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Auditory Display Design

An Investigation of a Design Pattern Approach

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Declaration

Unless clearly indicated otherwise, the work presented by this thesis is the author's. Parts of this work have been presented in academic conferences or workshops, and references to related publications are given at the appropriate sections.

Christopher Frauenberger London, April 7, 2009

Abstract

This thesis investigates the design of audio for feedback in human-technology interaction—*auditory displays*. Despite promising progress in research and the potential benefits, we currently see little impact of audio in everyday interfaces. Changing interaction paradigms, new contexts of use and inclusive design principles, however, increase the need for an efficient, non-visual means of conveying information. Motivated by these needs, this work describes the development and evaluation of a methodological design framework, aiming to enhance knowledge and skill transfer in auditory display design and to enable designers to build more efficient and compelling auditory solutions.

The work starts by investigating the current practice in designing audio in the user interface. A survey amongst practitioners and researchers in the field and a literature study of research papers highlighted the need for a structured design approach. Building on these results, **paco** – **pa**ttern design in the **co**ntext space has been developed, a framework providing methods to capture, apply and refine design knowledge through design patterns. A key element of **paco**, the context space, serves as the organising principle for patterns, artefacts and design problems and supports designers in conceptualising the design space.

The evaluation of **paco** is the first comparative study of a design methodology in this area. Experts in auditory display design and novice designers participated in a series of experiments to determine the usefulness of the framework. The evaluation demonstrated that **paco** facilitates the transfer of design knowledge and skill between experts and novices as well as promoting reflection and recording of design rationale. Alongside these principle achievements, important insights have been gained about the design process which lay the foundations for future research into this subject area.

This work contributes to the field of auditory display as it reflects on the current practice and proposes a means of supporting designers to communicate, reason about and build on each other's work more efficiently. The broader field of human-computer interaction may also benefit from the availability of design guidance for exploiting the auditory modality to answer the challenges of future interaction design. Finally, with **paco** a generic methodology in the field of design patterns was proposed, potentially similarly beneficial to other designing disciplines.

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Chapter 1

Introduction

Human interaction with digital technology has changed rapidly over the past decade. Computing devices have been set free from the office environment and are nowadays to be found everywhere and anytime. The Internet has evolved into a virtual, social environment defining the contexts for many activities that did not exist 10 years ago such as micro-blogging from your mobile phone[1]. In this time of rapid change, the design of the interface between humans and machines faces new challenges. Human-computer interaction (HCI) as a discipline needs to respond to new contexts of use, new interaction paradigms, new technologies and shifting social constructs. The traditional window, icon, menu, pointer (WIMP) paradigm that emerged from desktop-computing performs poorly in many of those new contexts and radically different concepts and techniques have been devised to overcome the limitations of traditional approaches.

This thesis is about the design of auditory feedback in human-computer interaction as a contribution to the remodelling of interaction design to tackle these new challenges. Although sound has played a role in interacting with technology for a long time, it can be argued that its potential has not been exploited to its full extent. Despite the variety of options available when designing sound in technology, it is commonly reduced to speech and alarms, if present at all.

A good example for the current impact of audio in mainstream digital technology is the

[1]Twitter (http://twitter.com) is a popular example.

interface design of the Apple iPod. The device has implemented all necessary hardware to produce high quality sound, its users wear headphones and operate the device in contexts that do not always allow for using its visual display. Nevertheless, the interface is predominantly visual and functional auditory feedback is reduced to the artificial click of the wheel. This makes the iPod almost inaccessible for visually impaired users or for people in mobile contexts. For example, Salvucci et al. (2007) demonstrated the negative effects of using the existing iPod interface in a vehicle on the performance of the driver.

Research into the design of functional sound in technology—or *auditory displays*—suggests that sound can be used effectively to address contexts of use in which other modalities fail. In fact, Zhao et al. (2007) have presented an audio only, eyes-free menu selection technique based on the iPod metaphor of the turning wheel. Their evaluation showed that *earPod*, the menu system developed, outperformed the visual counterpart in terms of speed within 30 minutes of practice.

This thesis aims to reveal obstacles for audio to be used more commonly and efficiently for feedback in digital technology. It investigates the current practice of auditory display design and proposes a methodological framework to support designers in building on previous work effectively and bring auditory display design closer to mainstream HCI. As a core concept in this framework, it is proposed to adopt design patterns for auditory displays to capture and communicate design knowledge.

1.1 Motivation

The human ear is a precise and versatile instrument that provides us with detailed information about our acoustical environment. We use it for communication purposes or, more subconsciously, for orientation or guiding our eyes to targets outside the field of view. The sophisticated physiological features of human hearing allow us to perceive microscopic differences in sound qualities such as timbre as well as macroscopic structures such as chords or other musical forms. The temporal resolution of auditory perception makes us highly sensitive to changes in pitch and rhythm. But also from a higher level cognitive perspective, human hearing provides a sophisticated means of filtering and focusing of perceived information. For example, we can effectively adjust the required attention between parallel audio streams and follow one out of many equally loud conversations—the so called *Cocktail Party Effect* (Arons, 1992). Equally, we are highly effective in masking monotone and annoying sounds such as the noise produced by an air condition—its presence only comes to mind when it is switched off. All these properties of human hearing make it a high-bandwidth communication channel and an appealing candidate for human-computer interaction.

The following reasons motivate the use of functional sound in technology from a design perspective:

Why? Six reasons for sound in technology:

1 **Accessibility** Access to information through digital technology is a key requirement in today's information society. Assistive technology for users with visual disabilities is still far from providing equally efficient access imposing difficulties to their social and professional life (e.g. Tobin, 2008). The knowledge to design alternative interaction modes, such as sound, will bring us closer to create universal and inclusive access.

2 **Visual overload** With the increasing information and functionality to be conveyed through interfaces, the visual channel is increasingly overloaded. Research has shown that balancing load between modalities can support users' performance and decrease cognitive load (Oviatt et al., 2004). By using sound cues in interfaces, designers can therefore convey more information or effectively double up information of high importance.

3 **Shifting contexts** Advances in technology have resulted in computing devices being incorporated pervasively into our environment. Miniaturised devices are built into everyday objects or clothes and we use them on the go or while occupied by other tasks. This shift in context of use demands alternative interaction paradigms, such as auditory displays, as visual screens become an increasingly inappropriate interface in many contexts. As Walker and Brewster (2000) highlight: *"audio display space is not wedded to the disappearing resource of screen space"*.

4 **Scientific exploration** Visualisation is the dominant means of communicating data.

Graphs and diagrams can build on common conventions to effectively perceptualise[2] numbers or relationships. However, the *"medium is the message"*[3] and perceptualising data differently—e.g., by auditory means—can result in different insights or more appropriate representations. Sonification, the perceptualisation of data by auditory means (Kramer, 1994b), is the natural companion of visualisation and statistics for perceptualising or exploring data.

5 Naturalness Our mental picture of the environment is formed by a wealth of sensations from all available modes of perception. This mental picture is not entirely amodal, however. Cognitive processes seem to be grounded in modal systems. Barsalou et al. (2003) suggest that conceptual tasks and knowledge have strong links to the underlying modalities. This further suggests that evoking specific concepts has to be linked to the appropriate modality. As designers of human-computer interaction, we therefore have to carefully choose the right modality by its natural links to the concept to be conveyed—e.g., temporally structured information is often better conceivable through sound than visually.

6 Emotional power The history of music demonstrates the emotional power of audio. While it can prove difficult to control—annoyance is a common reaction to inappropriately designed sound in technology—this dimension of the design space has great potential.

1.2 Aim, Research Question & Approach

The aim of this thesis is to contribute to the unlocking of the potential of audio in human-computer technology. A key stepping stone towards this aim is the ability to communicate existing design knowledge to allow researchers to build effectively on their results and practitioners to adopt good design practices. To this end, this thesis describes the development and the evaluation of a methodological design framework that supports

[2]The term 'perceptualise' is introduced here to signify a semantically meaningful representation of data without indicating the mode of presentation which could be visual (i.e., a visualisation), auditory (i.e., a sonification), tactile etc.

[3]A quote originating from the semiological analysis of media by McLuhan and McLuhan (1967)

experts and novice designers in capturing and applying design knowledge in the field of auditory display. The research question pursued by this work can therefore be summarised as:

Can a methodological design framework be developed that facilitates the efficient transfer of design knowledge from experts in the field of auditory displays to novice designers?

This research question implies a number of sub-questions: firstly, regarding the format and method of capturing design knowledge: in which form can design knowledge be captured in this particular field and how can we support domain experts in the process of capturing it? Secondly, how can the transfer of this knowledge to new, different design problems be facilitated? And subsequently, how can novices be provided with sufficient guidance to implement the design knowledge? Finally, to the benefit of the collaborative knowledge in the field, how can the experience made in applying the design knowledge be fed back into a shared body of knowledge to improve or expand its scope or validity.

In order to investigate these questions the following approach has been adopted:

- Understanding the current design process
- Deriving requirements from current practices
- Developing methods and concepts to capture, apply and refine design knowledge
- Evaluating the impact of these methods and concepts in a study with expert and novice designers

Understanding the design process as currently exercised is key to the development of any supportive design framework. This work will investigate how sound in technology is designed, which guidance informs the process and what the barriers are that hinder the effective re-use of design knowledge the discipline has produced. Building on the results of this first phase of the work, requirements are derived and a methodological design framework is developed that supports designers in capturing and communicating design knowledge in the context of auditory display. Finally, the last phase aims to evaluate this framework and test its usefulness for novice and expert designers of auditory displays.

1.3 Scope, Audience & Contribution

This work focuses on the design of the auditory feedback channel in human-computer interaction, an area commonly referred to as *"auditory displays"*. One of the main arguments in this thesis, however, is that designing specific modalities or interaction paradigms in isolation is inappropriate. Therefore, other topics, such as semiotics, multi-modal interaction or architecture will inevitably invade this text in support for the argument that those higher-level connections are valuable.

The intended audience of this thesis and the areas in which this work seeks to make contributions to are threefold. Foremost, it aims to address the scientific community of auditory display. The methodology developed called **paco** and the background on which it is based, specifically targets auditory displays. It aims to support scientists to create a body of knowledge that will enable us to build on each other's work and accelerate the progress in this field. However, it is important to emphasise, that this work is not about creating such a body of knowledge, but about developing a means for the community to do so.

Similarly, a broader audience of interaction designers is addressed who can potentially benefit from such a body of knowledge. The methods and concepts developed intend to fill the gap between the research conducted within the field and the application of the knowledge in real-world design tasks. By considering this audience, it is hoped that this work contributes to increase the impact of auditory display design in the mainstream practice of human-computer interaction design in the long term.

The third intended audience is related to the concept which was adopted as the core of the methodological framework: design patterns. The methods developed around design patterns constitute a novel approach to create, apply and organise design patterns. It is hoped that this approach can provoke discussion amongst this community as to how the process of creating and using design patterns—no matter which field of application—can be demystified and embedded in a principled framework. The approach of organising design patterns and matching them with design tasks may also be valuable in other application domains with similar properties to the one of auditory displays.

1.4 Overview

The thesis is organised in six chapters. The first **introduces** the problem domain and specifies the scope and the main objective of the work. Chapter 2 provides a review of **related work**. It lays out the necessary foundations, for example the history and the terminology of the domain. Previous efforts in capturing design knowledge in auditory display design are covered and related topics in the general field of human-computer interaction are discussed. A more detailed background on the concept of design patterns is also included.

Chapter three focuses on the **current design practice** in auditory display. It describes a literature study that investigates the practices as exhibited in the published proceedings of ICAD 2007[4]. The second part of this chapter reports on an online survey about the use of audio in interaction design.

Chapter 4 introduces the methodological design framework **paco** – pattern design in the context space. It starts with deriving the requirements for such a framework and providing the rationale for the choice to adopt design patterns. A key concept in **paco** is introduced in section 4.3: the context space, around which the methods of the framework are subsequently developed. A case study on designing an auditory menu system with **paco** illustrates the workflow and section 4.6 summarises the essential features of the framework.

Evaluating paco is the topic of chapter 5. After discussing the detailed research questions addressed by this evaluation, the methodology of the study is laid out. Section 5.3 describes the first phase of the study in which experts of auditory display design use **paco** to capture some of their designs through design patterns. The following section describes phase two, in which novices (i.e., students) are given these design patterns and use **paco** to apply the design knowledge on pre-defined tasks. The results of the evaluation are used towards finding answers to the research questions previously defined.

Finally, chapter 6 **concludes** this thesis by reflecting on the work conducted. As a valuable side-product of the evaluation of the evaluation of **paco**, a small collection of

[4]International Conference on Auditory Display 2007, in Montreal, Canada.

design patterns is presented that could be seen as the seeds for a larger community effort towards a body of collaboratively developed and shared design knowledge.

Chapter 2

Related Work

This chapter reviews strategies and approaches to the design of auditory displays and relevant aspects in human-computer interaction and other related areas. The term *design* itself leaves a great freedom of interpretation. As a noun, it refers to a plan or drawing to show the look, function or workings of any object before it is built as well as to the art of producing these plans (Soanes and Hawker, 2005). The verb implies the creative process and the decisions made while producing such a plan. It also can imply that something was planned with a specific purpose or intention in mind. In the context of this work, *design* is seen as an activity that involves problem-solving, creativity, æsthetics and the management of constraints as key aspects. A *design process* depends on the problem domain, but typically consists of the following steps: design brief, analysis and requirements, specification, implementation, evaluation and redesign. In human-computer interaction similar phases have been defined, for example prototyping and envisionment, requirements, conceptual design, physical design and evaluation (Benyon et al., 2005, p. 39). These stages will be used as a natural organising principle for related work throughout this chapter.

In more detail, this chapter is organised as follows: section 2.1 lays out foundations including a short history of audio in the user interface and a clarification of the terminology used. Section 2.2 provides details about previous approaches to auditory display design, principles and guidelines. Section 2.3 covers relevant research in human-computer interaction in the broadest sense. To provide a full account of the variety of design strategies in

HCI is beyond the scope of this thesis, some aspects, however, have direct impact on this work such as some theoretical approaches, the development of design tools or frameworks for multi-modal user interface design. Design patterns, being a key concept in the proposed methodological framework for auditory display design introduced in chapter 4, will be discussed in detail in section 2.4. Finally, section 2.5 concludes the chapter.

2.1 Foundations

This section is intended to provide the reader with a background to audio in the user interface and terminology commonly used in auditory display research.

2.1.1 The History of Sound in Technology

It was in 1981 when IBM introduced their first personal computer, the PC model 150, that enabled a broader public to use computers and revolutionised the forms of interaction with technology. Many of these interaction paradigms still exist and a modern desktop computer awkwardly resembles this first PC.

In terms of sound the first personal computer provided a single, small speaker, also still present in most modern desktop computers. At the time, binary signals were used to drive the speaker at a fixed volume, which limited its use for any musical applications. The game industry, however, found techniques to circumvent these restrictions: exploiting the mechanical properties of the speaker and doing clever pulse code modulation they were able to create signature sounds and simple audio feedback in games of surprising quality (Winter, 2009). In terms of feedback in the user interface, the PC speaker was—and still is—mainly used to indicate system status information and alarms on a low level when the operating system has not yet taken, or lost, control over the more sophisticated sound capabilities of a computer.

When Apple introduced its Macintosh in 1984 it incorporated sound that also allowed speech output. The Macintosh 128 was equipped with an eight bit mono sound chip with a 22 kHz sampling rate and came with four voices, one of which was used in the legendary presentation of the Macintosh by Steve Jobs during his keynote speech in 1984. In 1987, along with the introduction of a colour display, the Macintosh II also featured stereo audio output. In the same year, the introduction of expansion slots in PCs led to the first sound cards and after a further two years the first Sound Blaster cards hit the market. With on-board digital signal processors (DSPs) multi-channel playback and recording of high quality sound became possible. Additionally, the MIDI (Musical Instrument Digital Interface) and wavetable synthesis were incorporated into sound cards which allowed for generating more complex sounds. The most recent sound cards found in common, off-the-shelf computer systems provide multi-channel input and output (most commonly the 5.1 speakers format) in CD quality (16 bit, 44.1 kHz), but provide little hardware support for sound synthesis. Hence, complex sound synthesis remains a task for specialised software and is not available at the operating system level as, for example, graphical 3D rendering is. In general it is remarkable how big the gap is between the capabilities of modern video cards and up-to date sound cards. While video cards have the computational power of whole computer systems and are responsible for many high-level tasks, sound cards are still comparatively simple.

