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Auditory display design—An investigation of a design pattern approach

Christopher Frauenberger*, Tony Stockman

Interaction, Media and Communication, School of Electrical Engineering and Computer Science, Queen Mary, University of London, Mile End Road, E1 4NS London, UK

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Abstract

We present the evaluation of a methodological design framework that supports expert and novice designers in creating auditory artefacts in human–technology interaction. We first motivate the development of our framework by analysing available guidance and the current practice in the field. Subsequently, we recapitulate on the design of the framework—*paco*, *pa*ttern design in the *co*ntext space—and present its key concepts and methods. The evaluation of *paco* aimed to investigate how useful this framework is in a real-world environment. It was conducted in two phases: experts in auditory display design first captured successful designs through *paco* and created a body of design patterns. These patterns were subsequently used in a controlled experiment with novice designers who were given a design task that forced them to use audio. The results demonstrate that *paco* has facilitated the transfer of design knowledge and good practice from experts to novices through design patterns. The context space, a key concept in *paco*, improves the contextual awareness of designers and provides an organising principle for problems, patterns and artefacts. We close by reflecting on the results and discussing future lines of research.

Keywords: Auditory display; Design patterns; Design methodology

1. Introduction

The auditory channel in human–technology interaction has received increasing attention as shifting contexts of use and interaction paradigms expose the limits of traditional, vision-dominated computing. Despite our growing knowledge about sonic interaction and promising results in related research, the impact on design practice has been limited. Much of the sound produced by today's technology fails to exploit the sophisticated abilities of human hearing. We aim to address this gap by presenting a methodological framework constructed around design patterns to improve the transfer of design knowledge.

Auditory display—audio as a means to convey information—provides interaction designers with a distinct set of features that effectively extend the available design space. For example, through its flexibility in managing user attention or exploiting the sensitivity to temporal structures. This allows designers to address key challenges in modern interaction design such as the "visual overkill" resulting from the ever growing demand for conveying still more information to users. Auditory displays can help to overcome some limitations by reducing the cognitive load and increasing performance in complex tasks when used in complement to visual displays (Oviatt et al., 2004). Interaction designers also face a whole new era of computing with contexts of use being freed from the traditional desktop environment. Ubiquitous and mobile computing are emerging fields with users requiring eyes-free interfaces, with devices too small to carry a visual display and with environments that make conventional interaction design inappropriate. The exploitation of auditory interaction in these contexts shows great potential (e.g. Brewster, 2002).

Auditory display also plays a key role in making information technology accessible to the visually impaired. The growing impact of technology on our everyday lives makes access to these resources a key factor in being fully

*Corresponding author.
E-mail addresses: frauenberger@dcs.qmul.ac.uk (C. Frauenberger), tonys@dcs.qmul.ac.uk (T. Stockman).

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integrated and self-dependent. However, despite the rapid development of technology, the means of access has changed very little for visually impaired users over the years, remaining predominantly based on Text-To-Speech (TTS) systems. This inadequacy reflects the more general argument about the limited impact of auditory display on technology we use every day. Mobile phones, portable music players and kitchen appliances incorporate sufficient technology to produce pleasant, functional and informative sounds, but the designs of their interfaces are often limited to simple alarms or speech. We argue that the field of auditory display design could benefit greatly from an efficient means to capture and transfer design knowledge for designers to build on the expertise in the field and apply it in different contexts. By the introduction of a methodological framework for designing auditory display we aim to facilitate this transfer and contribute to the wider use of sound as an efficient means for conveying information.

This article is organised as follows: the subsequent section provides the background to this research including a review of related work and two studies that investigate current practice in auditory display design. The results of these studies informed the design of the *paco* framework (*pa*ttern design in the *co*ntext space) introduced in Section 3. This is followed by a report on an evaluation study investigating the usefulness of *paco* in real-world design tasks with novice and expert designers of auditory displays. Section 5 summarises the work and examines the future of this line of research.

2. Background

2.1. Guidance and methods in auditory display design

At the International Conference on Auditory Display 2008 in Paris, a workshop on re-usability of design knowledge[1] produced a valuable taxonomy of fundamental approaches to auditory display design. This taxonomy provides a useful classification of design processes within the field[2] and we shall adopt it here to structure the review of available guidance and methods.

Perceptual design: The majority of guidance is focused on the perceptual and cognitive aspects of human hearing. The principles by Kramer (1994a), for example, link perceptual issues with implementation techniques, mainly in relation to mapping strategies. Other guidance draws on auditory scene analysis (Bregman, 1990) and links perceptual issues such as stream segregation with design issues of auditory display (e.g. Mitsopoulos, 2000). Gestalt principles have also driven the work of Blattner et al. (1989) on earcons and led to the guidelines presented by Brewster et al. (1993).

Ecological design: This approach is informed by studies in ecological hearing and everyday listening (e.g. Ballas, 1993). For example, Mynatt (1994) provides guidance for choosing sounds in a user interface or more recently Brazil and Fernström (2007) have proposed using the Repertory Grid Technique to classify auditory cues to be used in ambient information systems. Gaver (1993) was one of the first advocates of ecological acoustics informing sound design with his work on auditory icons. A similar argument is made by Coleman et al. (2008) who proposed the use of *earwittness*[3] accounts to prompt designers to think of future sound design possibilities.

Contextual design: It could be argued that this overlaps with the previous category, but contextual design not only considers acoustical ecology, but also other aspects of the context of use such as technological or social constraints. Barrass (1998) has used a case-based approach ("EarBender") to link sound designs to narratives. Similarly, Pirhonen et al. (2006) use rich use-case scenarios to inform sound design.

Task driven design: Task analysis is a very significant approach to interaction design (Redish and Wixon, 2003). The TaDa! analysis (Task and Data Analysis) introduced by Barrass (1998) aims to capture similar requirements for auditory display design, but extends it to the data to be conveyed. It also adds a short story to the semi-formal process bringing it closer to contextual design. Brewster (1994) has used the event and status analysis (Dix, 1991) to identify inaccessible information in user's tasks which he subsequently makes available by auditory means.

Semiotics: The meaning making of sounds, as in the interpretation of a sign, is a perspective on auditory display design that has gained increasing attention recently (e.g. Mustonen, 2008; Jakosch, 2005). The design methodology by Pirhonen et al. (2006) argues for rich use-case scenarios as syntagmas in analogy to approaches to musical semiotics. Their stance aims to ensure the correct interpretation of sounds by designing it in a rich context of use.

Compositional design: Composers are experts in creating music, i.e. expressing themselves through sound. Often, composers are asked to participate in auditory display design tasks to increase the æsthetics of the result (e.g. Stallmann et al., 2008). Vickers and Hogg (2006) argued for an "æsthetic perspective" for classifying auditory display and discussed the relationship between sonifications and electronic music. The creative nature of composition, however, makes capturing of expertise or provision of guidance difficult.

[1] Recycling auditory displays, organised by C. Frauenberger & S. Barrass, http://icad.org/node/499.

[2] A related, but more sonification specific taxonomy has also been discussed in Barrass (1998, pp. 7–28)

[3] A narrative-based approach to describe the acoustical environment (Coleman et al., 2008).

Exploratory design: The sonification design map by de Campo (2007) allows designers to conceptualise the design space and systematically explore design choices. It is, however, specifically tailored to data sonification. As we shall see in the next section, exploratory design approaches are applied more pragmatically in practice—e.g. defined by the capabilities of software—and lead to ad hoc solutions.

