Form Follows Sound: Designing Interactions from Sonic Memories

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ABSTRACT
Sonic interaction is the continuous relationship between user actions and sound, mediated by some technology. Because interaction with sound may be task oriented or experience-based it is important to understand the nature of action-sound relationships in order to design rich sonic interactions. We propose a participatory approach to sonic interaction design that first considers the affordances of sounds in order to imagine embodied interaction, and based on this, generates interaction models for interaction designers wishing to work with sound. We describe a series of workshops, called *Form Follows Sound*, where participants ideate imagined sonic interactions, and then realize working interactive sound prototypes. We introduce the S*onic Incident* technique, as a way to recall memorable sound experiences. We identified three interaction models for sonic interaction design: *conducting*; *manipulating*; *substituting*. These three interaction models offer interaction designers and developers a framework on which they can build richer sonic interactions.

Author Keywords
Interaction Design; Sonic Interaction Design; Methodology; Gesture; Sound.

ACM Classification Keywords
H.5.5. Sound and Music Computing: Methodologies and techniques; H.5.2. User Interfaces: User-centered design; H.5.2. User Interfaces: Interaction styles; H.5.2. User Interfaces: Auditory-non speech feedback.

INTRODUCTION
Sound has a long history in Human-Computer Interaction, often as a supporting function in the user interface as a way to notify the user about their actions. An early example is the SonicFinder [17], that introduced auditory icons defined as "everyday sounds meant to convey information about computer events by analogy with everyday event". Sound as a medium for interaction has recently emerged through the discipline of Sonic Interaction Design [16] making use of continuous interaction between user actions and sound feedback to help in accomplishing a task while performing it. While this approach has found several promising applications; for example, in rehabilitation [3], sport [33], or music, few insights have been given to interaction designers to allow them to realize such interactions. In this paper, we propose a participatory approach to extract insights for novel and rich sonic interaction designs.

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Sound can be thought of as an information medium, one that conveys clues about materials, substances and their environment, and reveals a sense of the physical dimensions of a space and its surfaces [2]. At the same time, sound is an affective medium evoking memory and emotion. High amplitude sounds, rich in low frequencies, can be physically felt by humans, as in the case of powerful sound systems [21]. Sound can even be used as a weapon using high frequencies and narrow beams [19]. Most importantly, sound is a temporal phenomenon and "exists in time: It is an inherently transient phenomenon" [17]. Listening becomes a critical activity for Gaver, who distinguishes *musical listening* from *everyday listening* [18], the former emphasizes musical qualities of sound while the latter focuses on causal and contextual aspects of a sonic event.

Sound is powerful in that it can provoke a visceral response and influence action. In cognitive neurosciences, couplings between the auditory and motor systems have been reported at the level of the brain [39]. The body is not passive in listening – human actions have been shown to have an effect on auditory perception [29]. Behavioral approaches of sound–action coupling have examined how a physical gestures can represent the sound it accompanies [27]. Considering environmental sounds, recent studies showed that corporeal representation of sound depends on the user's level of identification of the sound source [7]. This points out the possibility that sound sources, and possibly sounds themselves, can take on qualities we can think of as *affordances*, inviting accommodation, response, and possibly use, on the part of the beholder.

In this paper, we propose an approach for the design of sonic interaction where sound and the user's sonic experience serve as the starting point from which action–sound relationships are envisaged. We consider the perception–action loop as a fundamental design principle that facilitates forms of embodied interaction [8,10]. We introduce a methodology based on critical incident technique and workshopping to aid users in accessing memorable sound events, and use scenario building to aid them to prototype sonic interactions. Advanced interactive sound and gesture capture technologies are introduced to allow groups of participants to elaborate novel, functional action–sound relationships. From the insights we gained, we derive interaction models for continuous interaction with sound that could be useful for interaction designers to conceive rich sonic interactions for future products and interactive systems.

The paper is structured as follows. In the next section we review the state of the art in sonic interaction design and interaction models in HCI. We then present the workshop procedure and describe its evolution across four iterations. The Results section reports on outcomes from the workshops and insights they provide. The Discussion uses analysis of the results to frame our proposed interaction models for sound. We conclude by indicating how this research might inform the work of interaction designers and frame future research directions.

RELATED WORK

Sound as an interface

The use of sound in the user interface arises from the need to transmit information through a different medium than the visual (*sonification*). Sound HCI research has resulted in techniques such as audification (raw translation of data to sounds), earcons (audio messages made of short rhythmic sequences of pitched tones with variable timbre), auditory icons (sounds from everyday conveying information about events). For a review see [23]. Sound as a display for information communication has also been the core of the International Community for Auditory Display (ICAD) [26].