Vision is also ahead in terms of making hardware features available to developers or designers. While low-level application programming interfaces (APIs) are of comparable complexity and power, if not equally mature (e.g., OpenGL[1] and OpenAL[2]), there is no audio equivalent to high-level frameworks like Qt, Gtk+, Apple's Cocoa or the Microsoft Foundation Classes, that provide developers with tools and widgets to create user interfaces. Several attempts have been made to tackle this problem (e.g., Edwards et al., 1993; Kaltenbrunner, 2002), but the concepts that work so well in the visual domain do not translate well into the auditory domain and none of these efforts has led to a wide-spread standardised tool that would allow designers to create auditory displays easily from standardised building blocks. The difficulty in coming up with such tools and re-usable building blocks in this domain suggests that a different approach to auditory display design might be necessary.

The main driving force for the development of improved sound capabilities in computers

[1]http://www.opengl.org/
[2]http://www.openal.org/

was the gaming industry and many of today's built-in features in sound cards derive from film and movie special effects. Besides gaming and alarms, audio was used early to provide access for visually impaired users. In 1986 IBM announced its Screen Reader as one of the first audio access systems for personal computers. With the rise of graphical user interfaces (GUIs) the interaction changed rapidly and paradigms such as direct manipulation were increasingly difficult to represent in speech. Modern user interfaces include accessibility interfaces that allow screen readers to access more detailed information about the structure and content of the feedback to be provided. Up to now, screen readers use speech almost exclusively as the means of conveying information making interaction sequential and less efficient. In 2003 the most widely used screen reader system Jaws for Windows introduced the first significant use of non-speech sounds in a commercially available product. Jaws' *behaviours* are schemes that enable users to customise feedback on specific states or properties in the interface through non-speech sounds. A more elaborate approach to incorporate the potential of non-speech sound into accessibility interfaces was investigated in the research project *Clique*. Parente (2008) demonstrated that concurrent audio streams and the use of background non-speech sound in *Clique* had a beneficial impact on the abilities of visually impaired users to use the desktop and other desktop applications.

Audio plays a marginal role in today's interfaces to technology. The major operating systems for computers incorporate only a few auditory cues for warnings or notifications. Besides the intro sounds used for branding the product, most sounds indicate events like "new mail arrived" or "import finished" etc. The quality of the sound design has improved: for example, Apple's OS X "new mail arrived"-sound is appealing and uses spatial cues, but the functionality remains simple and does the potential of non-speech sound no justice. This is also reflected by the recommended design guidelines in the major operating systems: the Apple Human Interface Guidelines assist developers in creating applications that provide the user with a consistent experience and give detailed advice on good practice in user interface design (Apple, 2008). The use of audio as a means of conveying information as part of this experience is, however, not mentioned at all. Like in other operating systems, the only context in which audio seems to be relevant is accessibility.

2.1.2 Terminology

There is ongoing debate about the terminology used in the scientific field of auditory display. A possible reason might be the diversity of scientific communities and traditions involved, each placing emphasis on different aspects of auditory display. Another reason may be that the field is comparatively young and still needs to establish its jargon by popular convention. This section will provide an overview of the most common terms in auditory display research and will, wherever ambiguous, clarify how terms are used in this work.

Auditory display is the most generic term for the use of sound in human-machine interfaces. This includes any use of auditory means to convey information. Despite the fact that the International Community for Auditory Display (ICAD) focuses on non-speech sounds *"...auditory display rightly includes all uses of sound in the interface"* (Kramer, 1994b, p. 2), also speech output. Auditory display is not only the most general term regarding the medium, but also in terms of the use of the interface. It covers the auditory representation of (numerical) data as well as the use of sound in user interfaces, And as Kramer states in his preface *"...there is no distinct line between auditory data display and auditory interfaces."* (Kramer, 1994b, p. xxiv).

Auditory (user) interface is used in analogy to graphical user interface (GUI) and most commonly it signifies exclusively speech interfaces (e.g., Raman, 1997). However, the term is also used for interfaces that use any possible auditory means (e.g., Kaltenbrunner, 2000; Kramer, 1994b) and is hence, like auditory display, a very general term. The most important distinction is that the term *interface* implies a bidirectional communication, while *display* focuses on the presentation or feedback of information. Consequently, an auditory user interface would implement both channels of interaction in the auditory channel—e.g., an auditory display combined with speech recognition.

Sonification is commonly used as the umbrella term for any form of perceptualisation of data by auditory means. ICAD's report on sonification for the National Science Foundation states: *"Sonification is defined as the use of non-speech sound to convey information"* (Kramer et al., 1997) which would include every auditory display that uses non-speech sound. Scaletti, however, proposes a slightly different working definition of sonification as *"...a mapping of numerically represented relations in some domain under study to relations in an acoustic domain for the purpose of interpreting, understanding, or communicating the relations in the domain under study."* (Scaletti, 1994). While this definition is no contradiction to the previous one, it is more specific. By saying *"numerically represented relations"* it implies that the source of sonification is numerical data and hence, sonification is a form of data perceptualisation. In user interfaces most information has semantical rather than numerical relations which would make auditory information displays not sonifications.

Although *data* may be interpreted in many ways in this context, for the purpose of this work we will follow the latter definition and will not use the term sonification for user interfaces unless they incorporate the perceptualisation of data.

Audification is the direct conversion of numerical data into a sound wave. This form of sonification is particularly suitable for data that has an inherent time line and sufficient data points that make audification feasible like recordings of seismological activity over time (e.g., Hayward, 1994).

Auditory icon as a term, was first coined by Gaver. The concept stems from common theory about metaphors, graphical icons and ecological hearing. Auditory icons are defined as *"...everyday sounds that convey information about events in the computer or in remote environments by analogy with everyday sound-producing events."* (Gaver, 1994). A classic examples of an auditory icons is the sound of the Mac OS X trash bin.

Earcons were introduced by Blattner et.al. as a more generic term for auditory messages. Their definition derives also from visual icons and defines earcons as *"...non-verbal audio messages used in the user-computer interface to provide information to the user about some computer object, operation or interaction."* (Blattner et al., 1989). They distinguish between *abstract*, *representational* and *semi-abstract* earcons. Representational earcons are similar to auditory icons, but by common use of terms 'auditory icon' will be used in this work for any natural sound or cartoonification[3] thereof and earcons for any structured abstract sound that can be interpreted as an auditory message. A short musical motif, for example, could be used as an earcon. A roaring car sound, however, would be classified as an auditory icon.

Auditory information design is a term introduced by Barrass and follows Scaletti's working definition, but modifies it for his purposes to make it more succinct: Auditory information design is *"...the design of **sounds** to support an **information** processing activity."* (Barrass, 1998, p. 30).

2.2 Auditory Display Design

This section reviews guidelines, principles and methodologies that support the design of auditory displays. It focuses on design theory that emerged in the scientific field drawing upon the many prototypes the community has produced over the last 15 years.

The following sections are organised to reflect the typical activities in a design process similar to those identified by Benyon et al. (2005): analysis and requirement specification, concept design, detail design, implementation and evaluation. In practice, these stages are most likely to be iterated or interwoven. Hix and Hartson (1993), for example, make the point that their "star life cycle" minimises the ordering constraints to allow designers to switch between activities as needed. The intention is to provide an account of guidelines, principles and methodologies in the context of these activities without necessarily implying their temporal sequence.

2.2.1 Analysis & Requirement Specification

As in any design task the analysis and conceptualisation of the design problem is key to the success of the design. This includes the analysis of requirements and constraints

[3]A cartoonified sound is a simplified, synthesised version of a natural sound that offers the same perceptual invariants (as advocated by Gaver, 1994). Cartoonified sounds might also be used to exaggerate specific properties of a sound.

regarding functionality, the understanding of the context of use and the target user groups. The following reviews work that addresses this early stage in the design process in the context of auditory displays.

A concept widely known Task and Data analysis (TaDa!) constitutes the first stage of the case based design approach by Barrass to auditory information design and provides a formalised description of the task and the data as the basis for informed decisions in auditory display design (Barrass, 1998, p. 31). A TaDa! analysis has three parts: the first derives from classical task analysis and includes a free-text scenario and five classification attributes (generic questions, purpose, mode, type and style). The second part focuses on the information that needs to be conveyed and is driven by the questions of the task analysis. It is classified into five categories (reading, type, level, organisation and range) - *"A characterisation of these answers can specify the information requirements of a display to support this activity."* (Barrass, 1998, p. 41). Finally, the third part is concerned with the underlying data. The description reflects the subject key in part one, but goes into more detail about the properties of the data (type, range, organisation). Although TaDa! takes into account some important aspects in the requirements analysis, it neglects others like constraints regarding the environment in which the display is operated or the device it will be implemented on. Another point of criticism might be the over-simplification in categories. The bias towards data sonification also narrows the field of application and contexts of use.

Sanderson et al. (2000) have proposed to extend a concept known as Ecological Interface Design (EID) to accommodate the auditory interaction channel. While EID had previously been widely used for visual interfaces, it had not been applied to other modalities. EID stems from cognitive work analysis and provides several phases that address this early stage of problem framing and requirement analysis: work domain analysis investigates contextual properties, control task analysis focuses on the functional requirements, social organisational analysis addresses the social environment and workers competence analysis provides information about the people involved.

Another approach stems from use case scenarios and was proposed by Pirhonen et al. (2006). They enrich textual scenarios with sounds, which initially are empty placeholders only, and use those "rich use cases" to inform design decisions. Personas[4] are used to draw a compelling picture that has *"...qualities that enable the interpreter to identify him/herself with the character"*. Because of the free form of the scenario, all possible aspects of requirements may be incorporated. However, choosing the personas may be difficult and many scenarios might be needed to convey the full analysis. Furthermore, the interpretation of the analysis can be highly subjective and authors of scenarios are likely to introduce some bias towards design decisions. For example, the decision of when sound placeholders should be inserted is part of writing the scenario and already imposes a significant presumption on the further process.

Mitsopoulos (2000) adapts in his "principled approach to the design of auditory interaction in the non-visual user interface" a framework for dialogue design (Foley et al., 1990). His methodology consists of three levels: the conceptional level, the structural level and the implementation level. The objective of the conceptual level is *"...the specification of the information that an auditory representation should convey to the user"* (Mitsopoulos, 2000, p. 70). He investigates the possibility of basing this specification on the analysis of existing visual artefacts and makes a point of distinguishing information to be conveyed and information introduced by the mode of representation. He defines a number of specification primitives which include basic dimensions like volumes and scales, but also semantic entities to define the information necessary to accomplish a given task. While being very accurate on the definition of the information and tasks, his approach neglects other aspects of the requirements analysis like the characteristics of the user, which are equally important to inform design decisions.

Many designs of auditory displays are motivated by making existing, visual artefacts accessible for a different target group or in a different context of use. Approaches to "translate" these user interfaces have adopted different strategies to extract the information and re-code it into the auditory domain. On the one end of the spectrum, projects aimed to find auditory representations for the visual artefact (e.g. GUIB Weber et al., 1993)—that is a surface translation[5]. Other approaches incorporated the semantics in various degrees.

[4]Personas are fictional characters representing the requirements of the main user groups. For more background on the technique see Cooper (2003)

[5]Surface translation has commonly been used to refer to the technique of creating an auditory representation on the basis of the visual properties of the corresponding artefact.

The Mercator project, for example, aimed at finding auditory equivalents for graphical widgets (Edwards et al., 1993), rejecting graphical properties of the representation in favour of a hierarchically structured set of auditory interface widgets.

The principled design approach of Mitsopoulos (2000) also operates on this level although some visual properties are considered in the design (see also Edwards and Mitsopoulos, 2005). On the other end of the spectrum the author has argued for a complete detachment from visual presentations in favour of semantics (Frauenberger et al., 2004). The main argument has been that due to the different properties of the visual and the auditory interaction channel, cross-modal translations of artefacts are prone to introduce inappropriate mappings. A similar stance is made by Metatla et al. (2007) in their investigation of alternative, external representations of UML diagrams by abolishing all visual conventions. They exclusively use the semantic relationships of entities as basis for their auditory representation of UML diagrams.

2.2.2 Conceptual Design & Envisionment

At this stage of the process the designers should have a good understanding of the problem and start developing the concept of the solution. The details remain unspecified, but high level design decisions are made and determine the fundamental properties of the solution. Typical tasks at this stage include deciding which parts of the interface will incorporate audio, which type of audio is appropriate (e.g. speech vs. non-speech) or which overall concepts will be used (e.g. audification, sonification etc.)

These high-level design decisions are directly supported by the extended EID methodology proposed by Sanderson et al. (2000). The underlying cognitive work analysis specifically promotes a strategy analysis which aims to identify the range of design options and basic strategies. They emphasise that this approach provides designers with a method to decide which information should be presented in audio.

When using multiple modalities in a user interface the interplay of information presented in different modes is crucial. Brewster (1994) addresses this issue in a bottom-up approach by adapting the event and status analysis (Dix, 1991). In principle, the technique predicts failures in interfaces by considering the events and status changes on different layers such as the user, screen, dialogue and application. By naive psychological analysis designers without in-depth knowledge about the underlying interaction models can predict flaws and suggest improvements. Brewster uses this technique to identify failures in interfaces due to the inaccessibility of information and suggests that sound should be employed to reveal this information. He further links his findings to guidelines for constructing earcons.

Zhao et al. (2004) have made the attempt to translate the popular information seeking mantra (Ahlberg and Shneiderman, 1994) into the auditory domain. In their Auditory Information Seeking Principle, they propose that data sonification designs should provide for: gist (their name for an auditory overview), navigate, filter and details on demand. Notably, this is the only principle we are aware of that explicitly proposes an interaction paradigm in the auditory domain.

In Barrass's approach to auditory information design he deals exclusively with audio-only designs. He links, however, requirement specifications directly to sound design, omitting high-level design decisions or implying them either in the requirement analysis or in the sound design.

Barrass also proposed the use of design patterns which allow more flexibility at the level of concept design (Barrass, 2003). Adcock and Barrass made an attempt to spark a community effort to create a collection of patterns that would reflect common practice (Adcock and Barrass, 2004). Mode-neutral patterns have been proposed as the basis for auditory display design to emphasise the importance of semantic entities without bias towards visual representation (Frauenberger et al., 2004). Design patterns are a central concept in this work and will be discussed in more detail in section 2.4 and throughout chapter 4.

Pirhonen et al. (2006) present the rich use case scenarios created during the requirement specification to a panel of designers for discussion. After the first panel initial sounds are designed and incorporated into the scenario instead of the placeholders. Subsequently, two more iterations of the process are performed until the panel is satisfied with the quality of the sounds. This approach emphasises the link between the context (i.e., the scenario) and the sounds focusing on the semantics of the sound in the whole of the interface. However, the quality of the results rely solely on the quality of the panel and there is no other input to the process other than the panel's expertise.

At the structural level in Mitsopoulos' methodology he links the information defined at the conceptional level to an auditory representation (Mitsopoulos, 2000, p. 96). Notably, he distinguishes two fundamental modes of representation: fast representation mode and interactive mode. While the first enables the user to grasp information 'at a glance' and provides overviews, the latter supports detailed exploration. He proposes to inform design decisions at this stage mainly by psychological principles like attention theory or psychoacoustics. For fast representation mode he focuses on auditory scene analysis and stream segregation (Bregman, 1990) to bundle overview information per task. For his interactive mode he adopts Broadbent's filter theory (Broadbent, 1958) as a user model to define a performance baseline of users regarding listening performance and states guidelines to design voluntary and involuntary attention. While the approach is well founded in theory its complexity makes it inaccessible to novice designers. A high level of understanding of the underlying psychological principles is necessary to apply this methodology to the design process.

