The reacTable: Exploring the Synergy between Live Music Performance and Tabletop Tangible Interfaces

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ABSTRACT
In recent years we have seen a proliferation of musical tables. Believing that this is not just the result of a tabletop trend, in this paper we first discuss several of the reasons for which live music performance and HCI in general, and musical instruments and tabletop interfaces in particular, can lead to a fertile two-way cross-pollination that can equally benefit both fields. After that, we present the reacTable, a musical instrument based on a tabletop interface that exemplifies several of these potential achievements.

Author Keywords
Tangible interfaces, tabletop interfaces, musical instrument, musical performance, design, interaction techniques.

ACM Classification Keywords
H.5.2 [User Interfaces]: interaction styles, input devices and strategies J.5: [Arts and Humanities]: performing arts.

INTRODUCTION

In recent years there has been a proliferation of tabletop tangible musical interfaces. This trend started with the millennium with projects such as the Audiopad [26,27], Jam-o-drum [4] or SmallFish [33], but nowadays so many "musical tables" are being produced that it becomes difficult to keep track of every new proposal [22]. Is this just a coincidence or the result of a tabletop vogue? While arguably, not all the currently existing prototypes may present the same level of achievement or coherence, we believe that there are important reasons, perhaps often more intuited than stated, that turn live music performance and human computer interaction (HCI) in general, and musical instruments and tabletop tangible interfaces in particular, into promising and exiting fields of multidisciplinary research and experimentation.

In this paper we show that these binomials depict a fertile two-way cross-pollination situation that can equally benefit both fields. We begin by exposing the main reasons that turn live music performance into an ideal test-bed for advanced HCI, and then analyze the potential of tabletop tangible interfaces as new musical instruments. In the second part of the paper we present the reacTable, an ambitious tabletop musical instrument we have been developing for the last three years, built upon some of the principles exposed on the first part.

HUMAN COMPUTER INTERACTION: LEARNING FROM MUSICAL CONTROL AND LIVE PERFORMANCE

Research in Computer Music

Early and definite examples of the synergy between music and HCI can be found in the research and contributions undertaken by William Buxton during the 1970s and 1980s; it was in fact, the design and use of computer-based tools for music composition and performance, which led Buxton into the area of HCI [5]. Buxton has even ironized that there are three levels of design: standard spec., military spec., and musical or artist spec, being the third the hardest and most important [6].

From the musical side, several computer music researchers have studied the control of sound in musical instruments as well as aspects of the communication between players and their instruments. Pressing [29] studies and compares the sound control issues of a violin and a standard MIDI keyboard using no less than ten dimensions. Vertegaal and Eaglestone [37] evaluate timbre navigation using different input devices. Wanderley proposes a basic gesture taxonomy evaluating how such gestures relate to different sound control tasks, and approaches the evaluation of input devices for musical expression by drawing parallels to existing research in the field of HCI [38]. Great effort has thus been devoted into bringing general Engineering Psychology [10, 11] and HCI knowledge and research into the domain of sound control.

Musical Performance Bandwidth

Researchers from non-musical HCI related fields could find on their side, many reasons for considering musical performance. To start, musical instruments are among the most complex and sophisticated machinery humans have managed to design, construct and master, and musical performance may probably be the densest form of human communication. As pointed by Bischoff, "to bring into play the full bandwidth of communication there seems to be no substitute, for mammals at least, than the playing of music live." [3]. Robert Moog estimated that a skilled musician is able to generate about 1,000 bits/sec of meaningful information [24]. Apart from this demanding bandwidth, a very precise temporal control over several multidimensional and continuous parameters, sometimes even over simultaneous parallel processes is specially required in the interaction dialog that takes place between the performer and the instrument.

Creativity, Collaboration & Pleasure

Communication bandwidth and expert control are not the only interesting aspects of musical performance. Beyond the non-trivial aspects of skilled or virtuoso performance, we believe that many additional reasons turn live computer music performance into an ideal field for the experimental exploration of novel forms of HCI:

- Despite the very severe aforementioned control requirements, music performance outstandingly combines precision with freedom.
- It also combines expression and creativity with entertainment.
- Continuous and multidimensional control, naturally tends to avoid the ubiquitous *files*, *folders* and *hyperlinks* metaphors, still dominant in HCI.
- Playing and creating music with the help of digital tools can be a social and collective experience that integrates both collaboration and competition.
- It provides an excellent ground for studying and comparing interaction by both dilettantes and experts, both children and adults.