This brief overview illustrates the diversity of guidance and methods available, but is by no means exhaustive. Reflecting on these methods and guidance, however, makes apparent that there are gaps between the different approaches. For example, the extensive design knowledge on perceptual mapping is not connected well with high-level interaction design. Case-based or scenario-based design approaches which emphasise the context of use but fail to exploit the generative power of novel solutions in sound design. To bridge these gaps, Barrass (2005) calls for "a comprehensive framework for designing auditory displays that takes into account user tasks, data characteristics, device gamuts, semiotic schema, interaction metaphors, and the perceptual organisation of higher levels of information in an auditory display" (p. 406).

2.2. Auditory display design practice

Auditory displays are often designed in an "ad hoc" way which greatly limits their efficient use in interaction design (Lumsden and Brewster, 2001). A recent survey conducted by the authors with 86 participants from a general HCI background supports this view (Frauenberger et al., 2007a). Designers from the wider HCI community were surveyed about their approaches to auditory display design and the guidance they use. Analysis of the 86 responses highlighted the general preoccupation about audio in the user interface. Although the majority of participants thought audio can improve HCI, it is believed to provide low bandwidth and to be inefficient and difficult to design with a high chance of being annoying rather than useful. The design process is largely seen as a craft exercised, to be performed by musicians or professional sound designers. Asked for their ideas for designing a non-visual MP3 player with additional PDA functionality,[4] their accounts were very conservative; largely centring around text-to-speech solutions.

To find out about the practices within the scientific community, we examined the Proceedings of the recent 13th International Conference on Auditory Display (2007) in Montreal, Canada. Four aspects of application orientated papers were of particular interest for us: the design process, the guidance used, the rationale for design decisions provided and the practice of evaluation. Of the 82 papers (50 full papers, 32 posters[5]) published in the proceedings, we identified 23 (11 full papers, 12 posters) describing an actual design of an auditory display. We excluded papers on studies of low-level auditory perception, theoretical work on cognition, ecological hearing or design methodologies, because we were interested in the design practice on auditory artefacts, not the available theory of design.

Two of the 23 papers follow a specific *design process*, based on a methodology developed by the authors. The remaining 21 exhibit more or less clearly the phases of the design process the authors went through. Broadly, two different styles of design processes can be distinguished: nine papers are driven by underlying theoretical research questions and exhibit design processes in which uncharted terrain is explored and envisionment is emphasised. The remaining 14 papers are driven by the needs of real-world application domains and focus on the management of constraints. Although all of the papers introduce the application domain and motivate the work by highlighting potential beneficiaries, it is important to note that little contextual information seems to feed into the design process.

For *guidance*, the most cited body of work is the "Auditory Display" book by Kramer (1994b). Eleven references were made in total to seven different articles of the book. Brewster is the most frequently cited author with 11 citations, mostly for his work on earcons (e.g. Brewster, 1994). For auditory icons and everyday listening, the papers referred to Blattner et al. (1989) (4 times), various publications by Gaver (5 times, e.g. Gaver, 1989). Work by Herman was cited 5 times, mostly for specific approaches to sonification (e.g. Hermann and Ritter, 1999). Other work cited frequently include Zhao et al. (2004) (4 times) for their design principles on auditory information seeking and Shneiderman (1996) (2 times) for the visual counterpart. It has to be noted that it is impossible to quantify the impact these references made on design decisions. Many citations were made in the related work section of the papers without a clear linkage to design decisions described later in the paper.

Providing the *rationale* for design decisions is key in making design knowledge explicit and re-usable (Dix et al., 2004, p. 249). Following Kunz and Rittel (1970), the primitives of process-orientated design rationale are issues, positions and arguments. The 23 papers investigated showed significant gaps in providing alternative positions and arguments for decisions—this is not to say that there was no rationale, but it was not reported. Unsupported design decisions were found at all levels of the design process, from higher level interaction design to lower level choices of sound properties. For example, Horowitz (2007) and MacVeigh and Jacobson (2007) both propose

[4]Calendars, todo-items, etc. common in Personal Digital Assistants (PDAs).

[5]At ICAD 2007 full papers as well as posters were published in the proceedings as papers with an 8 page limit (http://www.music.mcgill.ca/icad2007/).

(different) interaction paradigms for aurally augmented, spatial maps, but do not discuss alternative positions or their arguments for the designs chosen. The sound synthesis used in Baier et al. (2007) is described in detail, but the rationale for the algorithms is limited to ''accurate timing'' and ''subjectively a good contrast in timbre''. Many alternative sounds would satisfy these requirements. Exploratory design approaches also often omitted rationale. For example, the sonification design for the EEG real-time player described in de Campo et al. (2007) is hand crafted and the mapping choices were ''prototyped''. While the foregoing highlights that significant gaps exist, equally, many decisions were well supported and this analysis does not mean to criticise the authors.

All but four papers (82.6%) reported on an *evaluation* of the design presented. In predominantly exploratory work, subjective evaluation is common as it allows for frequent and rapid iterations (Baier et al., 2007; Vogt et al., 2007, e.g.). A common pattern in evaluations is that they rarely contrast design positions. For example, Murphy et al. (2007) show that visually impaired users can collaboratively navigate web-sites with sighted colleagues using the auditory display designed, but there was no comparative analysis with alternative design features. However, this could also be related to the format of presentation: there is no particular type of publication in the community that would focus on evaluating design decisions and hence, this aspect might often be left out in favour of presenting the results.

3. The paco framework

The above illustrates that current auditory design practice is dominated by the skill, craft and individual expertise of designers. Effectively re-using design knowledge is furthermore hindered by gaps in reporting on design rationale. We therefore argue for a methodological framework that allows us to build more effectively on the body of work available within the scientific community and communicate design knowledge to a broader audience of designers and end users. The following summarises our approach (see also Frauenberger et al., 2007c) before Section 4 will provide an in-depth account of the evaluation study we conducted to investigate the usefulness of *paco*—*pa*ttern design in the *co*ntext space—and its embedded methods and concepts.

3.1. A pattern-based approach

paco provides methods to create, apply and refine design knowledge captured in a design pattern format.[6] The requirements for *paco* have resulted from our studies of current design practice (Frauenberger et al., 2007a) and are outlined in Frauenberger et al. (2007b). We have argued for design patterns as the carrier of design knowledge in our framework for their promising features and flexibility (also see Dearden and Finlay, 2006) and from work by Chung et al. (2004) we know that patterns have been used successfully to transfer design knowledge in the area of ubiquitous computing. However, we also identified issues that needed to be addressed in our context. Firstly, design patterns rely on multiple successful implementations to elicit the common features of the solutions that are key to their quality. In a comparatively young and immature field such as auditory display, successful prototypes are scattered in the design space and there is little overlap that would allow this process of pattern mining. Related to this issue, design patterns have been criticised for favouring conservative solutions because they build on invariance in existing work (Saunders, 2002). Again, for a young scientific field this is not desirable. Lastly, because of the diversity of contexts of auditory display work, a more sophisticated means of conceptualising the design space is needed to connect knowledge, problems, examples and patterns.

We argue that these issues have limited the impact of the work by Barrass (2003) and Adcock and Barrass (2004)[7] who introduced design patterns to auditory display design employing a conventional pattern mining process. We therefore propose to embed the concept of design patterns in a framework of methods to overcome these limitations. Before we briefly review these methods, we will recap a key concept in *paco*, the context space.