Sonic interaction design

Sonic Interaction Design (SID) brings together research and design works that use sound as an "active medium that can enable novel phenomenological and social experience with and through interactive technology" [16]. In this context sound is used to provide information about the nature of the interaction itself, helping the user to refine her actions under a given task [22]. SID also extends the use of sound in an interaction setting for non-task oriented and creative activities. For instance, previous works combined sound design and interaction design techniques to explore sonic augmentation of everyday objects [32,34].

According to Franinović et al. [15], a central element in SID "is the role that embodied action and perception plays, or how action can be guided by sound in a concrete, lived manner" based on theories of embodiment in cognitive sciences [38] and interaction design [10]. The authors added that embodied sonic interaction is a critical notion as "the body is continually navigating through space, attending to cross-modal phenomena […]" ([15], p.43). Embodied actions are crucial in sonic interaction. However, the field lacks an operational framework for designers to realize such interactions.

Techniques for sonic interaction design

Techniques for teaching Sonic Interaction Design are broad and often exploratory. Such techniques are: performing soundwalks [13], listening exercises, cinema sound effects foley analysis [25], and the writing of sonic dramas [31]. Vocal sketching is a technique that uses the human voice as a sketching "tool" for interaction design [11] and, according to Rocchesso, can be thought of as an extension of bodystorming, or "physically situated brainstorming" [6].

Workshops, and processes of *workshopping* are gaining acceptance in HCI as a key methods in qualitative and user-centric research [36]. Franinović et al. [14] propose the workshop as a means to investigate sound in the design of everyday products and to set the methodological basis for this practice, which includes elements of auditory display, product interaction design and ubiquitous computing. A recent study by Houix et al. [24] proposed the use of a participatory workshop to generate prototypes using sounds associated to manipulations of physical objects and prototypes implementing certain gesture–sound relationships. There, the workshop was used as an exploration to test gesture–sound relationships in object manipulation. There is a need, therefore, to formalize some of the very subjective methods in sonic interaction design and to extract insight from them to be transferred to interaction designers wishing to create new products and systems that make robust use of sound as a central part of human-machine interaction.

Interaction Models

Interaction design research has provided a number of different frameworks through the notion of interaction models. Beaudouin-Lafon defines Interaction Model as "an operational description of how interaction proceeds" [5]. Examples of interaction models in HCI include the instrumental interaction from the same author [4] or the direct manipulation model by Shneiderman [35]. While several interaction models have been developed for computer-based interaction through graphical interfaces, interaction models for sonic interaction still remain to be proposed.

METHODS: WORKSHOPPING SONIC EXPERIENCE

We designed and delivered a series of participatory design workshops that focus on participants' memory and direct experience of sound in the everyday. We used a two-phase structure, Ideation followed by Realization, as a way to move from the description of an affective experience to the elaboration of a functioning interactive sound prototype. Since the design process is driven by sound through sonic memories, we called the series of workshops *Form Follows Sound* (FFS), in reference to the idiomatic "form follows function".

We carried out the workshop 4 times in an 8-month period, with a total of 43 participants of varying degrees of experience with sound and music:

- **New York**. A two-day workshop at Parsons The New School for Design. 15 participants (8 female and 7 male), aged 22 - 44. Participants' background included graphic and interaction design, theatre and dance performance, music.
- **Paris.** A two-day workshop at IRCAM Centre Pompidou as part of the European summer school, Human-Computer Confluence (HC2). 6 participants (2 female, 4 male), between 24 and 35 years old. Participants were from a wide range of fields including engineering, rehabilitation, music technology, physics, bioengineering, and art.
- **London.** A one-day workshop at Goldsmiths College. 9 participants (2 female and 7 male). Their background was various including art and technology, social science, film studies, sound design and computing.
- **Zurich.** A one-day workshop at the ZHdK academy of art as an activity within a teaching module in Sonic Interaction Design. Participants were 12 students (4 female, 8 male) aged between 20 and 24 years, with beginner's experience in sound design.

Phase 1: Ideation

Phase 1 of the workshop was called *ideation* as the goal was to generate ideas for action–sound relationships based on memories of sounds from participants' everyday lives. This phase does not involve technology.

Sonic Incident Technique

Critical incident technique is a set of procedures in psychology that elicit specific memories related to particular recent moments lived by the subject [12]. This technique has then been used in HCI as input for design [28] and in evaluation [20]. As a design input method, it facilitates participants recalling situations, describing why they may be atypical, and highlighting the desired normal operation of an interactive system.