We believe that music performance and control can constitute an ideal source of inspiration and test bed for exploring novel ways of interaction, especially in highly complex, multidimensional and continuous interaction spaces such as the ones present when browsing huge multimedia databases. This type of interaction involves searching in complex, hyperpopuladed and multi-dimensional spaces, often looking for unknown and probably not single targets [39]; a process that could be better compared with playing a violin that being reduced to the six generic virtual input devices that constitute the GKS standard. In these types of "fuzzy interaction" environments, exploration can follow infinite paths, results can hardly be totally right or wrong, and the evaluation metrics can become so unclear, that joyful and creative use may become one of the essential assets.

While these interaction aspects are pertinent to many HCI research areas, it is not less true that many of the discussed topics are already especially linked to tangible and tabletop interfaces. We are talking about concepts such as "social interaction and collaboration" [13], or "ludic interaction" [12], which are both directly encouraged by the social affordances associated with tables. If real-time music performance application can thus be a good subject to implement in tabletop interfaces, in the next section we will see why tabletop interfaces have indeed the potential to become ideal platforms for new digital music instruments.

MUSIC INSTRUMENTS AND TABLETOP INTERFACES

Music Controllers

Whereas in most (non keyboard) acoustic instruments the separation between the control interface and the sound-generating subsystems is unclear, digital musical instruments can always be easily divided into a gestural controller (or input device) that takes the control information from the performer(s), and a sound generator that plays the role of the excitation source. The controller component can be a simple computer mouse, a computer keyboard or a MIDI keyboard, but with the use of sensors and appropriate analogue to digital converters, any control signal coming from the outside can be converted into control messages understandable by the digital system.

The list of currently available controllers could be infinite, ranging from MIDI-fied versions of traditional instruments, such as saxophones, trumpets, guitars, violins, drums, xylophones or accordions, to non imitative controllers, such as gloves, wearables, non-contact or bioelectrical devices, to mention just a few categories [9]. Moreover, many cheap and widely available control devices meant for the general market, such as joysticks or graphic tablets, are often being used as interesting music controllers. As a sign of the growing interest in this field, the annual conference on *New Interfaces for Musical Expression* (NIME), which started in 2001 as a 15-person workshop, now gathers annually more than two hundred researchers, luthiers and musicians from all over the world to share their knowledge and late-breaking work on new musical interface design. The yearly proceedings, available on-line at http://www.nime.org constitute the ultimate and more up to date source of information on this topic.

Interactive Music and Laptop Performance

In parallel to this research bloom, the laptop is progressively reaching the point of feeling as much at home on stage as a saxophone or an electric guitar. However, the contemporary musical scene does not clearly reflect this potential convergence. Most laptop performers seem hesitant to switch towards the use of new hardware controllers, as if laptop performance and the exploration of post-digital sound spaces was a dialog conducted with mice, sliders, buttons and the metaphors of business computing [34]. There may be some reasons for that, which lie precisely in the new musical possibilities of computer based instruments.

In traditional instrumental playing, every nuance, every small control variation or modulation (e.g. a vibrato or a tremolo) has to be addressed physically by the performer. In digital instruments nevertheless, the performer no longer needs to control directly all these aspects of the production of sound, being able instead to direct and supervise the computer processes which control these details. As a result of the potential intricacy of these ongoing processes, which can be under the instrument's sole control or under a responsibility shared by the instrument and the performer, performing music with computers often tends towards an *interactive* dialog between instrument and instrumentalist. These new type of instruments often shift the centre of the performer's attention from the lower-level details to the higher-level processes that produce these details. The musician performs control strategies instead of performing data, and the instrument leans towards more intricate responses to performer stimuli, tending to surpass the note-to-note and the 'one gesture-one acoustic event' playing paradigms present in all traditional instruments, thus allowing musicians to work at different musical levels and forcing them to take higher level and more compositional decisions on-the-fly [20].

