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TONETABLE: A Multi-User, Mixed-Media, Interactive Installation

John Bowers

Centre for User-Oriented IT-Design (CID), Royal Institute of Technology (KTH), Stockholm, Sweden
Mixed Reality Laboratory, University of Nottingham, UK
Work Interaction and Technology Research Group, King's College London, UK
Interaction Design Centre, University of Limerick, Ireland
bowers@nada.kth.se

1. Introduction: Mixed Reality and the Disappearing Computer

In various quarters in the computing and allied sciences, there is growing interest in research programs alternately known as 'mixed reality', 'augmented reality', 'augmented virtuality' and the like. Though different programs vary in detail, they share a concern to build and explore artefacts which combine digital materials with physical manipulanda and display devices in novel ways. Examples would include: constructions in which a computer graphical display is projected onto documents placed on a table-top enabling transitions between interaction with traditional paper materials and digital data; experimentation with 'mixed reality boundaries' where views on a virtual world are projected onto materials such as a fine mist of water through which a person can move thereby creating an illusion of passage between the physical and the virtual; combinations of video and computer graphics to hybridise real and virtual 'worlds'; amongst many others. All such explorations are attempts, not only to combine media in novel ways, but also to seek out alternatives to familiar human-computer interaction scenarios. The traditional desktop machine no longer provides the focus and locus of engagement between humans and technology. Rather people find themselves 'immersed' in environments which assemble several artefacts, devices and displays of heterogeneous kinds. In the terms of a recently initiated European IST research program, many researchers now have the ambition of fostering 'The Disappearing Computer'.

2. The SHAPE Project

The current paper presents early results from a project within this program which shares and extends several of these research themes. SHAPE is concerned to explore 'hybrid assemblies of mixed reality artefacts' in which a variety of displays and devices are combined to present participants with a thematically coherent environment. We are interested in moderate to large scale environments with an architectural scale of room-sized and up. We are particularly concerned to explore deployments in public settings such as museums and exploratoria and wish to address the challenges involved in engaging the public in collaborative, technically mediated activity in such contexts. Importantly, we wish to produce exhibits and installations which are sensorily rich, combining graphical/visual with sonic/musical materials, within non-trivial multi-participant interactive formats.

Our project consortium includes computer scientists and social scientists and is committed to developing technologies which are informed by and evaluated through empirical studies of people interacting with each other in/through mixed media artefacts in public settings. We are also committed to the public presentation of our own research through two 'Living Exhibitions' where, in close collaboration with a host musuem, we will develop exhibits and installations. Our collaborators include Tekniska Muséet (the Technical Museum) in Stockholm, the Hunt Museum in Limerick, and the museums of Nottingham City.

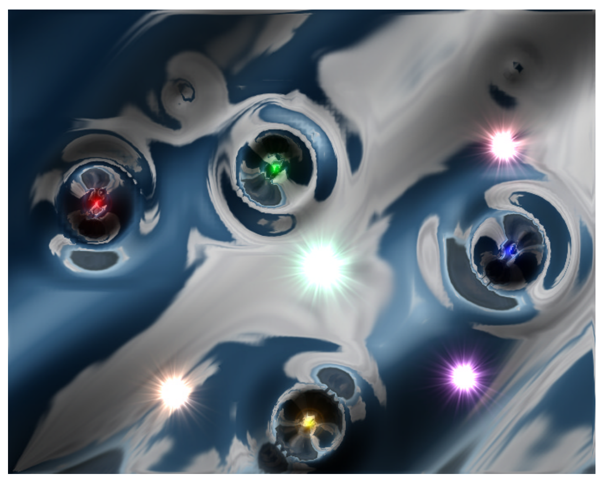

Figure 1. The graphical environment of ToneTable.