With the *Sonic Incident,* we have adapted critical incident technique to specifically address sound-based memories and experiences. We start by asking workshop participants to remember a particular incident that occurred within the last two days for which the sound was memorable. We guided the participants by encouraging them to think of incidents where the situation was frustrating, surprising, or funny, in which the sound contributed to that situation being memorable. The participants were asked to describe the incidents, the reason why they remembered them, the situation they were in while they heard them, and finally how those particular sounds were related to themselves.

The participants were asked to write a text and/or graphical description of the sonic incidents. As text, it might be a narrative of the event, or a textual description of the sound. As drawings, they could be a pictorial representation of the sound, or a storyboard recounting the incident. In all cases, the exercise required participants, independent of their level of prior experience with sound, to represent the sound in its original situation in words or pictures, and in a non-technical way.

The participants then shared their sonic incidents with the group through vocalization, a standard technique from Sonic Interaction Design. Each participant imitated the sound using their voice and the rest of the group tried to guess what the original sound was. This provides an interesting converse to the text/image description of sound. It required the participant to describe a sound by using sound. The activity remained without technology, and, by using the voice, exploited an intuitive and corporeal mode of sound production.

Imagining sonic interaction

In this part of the workshop we asked participants to imagine possible gestural interactions with their sonic incidents. They did not need to be realistic, and rather could be situations in which they could act upon the sound through their movements, or conversely allowed themselves to be moved by the sound. For this activity, we adopted two strategies to invoke corporeal engagement with sound in different iterations of the workshop.

A first strategy was based on the actions in sound (Parsons workshop). We gave the following task "*To see what actions and reactions the sound may provoke in you or in the space around you…. getting from the sound itself to its effect and to the actions that may cause it…. Sketch this interaction between the sound and your actions ... and how do you think this can happen.*" This task encouraged participants to focus on sound and action, and to explore interaction beyond volitional control.

A second strategy encouraged participants to think about having agency over sounds from their sonic memories (Paris, London and Zurich workshops). We introduced the metaphor of "*Superpowers"* asking participants to imagine themselves as all-powerful beings who could create and act upon sounds. The task was: "*Imagine you have super powers and through action with your body, you can manipulate the sounds/situations described previously in the sonic incident. So, look at your sonic incident, and imagine what happens and how it happens. It doesn't have to be realistic.*" This version of the task intentionally introduced volitional control as a mode of sound/gesture interaction.

Phase 2: Realization

The second phase of the workshop was an activity where the participants created functioning technology prototypes to play out their imagined sonic interactions. We created breakout groups where each group selected one imagined scenario from the set of sonic incidents described in the ideation phase in order to implement it.

Gestural Sound Toolkit

We provided a hardware/software toolkit to realize gestural sound interactions (Figure 1). The toolkit includes gesture sensors, and software tools for motion data processing, mappings and sound synthesis. The system affords real time, continuous interaction where sound is sculpted and modified live as movement is performed.

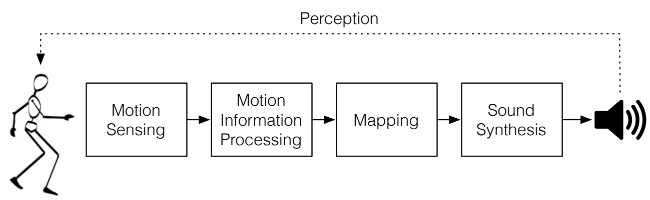

Figure 1. Architecture of the Gestural Sound Toolkit

The sensing hardware was chosen to minimize object-based affordance and cultural association [1,37]. To do so, we chose to use a small sensor to provide a suitable representation of the gesture, not too complex in order to be understood by the participants, non-specialist in motion sensing. We used the Axivity Wax[1], a miniature (the sensor is about the size of a thumbnail), low power wireless 3D accelerometer (see Figure 2) with a sampling rate of 100Hz.

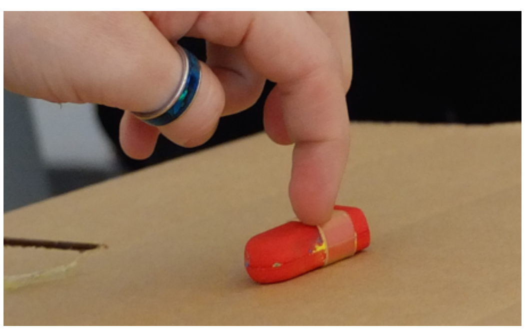

Figure 2. Sensing hardware used in the workshops

The software part of the toolkit was designed to allow participants with no background in interactive sound design, programming, or working with sensors to author forms of continuous sound manipulation through gesture. The software is a collection of high-level modules that can be freely linked to each other. These modules are the following:

- *Receiver module:* receives motion data from the sensing hardware.
- *Analysis modules:* analyze and process the accelerometer data. A Filter module can be used to reduce noise. The Energy module extracts gestural energy from the incoming signal. Velocity was calculated by computing the derivative. A Machine Learning module performs gesture recognition and neural network regression [9]. An Impact Detector, senses percussive gesture from the accelerometer signal.
- *Synthesis modules:* allow pre-recorded sounds (from the sonic incidents) to be played and manipulated. The toolkit integrates temporal modulation (scrubbing). A trigger module allows for triggering a sound from a sound bank. A manipulation module allows sound to be sculpted and modified live as movement is performed.