At this stage of design the need to externalise ideas arises to envision possible solutions (Benyon et al., 2005, p. 45). Usually this involves techniques like sketching, story boards, mock-ups or rapid prototyping. While those techniques are very powerful means to communicate initial ideas and concepts in the visual domain, the auditory domain lacks intuitive equivalents. Pirhonen et al. (2006) refer to this issue when they incorporated sounds into their use case scenarios that had *"...a 'mock-up' or unfinished quality to encourage participants to discuss alternative solutions"*. The intention was to encourage panellists to engage in a further creative process to develop the draft sound into a finalised version. The approach, however, backfired and resulted in participants rejecting the initial ideas of draft sounds altogether. They argue that: *"Sound is such a strong modality that if it is too obtrusive (which a draft sound easily is) listeners cannot respond constructively."*

2.2.3 Physical Design & Implementation

Building on high level design decisions made, the physical properties of the sound to be used have to be defined. While the concept design stage specifies which perceptional effects are needed to build the interface, detailed design is concerned with mapping these onto the properties of the physical stimuli to achieve these objectives. As is to be expected many of these methods are based on research in psychology, psychoacoustics, cognition and attention theory.

One of the first compilations of principles for representing information with sound was published by Kramer (1994a). He *"...presents a number of means for linking perceptual issues in auditory display with techniques for their practical implementation."* and introduces some of the fundamental techniques like audification, parameter mapping and parameter nesting. An overview of other relevant issues in auditory display design is also provided: orthogonality of sound parameters, gestalt and auditory streams, concurrent stimuli, metaphorical and affective associations. Although being universally valid for auditory displays, the presentation of the principles lends itself more to the task of data perceptualisation than to user interface design. However, as stated in section 2.1.2 on terminology this distinction is blurred and many tasks, requirements and constraints overlap and therefore, so do the principles in design.

Besides these guidelines for continuous sonification, many early guidelines were concerned about the design of auditory events; more specifically about auditory icons and earcons. Designers can use two strategies to create auditory icons: synthesise sound which mimics real-world sounds or re-use recordings thereof. Because the latter imposes several limitations in terms of shaping the sounds along relevant dimensions and meaningful real-time modifications, Gaver (1994) focuses on guidance on synthesising auditory icons. The main advantage of synthesised auditory icons over recordings lies in the possibility to parameterise them. Findings in ecological hearing and everyday listening have shown that humans associate perceived sounds directly with the physical objects that cause them (Ballas, 1993). Following this approach, Gaver proposed to parameterise auditory icons not in dimensions of the actual sound, but the properties of the physical object that is causally linked to the sound. For example, a physical model that simulates the impact of an object on a surface might be used to create a certain desired sound effect. The resulting auditory icon would not be parameterised along the properties of the actual sound (onset, loudness, pitch etc.), but by physical parameters like the velocity of the object, its mass or damping properties. Linking these parameters to ecological hearing, designers have direct control over some semantic properties of the auditory icon. Mynatt (1994) proposed a design methodology for auditory icons that she derived directly from factors that she identified as being key to the usability of auditory icons (identifiability, conceptual mapping, physical parameters, user preference). In two experiments she tested the identifiability and possible mappings on graphical interaction concepts and thereby determined the sounds most appropriate for certain parts of a user interface. However, she concluded by saying about choosing sound in interfaces: *"At this time this process is more of an art than a science, dependent on skilled and gifted designers."*

The first guidelines for earcons were developed by Blattner et al. (1989) and were derived from design principles for visual symbols. A "good" icon, for example, has the characteristics of closure, continuity, symmetry, simplicity and unity. Blattner et al. (1989) argue that this is equally true for earcons. Subsequently, they provide guidelines for creating families of earcons by defining rhythm and pitch as the fixed parameters (i.e., the properties that distinguish families) and timbre, register and dynamics as the flexible parameters (i.e., the properties a family of earcons share). Through rules for the combination of earcons they are able to create hierarchies and whole earcon languages. Brewster (1994) later extended these guidelines and investigated the concurrent use of earcons. More recently, McGookin and Brewster (2006) summarised the findings with concurrent audio presentations in auditory display. In the line of Brewster's research on enhancing graphical user interfaces by audio cues, Lumsden and Brewster (2002) presented guidelines for non-speech audio in the user-interface. This set of rules is an example where long term research was distilled into practical advice for designers of auditory display. Its strong focus on the enhancement of graphical widgets, however, makes it only applicable in this special context. Similarly focused guidelines include Brown et al. (2003) who provide hands-on recommendations for designing auditory graphs and the guidance provided by Vickers and Alty (2005) on using hierarchically structured musical motifs in program auralisation.

Further guidelines for designing auditory events also emerged from two areas of research: ecological hearing and attention theory. The former is concerned about creating semantic links between stimuli and the meaning they are intended to convey. Brazil and Fernström (2007), for example, propose to use the Repertory Grid Technique to classify auditory cues to be used in ambient information systems. Semantical mapping is also one of the phases in the EID methodology proposed by Sanderson et al. (2000). They argue, however, that this mapping of meanings is not sufficient to create appropriate auditory cues. They extend EID by adding another layer of attentional mapping to manage the split between the user's attention for different elements of the interface. They have successfully applied this method to design warning signals in a medical environment (Watson and Sanderson, 2007). Guidelines for other safety critical environments also focused on attentional and urgency aspects for designing alarms, for example in aviation (Patterson, 1982). In reality, however, it was found that there is a considerable gap between the results that research has produced and the application of guidelines in current practice of designing warning signals (Simpson, 2007).

The design methodology proposed by Mitsopoulos (2000) is also driven by attention theory to inform the implementation level. Although he states that the *"look-and-feel cannot be prescribed by the methodology, since the artefact also depends on the experience and skills of the designer, and the design context"*, he aims to provide the designer with constraints that narrow down the design options. These constraints are mainly derived from psychoacoustics (and here mainly from Bregman, 1990) and are dealing with stream segregation, masking and presentation rates (Mitsopoulos, 2000, p. 136).

Perceptual properties of the human hearing system also informed the development of the information sound space (Barrass, 1998, p. 107). The space offers a perceptual design space similar to colour spaces available in visualisation. A prototype, the SoundChooser, implemented such an information sound space and allowed users to explore sounds along the three dimensions of pitch, brightness and timbre (Barrass, 1998, p. 124). Related work has led to the development of a timbre space in which a metric is defined to determine perceptual distance between sounds (Terasawa et al., 2005).

Barrass (1998) also investigated an alternative approach. EarBender implements a case-based method to choose sounds from a database by matching them with real world stories and requirements gathered by the TaDa! analysis. He states a number of appealing advantages of this approach: it is top-down, meaning connected to the context, can be supported by tools and a potential source of more generic design principles. The approach is in many ways similar to design patterns as they too provide examples alongside a contextual description of its use as Barrass implies in his "pattern method" of using EarBender (Barrass, 1998, p. 53).

2.2.4 Evaluation

The evaluation of artefacts plays a central role within all of the activities discussed above and can therefore take a variety of forms. The field of human-computer interaction has produced manifold evaluation techniques to suit these demands ranging from user based evaluation, inspection based evaluation to formal verification. Many of these techniques remain valid for evaluating auditory displays, but little work addresses audio specifically.

The predominant method for evaluating auditory display design is through user tests. Within this area, it is perceptual studies which are the most common. Bonebright et al. (2005) provide a general methodological framework for evaluating the perceptual properties of auditory stimuli. Within this framework they provide guidance on how to design experiments including recommendations on sample sizes, stimuli, experimental tasks, data collection and analytical methods. Although they focus on perceptual user studies, they argue that *"Assessment of sound applications needs to continue into the actual use of the product or application in the 'real-world' environment."* and also include surveys and verbal protocols as evaluation methods. In a later comment on this work, the authors reflected on the practice of evaluation studies in ICAD and found that over the years an increasing number of publications in ICAD reported on perceptual or usability testing (Bonebright and Miner, 2005).

A popular evaluation method in HCI has recently been adapted to auditory display design: Ibrahim (2008) investigated usability inspection methods to evaluate sonification designs. They propose an HCI model for sonification that consists of the Sonification Application model and the User Interpretation Construction model. These models and their Task-Data State Diagram are the basis for the Task-Interpretation Walkthrough method they developed to address auditory display design evaluation. This inspection method allows designers to identify flaws in the design early in the process and with less effort than a full user study would involve. Ibrahim (2008) reports on a study with naïve inspectors and found that his method revealed significantly more design flaws in sonification applications than Nielson's heuristics (Nielsen and Molich, 1990) and the Cognitive Walkthrough method (Polson et al., 1992).

Another approach to adapt heuristic's and to extend them for non-classical interfaces was developed by Mankoff et al. (2003). They have developed heuristics for ambient displays by adapting the work of Nielsen and Molich (1990). Although they have tested their heuristics only on two visual ambient displays, their modifications to the original heuristics make them less mode dependent and therefore would also be applicable to auditory ambient displays.

2.2.5 Summary

The sections above have outlined guidelines, principles and methods that have been developed to design auditory displays. The guidance in this area is as diverse as the application domains and the context of the work often dictates the stages in the design process. It is noticeable, however, that the majority of work presented here is concerned about the physical and perceptual design of sound and less guidance is available for earlier stages of the design process. High level design decisions like where in the interface to use sound or how to interact with sounds are less supported than the implementation of the sound cue. One might argue that generic HCI methods might be equally applicable to address this problem, but as shown by the study on current design practice presented in the next chapter, they are used little in practice. There seems to be a significant gap between high-level interactional guidance and the low-level implementation guidance available for auditory display design. A similar argument is made by Barrass (2005) who 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".*

Inspecting the evaluation of the design methods presented above reveals another noticeable aspect. All methods have been evaluated by applying them to specific problems and assessing the quality of the result (see Mitsopoulos, 2000; Pirhonen et al., 2006; Sanderson et al., 2000). There is, however, a lack of comparative studies that compare different approaches and their impact on the effectiveness of the design process. The study to evaluate the **paco** framework presented in this work is novel in this respect by including novice designers and assessing their solutions to given problems.

2.3 Human-Computer Interaction Design

The scientific discipline of human-computer interaction has been with us for over 50 years and is considered to be a major success story (Myers, 1998). Auditory display design is only one of the many fields within HCI and, in comparison, has not yet reached a level of maturity as other fields like graphical user interfaces. This difference manifests itself in that researchers in traditional areas of HCI can draw on many years of experience not only to design artefacts, but also to study and re-invent the design process as needed (e.g., Fischer and Scharff, 2000; Kay, 2007). This form of self-reflection has yet to evolve in auditory display design, but it is hoped that this work is making a contribution to this.

This section intends to provide the reader with a background in HCI work relevant to the topic of this thesis. This includes work concerning the diversity of design processes in HCI and available design guidance. As a natural area of contact, section 2.3.3 will also discuss related work in the field of multi-modal interfaces followed by a brief overview of context aware user interfaces.

2.3.1 Design Processes

As HCI emerged as a form of software engineering, so did the design process and hence the focus lay predominately on engineering activities. The most well-known process models include the waterfall model of the software life cycle and its successor, the spiral model

(Boehm, 1988). However, the need for less rigid processes in the design of interaction was evident as the user took a more central role in the design. Hix and Hartson (1993) argue that due to the largely unpredictable human user behaviour, the process of user interface design must be *"essentially and inherently iterative"* (Hix and Hartson, 1993, p. 97). Their observations of developers and designers at work subsequently led them to propose the star life cycle, a far more flexible process model suiting the needs of interaction design.

Several theories, models and techniques have been developed to support or shape the design process of interactive systems. For example, Task Analysis (Redish and Wixon, 2003), Participatory Design (Muller, 2003) or more theoretical approaches like Activity Theory (Kaptelinin, 1995) or Distributed Cognition (Hollan et al., 2000) aiming to support new challenges in HCI such as collaborative work or ubiquitous computing. Amongst the many frameworks available for designing interactive systems, the following are highlighted as examples for the paradigm shift in HCI from purely functional design towards user and context centred design.

Contextual design is a holistic design process that emphasises the need to understand and interpret the context of use of artefacts (Beyer and Holtzblatt, 1999). Its initial phase, the 'Contextual Inquiry', uses ethnographic methods such as observation or interviewing to collect data about the context of use which forms the basis for the subsequent creative phases of the process. A similar stance is taken by Beaudouin-Lafon (2004) promoting the design of 'situated interaction' by emphasising the importance of the understanding of the context of use. Another design framework focusing on closing the gap between the context of use and technology was introduced by Benyon et al. (2005). With PACT (People, Activities, Contexts and Technologies) they provide a framework that embraces many different techniques to design technologies for activities of people in certain contexts—the main objective being to achieve harmony between these aspects of interaction.

Scenario based design strategies are one way to ensure people, their activities and contexts are informing the design of technology. Carroll (2000) states five advantages of the scenario-based design approach: scenarios allow designers to reflect on design issues based on vivid descriptions of the end-users, they can be adapted to changing design problems, allow users to participate in design activities, they can be written for multiple levels and perspectives and they can be abstracted to accumulate design knowledge across problems. These properties make scenario-based design complementary to the concept of design patterns as we shall see in section 2.4. While scenarios focus on concrete settings to describe the context, patterns seek to capture design knowledge through abstracting across multiple scenarios and their solutions. With the methodological framework proposed in this work, this boundary between concrete scenarios and abstract knowledge will be blurred further by the introduction of the context space and the description of single solutions in a pattern format (see chapter 4).

In auditory display design, two approaches could also be classified as scenario-based design: Pirhonen et al. (2006) borrows these strategies to design sounds in rich use case scenarios and Barrass (1998) matches sounds with stories in his case-based design system EarBender.

2.3.2 Design Guidance

While the design process applied might intrinsically inform design decisions (e.g., through user research), design guidance captures good practice or established design knowledge and aims to restrict the design space. Such guidance can take various forms such as guidelines, principles, rules, claims, standards, heuristics or design patterns. They can be rooted in theory, be proven empirically or simply be based on common practice. Also, the field they originated from determines the way they can be applied to inform design decisions. Common sources of guidance in HCI are psychology, sociology, ergonomics or computer science.

Dix et al. (2004) provide a useful taxonomy for principles in interaction design, which represent the most abstract form of guidance. Their three main categories for principles are learnability, flexibility and robustness in which they present other general principles supporting them (Dix et al., 2004, p. 260). Guidelines provide a less abstract and more authoritative form of guidance; amongst the best known are the guidelines for designing user interfaces by Smith and Mosier (1986). In order to simplify the guidance and lower the barrier for practitioners to use guidelines, golden rules and heuristics have emerged.

Although not always applicable to every design problem, they have proven useful for designers (e.g., Shneiderman, 1998). On the other end of the spectrum, the least abstract form of guidance is provided in case-based design, which relies on the designer's ability to transfer solutions from example cases (Maher and de Silva Garza, 1997). Design patterns fit into this range of forms of guidance between guidelines and case-based design. They provide generalised design knowledge, but also link it to specific implementations and examples (Dearden and Finlay, 2006, provide a detailed discussion on differences and similarities of design patterns and guidelines, standards and claims).

Most guidance, in whatever form, supports the actual design knowledge with a rationale. As Fischer et al. (1991) point out, besides *"being invaluable for maintenance, redesign, and reuse, [design rationale] promotes critical reflection during design"*. Several systems have been developed to capture design rationale and describe and support the path through the design space a designer takes while solving a problem. The most prominent are IBIS (Issue Based Information System, Kunz and Rittel, 1970) and QOC (Questions, Options and Criteria, MacLean et al., 1991).

2.3.3 Multi-Modal Design

The interaction with technology could be seen as multi-modal from the very start; the keyboard, the computer mouse, a system beep and the visual screen are the most common components of the audio-visual-tactile interaction loop we are used to nowadays. However, for presenting information or providing feedback, the visual display is the predominant choice. Multi-modal design of HCI therefore focuses on the exploitation of alternative human sensory channels for conveying information.