Multithreaded musical instruments with shared control

However, most of the music controllers currently being developed do not pursue this multithreaded and shared control approach, prolonging the traditional instrument paradigm instead. Many new musical interfaces still tend to conceive new musical instruments highly inspired by traditional ones, most often designed to be 'worn' and played all the time, and offering continuous, synchronous and precise control over a few dimensions. An intimate, sensitive and not necessarily highly dimensional interface of this kind (i.e. more like a violin bow, a mouthpiece or a joystick, than like a piano) will be ideally suited for direct microcontrol (i.e. sound, timbre, articulation). However, for macrostructural, indirect or higher level control, a non-wearable interface distributed in space and allowing intermittent access (i.e. more like a piano or a drum), and in which control can be easily and quickly transferred and recovered to/from the machine, should be undeniably preferred [20].

Moreover, not many new instruments profit from the display capabilities of digital computers, whereas in the musical performance approach we are discussing, in which performers tend to frequently delegate and shift control to the instrument, all affordable ways for monitoring ongoing processes and activities are especially welcome. Visual feedback becomes thus a significant asset for allowing this type of instruments to dynamically 'communicate' the states and the behaviors of their musical processes [17]. It is the screen and not the mouse, what laptop performers do not want to miss, and it is in this context where tabletop tangible interfaces may have a lot to bring.

INTRODUCING THE REACTABLE

The reacTable, the first tabletop project conceived and developed by this team, did not start from the idea of exploring musical applications on tabletop interfaces, but rather from our more than 15 years experience as digital luthiers and computer music performers [16]. The reacTable conceptual precursor was in fact a GUI based software synthesizer, FMOL, developed by the first author between 1997 and 2002.

Visual Feedback on FMOL

FMOL is a software synthesizer and musical instrument with a peculiar interface. Its sound engine supports six real-time synthesized audio tracks or channels, and its mouse-controlled GUI is so tightly related to this synthesis architecture, that almost every feature of the synthesizer is reflected in a symbolic, dynamic and non-technical way in the interface [15, 17]. In its rest position the screen looks like a simple 6x6 grid or lattice, where each of the six vertical lines is associated with one voice generator, and each horizontal line is associated with an effect processor, controlled on its turn by a low frequency oscillators (LFO). In performance, all of these lines work both as input devices that can be picked and dragged with the mouse, and as output devices that give a dynamic visual feedback, drawing the sound waveforms and showing all the music activity. When multiple oscillators or segments are active, the resulting geometric "dance", combined with the six-channel oscilloscope information given by the strings, tightly reflects the temporal activity and intensity of the piece and gives multidimensional cues to the player.

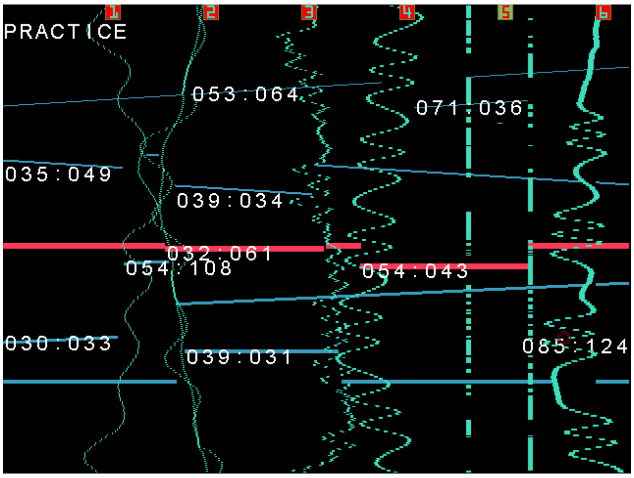

Figure 1. FMOL in action

Looking at a screen like figure 1, which is taken from a quite dense FMOL fragment, the player can intuitively feel the loudness, the dominating frequencies and the timbrical content of every channel, the amount of different applied effects, and the activity of each of the thirty low frequency oscillators. The 'audio' feedback presented to the performer in a visual form, intuitively helps the understanding and the mastery of the interface, enabling the simultaneous control of a high number of parameters that could not be possible without this visual feedback. More essentially, no indirection is needed in order to modify any of these parameters, since anything in the screen behaves simultaneously as an output and as an input, as both *representation* and *control* [35]. In spite of being controlled by a mouse, FMOL was already a musical *abacus*, in the *Ishiian* sense of the term [14]. From an empirical point of view, FMOL had proved to be a good musical instrument used for years in live performance by many musicians including the first author. It was with this know-how and with the idea of surpassing mice limitations that the reacTable project started in 2003.