The toolkit uses the Max/MSP visual programming environment[2]. Our library is available online and open for contribution[3] and is based on the FTM[4] and MuBu[5] libraries. A screenshot is reported in **Figure 3**. This architecture allows sound selection, triggering, and most importantly continuous manipulation of amplitude, pitch, and effects, articulated from user or object movement as captured on the sensors. The sensors are mounted by workshop participants on part of the body, on objects, or in the environment, as imagined in their scenarios.

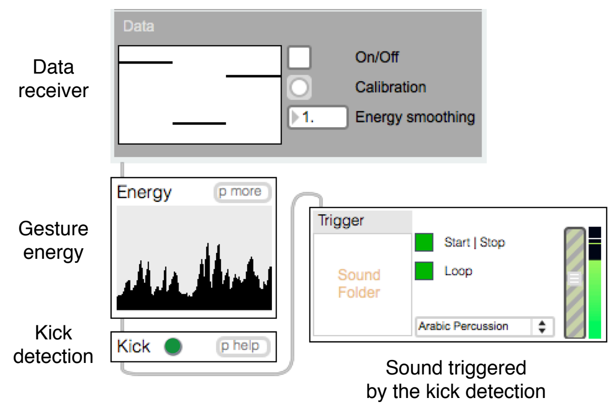

Figure 3. Gesture Sound Tookit software, showing modules which can be interconnected and reconfigured

Group Activity

The Gestural Sound toolkit was presented in a tutorial introducing general notions of gestural sound interaction followed by a short session where participants build simple interaction examples. With this basic guidance, each group created a storyboard of their chosen scenario and implemented using the toolkit. The participants were asked to define, find, or record sounds to be used, and define the actions or gestures involved in the interaction, and the consequences of these gestures on the sounds based on the imagined situation that has been chosen. This was done with minimal guidance from the workshop facilitators, who guided the participants in basic operation of the system and

[1] http://axivity.com/v2/index.php?page=product.php&product=wax3

[2] http://www.cycling74.com

[3] https://github.com/bcaramiaux/Gestural-Sound-Toolkit

[4] http://ftm.ircam.fr/index.php/Main_Page

[5] http://imtr.ircam.fr/imtr/MuBu

its technological constraints. The workshop ended with live performance and demonstrations of the final prototypes to the group, and a general discussion.

Data collection and analysis

All workshop activities were filmed. We collected graphical and textual descriptions from participants of their sonic incidents and scenarios. Two authors performed the analysis and annotated the videos against the graphical and textual descriptions. They then generated a table describing each step from sonic incidents (columns) to the realized project for each participant in each group (rows). This table was the basis to identify emerging interaction strategies. Finally, each participant completed a questionnaire at the end of his or her workshop.

RESULTS

Phase 1

This section presents results from the ideation phase of the workshop, participants' sonic incidents and imagined sonic interactions.

Sonic incidents

All participants across the four iterations of the workshop were able to describe one or two sonic incidents, with several describing more than three incidents.

Of the 61 total sonic incidents, and 57 were sounds produced by non-human events from the everyday. Of these, 20 sonic incidents referred to transport situations: "beep before tube's doors closing", "squeaking doors in the bus", or "bike hitting a manhole". 14 sonic incidents referred to domestic situations: "bubbling of oil while cooking", or "stormtrooper wake up alarm impossible to stop". Two other categories are: environmental sounds such as "wind" or "rain" happening in a particular situation such as "rain at the train station"; and electronic sounds such as "Skype ringing" while not being in front of the computer. Human-produced sonic incidents mostly involved social situations (8 sonic incidents) referred to such situation, for example "children playing football.

Every sonic incident involves a sound that was not produced by the participant but that happens in a situation in which the participant was an observer.

Interaction scenarios with sonic incidents

The second activity encouraged participants to imagine scenarios where they could actively interact with the sounds evoked in the sonic incident. We used two different strategies to invoke corporeal engagement with sound: 1) Sound interaction without volitional control, and 2) Volitional control using the superpowers metaphor.