3.1.1. The context space

The context space is an organising principle for design patterns, design problems, solutions and artefacts. It is a multi-dimensional space that classifies its content according to the possible contexts of use. Besides serving as a taxonomy, it provides a meaningful syntax to inter-link its content.

Fincher and Windsor (2000) identify four key properties of organising principles for pattern collections: taxonomise, proximate, evaluative and generative. While the first two are merely properties of any Euclidean space, the latter unlock appealing features in pattern languages[8]: being able to conceptualise the design space through an organising principle allows designers to consider the design task from different perspectives and promotes the creation of rationale and evaluation. Also, gaps in the design space can be identified and existing solutions can be meaningfully combined to generate new solutions.

Although patterns are intrinsically contextual, employing the context of use explicitly as an organising principle brings a number of advantages. Firstly, it allows designers to conceptualise problems and solutions in the same, task

[6] A semi-structured textual format introduced by Alexander (1979). For an example, see Fig. A1.

[7] The development of the 12 patterns they extracted from ICAD proceedings and during one conference stalled in 2006 and no publication at ICAD reported to be using the patterns.

[8] Alexander (1979) compared the generative power of inter-linked patterns to natural languages.

orientated space. As a consequence, the context space facilitates efficient matching of problems and solutions. Also, it emphasises situated interaction design that embeds designs in their context and seeks to create solutions that work for people in their environments (Dourish, 2001). A similar argument can be made from a semiotics perspective. The context space makes visible the semiological code in the sign-system of interaction that allows users to interpret the design as intended by the designer. The semiological code that triggers this preferred reading is the context in which a sign is embedded. Hence it is key to understand the code—i.e. the context—to create meaningful designs.

Inspired by Thevenin et al. (2003), we have defined the following dimensions for the context space: user, environment, device, application domain, desired user experience and social context. We have chosen the tagging paradigm to define these dimensions for its simplicity and versatility. The paradigm has become popular with taxonomies for web content (e.g. bookmarking) and recent studies have shown that tagging leads to stable categorisations given sufficient time and number of users (Halpin et al., 2007). They state that ‘‘It's like 90% of the value of a proper taxonomy but 10 times simpler’’. Besides these nominal values, all but the last two dimensions also provide ordinal values to denote the scope of the context. These scope values are intended to support the process of generalising content by attaching a value to the ‘‘area’’ the solution or problem covers, e.g. narrow, special target group (5) versus generalised, mass market (1). Table 1 shows typical uses of tags in their dimensions.

There are many possible ways to represent the context space. For the evaluation described below we have developed an interactive visualisation for participants to explore the space (see Section 4).

Table 1
Dimensions of the context space showing example tags and scope values.

Dimension	Example tags	Scope
User	Visually impaired, surgeon, teacher	1–5
Environment	Noisy, bright, classroom, office	1–5
Device	Mobile phone, web browser, headphones	1–5
Application domain	Mass media, neuroscience, sports	1–5
User experience	Fun, trust, home, cool, intuitive	N/a
Social context	Privacy, family, dating	N/a

3.2. Methods

Although the methods presented here were developed with auditory displays as the target domain, in principle they are applicable to any design discipline. The methods address fundamental issues in (a) creating re-usable design knowledge with patterns—*pattern mining*—in young and multi-disciplinary scientific areas, (b) the organisation of

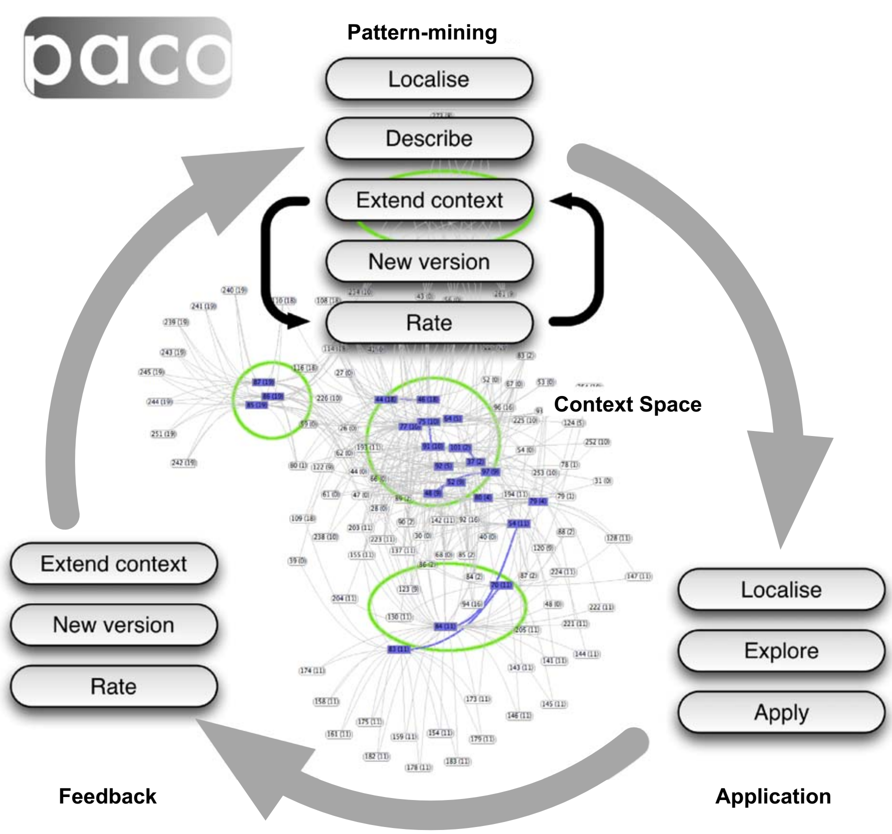


Fig. 1. The *paco* framework and its methods.

this design knowledge and its matching with design problems and (c) incorporating feedback from the experience of implementing the design knowledge. Fig. 1 illustrates this life-cycle of methods and provides a general overview.

Contrary to common pattern mining, the process of creating a design pattern in *paco* starts from a single, working prototype. First the author "locates" the prototype in the context space by assigning tags and values to its dimensions describing the context of use. Subsequently the prototype is described in a pattern format. This is, strictly speaking, not a pattern as it is only supported by one implementation, but it provides the seed for a process of methodical generalisation. The author iterates over two steps in this process: (a) extending the location of the pattern in the context space and (b) rewriting the pattern to accommodate the new context. All intermediate patterns are stored as different versions and linked to each other to preserve the chain of inheritance. A system of self-assessed rating supports the author in conceptualising progress and provides a natural condition for termination in the iterative process. Seed patterns, supported by one implementation, are rated at 3, out of a 0–5 scale. They provide proven solutions in a specific context. Generalisations without further support of other evaluated implementations are rated lower. They allow the author to capture novel ideas that build on her/his experience. Patterns that are generalised from one prototype, but are supported by other implementations are rated higher, until multiple authors have revised a pattern and it becomes common, good practice—rated 5.

The context space allows designers to efficiently match design problems with design knowledge. The first step in using *paco* to solve a new design problem is to locate it in the context space. This links the problem and patterns by common tags or values and allows the designer to explore work in the context of the problem. By exploring the context space from this starting point the designer can conceptualise the design space. Proximate patterns can be of different qualities. The rating system conveys the reliability of the design knowledge presented. Also, the links to other patterns in the chain of inheritance show where the knowledge came from and how "far" from an evaluated prototype it is. All this information supports the designer in considering which patterns to instantiate for the solution.