The most appealing benefit of using multiple sensory channels is the decrease of cognitive load by distributing information across modalities. Oviatt et al. (2004) states that *"there are reasons to believe that a multimodal interface may be effective at minimizing users' cognitive load and supporting their performance"*. This effect is particularly desirable when users have to perform complex tasks or are easily distracted by the environment.

Besides the potential benefit, the use of multiple modalities poses the danger of cross-modal interference. For example, Brock et al. (2004) found the performance of users decreasing in an identification task with auditory and visual cues. Their results suggest that the discrepancy in spatial location in the task environment between the auditory and visual stimuli caused this negative effect. Coutaz et al. (1995) proposed the CARE properties to assess and predict the usability of multi-modal user interfaces. CARE stands for Complementarity, Assignment, Redundancy, and Equivalence and formally defines properties of multi-modal systems through the notions of state, goal, modality, and temporal relationships. These formal definitions aim to enable designers to reason about the design of multi-modal systems.

While focused on auditory display, multi-modal work was also well represented at ICAD conferences. For example, Nesbitt and Barrass (2002) compared the performance of sonification, visualisation and multi-modal (audio and visual) representation of stock data. Both sonification and multi-modal conditions outperformed the visualisation in this study, differences between them, however, were less clear. McGookin and Brewster (2002) used an audio-visual approach to represent maps of theme-parks in a mobile context of use. Recently, there has been increasing interest in combining auditory displays with tactile interfaces. For example Murphy et al. (2007) have used auditory and tactile feedback to convey spatial information to visually impaired web-users. This trend is also shown by the success of the HAID (Haptic and Audio Interaction Design) workshops—at the time of writing in its third annual incarnation[6].

2.3.4 Context-Aware User Interfaces

The need to develop multiple user interfaces to the same application arose from the increasing variety of contexts of use in which users interact with technology. This problem of a *"moving target"* (Myers et al., 2000) multiplies the efforts for designing efficient user interfaces and poses the danger that the results are inconsistent. Motivated by these challenges, Thevenin and Coutaz (1999) introduced the notion of *"plasticity"* as an additional property of the usability of a system. Plasticity denotes the ability of a user interface to adapt to changes of the context of use without decreased usability.

[6] http://www.haid2008.org/

Calvary et al. (2001) proposed a unifying reference framework for the development of plastic user interfaces. This framework defines a user interface at multiple layers of abstraction which are defined by ontological models for the context of use. As figure 2.1 illustrates, the ontological models define the target contexts for which the specifications for the user interface is derived. The approach emphasises the formal modelling of the

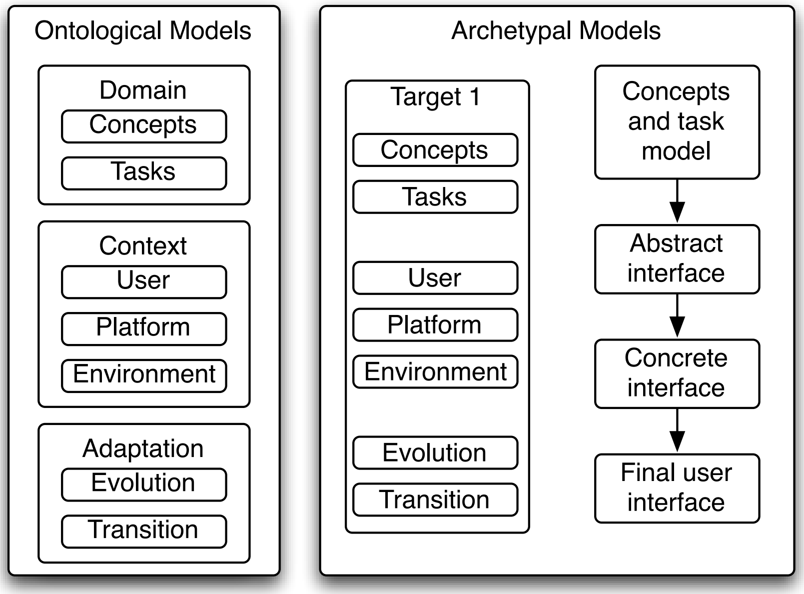


Figure 2.1: Process Reference Framework, simplified after Thevenin et al. (2003)

context of use (hence also called model-based user interface design, MB-UID) in order to facilitate automated reification and adaptation of the final artefact. Research showed how model-based user interface design can be applied to create variations of one interface for a desktop, a PDA and a mobile phone (Eisenstein et al., 2001). It also was used to automatically create user interfaces in different modalities (Stanciulescu et al., 2005). However, the complexity of the models, the limited flexibility of rules for the automated generation of artefacts and the unpredictability of the result are the main points of criticism of MB-UID techniques (Molina, 2004; Myers et al., 2000).

A line of research tried to simplify MB-UID by marrying the rigour of models with the flexibility of design patterns (Sinnig et al., 2004a). The authors emphasise the value of patterns in capturing proven design knowledge and define them in all stages of MB-UID: patterns for the envisioned task model, in the dialogue model, in the abstract user interface description and in its implementation. The question remains whether the strengths of both concepts are moderated by the weaknesses of the other in this approach. The semi-structured format of patterns makes rule-based generation increasingly difficult, while the strictness of models limits the power of design patterns.

2.3.5 Summary

The above provides a brief overview of topics and techniques in human-computer interaction which are relevant to this work. Various design processes were discussed to illustrate the paradigm shift from purely functional design to a more holistic and context orientated approach. Fundamental forms of design guidance were compared along with design patterns and how they fit into the bigger picture. Multi-modal interface design is the overarching theme in HCI that is largely concerned about other, non-visual, forms of interaction and contact points to the field of auditory display were highlighted. Finally, context-aware user interface design is also relevant to this thesis as the **paco** framework shall borrow some of those concepts to emphasise the importance of context in the design of auditory displays with design patterns.

2.4 Design Patterns

Design patterns have first been introduced in the field of architecture and subsequently deployed in many other designing disciplines. They play a central role in the approach taken in this work and are hence discussed here in more detail. The following sections describe design patterns as they were devised by Christopher Alexander, followed by an overview of disciplines which adopted the concept. Subsequently, design patterns in human-computer interaction, pattern formats and analogical problem solving are discussed in more detail.

2.4.1 Alexander's patterns

Christopher Alexander has published a series of books on the concept of pattern languages in architecture that originated from his early work 'Notes on the Synthesis of Form'

(Alexander, 1964). The first volume 'The Timeless Way of Building' (Alexander, 1979), although published later than the others, lays out the theoretical foundations of his ideas. 'A Pattern Language' (Alexander et al., 1977) provides an extensive collection of patterns and 'The Oregon Experiment' (Alexander, 1975) illustrates an implementation of the concept in the planning process of the University of Oregon.

At the centre of his approach Alexander defines the 'Quality without a Name' which makes architectural environments good for the people inhabiting them. He links this quality to properties like 'alive', 'whole' or 'free', but insists that there is *"...no single name to capture it"* (Alexander, 1979, p. 39). He argues that this desirable quality is defined through patterns of events that keep on happening in spaces. This leads his argument to patterns in spaces which describe solutions for architectural design tasks that provide for this quality. Patterns, in the Alexanderian sense, therefore emerge by determining the invariant, spatial properties of solutions that possess the quality without a name (Alexander, 1979, p. 85). Another commonly quoted definition of design patterns states:

> *"Each pattern describes a problem that occurs over and over again in our environment and then describes the core of the solution to that problem in such a way that you can use this solution a million times over without ever doing it the same way twice"* (Alexander et al., 1977, p. x).

Alexander stresses that design patterns work on different scales, from single rooms to urban environments, and that they merely remind us of what we already know. This notion illustrates his emphasis on collaborative and participatory design, including all stake-holders in the process: the architect (or designer), the contracting body and the inhabitants (or users). The textual form of design patterns and their accessible writing style are intended to make them a *lingua franca*[7] for all involved to communicate design. This democratisation of the design process led Alexander to introduce another concept: the process of repair. *"No building is ever perfect"* (Alexander, 1979, p. 479)—and no user interface for that matter. The way design patterns empower users is intended to allow them to mend the design while using it. In the case of architecture this would mean that people

[7]lingua franca: a language used as a common language between speakers whose native languages are different (Soanes and Hawker, 2005).

who inhabit a space constantly reshape its architecture within their possibilities—e.g., by painting a wall or removing a gate. In user interface design the design space left to the user to shape varies and ranges from simple customisation (e.g., changing the desktop wallpaper) to more substantial and functional changes such as redesigning one's Google start page.

A common misconception is that design patterns are blueprints or templates. Design patterns in the Alexanderian sense reflect generic solutions, *"but there is always variation and uniqueness in the way the patterns manifest themselves"* (Alexander, 1979, p. 147). He arguers that this is due to the unique forces that are implied by the surroundings, i.e., the context of use. Furthermore, patterns are not instantiated in isolation, but in connection with other patterns, adding to the variety of possible outcomes. Alexander calls these systems of related patterns *pattern languages* and compares them to natural languages (Alexander, 1979, p. 187). Both are *"finite combinatory systems which allow us to create an infinite variety of unique combinations, appropriate to different circumstances, at will"*. The concept of pattern languages also addresses the different scales of patterns and connects patterns that create a room with those related to a building and those related to a town. Alexander states:

> *"In short, no pattern is an isolated entity. Each pattern can exist in the world, only to the extent that is supported by other patterns: the larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded in it"* (Alexander et al., 1977, p. xiii).

The idea of design patterns has been controversial and Alexander's work has been criticised the way it commands (Saunders, 2002). Especially, his collection of patterns, describing a timeless way of building, lacks empirical evidence and consensus in the wider community of architects. Another problematic aspect highlighted by Saunders (2002), editor of Harvard Design Magazine, is the conservative notion of Alexander's approach by *"assuming that new ideas are almost never going to be as good as ideas that have evolved over centuries of vernacular building"*. That is because they capture good, established practice, design patterns might make it difficult to introduce radically different approaches.

Despite being a controversial concept in architecture, design patterns have been successfully adopted by many other disciplines. The following section provides a brief overview.

2.4.2 Patterns in Other Disciplines

The concept of design patterns has spread amongst other designing disciplines mainly for its power to capture design knowledge and expertise. Rising (1999) states

> *"A pattern is, on the surface, simply a form of documentation. ... The power of this kind of documentation is that knowledge, previously found only in the heads of experts, is captured in a form that is easily shared".*

She goes on to cite a Japanese proverb reflecting how important sharing knowledge is: *"None of us is as smart as all of us".*

Arguably the most influential work following up on Alexander's ideas was the application of design patterns in the field of object-oriented programming. Gamma et al. (1994), commonly referred to as the 'Gang of Four' (GoF), popularised the concept within the software engineering community and their patterns are still widely used to communicate expertise in object-oriented programming. Despite undoubtedly being a valuable resource in this discipline, the pattern community has criticised the authors for misinterpreting Alexander's ideas by solely exploiting the re-usability aspect, but ignoring the power of inclusion of users and other stake-holders (Borchers, 2000a; Tidwell, 2000).

Since the GoF book, many areas within software engineering have taken up the concept of design patterns. Henninger and Correa (2007) have conducted an extensive survey of pattern collections in this field (121 collections containing 2178 patterns) covering areas such as user interfaces, programming languages, security, fault tolerance, networking or databases. Notably, almost one third (31%) of the patterns are published as hardcopies[8] only, greatly limiting their dissemination. Only 24% are published through web-sites using HTLM/XML formats. The authors advocate a federation of pattern collections and state six challenges to achieve this goal: electronic accessibility, standardised pattern formats,

[8]By hardcopy the authors mean books or other publications only available in printed form.

inter-pattern relationships, software pattern validation, tracking variants and duplicates, and updating mechanisms. Their efforts have led to the creation of a Semantic Framework for Patterns[9] (SFP) that collects information about software collections in a registry.

A related concept that has been introduced to software engineering is problem frames, a problem space classification scheme (Jackson, 2001). Problem frames are generic abstract problem structures consisting of principal parts, structure and solution tasks which make them appear similar to design patterns. However, problem frames are much more rooted in formal specification rather than practice and help shaping the problem space, while patterns map forces into the solution space. (Wirfs-Brock et al., 2006) show that it is possible to link the two concepts and describe the development of design patterns from the original problem frames by Jackson (2001).

Design patterns have also been adopted by other non-engineering disciplines. For example, the pedagogical patterns project[10] provides pattern languages for teaching seminars effectively or for developing a computer science course (Fincher and Utting, 2002). Rising and Manns (2004) have derived 48 patterns for implementing change in organisations. These patterns draw on interviews and observation about organisational structures in companies and how they change.

The following section will review the use of design patterns in the field of human-computer interaction.

2.4.3 Patterns in HCI Design

Borchers (2000a) has argued that the field of human-computer interaction is closer to architecture than to software engineering. The interaction designer creates environments in which her users interact, work or live in—very similar to how architects work with physical environments. Patterns of good interface design equally emerge from patterns of events and usage by humans who inhabit the interactional space. In contrast, designers of software create systems that aid the greater aim of usability, but are not inhabited by the user. The analogy in architecture might be the relationship between the architect and the

[9] Available at http://cse-ferg41.unl.edu/SFP

[10] See http://www.pedagogicalpatterns.org/ (last checked July 2008)

1	A pattern implies an artefact.
2	A pattern bridges many levels of abstraction.
3	A pattern includes its rationale.
4	A pattern is manifest in a solution.
5	A pattern captures system hot spots.
6	A pattern is part of a language.
7	A pattern is validated by use.
8	A pattern is grounded in a domain.
9	A pattern captures a big idea.
10	Patterns support a lingua franca.
11	Different patterns deal with problems at different scales.
12	Patterns reflect design values.
13	Patterns capture design practice.

Table 2.1: Essential characteristics of design patterns used in literature to describe what patterns are (from Dearden and Finlay, 2006)

plumber. While equally important for the building to work, people inhabit houses and not the system of water tubes. In this sense, HCI patterns relate more closely to the initial ideas of Alexander, exploiting their powers of communication, inclusion, re-usability, contextual sensitivity and diversity of solutions.

A critical review of design patterns in HCI is provided by Dearden and Finlay (2006). In their article they discuss four fundamental issues in the scope of HCI: Firstly, what is a design pattern? Dearden and Finlay (2006) identify essential characteristics of patterns (see table 2.1) and discuss how to identify patterns in a domain and existing representations. They also contrast design patterns with style guides, standards, guidelines, claims and heuristics. Secondly, they discuss what is gained by organising patterns in pattern languages. Notably, they elaborate on the notion of generativity, i.e., the power of pattern languages to generate novel solutions by defining relations similar to grammar in natural languages. Thirdly, they discuss how patterns and pattern languages are used in HCI, identifying five major themes as strongholds of design patterns: participatory design, technical lexicon, organisational memory, lingua franca and design rationale. Finally, they discuss the power of patterns to convey design values. They conclude with proposing a research agenda for design patterns in HCI which is worth re-iterating here, because the work presented in this thesis is directly addressing the issues raised (see discussion in section 4.2).

Theme	Quotes
Enriching pattern languages	*"We need to develop generative frameworks for organising pattern languages and to focus on patterns at different levels: from the social context of systems to the detail of interfaces."*
Understanding pattern development	*"To date pattern development has been relatively ad hoc, based on designer experience ... Frameworks for analysing design to identify the elements that make it successful are needed ... The results need to be managed to enable discussion and sharing."*
Using patterns in design	*"One of the most obvious weaknesses in HCI research on patterns to date is the lack of genuine evidence of their benefits to design practice."*
Values in pattern-led design	*"Values is an area where more attention is needed in HCI generally."*

Table 2.2: Research agenda for patterns in HCI as proposed by Dearden and Finlay (2006)

Table 2.2 summarises the agenda proposed by Dearden and Finlay (2006).

The largest collections of patterns related to interaction design are provided by Tidwell (2005) (94 patterns), Schümmer and Lukosch (2007) (80 patterns) and van Welie (2006) (61 patterns). As noted by Henninger and Correa (2007), there is some overlap in these and other collections, but each author applies their own perspective and emphasises different application domains. Tidwell (2005) provides an extensive range of patterns for all types of user interfaces. With the exception of the first 12 patterns (on user behaviour), they emphasise visual design issues. Schümmer and Lukosch (2007) focuse on groupware applications and provide patterns to build systems that mediate communication in groups emphasising the importance of social context. Unlike the first two, van Welie (2006) publishes design patterns through a repository on a web page. It is constantly updated and allows for feedback and discussions by designers who used the patterns.