3. ToneTable: Interactive Graphics

To demonstrate the work of the SHAPE project, and to further concretise our research concerns, this short paper describes ToneTable in a little more depth. ToneTable is a sound and computer graphics installation which enables up to four people to collaborate on exploring varied dynamical relationships between media. Physically the installation consists of a table as the focus of a room-sized environment which also contains a multi-speaker sound system. Top-projected onto the table is a visualisation of a real-time updated physical model of a fluid surface. The 'virtual fluid' has its own autonomous flowing behaviour, as well as being influenced by the activity of participants. Floating on the surface are a small number of virtual objects (initially, five). These move around the display in response to the dynamics of the modeled fluid surface. Through the use of trackballs, participants are able to move sources of virtual 'wavefronts' around the display. These wavefronts further perturb the virtual surface and enable participants to 'push' the floating objects. If the local force upon a floating object exceeds a certain threshold, the object suddenly orbits around the display before gently coming to rest and resuming the more gentle meandering behaviour characteristic of the objects moving as a result of the flowing surface alone. This sudden interruption in object-behaviour is intended to add interest to the graphics as well as being an outcome that is easier to achieve through concerted collaborative activity between participants. Thus, the threshold for the occurrence of orbiting behaviour is set so that it will tend to be exceeded by a local force produced by two or more proximal wavefronts. That is, two or more participants need to align their perturbations of the surface to produce the orbiting effect.

4. ToneTable: Sound Environment and Sonification

To achieve a mixed media installation, several notable features of the interactive computer graphics have sonic correlates. The floating objects each have a sound texture associated with them. A set of four speakers placed distally from the table creates a soundfield (approx 3mX3m) within which these sounds are heard. The sounds are spatialised so that their position on the table is spatially consistent with their heard-location in the soundfield. If an object gently meanders in the graphical environment, so will its location in the soundfield slowly change. If the object orbits the display, so will its sound orbit around the outer four speakers.

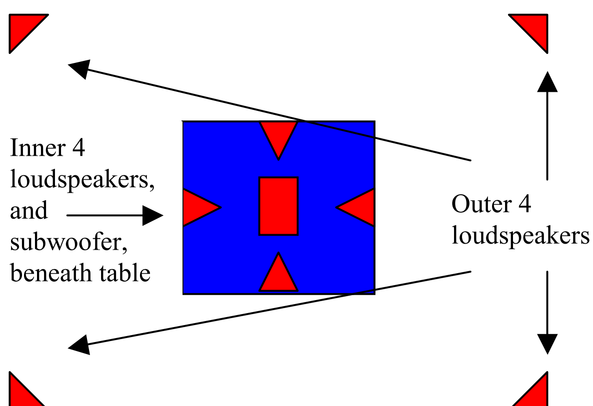

Figure 2. Loudspeakers around and under the table.

Beneath the table is a set of four further speakers, and a sub-woofer. These are principally used to carry sonifications of participants' activity and its effects on the virtual fluid surface. Associated with each trackball is a tone. The greater the movement in unit time of the trackball (and hence the greater the change in position of the wavefront associated with it), the greater the amplitude and high-partial content of the associated tone. The collective activity of participants is also sonified. A measure of the sum of individual trackball movements in unit time is taken, along with a measure of the separation of the four wavefronts in the display. These, when normalised, give two parameter values to a sound synthesis algorithm which generates various species of 'splashing' sounds. Great and little collective activity, close together and far apart wavefronts in the display all produce different splashing effects.

5. ToneTable: Implementation

ToneTable has been realised using a variety of inter-working machines, devices, systems and application development environments. MAX/msp applications were authored to manage the mixing and diffusion of sounds and to calculate appropriate measures of participant-activity and surface perturbation for sonification purposes. Pulkki's VBAP algorithm was employed to spatially locate sounds. Activity sonifications involved synthesis models implemented on Clavia Nord Modular synthesisers. The data from the trackballs is managed using the Multiple Input Device (MID) package developed at the University of Maryland. An OpenGL application was authored to render the graphical surface in terms of the behaviour of its underlying virtual physical model. A local MIDI network linked machines and synthesisers. Where needed, Java/NoSuchMIDI applications provided the glue to attach some machines/applications to this network.