The reacTable: Conception and Description

The first step was to believe that everything is feasible, assuming access to a universal sensor which can provide all the necessary information about the instrument and the player state, and enabling thus the conception and design of an ideal instrument without being constrained by technological issues. Luckily enough, the current implementation almost fully coincides with the original model [19].

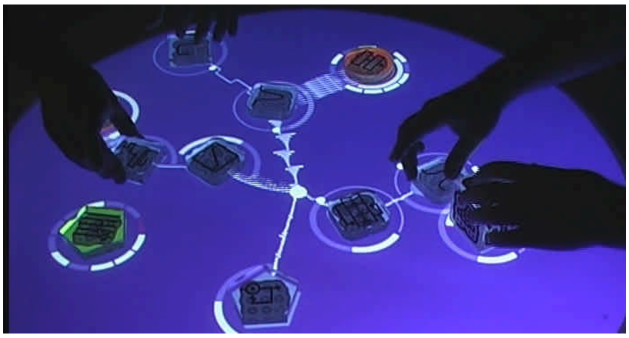

Figure 2. Four hands at the reacTable

The reacTable, has been designed for installations and casual users as well as for professionals in concert. It seeks to combine immediate and intuitive access in a relaxed and immersive way, with the flexibility and the power of digital sound design algorithms, resulting in endless improvement possibilities and mastership. It is based on a round table, thus a table with no head position or leading voice, and with no privileged points-of-view or points-of-control. Like in other circular tables such as the Personal Digital Historian (PDH) System [32] the reacTable uses a radial coordinate system and a radial symmetry.

In the reacTable several musicians can share the control of the instrument by caressing, rotating and moving physical artifacts on the luminous surface, constructing different audio topologies in a kind of tangible modular synthesizer or graspable flow-controlled programming language. Each reacTable object represents a modular synthesizer component with a dedicated function for the generation, modification or control of sound. A simple set of rules automatically connects and disconnects these objects, according to their type and affinity and proximity with the other neighbors. The resulting sonic topologies are permanently represented on the same table surface by a graphic synthesizer in charge of the visual feedback, as shown in figure 2. Auras around the physical objects bring information about their behavior, their parameters values and configuration states, while the lines that draw the connections between the objects, convey the real waveforms of the sound flow being produced or modified at each node.

THE REACTABLE IMPLEMENTATION

Computer Vision

In the previous years, researchers have often criticized the application of computer vision techniques in tabletop development, pointing out drawbacks such as slowness and high latency, instability, lack of robustness and occlusion problems, while favoring other techniques such as electromagnetic field sensing with the use of RFID tagged objects [25] or acoustic tracking by means of ultrasound [23]. Recent implementations such as the PlayAnywhere [40] or the reacTable itself, clearly demonstrate that these reservations are not applicable anymore. For tracking pucks and fingers, the reacTable uses an IR camera situated beneath the translucent table, avoiding therefore any type of occlusion (see Figure 3).

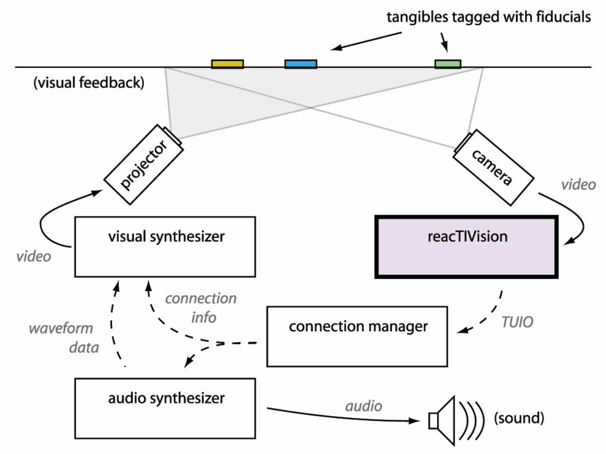

Figure 3. The reacTable components

Additionally, some of the advantages we have found in the use of computer vision (CV) are:

- CV can be combined with beneath projection, permitting a compact all-in-one system, in which both camera and projector are hidden
- Almost unlimited number of different markers (currently several hundreds)
- Almost unlimited number of simultaneous pucks (only limited by the table surface), and with a processing time independent of this number (>= 60 fps)
- Possibility to use cheap pucks (such as for example, specially printed business cards)
- Detection of puck orientation (pucks are not treated as points)
- Natural integration of pucks and finger detection for additional control