Any solution derived from patterns will differ significantly from previous implementations and will hence be subject to user evaluation. For a common body of design knowledge to grow, it is essential that designers feed back their experiences with patterns. This can mean that patterns are rated higher, because they are supported by more implementations. Or lower, because they have been shown to be inaccurate or inappropriate for the context for which they were intended. This also leads to the concept of *anti-patterns* (van Biljon et al., 2004), patterns that describe bad design practice.

4. Evaluation

This section reports on a study that investigates the efficiency of the *paco* framework. Our approach in conducting this evaluation represents a departure from common practices. Until now, design methodologies in auditory display design have been evaluated by applying them in case studies, showing that they can produce the desired results (see for example Murphy, 2007; Barrass, 1998; Mitsopoulos, 2000). This raises a number of issues that we aim to address with this study: firstly, little can be said about how well these methodologies generalise in terms of other problems and the average designer. Secondly, no evaluation has yet examined the gain comparatively of applying a methodology in auditory display design. Lastly, from Chung et al. (2004) we know that carefully crafted design patterns have been used successfully to transfer design knowledge in ubiquitous computing. We aim to extend this by involving domain experts to create design patterns using *paco* which then in turn will be made available to novice designers—assessing the transfer of design knowledge from the domain expert to the novice without interference.

4.1. Aims and overview

The overall aim of this study is to find the answer to the following research question:

> Do the methods provided by *paco* facilitate efficient transfer of design knowledge, skill and expertise in the domain of auditory display?

The overall aim gives rise to the following sub-questions which further define the scope of the study:

Can experts capture design knowledge through paco? This question covers aspects of the pattern mining process. Can experts identify potentially re-usable entities of design knowledge in their work and whether *paco* supports experts in generalising their knowledge. Two further aspects are key in this process: this is whether *paco* triggers the capture of design knowledge unavailable through other sources and whether the pattern format encapsulates all necessary information for the design knowledge to be re-used.

Does paco support the conceptualisation of the design space? The context space in *paco* was specifically designed to support designers in this regard. We examine here whether the context space allows expert designers to conceptualise how their work fits into the bigger picture and whether novices can meaningfully explore the context space to become aware of their design options and related work.

Can novice designers benefit from using paco? There are two aspects of this question of interest here. Firstly, whether design patterns created by domain experts were able to capture and transfer design knowledge for novices to apply to relevant problems. Secondly, whether the methods in *paco* for exploring, choosing and applying these

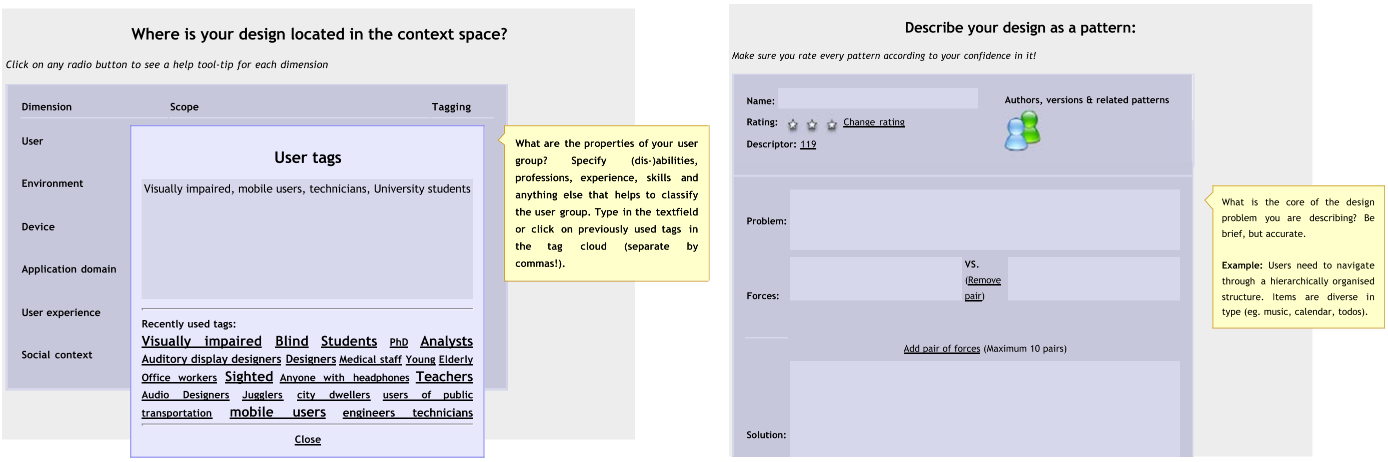


Fig. 2. Screenshots of the online system. Left: defining the context of the pattern by tags. Right: part of an empty design pattern form.

design patterns had a beneficial impact on the design process.

In order to find answers to the questions above we designed the study in two phases. In phase one, expert designers were asked to describe two of their most successful designs using an online implementation of the *paco* framework. Subsequently, phase two brought the results of phase one to the laboratory. In a controlled experiment we presented novice auditory display designers with design tasks and asked them to develop a conceptual solution. Different conditions determined the level of support the novices were given and allowed us to measure the impact of *paco* and its concepts.

4.2. Phase 1: creating design patterns

Participants for this phase were recruited during the annual International Conference on Auditory Display (ICAD) 2007 in Montreal, Canada. Attendees with a good record in the field—i.e. multiple publications in ICAD over a number of years—were approached individually and were given an information sheet. Responding to a follow-up email, 13 experts agreed to participate.

4.2.1. Method

The method applied consisted of three parts: a *pre-questionnaire* to gather information about the participants. More specifically, it targeted demographic background, design practice and the participant's overall view of the field.

Secondly, participants undertook a phase of unsupervised work to create patterns through an *online system*. This system implemented the workflow of the *paco* framework as a set of four web-pages. The start page provided the participants with information about the process and a list of any design patterns they had created. Each pattern could be edited, deleted or used to derive a new version of a pattern—i.e. facilitating the iteration over design patterns. A *New pattern* link would allow participants to start a pattern from scratch. The second page provided the means to define (or alter) the dimensions of the context space. Nominative values were entered through a scale of radio-buttons, tags were available through a tag-cloud.[9] All inputs were guided by contextual help notes that explained the meaning of the dimensions and the values. A *Next* button would lead participants to page number three on which they could create (or alter) the actual design pattern. The page offered sections for the different elements of a pattern and provided contextual help on filling in each individual section. Notably, participants were able, and explicitly encouraged, to include sound files in the design patterns. Finally, page number four closed the loop and provided the participants with the options available at this point of the process—i.e. iterating over the design pattern, starting a new pattern or going back to the main page.

Fig. 2 shows the two core pages: defining tags in the context space and creating a pattern.

Thirdly, a *post-questionnaire* allowed participants to reflect on their experience with the process of pattern-mining. The whole procedure was facilitated remotely, via email and the online system. A necessity imposed by the length of the tasks and the limited availability of experts that could easily be visited.

4.2.2. Results

The 13 experts had published 110 papers or articles on auditory displays in total, 40 of them in ICAD. Every participant held a degree in computer science (three PhDs and 10 MScs studying for PhDs in the field) and three also held a music degree. All participants had heard about design patterns, however, only one had prior experience of writing design patterns.

In the *pre-questionnaire*, most participants described their design practice as a generic process of requirement

[9]A tag-cloud represents keywords (i.e. tags) in different font sizes according to their popularity.

specification, implementation and evaluation. Interestingly, four participants mentioned explicitly that the sound design is driven by the properties of the information to be conveyed. One participant stated in more detail the identification of possible metaphors to be exploited in the design. The main source for guidance for design decisions seems to be perception related. Five participants referred to literature on auditory perception, a further three mentioned ICAD literature in general.