6. ToneTable: Critical Design Features

Let us bring out a number of critical features from the foregoing description of ToneTable, as these express some of our early lines of exploration of principles for the design of interaction for such mixed media artefacts. These include:

Layers of interaction and varieties of behaviour. ToneTable manifests a variety of sonic and graphical behaviours which can be progressively revealed through engagement (both individually and collectively) with it. This can give a 'structure of motivation' to its use. That is, we intended to provide an 'in-built' incentive to explore the table and its varied behaviours and image-sound relations. Indeed, in detail, the dynamical behaviours of ToneTable were defined and calibrated with various non-linearities. Our intention here was to make the exploration of ToneTable an open-ended affair with, indeed, some of the behaviours it is capable of being 'emergent' and not necessarily known to the designers in advance. As such we were hoping that ToneTable would make for a contrast with interactive installations where there is a 'key' or hidden, underlying principle that needs discovery and, once discovered, exhausts the interest of the piece. Finally, by 'layering interaction' in the manner we have described, allowing the behaviours of ToneTable to be progressively revealed and explored, we wanted to create an artefact which could be explored over various timescales. There is immediate responsivity to use. There are further behaviors revealed with more extended engagement. In this way, ToneTable was intended to give some value to participants no matter how long they had available to engage with it.

Interaction through a shared virtual medium and collaborative added value. ToneTable supports interaction between participants through them sharing a virtual medium. By coordinating their activity in that medium, they can engender 'added values': behaviours of ToneTable which parties acting individually do not so readily obtain. However, ToneTable does have a variety of behaviours available when just one person is engaging with it. Its resting state is also not without interest and variety. The intention here is to design an artefact which permits variable forms of engagement, both individual and collaborative, both 'hands-on' and spectating. What is more, by coordinating activity through a common virtual medium, we hoped that participants could gracefully move between one form of engagement and another. They could work individually or in close coordination with others through the use of the same devices and gesture-types. As such, collaboration does not require a switch of 'interface mode' over individual activity.

Variable image-sound-activity associations. ToneTable relates image, sound and participant-activity in a variety of ways. Sound is associated with individual graphic objects. Sound is also associated with individual device-usage (the trackball tones). And so forth. This variety of strategies was intended to enable an approach to the mixing of media which is rich and more satisfying for participants than if just one technique had been employed. It has the consequence that a single gesture may well produce multiple sonic effects, each associated with a different aspect of it. This gives participants a rich set of resources in terms of which to compare their perceptions of ToneTable's dynamical behaviour.

7. ToneTable: Public Exhibition and Evaluation (I)

ToneTable has been presented to the public on a number of occasions. We will concentrate on two such public presentations as these have been formerly studied by us. ToneTable's first exhibition was as part of a workshop of the SHAPE project. About thirty people were in attendance. One of us started by giving a welcome and a brief account of the SHAPE project and the Workshop, as well as the broader Disappearing Computer research context. The in-development status of ToneTable as a demonstrator was emphasised, as was the intention to create something 'abstract yet suggestive'. Suggestions at any level were welcomed. Following this, people were invited into a separate room to see and explore ToneTable.

First, from a technical perspective, it can be noted that setup for the ToneTable worked very well. Using Java for managing multiple input devices and conversion between positional data and MIDI was very straightforward. In addition, the MID package made it unnecessary to use one computer for each input device. The graphical visualisation was effective in the sense that participants perceived it as a watery surface (as intended). The projection onto the table seemed to reinforce this illusion. However, the relatively low resolution of the water surface lattice caused some aliasing artifacts. These did not appear to interfere with the total experience, though. Feedback from participants at the first public demonstration was generally very positive. Indeed, some of it was extremely complimentary. A commonly praised point was that people experienced the ToneTable as having several different behaviour types and relationships between activity, sound and graphics and that these unfolded over time with increasing engagement and prolonged periods of observation.

Figure 3. Publicly exhibiting ToneTable.

The sonification of activity at the table was also well received and clearly several participants took some delight in making loud noises with vigorous trackball movements. The fact that a sound could be heard in an immediately responsive way to one's individual activity through the presence of a tone emanating from under the table gave a clear indication that one was having an effect. The synthesised splashing sound was also appreciated. Good feedback was received about the high quality of the computer graphics and the sound, a quality far exceeding that ever experienced before in a computer-related installation by some of the attendees. Our public demonstration raised a number of interesting critical points and these are worth discussion.

