
approach to practice-based research which has enabled me to ground the exploration
and study of new kinds of musical interaction in practice, an approach which is well
matched to my background in music performance. The evidence I acquired from
empirical studies directly influenced my practice by revealing different models of
musician engagement.

This approach has its challenges. The time-consuming nature of the user studies may
deter many artists, and the intimate link between creative work and research may not
sit well with researchers who have expertise primarily in technical or scientific areas.
For artists who are prepared to give time in order to gain new perspectives on their
practice, or for technologists who prefer a more artistic approach though, I hope I
have shown one way forward.

Through the work described here I have established a foundation - artistic, technical
and methodological - for continuing practice and research in this area. I have also
begun to take a more active role in performance, moving portions of instrument
design process onto the stage. Along with this, I am exploring how the use of physical
models in user interfaces can lead to conversational interactions in broader contexts.
The virtual instruments I have described in this chapter are all driven by live acoustic
sounds: musicians use sound to manipulate the physical model. Ongoing
developments in motion capture and gesture-tracking technologies provide opportunities for the creation of interactive dance works which involve direct manipulation of physical models. Dancers or musicians would then be able to grasp, hit and throw parts of the virtual instrument around, opening up some fascinating possibilities for blurring boundaries between music and dance in live performance.

\[\text{Vocoder (short for voice encoder)}\] is a sound effect that can make a human voice sound synthetic. It is often used to speak like a robot, with a metallic and monotonous voice. The group Kraftwerk used a lot of vocoder effects in their songs ("We are the robots" for example). It was originally developed as a speech coder for telecommunications applications in the 1930s, the idea being to code speech for transmission. [http://en.wikipedia.org/wiki/Vocoder](http://en.wikipedia.org/wiki/Vocoder)