ReacTIVision, the reacTable vision engine, is a high-performance computer vision framework for the fast and robust tracking of fiducial markers in a real-time video stream. Fiducial markers are specially designed graphical symbols, which allow the easy identification and location of physical objects with these symbols attached. The ‘amoeba’ symbol set [1] shown in Figure 4, and the related detection algorithms [2] were specifically developed for the reacTable, taking into account the special needs of a real-time musical instrument such as low latency and high temporal resolution (~60 fps). Since November 2005, reacTIVision is available to the general public, including the binaries for all three major operating systems (Win32, MacOS and Linux) as well as the source code under an open source license (GPL, LGPL). Along with the actual sensor component, a collection of free example client projects for the rapid development tangible user interfaces in many programming languages such as C++, Java, Processing and Pure Data are also available on the project site [31].

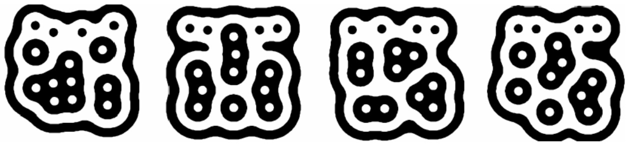

Figure 4. Four markers from the reacTIVision ‘amoeba’ set

Modular Synthesis and Dynamic Patching

The idea of creating and manipulating data flows is well acquainted in several fields, such as electronics, modular sound synthesis or visual programming. Modular synthesis goes back to the first sound synthesizers, in the digital and especially in the analogue domains, with Robert Moog’s or Donald Buchla’s Voltage controlled synthesizers [7]. This sound synthesis method, based on the interconnection of sound generators and sound processors units has largely proved its unlimited sound potential. It can also be considered as the starting point of all the visual programming environments for sound and music, which started with the Max environment in the late 1980s, and constitute nowadays one of the more flexible and widespread paradigms for interactive music making [30]. The reacTable outdoes these models applying what we call *dynamic patching* [21], i.e. managing automatic connections depending on the type of objects involved and on the proximity between them.

Each reacTable object has a dedicated function for the generation, modification or control of sound. By moving them and bringing them into proximity with each other, performers construct and play the instrument at the same time. Since the move of any object around the table surface can alter existing connections, extremely variable synthesizer topologies can be attained resulting in a highly dynamic environment.

Albeit not so popular in regular HCI, the use of rotary knobs is a well-acquainted tradition in electronic music practice. All reacTable objects can always be spun, which allows controlling one of their internal parameters; a second parameter is controlled by dragging the finger around the objects’ perimeter (see Figure 5). Although the exact effect varies from one type of object to the other, rotation tends to be related with frequency or speed and finger dragging with amplitude.

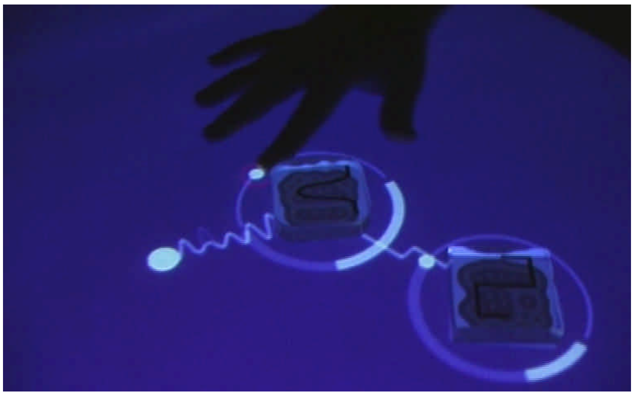

Figure 5. Modifying a parameter with the finger

The reacTable Syntax

ReacTable’s objects can be categorized into six different functional groups: audio generators, audio filters, controllers, control filters, mixers and global objects (which affect the behaviour of all objects within their area of influence). Each family is associated with a different puck shape and can have many different members, each with a distinct (human-readable) symbol on its surface (see Figures 5 and 6). Table 1 summarizes several characteristics of each family or type.