The above collections go as far as including multi-media content, but do not touch on multi-modal interaction design. Bridging between modalities with design patterns was first demonstrated by Borchers (2001) with his patterns for designing interactive music exhibits. Other work that touched on the use of sound in HCI includes Schnelle et al. (2005) who developed audio navigation patterns for Voice User Interfaces (VUIs) and the aforementioned efforts by Barrass (2003) and Adcock and Barrass (2004) to establish design patterns for sonifications and auditory display. Godet-Bar et al. (2006) proposes a formalised system of patterns to design multi-modal user interfaces. They provide an initial set of 15 patterns and discuss possible next steps to evaluate the usefulness of their approach.

Mahemoff (2001) was first to study the impact of patterns on designing human-computer interaction. He presents several pattern languages at different levels of abstraction with the aim to incorporate usability aspects into the software engineering process. In a controlled experiment he asked groups of two novice designers—Computer Science students—to produce sketches for a design problem provided. Half of the groups were given a simple set of design principles, the others additionally were provided with design patterns. The small number of participants (16 overall, eight groups) did not produce conclusive evidence regarding the impact on the solutions, but the qualitative analysis of observational data revealed insights into the way designers use patterns.

More recently, Chung et al. (2004) presented an empirical evaluation of the effect of providing patterns to designers. They developed 45 patterns for ubiquitous computing and presented them to designers with varying levels of expertise in the field. In two controlled experiment they asked pairs of designers to design a location-enhanced application. Participants had 80 minutes to create an initial sketch followed by 10 minutes in which they presented the results to a panel. The solutions were analysed to reveal any evidence of patterns being useful to the designers. The presentations were video-taped and anonymously judged. The results demonstrate that their patterns had significant impact on the rating of the produced solutions. They also showed that patterns helped novice and experienced interaction designers with limited knowledge of ubiquitous computing with generating and communicating ideas and in avoiding design problems in the early stages of the design process. In chapter 5 a similar approach will be described to evaluate the methodological framework proposed in this thesis, however, extended in scope to include the pattern creation phase.

Design patterns have also been introduced to model-based user interface design to aid with the creation of the complex models underlying this approach (Sinnig et al., 2004a,b, 2005). Javahery et al. (2006) proposes a framework that also aims to support designers with appropriate tools while taking advantage of the simplicity of design patterns. They propose a combination of design patterns and context variables derived from models. Their tools support designers in selecting the right combination of patterns based on the formal description of the context and the user.

The management of pattern collections is also often supported by tools. These range from inter-linked web-pages to more complex tools to visualise the relationships in pattern languages. Deng et al. (2005) provide an overview of commonly used tools such as CoPE (Schobert and Schümmer, 2006), MODUIL (Gaffar et al., 2003) and Damask (Lin and Landay, 2003). From analysing currently available tools and the key problems Deng et al. (2005) identified for managing pattern collections they derive the following requirements for their tool MUIP (Management of User Interface Patterns) (Deng et al., 2006). A formal evaluation showed the usefulness of the tool.

- support for pattern authoring activities
- manipulation of forces
- browsing and searching facilities
- modification and versioning of patterns
- relating patterns
- managing pattern collections
- import and export of patterns in different formats

Summarising, the use of patterns in interaction design is wide-spread and has proven to be beneficial for the design process. The following section introduces different styles of pattern formats and formalism.

2.4.4 Pattern Formats

Pattern formats have been adapted to suit specific application domains or management requirements. They range from free-form text to strictly formalised representations. As Henninger and Correa (2007) state in their survey of pattern collections: *"Almost every* *pattern collection we surveyed used a different pattern form"*. This section provides an overview of the most commonly used formats and their differences.

The original format introduced by Alexander is the most textual and least formal (Alexander et al., 1977). It does not explicitly provide section headers, but each pattern is composed of the same elements: the pattern name, an illustration, a problem statement, the explanation of the context, a solution to the problem, the explanation of the solution and a list of related patterns. In principle, most pattern formats still conform to this basic structure.

The GoF book on software engineering patterns made slight alterations to accommodate the requirements of the domain. The authors introduced explicit headers and sections such as code examples, implementation, consequences and applicability. Tidwell (2005) gave the sections new names and simplified the format for her collection to: illustration, what, use when, why, how and examples. This is similar to the format used by van Welie (2006) in his online repository.

At the other end of the spectrum, task model patterns as discussed in Gaffar et al. (2004) are amongst the most formalised. The authors proposed the Task Pattern Markup Language (TPML) consisting of five descriptors: name, problem, context, solution and rationale. The currently most widely accepted effort to unify pattern formats is also based on XML[11]. The Pattern Language Markup Language (PLML) was introduced during a workshop at CHI 2003 (Fincher, 2003) and further developed by Deng et al. (2006). It seems to be the best compromise so far for making pattern formats machine-readable, but also flexible enough to accommodate the requirements of special application domains. Appendix A provides the schema of PLML. Henninger (2007) however, argues for using semantic web techniques to further unify the format of patterns. He proposes PFOWL (Pattern Form in Web Ontology Language) which is designed to be compatible to XML, but sets out to facilitate inter-collection relationships and semantically meaningful organisation.

[11]XML: eXtensible Markup Language

2.4.5 Patterns and Analogical Problem Solving

Design patterns fit well into the theory of analogical problem solving—a well studied area in cognitive psychology. Experiments by Gick and Holyoak (1980) investigate how participants derive solutions to given problems by transferring solutions from stories that provide analogies, but are set in a different domain. They show that the spontaneous knowledge transfer from an analogy-story to a new problem is more difficult for participants than one would naïvely expect. The ability of participants to conceptualise an abstract problem-solving schema in an analogy-story and its application onto a different problem is generally low. In subsequent work they investigated what factors might improve this ability. The role of semantic retrieval cues and the impact of various forms of schema induction were compared. They found that providing two stories with a similar problem-solving schema greatly added to the participant's ability to identify analogies and develop similar solutions (Gick and Holyoak, 1983). This means that the availability of an abstract schema—in this case induced by comparing two stories—is key to our ability to transfer solutions. Similar results were produced by Gentner et al. (2003) who investigated learning effects with analogies.

Abstract schemata are, of course, very similar to design patterns. They are the core of a solution to a recurring problem. Design patterns therefore should enable designers to create better design solutions than by making similar cases available. This line of thought could bridge the issues with case-based design methods as discussed by Maher and de Silva Garza (1997) and Maiden and Sutcliffe (1992). If extracted fully from analogous cases, design knowledge captured by design patterns becomes a powerful tool for re-use. This implies that the process of creating patterns and the quality of the abstraction is key to the success. The theory of Model-based Analogy (MBA) addresses this step and provides formalised methods for abstracting over design cases to create design patterns (Bhatta and Goel, 1997). This theory also links design patterns to the field of Artificial Intelligence (AI). Gael (1997) discusses how case-based design, analogical reasoning and design patterns could be used to introduce creativity to AI methods.

The area of analogical problem solving not only provides a valuable, theoretical perspective on design patterns, but also offers experimental methodologies to investigate the effectiveness of transferring problem-solving abilities. The studies presented by Gick and Holyoak (1980) therefore inspired the methodology used in the experiments to evaluate the design framework proposed in this work.

2.5 Summary

This chapter has aimed to provide the reader with a background in the areas in which this work is rooted. The historical development of sound in technology was discussed and domain specific terminology, as used throughout this thesis, was clarified. Subsequently, previous approaches to auditory display design were reviewed and how they relate to the different phases in the design process. Human-computer interaction can be seen as the overarching field accommodating auditory display. In section 2.3 HCI concepts of specific relevance to the topic of this thesis were revisited. Design patterns have been discussed in extra detail as they are central to the proposed methodological framework.

Chapter 3

Auditory Display Design Practice

The use of audio to convey information in the interaction of humans with technology goes back a long time in history. An early example is Galileo's free fall experiments with the inclined plane in 1603 in which he used sound patterns caused by rolling balls in his apparatus to determine the law of retarded free fall (Riess et al., 2005). Other popular examples include the Geiger counter and Pulse Oximeters which take advantage of the distinct abilities of human auditory perception. More recent applications of audio in human-computer technology were presented in the previous chapter. In 1992 the first conference on auditory display laid the foundations for developing this area of interest into a scientific discipline. Now, 16 years later, the International Community of Auditory Display (ICAD) holds annual conferences with its members being active researchers in many diverse application domains such as gaming, mobile computing, ubiquitous computing, aeronautics, medical informatics and economics.

This chapter inspects how far the scientific discipline of designing auditory display has come and how its achievements are perceived by the wider community of people designing interaction with technology. In the first section the current practice of auditory display design will be investigated by means of a literature study of recent proceedings of ICAD (2007). The second part of this chapter presents a survey conducted amongst researchers and practitioners in human-computer interaction with the aim to draw a picture of the scientific field and how it is perceived. Finally, section 3.3 concludes the chapter by summarising the material presented.

3.1 Current Design Practice

This literature study aims to reveal aspects of current design practice for auditory displays. More specifically, the following themes reflect the research questions that have driven the study:

Process What processes have been adopted to design auditory displays? This theme focuses on finding footprints of structured methods or recurring processes that researchers use to create auditory displays. For the purpose of this study, the design process has been defined as the sequence of activities of designers from the definition of the problem to the realisation and evaluation of an auditory display.

Guidance What guidance is considered to inform design decisions? In every design process, a manifold of design decisions have to be made that determine the result. This question aims to reveal what sources of guidance are used by researchers and how they are applied to their design problems.

Rationale Are design decisions supported by a rationale? A key property for understanding designs, and hence a prerequisite for re-using design knowledge, is to provide reasoning for design decisions. This theme aims to identify if and how researchers in the field argue for their design choices.

Evaluation Are design decisions supported by the results of an evaluation? Scientific practice almost always implies the experimental validation of hypotheses. However, this is not necessarily the same as providing empirical evidence that design decisions made were beneficial or valid. This theme investigates to which degree evaluative experiments are employed to support design choices.

3.1.1 Method & Body of Data

The proceedings of the annual conference on auditory display (ICAD) in 2007 at McGill University, Montreal, Canada, serve as the body of data for this study. ICAD proceedings were chosen as they report on the most recent research trends in the field as well as on systems that make use of auditory displays—i.e., they provide accounts of current research and its application. The sample size was reduced to the proceedings of one year as this study aims to qualitatively assess the practice of reporting within the community from the perspective of the above themes rather than providing a quantitative analysis of approaches. The number of papers in this sample is sufficiently large and representative to reveal issues in the current practice and support them by concrete examples.

From 82 papers (50 full papers, 32 posters[1]) published in the proceedings, 23 (11 full papers, 12 posters) were identified as describing an actual design of an auditory display. The selection criteria included papers describing an auditory display that was built in a specific application domain motivated by a real-world problem. This could include prototypes that were driven by theoretical research questions, but extended their context into an application area of auditory display.

However, the selection excludes work on low-level auditory perception, theoretical work on cognition or ecological hearing. Papers focusing exclusively on design methodologies were also excluded, because it is not the theory, but the application of auditory display design that is under investigation in this study. Also excluded were papers describing purely artistic projects. Although studying such papers would be highly interesting, themes like rationale and evaluation have little relevance in these contexts. The application domains covered by the paper selection is diverse and representative of the range of applications addressed within ICAD. Figure 3.1 provides the number of papers in the selection over application domains; all papers used for this study are listed in appendix B.

The 23 papers were analysed qualitatively according to the above themes following a grounded theory approach (e.g. Charmaz, 2006). Whenever possible and appropriate, categories were defined by what similarities emerged from the data. Underlying notions found are supplemented by quotes and due to the public availability of the source data, citations are given in full rather than anonymising the data.

It is important to note that this analysis is not assessing the quality of the work itself, but the way it was conducted and what was reported in a publication. The actual practice in

[1]Both categories, full papers and posters, are included in the proceedings of ICAD as papers with an eight-page limit.

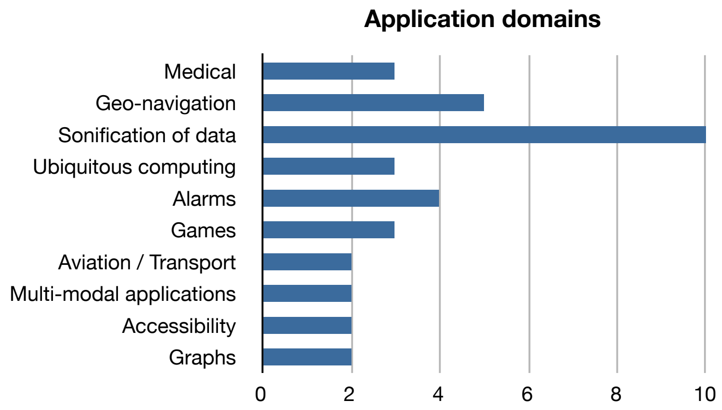


Figure 3.1: Application domains covered by number of papers in the selection for the literature study on design practice (23 papers, many falling into more than one category)

the projects might have had features that were not ptovided in the publication for practical reasons such as space constraints. However, in terms of knowledge transfer—i.e., what design knowledge others can extract from a paper to re-use in different contexts—it is not only key what the actual research has achieved, but also what was chosen to be presented.

3.1.2 Results

The following sections present the results organised along the themes stated above.

Process

Two of the 23 papers explicitly follow a structured method for designing the auditory display (Metatla et al., 2007; Murphy et al., 2007). Both methods were developed by the authors themselves and are demonstrated by applying them to concrete applications described in the papers. The remaining 21 papers do not state that they used a specific design method, but exhibit more or less clearly the phases of the design process the authors went through.

In broad terms, different styles of design processes can be distinguished: As expected in a scientific conference, many of the papers describing applications are driven by theoretical research questions. This leads to design processes in which uncharted terrain is explored and envisionment is emphasised rather than the management of constraints. Nine of the 23 papers can be classified as such. The majority of papers (14), however, are more application orientated. The difference can be illustrated by two papers from the same application domain: Baier et al. (2007) explored new techniques in sonifying EEG data based on the affordances of the data, while de Campo et al. (2007) developed real-time sonification tools for screening EEG data for doctors in a hospital. Four of these application orientated papers also exhibit a strong artistic style: notably, both papers dealing with auditory games (Liljedahl et al., 2007; Oren et al., 2007), which emphasise the craft aspect in the process, e.g., *"...the designer still has to trust her aural sensitivity and intuition, her general knowledge, experience and common sense.."* (in Liljedahl et al., 2007). And the other two make strong connections to music with Jung and Schwartz (2007) embedding awareness information in functional music and Wallis et al. (2007) using musical features in a multi-modal stroke rehabilitation system—*"...using our musical backgrounds to help us decide which variables had the greatest likelihood of achieving a certain goal."*

Looking more closely at the various phases of the process, roughly following the most fundamental design activities mentioned in 2.2, reveals more interesting aspects. Although all of the papers introduce the application domain and motivate the work by highlighting potential beneficiaries, there seems to be little sign of this contextual information feeding into the design process. In some cases, domain experts were directly involved in the projects (e.g. Brungart et al., 2007; de Campo et al., 2007; Vogt et al., 2007) or potential users were involved very early in the process (e.g. Oren et al., 2007; Stockman et al., 2007). None of the papers, however, reported on any form of user research or ethnography and it remains unclear how the rudimentary information gathered informed design decisions. Oren et al. (2007) were the only ones to briefly report that a related HCI method has been used: *"...and after a couple of focus group meetings with students we decided to make an audio game in the platform genre."* However, no further details on the impact these focus groups had on the design process have been revealed. Murphy et al. (2007) is an exception to this as it proposes a design methodology that is based on rich user-scenarios which imply a thorough understanding of the context of use.