Crowding the space. The room in which we first demonstrated ToneTable could not 'carry' a large number of people. While space existed between the table and the outer set of speakers, this could only be comfortably occupied by the four principal participants and a small number of on-lookers. When the environment become crowded, people could find themselves right next to a single loudspeaker and very far from any audio 'sweet spot'. Indeed, from such a position, they would absorb some of the sound themselves! Generally, we had not allowed for large enough viewing and listening positions, except to support a small number of users and onlookers. Furthermore, we hadn't specifically designed ToneTable to give a listening position for onlookers. While they might be within the outer set of speakers, their impression of both stationary and moving sounds would have been compromised.

Object-sound associations. While it was clear to participants that their activity was being sonified and that objects while orbiting moved around the sound space, it was not clear exactly which object related to which sound or whether, indeed, there was a fixed 'standing-for' relationship. It is possible that five sound objects is too many to individuate in such a setting.

Collaborative added value gained too cheaply. While we designed in a mechanism to allow new behaviours (specifically the orbiting animation) to emerge as a result of combined activity from participants, this outcome could be gained rather too cheaply. If two participants just thrashed around with their trackballs, there would be a good chance that sooner or later their ripples would coincide in such a way as to push an object into orbit. Accordingly, we observed few examples of the careful concerted coordination to move objects and yield new behaviours that we were hoping to provide for. Ironically, the sonifications of gestural activity might have been excessively rewarding, as thrashing around would have very notable sonic effects (a louder and more complex trackball-tone, a louder and more complex watery-splashing sound). This might have relatively reduced the incentive to concerted collaborative activity between participants. Finally, the crowding of the space already noted created a situation where participants did not want to overstay their time at the table. Again, this might have not allowed enough time for concerted coordinated activity with a co-participant to be explored.

Gestural legibility. A feature of trackballs (and mice) as devices is that they disassociate the locus of gestural engagement from the locus of display effects. This occasionally made it hard for participants to see which trackball was associated with which set of ripples. In turn, this made it hard to concertedly coordinate trackball activity with another as it would not be clear which other person was producing which effects on the surface. Trackball gestures then were not readily legible to other parties.

8. ToneTable: Public Exhibition and Evaluation (II)

In the light of these experiences we made a number of modifications to ToneTable for its second exhibition. This took place as part of the Connect Expo in Stockholm in April 2001, a major Swedish technology fair, where ToneTable was encountered by (we estimate) 600 visitors over a three days period. Our modifications were of four sorts.

Configuring the architectural space. To address some of the over-crowding problems, we gave careful consideration to the environment in which ToneTable would be embedded. Most notably, ToneTable was placed within a plexiglass room-within-a-room. This gave a 5 meter square space which could be occupied by people interacting at or around the table while giving those outside sight of it. The enclosure also contained the sound somewhat so that adjoining exhibits were less disrupted. The dimensions of this space, and the visibility of those already in it, helped to regulate the flow of people in and out, and prevent over-crowding problems.

A more integrated soundfield. In our first demonstration of ToneTable, the sounds corresponding to the floating objects were exclusively mixed to the outer four loudspeakers. When the graphical objects orbited and the sounds moved rapidly around the four loudspeakers, this gave effective results for those close to the table who would be within the 'sweet spot'. However, stationary sounds tended to 'collapse' into the nearest loudspeaker to the listener which was carrying the sound, and a poor impression of location or movement would be given to listeners positioned away from the table. To address this, we mixed a portion of the signal going to the outer four to the speakers under the table. We boosted this portion in the 2.5kHz region. This added notably to the overall liveliness of the sounds, especially when orbiting. It also did something to ameliorate the problem of sources collapsing into the nearest speaker, as listeners both at the table and standing near it would hear sounds from speakers all around them. Finally, distributing the mix of the sounds associated with the floating graphical objects between the outer and inner speakers had the effect of heightening the perceptibility of the associations between the floating graphical objects and their sounds.

Smaller number of object-sound associations. Initially, we placed five graphical objects on the watery surface and associated a sound with each. We found it hard for participants to individuate five and notice the relationships. In our second exhibition of ToneTable, we reduced this number to four, which, together with the other changes we implemented, enabled participants to more readily map particular behaviours with particular graphical objects.