Unsurprisingly, the majority of experts (11) thought that audio was underused in commercial products. Reasons were given scarcely, but included limited guidance on effective design, difficult properties of the auditory channel (e.g. privacy and æsthetics), technical limitations and the current practice of poorly designed audio. Our experts regarded mobile computing, assistive technology, data exploration and monitoring and alarms as the most promising application areas for auditory display. Considering the propagation of design knowledge, participants expressed several interesting issues. One expert reflects:

> Furthermore, a majority of the knowledge base specific to auditory display has been generated with a focus upon only narrowly contrived, highly specific applications. Usually no attempt is made to refer to, draw upon, or contribute to any greater theoretical framework... .

Related issues are identified by another participant:

- The most creative sound designers don't document their practice, and if so, not in an engineering fashion
- Sound designers don't belong to a single community
- The creativity involved in sound design may be hard to capture/document
- Good design isn't as valuable as good engineering"

Nine of the 13 participants who returned the pre-questionnaire also created *design patterns* through the online system, four participants did not find the time. Participants had approximately two months to complete the task, during which no email conversation took place except for regular reminders. The 25 patterns created were 270 words long in average ($\sigma = 101.3$ words) and 34 audio files were attached in total. Over half of the patterns (14) were seed (starting) patterns, three participants did not derive any patterns from their seeds. Only one expert created a chain of inheritance with four patterns derived from each other. Changes to scope values, tags and ratings for patterns were also limited indicating that the iterative workflow proposed has not been followed as extensively as hoped. Those patterns which were derived, however, showed clear signs of generalisation demonstrating that if applied, the workflow produced the desired output.

Participants used 21.8 tags in average to localise a design in the context space ($\sigma = 13.1$) and all dimensions were equally exploited. Of all tags created by the participants, 36 (or 14.6%) did not fit the dimension they were created for. Most of these (25) could be found in the "User experience" dimension, suggesting that this dimension confused participants. In general, the tagging paradigm proved effective in producing a working taxonomy of designs. The relations of patterns through assigned tags in the dimensions of the context space produced clusters that span a meaningful design space.

The pattern format worked well with the participants. They had no difficulties describing their solutions by filling the appropriate pattern sections. The most common confusion occurred between the solution and the rationale section. However, patterns were also heavily cluttered with domain specific jargon, reducing their usefulness for novices. A thorough analysis of the patterns, comparing them to relevant publications by the same authors, shows that the patterns exhibited distinct features supporting the transfer of design knowledge:

> *Rationale*: As shown above, research papers in this field do not always reveal the rationale for design decisions. Prompted by the rationale section in the pattern format the experts provided reasoning that would only be implicitly given, or not present at all in their research papers.
> *Trade-offs*: Many design decisions are trade-offs between forces that work on the problem. And many of those are not explicitly expressed in the research literature because they are of no direct concern to the result, but crucial for adaptation and re-use. Again, the forces section in the pattern format made these trade-offs explicit.
> *Values*: Good practice also incorporates values being conveyed by expert designers that are not strictly scientifically proven or provable such as æsthetics. The pattern format allowed the experts to include such information.
> *Synopsis*: Patterns are condensed resources of design knowledge and as such can provide a synopsis of a larger body of work that would be more difficult to comprehend for novices by reading all the relevant papers.

Only six of the remaining nine participants returned the *post-questionnaire*. Their experience reports show that despite our best efforts to make the process as simple as possible, there has been confusion about the method. One experts stated:

> I created three patterns. For each, I answered the initial Likert questions as if the patterns were about my specific application of the patterns, but I filled in the text as if the patterns were general. Only once I noticed the part about modifying the patterns did I go back and read the instructions!

These notions explain the limited extent to which experts iterated over their designs and call for improvements in

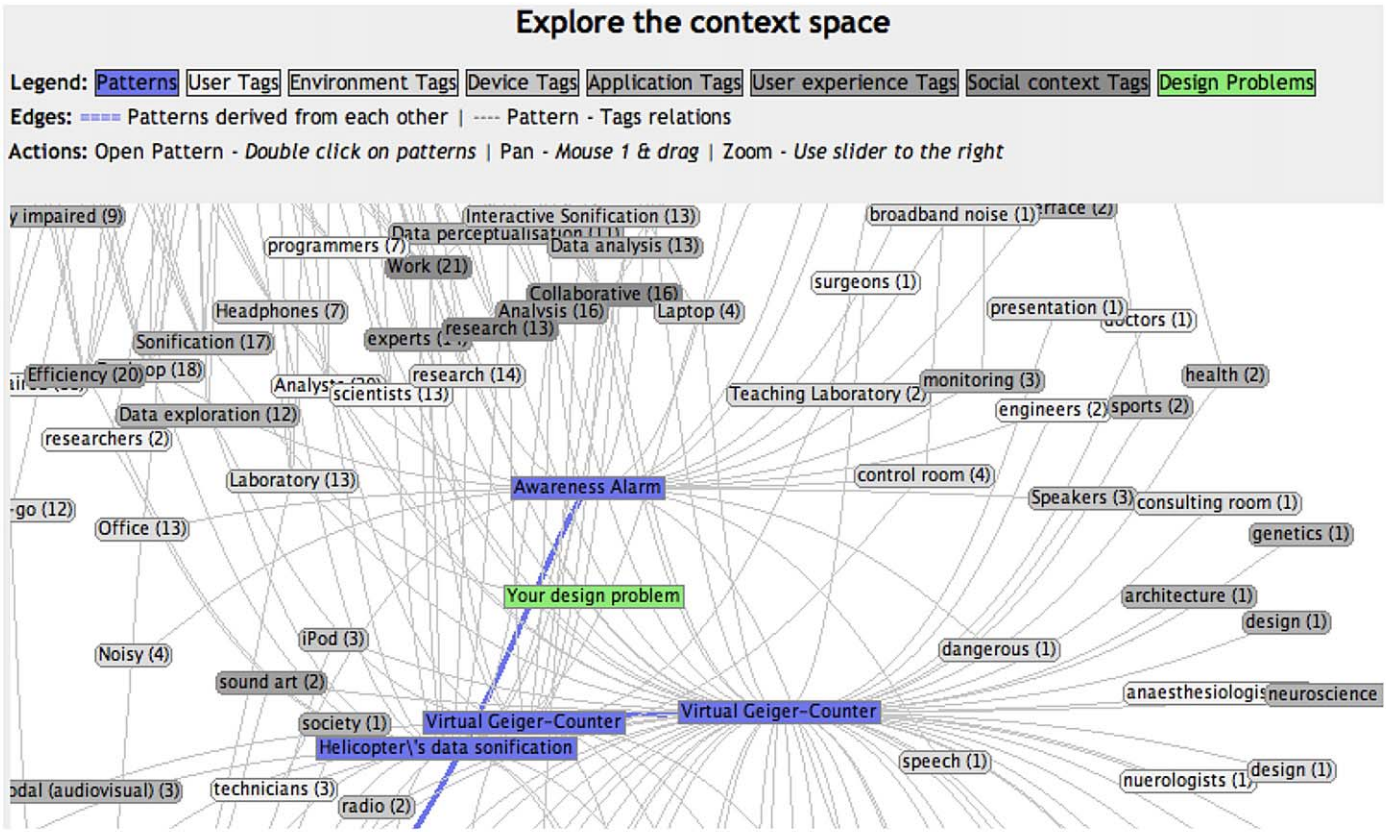


Fig. 3. The visualisation of the context space as provided in condition D. The design problem in the centre of the screen (green) is linked through common tags (items in shades of grey with round corners and number of links in parentheses) to relevant design patterns (blue items with square corners). Patterns derived from each other are connected through a blue link. Double clicking the pattern tokens, will open the full description of the pattern in a separate window. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

terms of simplicity of the proposed methods. Participants reported a number of aspects they found valuable to their design practice: all but one stated they had learned something about their designs by turning them into patterns. They expressed that *paco* enabled them to break-down their designs into re-usable chunks and made them aware of conflicting requirements. Two participants stated that the process made them think more carefully about the contextual properties of their designs. Most notably, one expert stated: "I became more consciously-aware about their characteristics and the place they fill within the whole scope of users and applications", which illustrates notions of conceptualisation of the design space.