From the set of 15 interaction scenarios generated by the first strategy, we took the textual description of the sound incidents and the subsequent interaction scenarios and traced their evolution.

- 9 scenarios are (graphical) **representations** of either the cause of the sounds or the actions on the sound on the participant. For example, reported Figure 4, a sonic incident was a "*Stormtrooper wake up alarm impossible to stop*" for which the interaction representation was a sketch with arrows pointing down and a pushing mechanism, an abstract view of the effect of the alarm on the participant.

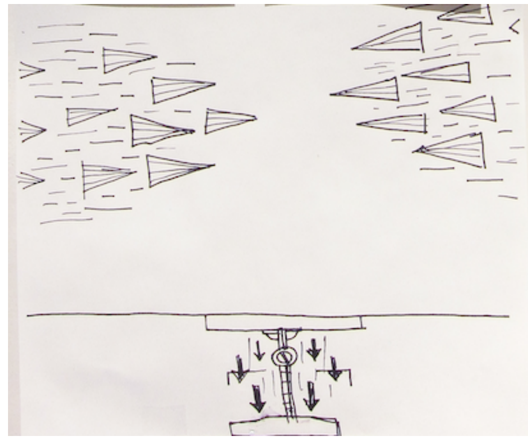

Figure 4. Sketch of sonic incident: *Stormtrooper Alarm*, showing effect of being awoken by an alarm clock

- 3 scenarios described **reactions** of the participants after hearing the sound from the sonic incident. For example, a sonic incident was "*cats jumping after [the participant] steps on it"* and the interaction scenario was "*stepping on cat, cat reactions* [sound]*, my movements in reaction to the cat's reactions*" (Figure 5). These produced reaction scenarios kept the same situations in which the sonic incident occurred.

Figure 5. Sonic incident as reactions: *Stepping on Cat*, a series of reactions, first by cat, then of the user to the sound

- 1 scenario describes the **manipulation** of sound from body movements. The sonic incident was "*Squeaking ventilation in the workshop room*" and the imagined was a "*man controlling characteristics of sound by moving*"
- 2 are scenarios that are not related to the earlier sonic incidents. For example the sonic incident was "*Car's tires on wet asphalt*" and the imagined scenario was "*Springs connected together playing Jingle Bell*".

From the set of 26 interaction scenarios generated using the superpower strategy, we performed the same analysis, tracing the evolution from textual description to interaction scenarios. We observed differences across the scenarios imagined, finding that 22 scenarios involve both the sound and the situation in which the sound takes place in the corresponding sonic memories, while only 4 used just the sound, isolated from its initial situation. Of the former, we found differences in how the participants relate body movement to the sound material.

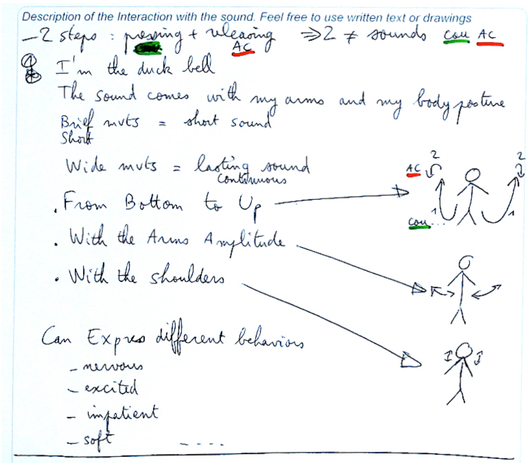

Figure 6. Substitution as interaction scenario: *Duck Honk*, user becoming the duck

- 3 scenarios described movements that **substitute** the sound or the cause of the sound. For example, a sonic incident was "*Duck honk on the bike that was inappropriate"* and the interaction scenario was "*Being the duck, limbs control different qualities of squeaking*" (Figure 6).
- 7 scenarios described gestures that **manipulate** sound parameters. For example, a sonic incident was "*Walking in the woods, snow cracks under his feet, breaking ground"* and the interaction scenario was "*Sound: Crack + Swoosh + thud; with actions: Crack/Crush by moving the fist + slide and stop using legs*" (Figure 7).