Simplifed sonification of gesture. In our first demonstration, a trackball movement would have two sonic consequences in addition to any effects it had on the sounds associated with the floating objects: the trackball-tone and the splashing sound. We simplified this by removing the trackball-tone and just sonifying the overall 'perturbation' to the virtual fluid surface through splashing sounds. In this way, we did not 'over-reward' large individual gestures, while making the sonification of participant-gesture more coherent. Though simplified, ToneTable still manifested a variety of image-sound-activity relationships and sonification strategies.

These changes, though not dramatic, enabled a more satisfactory exhibition of ToneTable than our first presentation. Once again, visitors endorsed the points that were already strong in our first exhibition: the quality of sound and graphics, the existence of different behaviours which could be progressively uncovered. However, with our changes in place, we were able to see more examples of careful collaborative interaction between participants at the table as, on a number of occasions, people coordinated their gestures to jointly elicit the orbiting behaviour and other effects. The environment did not become over-crowded and the more careful design of the soundfield enabled participants at the table and those nearby to equally benefit from an 'immersive' sound experience. Interestingly, although we did not replace the trackballs, the difficulties participants had in the earlier demonstration with working out which trackball corresponded to which co-participant were not noticeably reported. The circumstances of the exhibition as well as our simplified gesture sonification scheme enabled participants to take a little more time to work such details out with a clearer sonification of activity to assist them. Finally, we noted numerous examples of visitors returning to ToneTable, bringing new people with them and encouraging them to explore the table and its behaviours. Again, the exhibition setting, together with our design of a special environment for ToneTable facilitated people in pointing the table out and instructing others in its features, even if they did not have hands on at the time.

9. Conclusions: Designing for Mixed Realities

In this short paper, we have presented ToneTable, an installation developed within the SHAPE project. ToneTable combines, in a number of different ways, high quality computer graphical and sonic materials in a room-sized environment. Let us finish this account of ToneTable by drawing out some lessons of more general interest from our design work and our evaluations of people's experience interacting with ToneTable. We do this under three headings.

Designing for variable participation. When interactive artefacts are deployed in public environments, it is noticeable that people take very varied orientations to interaction with them. They may be 'hands on', 'overseeing', 'passing by', 'in the distance, yet taking an interest', and so forth. They may encounter the artefact on their own or as part of a small group, in the presence of others and other groups, and so forth. An important challenge is to think how these multiple and varied participation formats can be designed for in an integrated fashion when developing an artefact (installation, exhibit or whatever) for a public environment. This is a much more complex question than those traditionally discussed in human-computer interaction research under the rubric of 'usability', and points beyond 'interface design' narrowly considered to the careful design of all environmental elements, both computational and architectural. In our development of ToneTable, we have tried a number of design strategies for addressing such settings. We have explored notions of 'collaboration through a virtual medium', 'collaborative added value', 'layers of noticeability', 'structures of motivation'. These are all concepts intended to suggest ways for orienting design for variable participation.

Multiple, coexisting inter-media strategies. We have also explored a number of strategies for relating media. We have sonified device gesture. We have sonified the effects such gestures have on a virtual medium. We have associated particular sounds with particular graphical objects. We have variably mixed sounds to different loudspeaker groupings, these different groupings having different relations with a graphical projection. Our experience is that a rich and varied set of strategies can be made to work together to create engaging environments, though it is important to ensure that one does not build excessive complexity.

Understanding practical contexts. It is important to understand the practical contexts in which artefacts are encountered. Specifics of particular settings may precipitate redesigns (e.g. the way in which we accommodated ToneTable within a larger exhibition) and observations of what participants actually make of an artefact should be taken into account (e.g. redesigning sound diffusion algorithms to minimise the 'damage' done by someone standing in front of a loudspeaker). In many ways, the concern to understand practical contexts of use and evaluating real participant-experience becomes more intense the more ambitious one's design goals are, not less. If we are now seeking radical ways of embedding computation in everyday environments or producing perceptually rich inter-media installations, we need an equally radical understanding of what those environments and people's activity in and perception of them is like.

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