4.3. Phase 2: applying design patterns

In the second phase of this evaluation study we investigated the impact of patterns and the *paco* framework on novice designers presented with a related design task. For the purpose of this study, novice designers were defined as people with basic knowledge about interaction design, but no experience with designing auditory displays.

4.3.1. Method

The basic structure of the experiment was as follows: participants were given the context and purpose of the study and filled in a pre-questionnaire that captured relevant background information. Subsequently, they were presented with a design task and had 40 min to develop a conceptual solution. After this period of time, they were asked to present their concept to a fictional client. At the de-briefing of participants they were asked to rate the patterns made available to them.

Four conditions determined the guidance participants were able to access during the design phase:

A No guidance. The baseline condition provoking spontaneous solutions.
B A sub-set of four design patterns. The four patterns were selected to be the most relevant for the task given and presented on a computer screen as a simple list of titles linked to the actual patterns.
C All design patterns.[10] The 16 patterns were presented similarly as in condition B as an alphabetically ordered list.
D *paco* online system. Two web-pages, similar to the online system used in phase one, allowed participants to describe the context of their problem and explore relevant design patterns in the context space. Fig. 3

[10]Nine of the 25 patterns created in phase one were dropped to provide a balanced variety in terms of form and content.

shows a screenshot of the interactive visualisation developed.

The conditions outlined above allow us to measure the impact of patterns in general and enable the investigation of the process of selecting appropriate guidance and the conceptualisation of the design space through the *paco* framework. We decided against conditions with other forms of guidance, such as papers or heuristics, because the different formats and maturity of guidance would not have allowed a fair comparison. We video-taped the whole process, logged any interaction with patterns and captured further data by encouraging participants to use pen and paper during the design phase. In our analysis we employed qualitative and quantitative content analysis of the collected material.

To control for the variability in design patterns we developed two different design tasks to which participants were assigned randomly. They were presented as short design briefs (around 250 words) and were not directly linked to any of the patterns, but left room for incorporating some of them and forced the participants to use audio. The first problem was to design an MP3 player without a visual screen that included basic PDA functionality (calendar, todo, etc.). The second was a system that would allow analysts to monitor stock data in the background without using visual screens. Contextual information was included in the briefs and it was stressed that technical feasibility was not important. Participants were encouraged to think out of the box.

4.3.2. Results

After conducting an informal pilot study 29 people participated in the main study. Roughly one-third of the participants were female (nine), all were under 40 years of age. Two of the participants had to be excluded from the analysis for having been involved in audio related courses that might have biased the results. All participants were students in computer science with a basic understanding of HCI techniques. Two were in their third year of undergraduate studies, 11 were in a masters programme and 14 were PhD students. Participants were assigned to conditions to balance these different levels of qualification. Almost half of the participants (13) had basic knowledge about design patterns, mostly, however, in the domain of software engineering (e.g. Java programming patterns). Two-thirds (20) had not used any audio in previous designs. The remaining participants reported on using background music for games, clicks for buttons and simple alarm sounds. One participant had experience with speech-based user interfaces. Summarising, the participants can be considered as sufficiently naïve regarding design patterns and auditory display design. The analysis of the results confirmed this to be the case.

The period of 40 min that participants were allowed was not strictly enforced, participants could overrun if needed. On average though, participants spent 40.8 min on the problem with 38.66 min average in condition A and 44.2 min for condition D. During this time, all but two participants in condition B (out of seven) read all four patterns. This figure increased to over eight patterns (of 16 available patterns) for conditions C and D (8.63 and 8.64). The written material produced followed an inverse trend: the more patterns were available, the less notes were written. A closer analysis reveals that participants in pattern conditions (B, C and D) made 2.06 direct references to one of the patterns on paper on average. Interestingly, however, condition D (3.21) produced more written references than B (1.08) and C (1.88).[11] We interpret this difference as an improved exploitation of the design knowledge made available.

Participants in condition D on average used 11.71 tags for the six dimensions ($\sigma = 3.81$) and connected their problem with 13 ($\sigma = 2.14$) of the 16 patterns. Patterns considered to be highly relevant for the problem (as selected for condition B) were not better linked than the others. This caused the design problem not to be particularly close to relevant patterns in the visualisation of the context space. This mismatch can be explained by the immaturity of the taxonomy produced by the tagging of experts. There has been no broad consensus over the type and number of tags for the design patterns and we would expect this aspect to improve if a community were to collaboratively produce and apply design patterns over a longer period of time (compare also Halpin et al., 2007). The observation of participants navigating the context space, however, highlighted an important feature: the common tags between patterns and the design problem were commonly used as stepping-stones and participants explored the context space selectively. The semantic value of the link—i.e. the tag—enabled users to pick patterns for specific aspects of their problem.

Participants presented their designs to the camera for an average duration of 6.37 min ($\sigma = 2.2$). The facilitator played the fictional client and was able to ask question to clarify aspects or probe for features of the design. Participants were asked not to refer to patterns as they would be unknown to the client, but explain the design they developed. The analysis presented here aims to reveal links between the patterns accessed and the features of the solution presented. Fig. 4 categorises the solutions in relation to the most basic auditory techniques. Several aspects are of particular interest in these numbers. The use of TTS was generally high, particularly with the MP3-Player design task. In comparison, non-speech sound was used far less, but significantly more when participants had patterns available with condition D being the strongest.[12] The differences in using speech recognition with four out of five in condition A and none in condition D were

[11] Independent-samples t-test. B–D: $t = -2.56$, $p = 0.025$, C–D: $t = -1.33$, $p = 0.205$.

[12] Independent-samples t-test. A–D: $t = -4.83$, $p = 0.01$, differences A–B and A–C are not significant.

TTS

	MP3 Player	StockMarket	All
A	3 of 3	2 of 2	100%
B	4 of 4	1 of 3	71%
C	4 of 4	3 of 4	88%
D	3 of 3	3 of 4	86%
All	100%	69%	79%

Non-Speech

	MP3 Player	StockMarket	All
A	0 of 3	1 of 2	20%
B	2 of 4	2 of 3	57%
C	2 of 4	4 of 4	75%
D	3 of 3	4 of 4	100%
All	50%	85%	66%

Speech Recognition

	MP3 Player	StockMarket	All
A	3 of 3	1 of 2	80%
B	1 of 4	0 of 3	14%
C	0 of 4	1 of 4	13%
D	0 of 3	0 of 4	0%
All	29%	15%	21%

Fig. 4. Basic auditory interaction techniques in the solutions presented depending on condition and design problem (occurrence in overall number): TTS (Text-To-Speech), non-speech sound, speech recognition.

unexpected as none of the patterns mentioned the technique. A possible explanation is that the increased awareness of alternative auditory means for feedback made participants less focused on speech as the single auditory form of interaction.