	Connections	Shape	Examples
Generators	▪ 1 audio out ▪ N control in		▪ square wave ▪ sampler player
Audio filters	▪ 1 audio in ▪ 1 audio out ▪ N cntrl in		▪ resonant filter ▪ flanger
Controllers	▪ 1 cntrl out		▪ sine wave low frequency oscillator ▪ 12-step amplitude sequencer
Control filters	▪ 1 cntrl in ▪ 1 cntrl out		▪ decimator ▪ sample & hold
Audio mixers	▪ 2 audio in ▪ 1 audio out ▪ N cntrl in		▪ mixer bus ▪ ring modulator
Global	▪ N cntrl in		▪ metronome ▪ tonalizer

Table 1. A summary of the reacTable objects types

Connections between objects are determined by the objects’ affinities (see Table 1, column 2) and simple proximity rules. In the example shown in Figure 6 (a real snapshot of the visual synthesizer), the sound generator **A** (a sample player) is sounding alone, while sound generator **B** (a frequency modulation synthesizer) is being controlled by the step-sequencer **D**, and the resulting sound is being filtered by **C** (a resonant filter), which on its turn, is being modulated by **E** (a low frequency sine wave oscillator). The metronome **F** only affects the generator **A** because the other objects are out of the metronome's current influence range. **G** is a global object (a tonalizer) which corrects the notes being generated by **A** and **B**, according to the pitches that are active (dark) on its 12-note perimeter (in this case, C,D,D#,F,G,A and A#). **H** is the audio output or sink, where all sounds converge (in a quadraphonic setup, the angle with which each audio thread arrives to **H** determines the panning position of this voice).

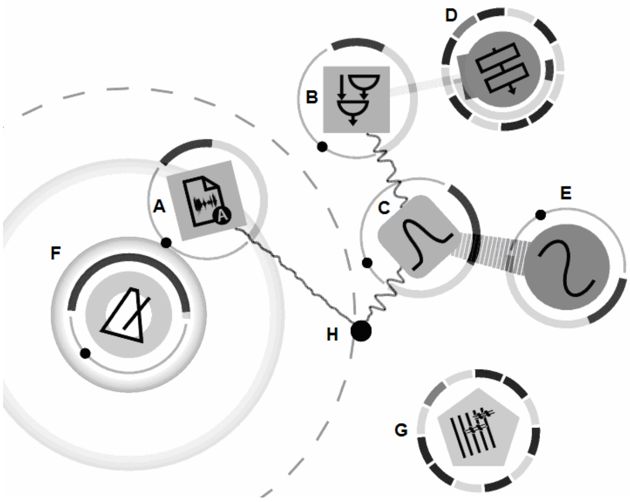

Figure 6. A snapshot showing connections between several objects

In a simplified approach that would only consider generators, filters and controllers, and omit all the proximity rules that manage the system, the reacTable syntax could be described with the following regular type-3 grammar [8]:

$S \rightarrow aNt$

$N \rightarrow cN \mid bN \mid \varepsilon$, where a represent generators, b filters, c controllers, t is the audio output, and ε is the empty string.

This results in the equivalent regular expression: $ac^*(bc^*)^*t$, with each of these strings representing a reacTable audio thread. As seen in Figure 6, several simultaneous threads are possible, each starting with its own generator (a). The combination of this syntax with proximity rules and global objects (that affect all objects within their access range) provides a playful and rich interaction which seamlessly combines the three categories proposed by Ullmer et al. [35] for relating physical elements on a tabletop interface: spatial, relational and constructive.

Visual Feedback and advanced interaction

As we have previously advocated, visual feedback becomes and essential component for playing with the reacTable and dealing with all its complexity. One of our initial design dogmas was to avoid any type of textual or numerical information, while banishing at the same time any decorative display. In that sense, any shape, form, line or animation drawn by the visual synthesizer is strictly relevant and informational. The audio lines that connect objects show the real resulting waveforms; control lines indicate the density and intensity of the values they transport; low frequency oscillators, metronomes and other objects that vibrate at visible rates are animated with their precise heartbeats.

Visual feedback is also important for constantly monitoring the objects' states and internal parameters, such as in the white 180° circular fuel gauges that surround any object indicating their rotational values, in the dots that show the position of the second parameter slider (see all objects in Figure 6, except D and G), or on the finger-activatable discrete steps that surround objects as the step-sequencers or the tonalizer (see respectively D and G in Figure 6). The use of fingers is not limited to modifying objects' parameter. Fingers can also be employed for temporarily cutting (i.e. muting) audio connections. Muted connections, which are represented with straight dotted lines, are reactivated touching again the object that has been muted.