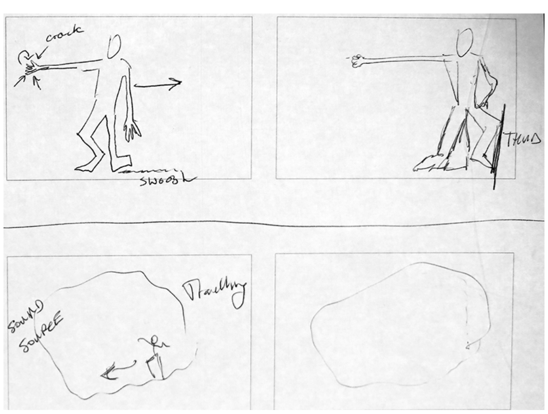

Figure 7. Manipulation in interaction: *Snow Cracks*, limb movements crushing snow, zooming into imagined actions

- 7 scenarios described movements that **conduct** sounds. This differs form the previous case by the existence of an explicit gesture vocabulary. For example, a sonic incident was "*Annoying sounds of neighbors' children playing"* and the interaction scenario was "*Transforming children's screams in music by conducting them as a musical conductor*".

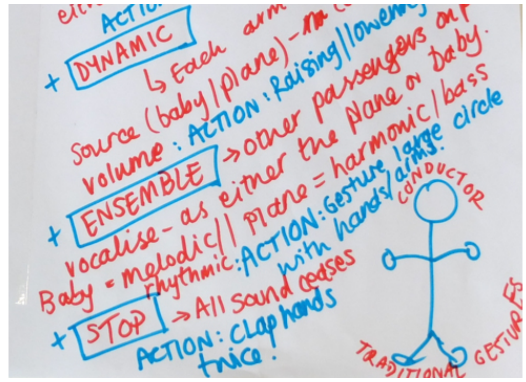

Figure 8. Reaction in interaction: *Laser Destroy Alarm* where a user's gesture conducts sound in reaction to sonic incident

- 3 scenarios described **reactions** of the participants after hearing the sound from the sonic incident (similarly to Workshop 1). For example, a sonic incident was "*Phone alarm + Clock failing to wake her up"* and the interaction scenario was "*Destroying loud alarm with laser vision explosion*" (see Figure 8).
- The two last scenarios involved **unrelated relationship** to the actual sonic incident even if using the sound and situation. For instance, a sonic incident was "*Sizzling sound of oil in fraying pan"* resulted in the unrelated the interaction scenario, "*Sound to navigate through locations"*.

The strategy used in facilitating embodied sonic interaction, therefore had an impact on the action–sound relationships imagined by workshop participants in their interaction scenarios.

Phase 2

In the realization phase, each breakout group chose one scenario from their group to develop into a functioning prototype. They first created a realizable interaction scenario by storyboarding it, describing actions, sounds and interactions. They then recorded or searched online databases for sounds that approximated the sound of the incident. With this, they authored a movement/sound interaction using our hardware/software toolkit.

Despite the potential difficulty of working with interactive sound software, the high level abstractions and workflow of our gestural sound toolkit was generally well understood by the participants. During all the workshops, the participants were highly independent and asked for help from the facilitators only when they wanted a software feature that was not included in the toolkit, for instance a sound synthesis engine such as sine wave generator (IRCAM). This was facilitated by the modular architecture of the toolkit and also by working in breakout groups.

During the four workshops, 14 projects were realized. In 13 cases, participants produced fully working prototypes that were presented to the whole group, while in only one case participants were not able to complete a final implementation. In complement with this, only one project was realized without using sound material from the sonic incident activity in the first phase. Although all the 12 other projects made use of a recalled sound from sonic incidents, the final projects made different uses of the situation in which the sound from the sonic incident occurred.

There were two types of project – those that implemented a scenario, or part of a scenario, from the ideation phase, and others that implemented a scenario that used only the sound from the sonic incident and implemented a totally different situation and interaction than originally imagined.

Of the first type of project (8 total), an example includes: "*Hum of airplane revealed by baby crying*" and imagined "*conductor gestures, e.g. dynamic responding to raising/lowering hands*" as interaction mode. The prototype recognized three gestures. The first one triggers the hum of airplane, the second one start a baby crying, the last one stops the sounds. In this case, the participants found sounds in the Freesound[6] online sound database. During the demonstration, the participants placed the sensor on the hand. Accelerometer data was low-pass filtered to take out noise and then sent to the gesture recognizer. The recognized gesture was used as a selector for a sound in a playlists and subsequently played. This shows a conducting situation.

In another example, the sonic incident was "*vibration ring of phone on a shelf while sleeping*", which was characterized as "*wrong rhythm, it was like a call, instead it should have been like an alarm*". The imagined interaction was the "*Snooze action to fall asleep again and creating a sound that would suggest me as being awake while still sleeping".* The group implemented a scenario in which after the clock alarm is heard, moving (mimicking the movement in the bed) against the clock activates a "snoozy melody". Subtle movements change the speed of the melody played back to help waking up. When moving towards the clock, the alarm sound plays back to wake up the user. Here, participants substitute the alarm mode of operation through actions related to sleep.