A more detailed analysis of the features present in solutions provides a clearer picture of the knowledge transfer. We coded patterns and solutions for the following techniques specific to auditory display design:

Mapping: The use of data or information to change properties of a sound, e.g. mapping stock values onto pitch of a particular sound.
Events: Non-speech sound events, covering the range from alarms to more complex compound sounds.
Continuous sound: Any sound that is not a sound event, but used over a longer period of time in the interface, e.g. sounds designed for continuous monitoring.
Background: Sound that is intentionally designed to go into the background, i.e. not attracting the highest level of attention.
Parallel: The use of multiple sounds simultaneously and hence any sign of managing the attention of the user when presented with concurrent sounds.
Themes: The use of sound families that, following the idea of leitmotivs, have a similarity making them part of a functional group of sounds, e.g. coherent representation of related menu items.
Semantics: Sounds that are chosen for their semantic relationship with the information that they represent, e.g. auditory icons.

This list, of course, is not exhaustive in terms of features provided by the design patterns. But the level of detail available from the presentations limits the granularity of this analysis. Appendix A1 provides an example of how the features of a design pattern had direct impact on the solution of a novice designer.

Fig. 5 presents a matrix of participants over features implemented indicating whether participants read a relevant pattern promoting the specific technique. The emerging pattern shows a trend towards condition D with 2.9 features implemented from a pattern participants read, compared to 2.0 in condition C and 1.6 in condition B. Only the difference between all pattern conditions and the control condition, however, proved statistically significant.[13] Fig. 6 provides the overall numbers over the conditions. In summary, this analysis demonstrates a strong correlation of features in the auditory designs and the design patterns. In 47 cases, features were implemented in the solution when relevant patterns have been read by the participants. In comparison, only three features were implemented spontaneously. Or in other words, 62.7% of all participants implemented a feature they read about in a pattern while 11.1% implemented a feature without having read a related pattern. Although there seems to be a trend in favour of condition D in terms of features implemented, they are not statistically significant to the other pattern conditions.

4.4. Summary

The above evaluation has shown that *paco* has enabled experts in auditory display design to capture design knowledge in a way that allowed novice designers to re-use relevant concepts in a related, but different design task. We did interfere neither with the design patterns produced by the experts, nor with the processes of pattern mining or the application in the design tasks. Although the quality of the design patterns cannot be compared to collection like those by Tidwell (2005), a significant transfer of design knowledge occurred and indicates that the concepts in *paco* met the requirements we set out.

Referring back to our initial research questions, we were able to establish that *paco* enabled experts to identify and describe suitable entities in their designs through design patterns, although the level of generalisation and blue-sky thinking has not been achieved to the degree we hoped. There are indications that *paco* supported experts and novices to conceptualise the design space. In particular, the semantic quality of links between design problems and patterns through the tagging mechanism looks promising. Finally, the above has shown that *paco* benefited the quality of designs novices produced by introducing

[13]Independent-samples t-test. A–(B,C,D): $t = 2.4$, $p = 0.024$.

Participants over features in their solution

P ID	Condition	Mapping	Events	Continuous	Background	Parallel	Themes	Semantic
2	D StockMarket	---	X	---	X	---		
3	B StockMarket	---	---	---	---	---	+++	---
4	C Mp3 Player	---	X	X	---	X	X	---
5	A Mp3 Player							
6	B Mp3 Player	---	---				---	---
7	D Mp3 Player	---	---	---	---	---	X	---
8	C StockMarket	X		X	X	---		X
9	A StockMarket		+++					
10	B Mp3 Player	---	---					---
11	A Mp3 Player							
12	D StockMarket	---	X	---	---	---	---	
13	C Mp3 Player	---	X	X	---	---	X	X
14	B StockMarket	X	X	X	---	---		---
15	D Mp3 Player	X	X	---	---	---	---	
16								
17								
18	C StockMarket	---	X	---	---	---		
19	D Mp3 Player	X	X	X	X	X	X	X
20	B Mp3 Player	---	X			+++	X	X
21	C StockMarket	X	X	---	---	---		---
22	D StockMarket	X	X	---	---	---		
23	C Mp3 Player	---	---	---	---	---		---
24	B StockMarket	X	X	---	---	---		---
25	A StockMarket							
26	D StockMarket	X	X	X	---	X	X	---
27	C StockMarket	---	X	---	---	---	---	---
28	C Mp3 Player	---	---				---	---
29	B Mp3 Player	X	X				---	X
30	A Mp3 Player							

Read & implemented per Participant (green, X)

	MP3 Player	StockMarket	All
B	1.5	1.7	1.6
C	2	2	2.0
D	3.3	2.5	2.9
All	2.3	2	2.2

Read but not implemented per participant (blue, ---)

	MP3 Player	StockMarket	All
B	2.3	4.3	3.3
C	4	3.8	3.9
D	3.3	3.3	3.3
All	3.2	3.8	3.5

Not read but implemented per participant (yellow, +++)

	MP3 Player	StockMarket	All
A	0	0.5	0.3
B	0.3	0.3	0.3
C	0	0	0
D	0	0	0
All	0.1	0.2	0.1

Not read & not implemented per participant (white)

	MP3 Player	StockMarket	All
A	7	6.5	6.8
B	3	0.7	1.8
C	1	1.3	1.1
D	0.3	1.3	0.8
All	2.8	2.4	2.6

Fig. 5. Features present in solutions over participants (×: read and implemented; — — — read, but not implemented; + + +: not read, but implemented; none: not read, not implemented).

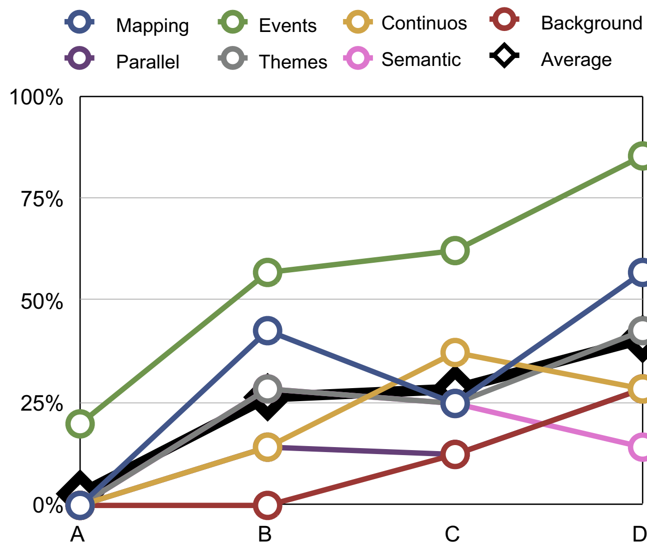
advanced features of auditory display design in their solutions.

5. Conclusion and future work

In this article we have made the case for a methodological framework for designing auditory displays. We motivated the work by evidencing shifting interaction paradigms, discussed current design practice and surveyed the scientific field to derive requirements for such a framework. This has led us to develop *paco*, a pattern-based approach for methodically capturing and transferring design knowledge. Despite the encouraging results in evaluating *paco*, a number of issues have surfaced which provide us with the leads for future work.