Scalability

As pointed by Ulmer most tangible platforms map interactive objects with physical world elements that have a clear geometrical representation [36]. This often poses problems with respect to the scalability of such systems, in terms of the physical objects that can be realistically manipulated on a table, and the restricted level of complexity that can be handled within these restrictions. The reacTable deals reasonably well with this scalability problem: while two objects can often be sufficient for a "solo" intervention, the level of musical complexity that can be generated by a table full of objects can easily surpass the cognitive load of several performers [28].

This satisfactory behaviour has not prevented us from considering container objects [35] for storing sub-patches. Substituting a group of interrelated objects by one unique sub-patch container is an acquainted habit in many visual programming languages including musical ones such as Max; finger drawing a closed area on the table surface and embedding all of its contents into a physical container object, seems also a quite natural and coherent way to interact with the reacTable. Although this has been implemented as a proof of concept for containers, we have yet to solve the question of how to control the high number of relevant parameters (i.e. 2 for each contained object) that can rule the sub-patch behaviour.

INTERACTING WITH THE REACTABLE

Since its first presentation at the Audio Engineering Society Conference in Barcelona on May 2005, the reacTable has undergone a very active life outside of the laboratory. It has been exhibited in several festivals, conferences or shows, such as the International Computer Music Conference (Barcelona, September 2005), Ars Electronica (Linz, September 2005), the ICHIM Festival (Paris, September 2005), the International Symposium on Intelligent Environments (Cambridge, April 2006), the Linux Audio Conference (Karlsruhe, April 2006), the New Interfaces for Musical Expression Conference (Paris, May 2006), the Sonar Festival in Advanced Music and Multimedia Art (Barcelona, June 2006), the Metronom Art Gallery (Barcelona, July 2006), SIGGRAPH (Boston, August 2006) the Emergences Festival (Paris, September 2006) or STEIM (Amsterdam, October 2006). In these different contexts, the reacTable has been played by several thousands users, of all ages and different backgrounds (musicians, computer music and computer graphic experts; electronic music, digital art or computer games aficionados; teenagers, families with kids, etc.).

The feedback has been very positive, often even passionate, showing that the reacTable can be very much enjoyed even without being fully understood. We have estimated that interested people start grasping its basic principles after 5 or 10 minutes of completely unguided and joyful interaction. Users who spend more than 5 minutes often become "addicted", and come back again many times, trying to find the special moments in which the installation is empty or at least less crowded. As a result of these exhibitions, the reacTable has also appeared in several international TV programs and magazines and undergoes an increasing presence in the blogosphere. In parallel to these public installations, thirteen festival concerts have taken place during the last year, typically performed by two to four players among Marcos Alonso, Chris Brown, Günter Geiger, Sergi Jordà and Martin Kaltenbrunner. These concerts have turned the reacTable into an already mature musical instrument. The ideal combination of these two very different test-beds fulfills our initial goal, which was to build a musical instrument conceived for casual users at home or in installations, as well as for professionals in concert. The two test fronts keep bringing very relevant and complementary information into the continual reacTable design process refinement.

CONCLUSIONS

We have shown the implementation of a tabletop based musical instrument, which is proving to be successful both as a musical instrument and as a tabletop application.

We firmly believe that tangible user interfaces and more precisely, table based tangible interfaces in which digital information becomes graspable with the direct manipulation of simple objects available on a table surface, can fulfill many of the special needs brought by the new live computer music performance paradigms. This type of performances often require the combination of intimate and sensitive control, with a more macro-structural and higher level control which is intermittently shared, transferred and recovered between the performer(s) and the machine. Tabletop interfaces favor multi-parametric and shared control, exploration and multi-user collaboration, while they can also contribute to delicate and intimate interaction (e.g. moving and turning two objects with both hands). Their seamless integration of visual feedback and physical control allows also for more natural and direct interaction.

We are also convinced that the deep involvement present in (both expert and novice) musical performance has much to bring to other interaction contexts which involve creativity in a very broad sense, understanding that creativity is present not only in the production of nice pictures or music, but specially in the process of creation or construction of anything. Creativity, related with expressiveness and with freedom, can thus become important in any interaction process enough complex or enough free, such as the ones in which the paths to a goal are open or when the goal itself is open.

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