Both the concept design phase and the implementation phase show design decisions that are not fully supported by a rationale, unless these decisions were implicitly given by the underlying research questions pursued. This aspect shall be investigated more closely in the rationale section below. The level of detail provided in the descriptions of the technical realisation of the design, however, is high in all papers. Six papers provide links to sound resources and one paper gives sample code to reproduce the sounds used (Baier et al., 2007).

All but four papers provided details on experiments that evaluate the design. In three cases, these were only first pilot tests and in a further three the outcome would only be assessed subjectively by the author. The majority of the remaining papers (seven) described qualitative and quantitative analyses of the experiments. Either one or the other (qualitative or quantitative analysis) was provided by further six papers (three each). A more detailed analysis of the evaluation phase is provided in the corresponding section of this analysis.

Guidance

The 23 papers used 17.1 references on average (9.1 standard deviation) with a maximum of 39 and a minimum of five. There was a significant difference between full papers and posters (21.3 versus 13.3, $p<0.025$, one-tailed t-test).

The most cited body of work is the "Auditory Display" book by Kramer (1994b). Eleven references were made in total to seven different chapters of the book. Brewster is the most frequently cited author with 11 citations (including one for his contribution to the book by Kramer). He was mostly referenced for his work on earcons (e.g. Brewster, 1994; McGookin and Brewster, 2006). For auditory icons and everyday listening, the papers referred to Blattner et al. (1989) (four times), various publications by Gaver (five times, e.g. Gaver, 1988, 1989) and Schaeffer (1966) (two times). Work by Herman was cited five times, mostly for specific approaches to sonification (e.g. Hermann and Ritter, 1999). Other work cited frequently include Zhao et al. (2004) (four times) for their design principles on auditory information seeking and Shneiderman (1996) (two times) for the visual counterpart. Bregman (1990) was cited twice for guidance in auditory stream formation and Gestalt principles and so was Loomis et al. (1998) for navigation systems for the visually impaired. Also two references were made to Mauney and Walker (2004) for creating soundscapes for monitoring and the NSF report published on the ICAD web-page (Kramer et al., 1997). The majority of papers (14) made references to earlier work by one of the authors.

It has to be noted that it is impossible to quantify the impact these references made on the design decisions. Many of the citations were made in the "related work" section, or for a specific quote. They could haven justified design decisions further into the paper, but coding of these links would be neither practical nor reliable in terms of assessing the guidance the references provided. The next section will look more closely at how authors chose to support their design decisions by stating a rationale explicitly.

Rationale

Reasoning for design decisions is a key aspect in making design knowledge explicit and reusable (Dix et al., 2004, p. 249). Following Kunz and Rittel (1970), the primitives of process-orientated design rationale are issues, positions and arguments. The following paragraphs, aim to identify such issues as they appear in the design processes described by the papers and highlight shortcomings in providing positions and arguments that support the decisions by the designers. Again, it has to be noted that this is not to assess the quality of these decisions, but to report on the practice of presenting them in a paper. It is difficult to judge design decisions retrospectively without knowing much more about the process than is available from the publications. However, as papers are the main means by which the community distributes design knowledge, the argument is that although design decisions might have been made very carefully, the re-usability of the design knowledge suffers from the unavailability of the rationale in a publication.

The sound synthesis used in Baier et al. (2007) is described in great detail, including code fragments, but the reasoning for the chosen algorithms is limited to *"accurate timing"* and *"subjectively a good contrast in timbre"*. Many sounds would satisfy these requirements—i.e., would represent alternative positions—and the reasons for choosing this particular sounds remain unclear. Baldwin (2007) uses a *"1000 Hz warning tone"* to compare it to speech warnings in his experiment. It is not stated what *"tone"* was used and why this particular frequency was chosen. Brazil and Fernström (2007) describe an ambient information display where they *"decided to employ natural sounds to serve as event signifiers, which have a direct mapping per event."* Although they provided the reasoning for using natural sounds over artificial tones, it is not explained why they ruled out continuous sounds and/or mappings onto sound qualities for their design. The stimulus chosen in Brungart et al. (2007) for an aviation navigation task was a male voice speaking the word "waypoint" in varying vocal effort levels. The authors refer to previous work that has shown this stimulus is effectively conveying the information needed, but there is no reasoning stated for not choosing non-speech sounds of equal affordances. The sound design in Grond (2007) was reported to be inspired by Goßmann (2005) in that both took linearised data as frequency information. While the latter used additive sound synthesis with trigonometric components, Grond (2007) used subtractive sound analysis with filtered white noise, but does not mention the rationale for this change.

The sonification design for the EEG real-time player described in de Campo et al. (2007) is admittedly hand crafted and the mapping choices were *"prototyped"*. A similar approach is stated in Liljedahl et al. (2007) and Oren et al. (2007), emphasising crafted, non-rationalised sound design. A typical form of arguing for sounds can be found in Oren et al. (2007): *"An organ sound was chosen because its 'spooky' tone might leverage a semantic link between a bottomless (dangerous) pit and the 'spooky' organ sound often associated with Halloween and funerals"*. Jung and Schwartz (2007) and Wallis et al. (2007) both used musical compositions in their designs. In an artistic context, choices for specific compositional features are hardly supported by a rationale as they are in the creative domain of the composer. In the scientific context of the above projects (peripheral event notification and stroke rehabilitation respectively), however, more elaborate reasoning for musical features would be beneficial to be able to create similar auditory displays. Wallis et al. (2007), for example, argue for their choice of background and foreground instruments, but omit why they restrict themselves to natural instruments. They go on and state *"...we worked with several [musical parameters] at once, using our musical backgrounds to help us decide which variables had the greatest likelihood of achieving a certain goal."* which demonstrates how difficult it would be to re-create such a design in a different context.

Horowitz (2007) proposes a radar-like scanning process to aurally discover objects on a map. While this is one possible interaction paradigm, alternative techniques would be possible: linear scanning, for example, or concentric waves which are not mentioned or argued against. In fact, a similar design problem with a different solution, can be found in MacVeigh and Jacobson (2007) where a sound layer is added to extend the data dimensions which can be explored in a geographical information system. The data to be sonified is extracted from a rectangular window around the pointer-device which is split into five regions to drive five sound streams. Whilst providing formulas for the mapping, the reasoning for these choices remains unclear.

TravelMan, an auditory, mobile navigation aid described in Kainulainen et al. (2007), restricts itself to speech and recorded auditory icons. Other possibilities would include abstract sounds such as earcons or synthesised auditory icons, but there is no reasoning provided why they were not considered. Metatla et al. (2007) present an auditory representation of hierarchical diagrams by using speech and non-speech. They support the navigation by abstract sounds *"so that the deeper the current list being browsed in the hierarchy, the higher in pitch the browsing sound"*. It remains unclear as to why this mapping was chosen and why they used abstract sounds over auditory icons.

The issues highlighted here demonstrate that design decisions without rationale are common in all phases of the design process, from low-level mapping choices to high-level interaction design. The list above is by no means exhaustive, but exemplary, and equally, on the other hand there are many design decisions to be found in all papers that are well supported by a rationale. For example, McGee-Lennon et al. (2007) argue for their choice of using earcons rather than auditory icons in their study: *"A related suggestion would be to replace earcons by auditory icons. Research shows however that users report auditory icons to be annoying after prolonged use"* (references removed). Equally, good reasoning is provided in Nickerson et al. (2007) for the chosen time difference for staggering concurrent sounds by referring back to Bregman (1990) and McGookin and Brewster (2003).

Evaluation

As stated above, all but four papers (82.6%) reported on an evaluation of the design presented. This ratio is in line with the informal study of Bonebright and Miner (2005) on evaluation practices in ICAD proceedings, reporting a general increase in usability and perceptual testing.

However, the aim of the evaluations presented in the papers and their methods vary substantially. In predominantly exploratory work, subjective evaluation is common as it allows for frequent and rapid iterations. Baier et al. (2007), for example, contrasts various sounds produced by different clinical data and variations of the approach presented. Although no formal evaluation was conducted, the properties of the results are discussed and provide valuable clues for designers. Grond (2007) and Vogt et al. (2007) follow similar approaches by discussing properties and features of sounds as a subjective form of evaluation.

Another group of papers describes rudimentary pilot tests with limited validity due to the small numbers of participants. Nickerson et al. (2007), MacVeigh and Jacobson (2007) and Wallis et al. (2007) report briefly on first results and promise a more thorough testing at later stages of the project. Low numbers of participants are a common problem of evaluations and prevent quantitative analysis of results. de Campo et al. (2007) states *"While we tested with the complete potential user group at our partner institution, a test group is rather small (n=4); thus we consider the tests ... more qualitative than quantitative data."*

In other cases, the nature of the project and the research questions suggest the use of qualitative methods over quantitative approaches. Brazil and Fernström (2007) argue:

> *"Combining the use of interviews and questionnaires we aim to qualitatively explore rather than empirically measure or verify the phenomenon of awareness or of lightweight interactions, as the possibility exists that these phenomenon were simply called into being by having been enquired about through post-event measures."* (Brazil and Fernström, 2007, p. 329)

A similar notion can be found in McGee-Lennon et al. (2007), they make the case that *"quantitative, experimental data needs to be supplemented by qualitative methods."*

In contrast, other papers provide a concise, experimental evaluation of the design. Brungart et al. (2007), for example, evaluates two positions—as in possible design choices—and finds evidence that highlights the importance of a proper frame of reference in 3D audio applications. Similarly, Baldwin (2007), Kainulainen et al. (2007), McCormick and Flowers (2007) and Metatla et al. (2007) investigate specific research questions experimentally.

However, a common pattern is for evaluations to show that a specific design works, but to refrain from contrasting possible design options. For example, Murphy et al. (2007) show that visually impaired users can collaboratively navigate web-sites with sighted colleagues using the auditory display designed. However, there was no condition that allowed for comparative analysis of design features. Brazil and Fernström (2007) argue for their method of designing the sounds in an ambient information display by semantic classification, but do not provide a comparison with arbitrarily chosen sounds. Liljedahl et al. (2007) show that the game Beowulf can be played by providing mostly auditory cues and that users form an inner, mental picture of the environment. Design decisions, however, were not evaluated against alternative positions.

3.1.3 Summary

23 papers from the proceedings of ICAD 2007 in Montreal, Canada, were analysed in the light of four themes: design process, guidance, rationale and evaluation. It was found that only two described following a methodological approach which was developed by the authors themselves. All papers introduced the application domain, but there is little sign of contextual information playing any role in the design process. Only one of the papers employed any user research or other HCI related methods to inform design decisions. The predominant guidance referenced is literature from within the ICAD community. However, the papers exhibit shortcomings in providing design rationale at all levels; from high-level interaction design to low-level mapping choices. Most of the papers provide information about the evaluation of the proposed design. Some evaluations, however, suffer from small numbers of experimental subjects or the lack of alternative conditions that would allow the support of design choices.

After this in-depth view on design issues in the proceedings of ICAD, the following section looks at the field from the point of view of the wider HCI community by means of a survey.

3.2 An Online Survey

Auditory display design is often approached in an "ad hoc" way which greatly limits its efficient use in interaction design (Lumsden and Brewster, 2002). It is important to understand these approaches to be able to methodologically support designers in their first choices. Hence, the aim of this survey was to reveal the rationale behind the first steps taken by designers when approaching a design problem. Subjective experiences and partly unjustified assumptions about auditory display design are the grounds on which many of the early decisions are made. This survey intends to provide data to identify some of those irrational approaches and myths and to draw a picture of auditory display design as perceived by designers outside and inside the scientific field. The target group for this survey therefore was the HCI community in the broadest sense.

The following sections show the design of the survey, the analysis of the collected data and an interpretation of the data (also see Frauenberger et al., 2007a).

3.2.1 Survey Design

To be able to reach a sufficient number of designers in the HCI community the survey was conducted via the Internet. An online survey has a number of advantages: the participants can independently fill in the survey at any time, it is available to all computers with an Internet connection, participants are fully anonymous and the collected data can conveniently be stored in a database. On the downside, it is possible for less accurate information to be elicited, there are no possibilities for an interviewer to clarify questions or to direct participants towards the topics in question. Also, the time to complete the online survey must be kept to a minimum as participants are distracted more easily. For a discussion of the potential benefits and risks associated with web-based surveys see Andrews et al. (2007). Figure 3.2 shows the start page of the online survey.

This survey was implemented using the Unit Command Climate Assessment and Survey System[2], a PHP based survey script running on the departmental server at Queen Mary,

[2]UCASS http://www.bigredspark.com/survey.html

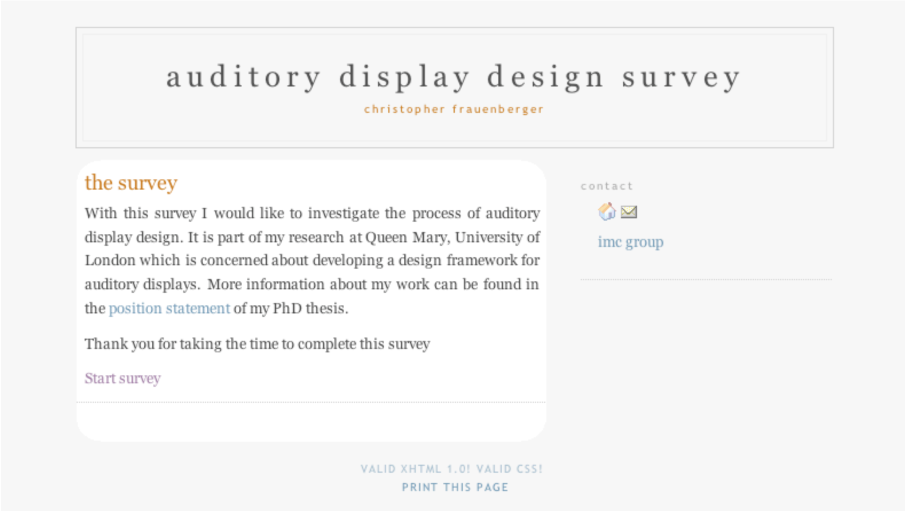


Figure 3.2: The start page for the online survey

University of London. It was advertised by requests for support in mailing-lists of the HCI community and communities related to auditory design, namely: chi-web@acm.org, chi-announcements@acm.org (both mailing-lists by ACM/SIGCHI), hcimail@napier.ac.uk (British HCI News), auditory@lists.mcgill.ca (Research in auditory perception) and icad@santafe.org (ICAD mailing list). Additionally, a call for support was published on the Usability News web page (http://www.usabilitynews.com)

Forty questions were distributed on a total of seven web-pages with a coherent design, "back" and "forward" buttons on each page, and a "finish" button on the last page. Each block of questions served to elicit information on a specific topic, the exact wording of the questions and their layout can be found in appendix C.

The first block was designed to collect basic demographical data about participants like sex, age, profession and education. The next block was concerned about audio related knowledge and the experience in interaction design. Audio related knowledge was assessed in terms of musical skills and other technical skills like creating or editing sounds. Regarding the experience in interaction design we asked for the self-assigned expertise in theoretical and practical user interface design, the modalities used and a simple classification of target platforms for their designs. If participants had prior experience with using audio in user interfaces they were asked more specifically which type of auditory cues they used and to describe one of their designs in a couple of sentences. One question specifically targeted the motivation for using audio. The subsequent block of questions was concerned with the working environment in which auditory displays are designed; e.g., which professions are called in when auditory display design is needed and to which extent these designers are integrated in the overall design of a product.

The following two blocks of questions aimed to collect information about the auditory design process itself with particular focus on the early stages. First, participants were asked about their initial steps towards any design problem that was restricted to auditory feedback. Two aspects, the creation of prototypes and the inclusion of the user were specifically highlighted and probed in this context. Second, participants were confronted with a concrete example of an audio-feedback only design problem. They were asked to describe a design for an MP3-player that has no screen, but buttons and a joystick for interaction. The task was to create an auditory display design for navigating the menu that provided access to the content including, besides music files, also a calendar, contacts and preferences. The first ideas of participants to solve this design problem were collected and participants were asked for the rationale behind their choices.