The limited use of the iterative method for pattern-mining shows that the process has to be simplified and requires more guided tool-support. The pattern format has to be made more flexible to incorporate ways of illustrating interaction with audio. We started exploring what auditory sketching could mean in this context, but future research needs to show what features such sketches would need to provide and how they could be implemented.

The context space has improved the contextual awareness of experts and novice designers. However, the nominal scales were scarcely used and tags were generally preferred by the participants. All dimensions, with the exception of "User experience", have produced distinct tags reflecting important contextual properties of the designs. Through these tags, the context space provided an appropriate organising principle producing meaningful taxonomies for auditory display design. The demand for an organised design space such as this was also highlighted by Hermann et al. (2008) in proposing the *Sonic Interaction Atlas*. We intend to collaborate with these fellow researchers and contribute to the development of a community driven,



Occurrences of Features

	MP3 Player	StockMarket	All	Mean	Std	Mean	Std
A	0	1	1	0.17	1.46	0.17	1.46
B	7	6	13	1.86	1.46	2.23	1.79
C	8	8	16	2.00	1.66		
D	10	10	20	2.86	2.10		
All	25	25	50				
M	1.79	**1.92**					

Fig. 6. Features present in solutions over conditions.

organised design space through our experiences with *paco*. We envision a space that provides the flexibility to accommodate generalised design knowledge, interaction scenarios and auditory artefacts. Such a space must feature versatile methods to filter, search and navigate the content and allow users to relate their design problems to solutions. The tagging paradigm and the dimensions we have developed for the context space, in combination with the power of design patterns, are promising candidates on which to base the foundations of such a design space.

Above all, it is important that such efforts are supported by a broad basis within the scientific community. Many of the issues we have identified in the evaluation of *paco* are related to the experiment ignoring longer-term community effects. The rating mechanism, for example, may still prove to be an important feature for quality control and for encouraging blue-sky designs, but it played no immediate role in the evaluation presented above. The unbalanced distribution of tags and its negative effect we observed on the matching of design problems with patterns is likely to disappear given more time and a sufficiently large community using the system. Both aspects, community and time, are required to provide a shared repository of design knowledge of sufficient credibility. It is hoped that the promising momentum we see now will result in such a repository and that designers and researchers in the field will be able to take advantage of the resources to design auditory displays more effectively.[14]

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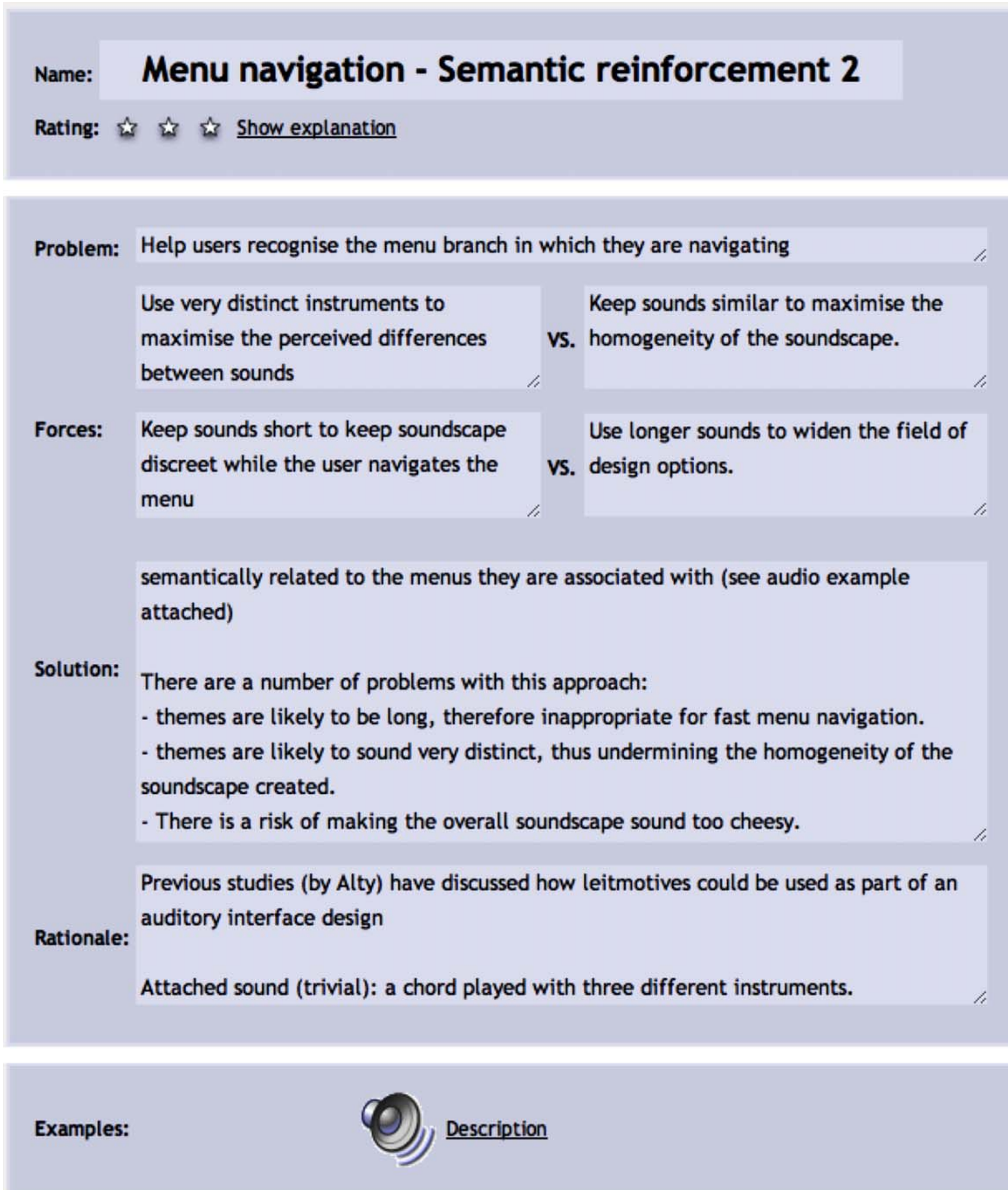
We would like to thank the participants of both phases of our study for their contribution to this work.

Appendix A. Example of knowledge transfer in phase 2 of the evaluation

Fig. A1 provides an example of how the features of a design pattern had direct impact on the solution of a novice designer.

[14]For a reworked collection of design patterns that resulted from this work and further developments towards a comprehensive space of design knowledge see http://cfabric.net/patterns.



"... Now, for the user to know what part of the hierarchy he or she is, I would use some kind of ambient background sound, so for the settings this might be some kind of technical sound, for the music option it might be something that - well, it might be snippets of music stored on that player, for personal items it might be, I don't know, the sound of people chatting or business noises, something related to the business functionality of the device. ...

... For the PDA functionality, there are hierarchies. So for the calendar, I would say, the next items in the calendar should be presented first, so they should appear at the top of the list. And as the user goes down this list, he should get some notion of being more distant from the present time than when at the top of the list. So a sound could be - a sound that has a high pitch in the beginning could go downwards, cold have a lower pitch at the end to denote being further in the future. Something similar could be done for Todo items as well. Items at the top of the list are more important and thus are accompanied by a higher pitched sound, while as further items could be denoted by a lower sound meaning they are less important.

Fig. A1. A pattern as seen by participants in phase 2 (above) and parts of the transcript (below) of a presentation by a novice designer that shows the impact on her/his design.

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