Of the second type of project (4 total), examples include a sonic incident "*Sound of filling water bottle, changing*" where the participant represented the action linked to the sound as "*Bottle being filled with water*" changing the pitch. The implemented prototype gives different sound feedback (based on the recorded sound sample of water poured in a bottle) according to the position of the arms. This resulted in an application, the "Yoga corrector" that facilitates adapting body position during a yoga exercise according to sound feedback similar to the rising pitch of the filling water incident. The sensor was strapped on the arm or on the leg. They used the variations in orientation of the sensor to control the reading cursor and pitch transposition. This shows how participants manipulated sound parameters through their actions.

[6] http://freesound.org

From the 12 projects, of the two types, we found that the prototypes involved actions that conduct the sound, substitute to the sound cause or manipulate the sound. No interaction scenario from the first phase that involved actions in reaction to sounds was retained for implementation. Interestingly, all were from the workshops where the superpowers metaphor was used. We infer from this that the use of technology to realize scenarios has an effect on previously imagined action–sound relationships and is dependent on the metaphor (actions in sound or the metaphor of superpowers) used in the task from the first phase.

DISCUSSION

We have presented a series of workshops that investigate participatory and sound-centered methods for the design of sonic interactions. This approach proposes the sonic incident technique, and the notion of sonic affordances, as parts of an ideation process for generating ideas for embodied sonic interaction. Importantly, the methodology leverages on a non technology-centered approach for authoring action/sound relationships. From the proposed methodology, we highlighted three types of actions-sound relationships in the final prototypes: actions that conduct sounds, substitute the sound source, or manipulate sound parameters. Here we discuss the methodological contributions presented in this paper and we show that the workshops provide interaction models for sonic interaction design.

Sonic incidents and sonic affordances

The sonic incident technique was successful in facilitating users' thinking about sound in context. Participants tended to describe sounds that happen to them rather than sounds that they cause. The technique makes the participants aware of why sound was an important part of the incident, why they remember it and what would be the normal situation with this sound [28]. Each sound is thus contextualized in an idiosyncratic situation from participant's everyday life. Engaging the everyday of the participants is an important conceptual aspect of the technique as it can provide a context of use through the sonic incident itself. As such, sonic incident can be thought as a technique that could facilitate the design of situated interaction (as defined in [5]). With Sonic Affordance, we propose the notion that sound can invite action. It was explored in the second part of the Ideation phase of the workshops by asking participants to imagine corporeal engagement with the sonic incident.

The small, non-descript, sensing technology became a "non-object" that served a function without carrying a physical affordance. Objects afford user actions based on their form factor, shape, size, and textures. Similarly, sound can have prior cultural association, such as musical context in identifiable instrument sounds. By using a miniature sensor, the sensing technology itself did not offer physical affordances to influence the interaction imagined. By working with sound from the everyday, we minimized musical association that may have colored the resulting gestures. In so doing we were able to use the workshops to drive participants to focus on the affordances from the sound itself and not the interface used, hence, *Sonic Affordance*. The concept of a Sonic Affordance is useful as a way to think about the corporeal response that a sound may invite on the part of its beholder.

Participants in general were not accustomed to imagining interactive scenarios with sound. A critical aspect of the ideation process was therefore to aid the participants to think about acting in the situation of the sonic incident. Mentioning actions in relation to sound did not lead the participants to involve the body in the interaction. The metaphor of superpowers was more successful in generating physical action–sound relationships in the imagined sonic interactions. We used this metaphor in three workshops (Goldsmiths, IRCAM and Zurich), and interestingly faced questions about the meaning of the task. Participants were questioning from which perspective they have to imagine the interaction: "*Can I be the sound?*" or "*Am I listening to the sound?*".

Methodological contribution

In our workshop procedure, the ideation phase takes place without computers. This encourages participants to focus on sounds and their context, without influence of technology. Interactive technology is introduced only in the subsequent realization phase, after sounds, incidents, and scenarios have already been imagined. The sonic interactions imagined, therefore, were not technology-driven. The creation of the scenarios has been grounded in the concepts of sonic incidents, resulted affordances and imagined interaction scenarios.

Figure 9. Physical constraints in the use of the Gesture Recognition System, the sensor is placed on the foot

Workshop participants were able to take the sonic interactions imagined in phase 1 and implement them using our toolkit. They overcame limits in their own technical knowledge to nonetheless use machine learning techniques in their prototypes. They were also tactful in working around limitations and constraints of the technology. For example in one prototype, participants transformed the physical space, creating an obstacle course to walk through to more clearly send distinct foot gestures and slowing down the user's walk to aid the recognition module of the toolkit in distinguishing gestures to trigger different floor crackling sounds (Figure 9).