The last block of questions probed for guidance in the context of auditory display design. First, the awareness of any guidelines or design principles specifically addressed at auditory displays was assessed along with their influence on which initial approach was chosen for the MP3-player design. Subsequently, we asked for guidelines from other areas that participants had in mind and how well they adapted to the problem at hand. Finally, the form of guidance designers would like to have for auditory display design was asked for and participants could provide any other thoughts or feedback on the topic.

Thirteen questions were designed as free-form text fields which provoked very different responses. It provided participants with the most flexible way of giving answers, but also left more room for misinterpretation of the questions and of the data which made the analysis of the data a serious challenge.

3.2.2 Results

A total of 86 participants completed the survey, which makes it the largest investigation of this sort in the context of auditory display. In this section we present the analysis of the responses using quantitative and qualitative methods.

Quantitative Analysis

The focus of this section lies on data from the survey that could be quantified. For free form text answers a quantitative text analysis was performed assigning tags to answers for occurrences of keywords or their implicit mentioning. It proved to be practical not to define the keywords prior to the coding, but have multiple iterations with keywords emerging from within the data.

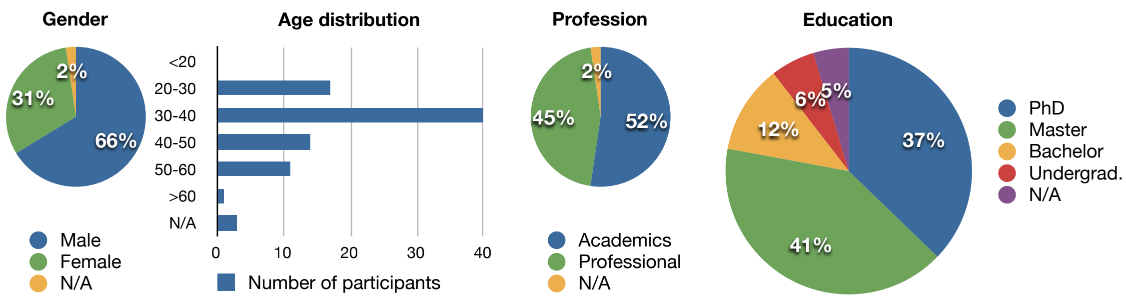


Figure 3.3: The demographics of participants in the survey.

Almost one third of the participants were female and almost half of all participants were between 30 and 40 years old. The professional background was balanced between professional HCI designers and academics. The level of education was high as could be expected. Over 80% held either a Masters or a PhD as their highest degree with many of the former group being PhD students. Figure 3.3 summarises the numbers. Less than two thirds played a musical instrument (59.52%) amongst which the piano was mentioned most often followed by the guitar. Participants assessed their level of of playing mostly as average, 8% were experts and 16% beginners. About two thirds said they can read sheet music (60%). Asked to rate their technical experience with audio (e.g., creating or editing sounds on the computer), the answers were distributed very evenly between 1 (lowest) and 5 (highest) with 2.84 on average ($\sigma = 1.35$). As expected the theoretical and practical expertise in designing user interfaces was high. On the same scale as above the average level for practical expertise was 3.94 ($\sigma = 1.03$) and 4.02 ($\sigma = 1.14$) for theoretical expertise respectively. In both cases the lowest level was by far the smallest group (2.38% and 4.76%). Almost all (97.62%) used the visual interaction channel in their designs, but also 71.43% the participants have used the auditory modality. Also, over a quarter mentioned tactile interaction (26.19%) and one participant used the olfactory modality in a design (1.2%). Most designers developed for the desktop (83.13%) and the web (75.90%). Slightly less than half of all participants also developed designs in a mobile context (44.58%). Figure 3.4 provides an overview.

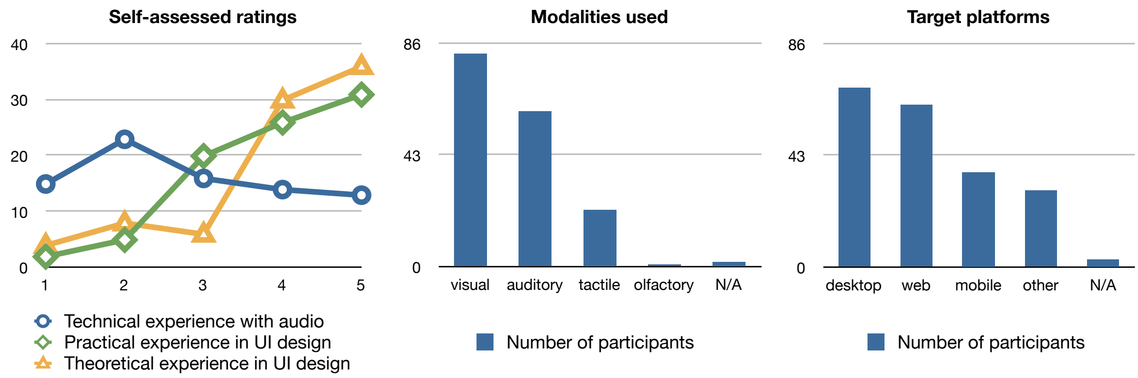


Figure 3.4: Self-assessed ratings, modalities used and target platforms across all participants.

The majority of participants who used audio (60) in their user interfaces used audio in less than 20% of their designs, almost a third (28.33%) in less than 10%. However, also 14.58% of those designers said they design exclusively in the auditory domain. User interfaces with audio were also mostly developed for the desktop (64.41%), but this means almost 20% less than in comparison to the overall numbers. The biggest drop, however, was observed for designs in the context of the web. Only 33.90% of the designs with audio were targeted to a web-context in comparison to 75.9% when including all participants. The second most answers were given for "other" contexts (40.68%), indicating that many of the designs are tailored towards a very specific context. Figure 3.5 shows these differences.

When asked to describe one specific application of audio briefly, a "user interface" was

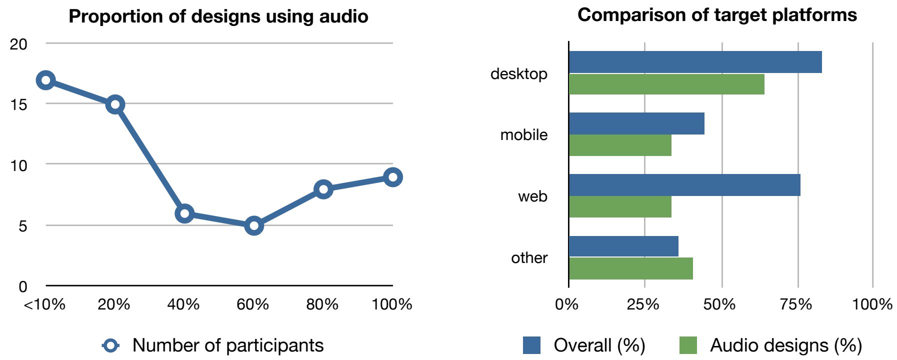


Figure 3.5: The proportion of designs with audio and a comparison of target platforms.

mentioned in every third description. Other application domains included the perceptualisation of data, the presentation of multi-media content and web-content. Also alarms, control room and monitoring type of applications were mentioned. Almost a quarter of the designs described incorporated some sort of "augmented reality". The most applications were targeted at improving accessibility, followed by educational designs, art projects and research projects. Other domains were finance, medical applications and games. Within the free-form descriptions participants mentioned the use of speech most followed by speech recognition systems, while auditory icons and earcons were mentioned only three times. Figure 3.6 provides the numbers for each classifier. Two-thirds of the participants said that

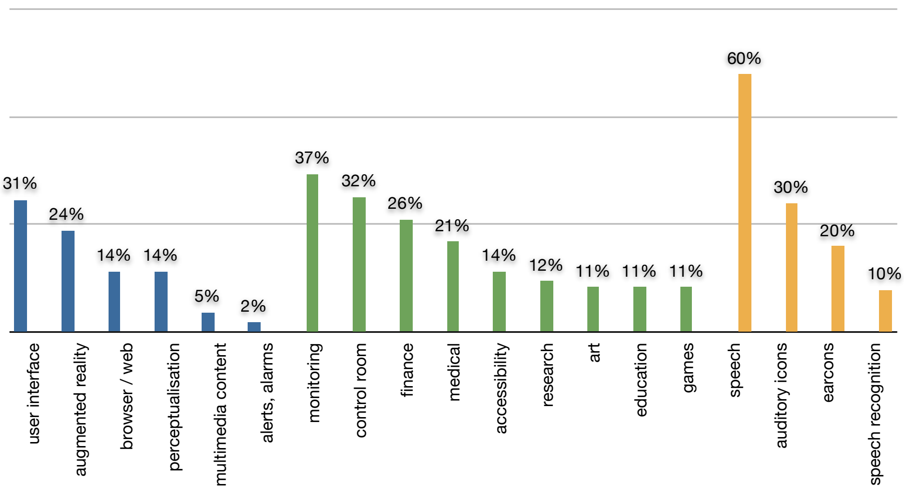


Figure 3.6: Percentages of classifications of previous audio designs described by the participants (multiple classifications possible).

they would use audio to complement other modalities while only 29.51% said they would mostly use it as an alternative interaction channel. Asked for which kind of audio they would use in their designs, most included “abstract sounds” (72.41%) followed by “speech” (48.28%) and “natural everyday sounds” (32.76%); 15.52% said they would also use “other” auditory cues.

Over a quarter of the participants who answered the question about their main motivation for using audio was to accommodate a specific context of use including specific needs of the user (25.58%), 18.6% explicitly mentioned accessibility. Another important motivation was to provide a naturalistic experience (23.36%) and to match the type of content to be presented with the appropriate human sense (16.28%). Also, 16.28% said that their main motivation is to reinforce information that is also available in other modalities and 11.63% mentioned the increase of bandwidth for conveying information. Some also stated curiosity as a motivation to use audio (three out of 43 or 6.98%). Figure 3.7 provides a summary of the above numbers.

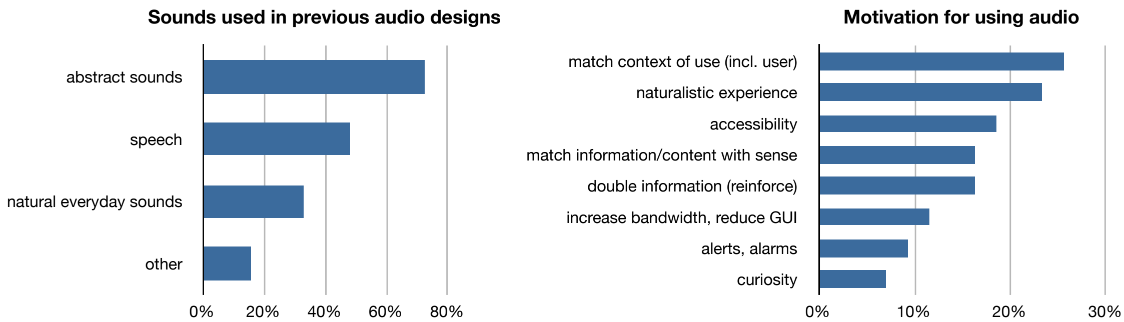


Figure 3.7: The types of sounds chosen in previous audio designs and the main motivation for participants to use audio.

Slightly less than one third of the participants had worked in design teams in which other people were in charge of designing sound for the interface (31.40%). Within such design teams the integration of these colleagues into the overall design was assessed very differently. Although 32.26% stated that they were integrated to a very great extent, 9.86% also said they were not integrated at all. The three levels in between have been receiving the same number of answers (6 out of 31 or 19.35%). Asked for the professions of the people who designed audio in these teams, all categories were almost checked equally often. “HCI experts" and "artists" received the most answers (12 out of 30 or 40%) followed by "sound designer", "sound engineer" (36.67% and 33.33%) and "others" (30%).

With the subsequent sequence of questions participants were asked about their approach to a design in which they were restricted to auditory feedback. Very broadly asked for the first things they would do over half of the participants stressed the importance of a user centred design approach (55.88%). Around one third said they would investigate the context of use (33.82%) and for 19.12% a task analysis was amongst the first things. Fewer than one out of ten explicitly mentioned to conduct a research literature review or seek for guidance in publications (8.82%). Other approaches mentioned were use cases, design space specification and (rapid) prototyping. For some 4.41% commercial implications were also important to be considered from the start. Interestingly, only 23.54% mentioned sound in any way and 5.88% were concerned about sound mappings at this early stage. Also, four in 68 questioned the requirement for audio only (e.g., P24: *"What made this a requirement when displays are easily available in most contexts"*). Almost half of the participants said that the user requirements are a main factor to determine the sound design (47.95%) followed by the context of use (35.62%) and the purpose of the application (32.88%). Other factors mentioned were the properties of the content to be communicated, any technical constraints, the task requirements and usability (all between 10% and 17%). Only 4.11% mentioned æsthetics as a main factor for the sound design. Figure 3.8 highlights the key answers.

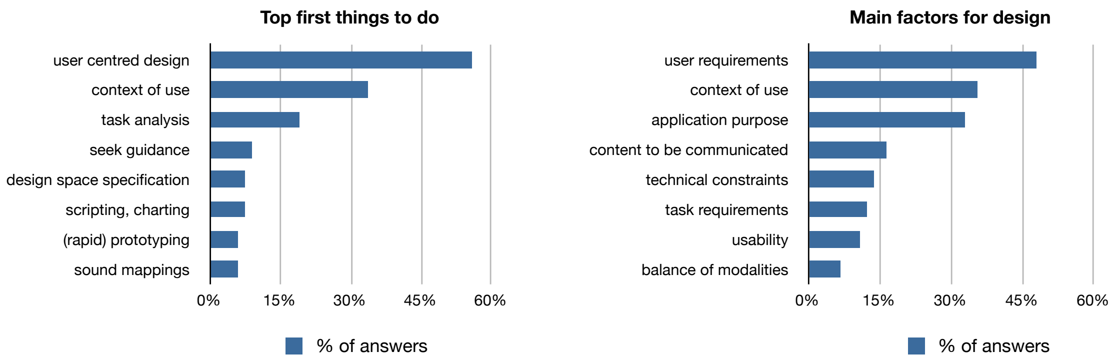


Figure 3.8: Approaches and major factors in the development of an audio only design.

Asked for techniques to create initial prototypes 30.19% stated recording, 22.64% synthesis software and 20.75% the use of sound editing or sound mixing software. Only 9.43% mentioned sound libraries in this context; one mentioned Foley [3]. Interestingly, a fifth of the respondents also mentioned work on paper like drawing or writing (20.75%, e.g., P51: *"Initially in paper so that users and designer can imagine what is the real scenario"*). For 18.87% a "Wizard of Oz"[4] experiment would be their method of choice. Web designers naturally tended to use sound embedded in HTML markup and Flash (11.32% and 9.43%). Four out of 53 (or 7.55%) said they had no idea how they would create a prototype at all (e.g., P10: *"Not really any idea, just include the sound in the prototype?"*). On the question of how to include the user in the design process two-thirds (65.28%) mentioned user/usability testing or more specifically listening/hearing tests (15.28%). One third mentioned some form of participatory design (31.94%) and 12.50% stated the users' involvement in specifying the requirements. Methodologically, (contextual) interviews were mentioned (15.28%), besides observation, quizzes, focus groups, wizard of oz experiments and cognitive task analysis. Figure 3.8 summarises the top answers.

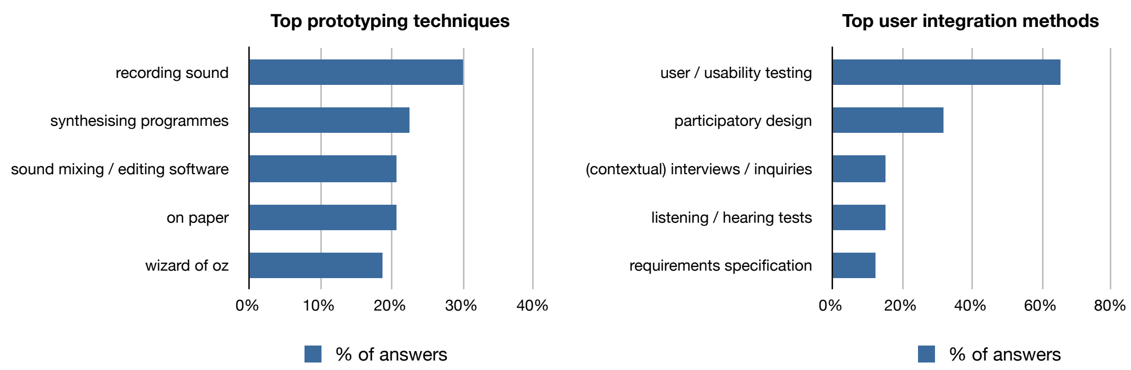


Figure 3.9: The types of sounds chosen in previous audio designs and the main motivation for participants to use audio.