It was a challenge to present advanced sound programming and interaction authoring techniques as just one part of a workshop program. Given that the workshop participants had no prior experience with the Max/MSP software, we were mindful that the workshop not become a tutorial on use of that software. The library of high-level modules we designed is effective in giving access to powerful, reconfigurable sound interaction functionality in a highly accessible manner.

Emerging interaction models for sonic interaction design

In the three workshops where volitional control of sound was explicitly mentioned, the scenarios that were generated showed interaction scenarios involving movements that *substitute, manipulate,* and *conduct sounds*, and their technology implementations capture user movements that reflect this. We propose these action/sound relationships as interaction models for sound. More precisely, these interaction models are described as:

- **Substituting**: the movements substitute the cause of the sound or the sound itself. Possible actions are defined by the sound itself and not constrained by an interface. Then there is a direct modulation of some aspect of the sound (volume, brightness, playback speed) by the participant's actions.
- **Manipulating**: where movements manipulate the sound. The possible actions in interaction should be let to the choice of participant/user. They can be constrained by the interface. Then there is a direct modulation of the sound through the participant's actions, similar to the previous model.
- **Conducting**: there is a semantic relationship between the participants' gestures and the sound. The gestures should be free to be chosen by the user but they are, eventually, part of a finite set of gestures (a vocabulary). Then there is a direct relationship between a symbolic feature of gestures (what gesture, how it is performed) and the sound.

These three interaction models provide respectively unique operational descriptions that can be used by interaction designers or developers to build innovative sonic interfaces that respond to particular contexts. Further, interaction designers can use these models to characterize interaction according to descriptive (incorporating existing interaction techniques), generative (facilitating new interaction techniques) and evaluative (comparing techniques) powers [5] and therefore to enhance the specificity with which they respond to a given sonic interaction design problem.

These models enhance the design process by describing distinct approaches to the design of a sonic interface, establishing criteria that can be used in the early stage assessment of a sonic design problem. The substitution model focuses the designer on sound and its source; manipulation addresses controllable aspects of sonic artifacts, such as instrumental control; and finally conducting introduces the symbolic and semantic meaning of gestural interaction with sound.

The models are further distinguished by the way in which they can be evaluated: while conducting and manipulating may involve quantitative measures to compare interaction techniques (time completion, accuracy), substituting necessitates a qualitative explanation of the relevance of chosen actions to an associated sound, its cause and its context.

Innovation in sonic interaction design

Norman and Verganti [30] argue that human centered design tends to produce incremental innovations that are constrained by users' past experiences. They further argue that radical innovation requires technological change or meaning change. The work presented does not introduce technological change: accelerometer sensors are commonly available and gesture recognition algorithms in the toolkit had been developed in our prior research. Meaning change, however, is explicitly addressed, by encouraging participants to think about, discuss, and manipulate sound through our methodology. Our method aids workshop participants without specialist audio engineering or musical training to work with sound, representing a change in meaning of sound for those participants. The process identifies sonic incidents and translates them into embodied interaction concepts and prototypes. Differences in the emphasis in the task (volitional or non-volitional), led to different interaction scenarios and models. This method can be replicated, and leveraged, by designers to expand the meaning and utility of sound in consumer device interaction.

CONCLUSION AND FUTURE WORKS

In this paper we presented a series of four workshops that explore the rich potential of action–sound relationships and their use in designing interactive systems where sound is a fundamental part of the interaction. The workshop structure is comprised of ideation activities including the *Sonic Incident* technique as well as graphical, textual and vocalized sound representations; followed by realization activities including scenario building and prototyping. Participants generated final projects that implemented three principal interaction models: *conducting*, *manipulating* and *substituting*. These three interaction models can be operationalized by interaction designers and developers building innovative sonic interfaces and products.

Sound in the user interface has heretofore been made up mostly of sound bites, events and triggers. The sonic interactions of the sort presented here involve continuous interaction between physical action and sound, putting the user in an action–perception feedback loop. Each of the three models described above is the basis for an interaction strategy within this feedback loop, which can help designers build better sonic interfaces that respond to specific circumstances and contexts. Together, these methods and interaction models can help designers to address sound as a continuous and informative phenomenon in the interface rather than as a simple display mode for alerts.

The research presented in this paper will be useful for interaction designers to conceive future products that integrate sound in the interface in a robust and continuous fashion. The proposed interaction models are not limited to sonic applications and might be considered for interaction with other continuous phenomena, such as light, and moving image. These interaction models fit into interaction paradigms that go beyond the desktop to objects, environments, and sounds, in our everyday lives.

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