Given the task to think about the design of an MP3-player with auditory feedback only, 63 participants provided quite extensive descriptions of their initial ideas; on average over 62 words per answer. The most striking fact is that over half of all solutions incorporated speech (55.56%) while only 26.98% mentioned non-speech sounds. Also, 11% had speech

[3]Named after Jack Foley, Foley artists create sound effects for movies as for example footsteps or horses' hooves.

[4]A Wizard of Oz experiment is a research experiment in which subjects interact with a computer system that subjects believe to be autonomous, but which is actually being operated or partially operated by an unseen human being.

recognition[5]. With non-speech sounds auditory icons were mentioned most often (four times in 63 answers) followed by earcons (three times) and spearcons (once). The use of spatial sound was suggested three times. A considerable proportion of answers were mainly concerned about the button layout (22.22%); e.g., which button would trigger which events. Two solutions incorporated gesture input and three participants suggested to leave out the non-musical features that were requested in the task (e.g., P71: *"I would kill the calendar and contacts"*). Two participants said they do not know MP3-players and gave no descriptions (P62: *"Don't know - not familiar with MP3-players - I must be old!"*). Probing for the reasoning behind the design decisions most participants stated that it was the first that came to their mind (12 out of 42 or 28.57%, e.g., P13: *"Just seemed the obvious one..."*). Slightly less (26.19%) stated usability related properties like speed, efficiency, simplicity, erroneousness, learn-ability or intuitiveness. 11.9% said the decisions are based on their experience. Some participants said they used speech for accuracy (11.9%) while reasoning for non-speech sound varied from efficiency for additional feedback to the learning-curve involved. Four out of 42 mentioned that their solution was was a natural "mapping". Only four mentioned that they were exploiting standards, one even said *"I can visualise it..."* (P11). Figure 3.10 compares the most important features and reasons for implementing them.

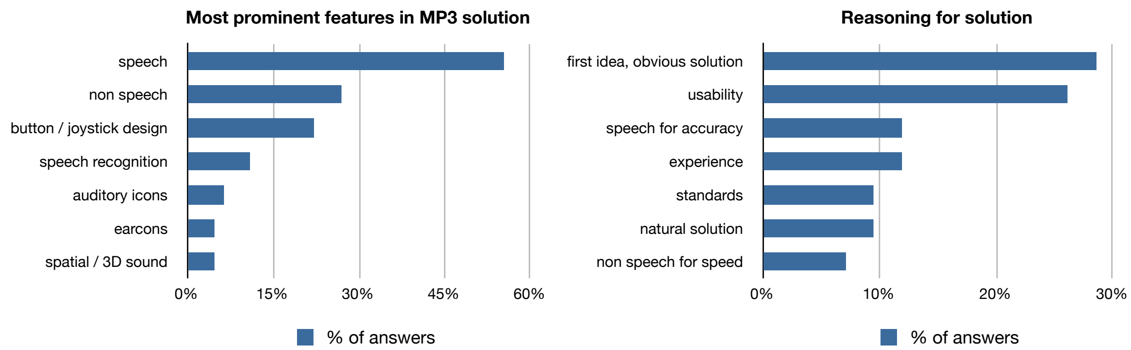


Figure 3.10: The features most often implemented in the solutions and the reasoning provided by participants.

Slightly more than half of all participants provided some answer to the question about techniques, programming languages and toolkits to realise audio. Eleven of these respon-

[5]Five of the seven solutions that featured speech-recognition also proposed to use speech output which is in line with the findings in section 5.4 that showed these two features correlating.

dents stated they would not know any related techniques. In the remaining 36 answers, 32 different toolkits and languages were mentioned of which the following were the most frequently cited: C and C++ (27.78%), Pure Data (25%), CSound (25%), SuperCollider (22.22%), Max/MSP and ChucK (19.44% each). Also 13.89% claimed they would know a lot or most of the available tools. Over half of the participants said they were aware of some guidelines or principles for the design of auditory displays (53.16%). In the group of participants who have not used audio in any of their designs this drops to 26.92%. On the other hand only 58.33% who used audio claimed then to be aware of guidelines[6]. When asked to provide the source of these guidelines or principles only just over a half of those who claimed to be aware of some did so (52.38%). Twenty different sources were mentioned of which the most popular were Stephen Brewster's guidelines for designing earcons (40.91%, e.g. Brewster, 1994), Stephen Barrass's auditory design space (31.82%, e.g. Barrass, 1998), Gregory Kramer's book on auditory displays (13.64%, Kramer, 1994a) and Bill Gaver's and Meera Blattner's work on auditory icons and earcons (9.09% each, Blattner et al., 1989; Gaver, 1994). Two out of 22 claimed to know a lot without specifying which. Again there is a difference between participants who did use audio in their design and who did not: only 3.85% of those who have not used audio mentioned guidelines while at least a third of those who had some prior experience with audio did provide some (35%). Half of the participants who were aware of some guidelines said they were influenced by them when thinking about the design of the MP3-player example (54.76%) while almost three-quarters said they used them in other designs of them (73.81%). About half of the participants who provided a solution for the MP3-player said they had other guidelines or principles, not specifically aimed at auditory display, in mind when designing (51.85%). Generic guidelines for user interfaces (six times), usability (five times), user centred design (three times) and accessibility (twice in 20 answers) were mentioned most often in this context. The majority said they were influenced to a great extent by those guidelines (58.33% either great or very great extent) while 25% said only to a moderate extent, 16.67% to a slight extent and none said not at all.

In general most participants believed that audio can improve human-computer interac-

[6]The discrepancy in the overall sum of percentages in this context was caused by the fact that some participants did not answer both questions.

tion. Roughly a third said to a very great extent (32.93%), 25.61% to a great extent, 35.37% to a moderate extent and only 4.88% to a slight extent. Only one single participant said not at all. Interestingly, there is only a slight shift between the participants who used audio and those who did not regarding this question: while 63.33% from the former group said audio can improve HCI to a great or very great extent, 53.85% believed this in the later group. The question on which guidance would participants like to be available for auditory displays provoked a great variety of answers which could not as easily categorised. This and other particular interesting answers are subject to further analysis by qualitative text analysis in the subsequent section. Figure 3.11 provides an overview of differences between participants who used audio and those who did not.

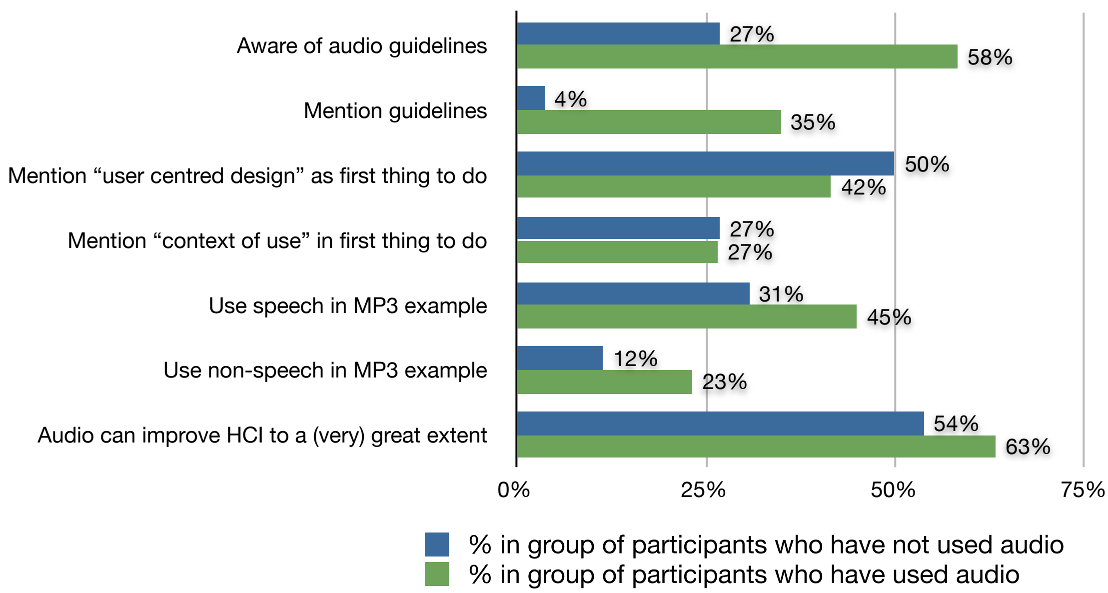


Figure 3.11: The features most often implemented in the solutions and the reasoning provided by participants.

Qualitative Analysis and Interpretation

The approach chosen to analyse the data from a qualitative perspective is based on grounded theory, often used in sociological studies of written text (e.g. Charmaz, 2006). Using a software tool to mark-up passages in texts we identified themes that were inherently conveyed. The TAMS Analyzer[7] allowed us to scan the responses conveniently and mark up phrases of significance with different tags and also provided powerful search and sorting features to analyse aspects in the data. As in our quantitative analysis, we did not define the tags in advance, but let them emerge as we worked on the texts. The method was to read the answers with each research question in mind and find themes that would either support or counter assumptions.

Scepticism

Many participants stated scepticism about the use of audio in human-computer interaction and doubted its efficiency. This was expressed in many different ways, some simply disbelieved in the capabilities of audio without providing any reason - P19: *"I'm not confident that any audio solution would make the system really usable."* Others explicitly listed issues with the auditory interaction channel, mostly regarding privacy and annoyance - P32: *"Verbal is less private than visual and interacts more with people's surroundings."* and P24: *"Have to be careful – could be VERY annoying."*. Another participant stated *"Due to its intrusive nature, I see audio solutions as more valuable for expert users than novices."* (P15), which is interesting as it positions audio as a specialised interaction mode that demands high efforts from users and requires high skill. Furthermore it implies that audio cues are less intuitive which research into ecological hearing is suggesting otherwise (e.g., Gaver, 1993). Another issue mentioned was cognitive load - P19: *"The burden on the user's memory has seemed to me to be a significant barrier to ease of use."*

Myths

In many cases participants were occupied with prejudices and based them on rather unjustified myths - P70: *"Audio output is a very low-bandwidth way to communicate."* or P36: *"Untrained people don't like 'musical interfaces'."* The latter statement again shows the belief that audio interfaces require some special skill to be usable or even enjoyable. Some participants were concerned about synthesised audio - P43: *"A lot of synthesised audio still has a rather low quality."* - and stressed the importance to create audio that mimics reality - P84: *"They need to be realistic and match the real world as much as possible."* Another interesting point of view was taken by three participants who all stated that *"...input and*

[7] Text Analysis Markup System Analyzer http://tamsys.sourceforge.net

output modality should be the same." (P24) so if audio is used for feedback, the logical counterpart is speech recognition. Even the most common paradigm for computing with a visual screen and a tactile keyboard contradicts this statement, but results presented in chapter 5 show that this is a commonly held view as far as the auditory modality is concerned.

Emotions

Also the way participants expressed their scepticism was interesting to analyse and ranged from cool and focused statements to more emotional answers in which one could discover the annoyed user rather than the designer. Statements like *"I don't want applications introducing auditory 'noise' into my environment. I want CONTROL over audible output."* (P63), *"I can't stand it when my desktop machine makes sound."* (P70) and *"Off by default."* (P22) show that some participants had their share of experience with badly designed audio in user interfaces. But also as designers there is quite some emotional resistance against an audio only interface and indicates some negative prior experience. Asked for the MP3-player design P16 answered simply: *"Put a screen on it!"* or as P30 put it: *"...no normal sighted users are expected to accept this player!"* Participants also questioned the task itself - P52: *"But I would seriously question why the client had decided not to have a screen"* and went on *"Perhaps show them some examples of how unusable this can be."* implying doubts about the success of such a design. Or as P62 expressed his resignation: *"Audio only interfaces have so many issues."*

Contribution

Besides all this negative talk, participants also expressed their belief in auditory display design as a valuable contribution to human-computer interaction. Again, the argument and the way they expressed themselves varied from stating features to simply *"I like sounds."* (P35). One participant said *"As compared to other forms of continuous feedback in artefacts, audio is inexpensive!"* (P86) and another highlighted *"User security encouraged us to prefer auditory interfaces over graphic ones for mobile apps."* (P27). But there were no other participants who outlined more advantageous properties of the auditory channel. Some made more general statements like *"It's a key sense that's often overlooked."* (P45) or *"A well-designed audio component greatly aides HCI."* (P66). There was no direct question that probed advantages or disadvantages of using audio, but it is notable that the scepticism outweighed the positive statements and more arguments against audio were provided than in favour of it.

Integration

Auditory display design is clearly perceived as part of HCI in general and therefore ought to share many high-level concepts. Almost every participant made references to generic HCI methods that are already established in HCI during the early stages of an auditory design. One stated *"I don't see that there's a difference here compared to ordinary design projects."* (P73) or *"Basic design is the same regardless of the specific UI."* (P23). Looking at the numbers in the quantitative text analysis above confirms this: task analysis, participatory design and context of use are all well known concepts in the field of human-computer interaction. Participants also suggest auditory display design being tightly integrated into a holistic, multi-modal approach - P69: *"A balanced design, using multiple senses and mental processes, allows for a wide range of effective and efficient interaction solutions."* The need for making the case for yet other modes in the future seems inevitable though - *"(Audio) It's 50% of your experience (if one counts visual as the other 50%)."* (P50).

Terminology

Scientific communities define themselves, and often seek to distinguish themselves from other fields, through the development of a certain terminology. Sometimes, this is a designed and intentional process, sometimes key terms are coined by mere accident. Some participants of this survey who clearly were outside the scientific community of auditory display commented, without being asked for it, on its very name: *"Ha, auditory 'displays', interesting metaphor."* (P63) or *"'Auditory display' sounds like nonsense to me, not a term I have heard before, nor one that I would use."* (P70). Apparently, the combination of the adjective 'auditory' with the term 'display' that is clearly associated with something visual has the potential to be perceived as contradiction. 'Auditory interface' might not as easily cause such contradiction, but signifies a different area as P16 notes: *"Be careful of how you use it... 'Auditory display' - you have auditory input and/or a display."* The term 'auditory display' might be controversial, but after the existence of a scientific community for over a decade the only way to deal with it seems to increase public awareness.

First Ideas

Asked to provide their initial ideas to design an auditory display for an MP3-player the majority of participants described their ideas quite extensively (see above). Notably, however, one participant expressed discomfort with the question - *"The expectation that designers should provide an instant solution is one of the reasons so many auditory interface are badly designed."* and goes on *"I would base my design on a structured analysis rather than the first idea."* (P37). This position might be valid for many design disciplines, but given the specific nature of auditory display design with its multi-disciplinary roots and its status in comparison with the predominant visual display design this might be particularly true.

Audio = Speech?

Others, who provided their first ideas, gave surprisingly conservative accounts, despite the explicit encouragement to think out of the box and not to bother much about technical feasibility. A possible explanation is that many participants associated with auditory displays only the use of speech - *"The display can be easily replaced with reading aloud the text that is supposed to be displayed."* (P18). This statement is also an example of how auditory display design is often driven by existing visual solutions. Another reason might be the unawareness of what is technically possible with audio and sound. This is supported by the fact that more innovative technologies like spatial audio were mentioned very little. Cutting edge technologies like virtual audio environments including real-time audio content synthesis for example were never mentioned. A related issue with auditory displays seems to be the problem of creating prototypes during the design process. Statements like *"Ooh, no idea... doing the equivalent of paper design ... but with sound."* (P12) show that a well known and easily accessible (as paper is without a doubt) way of creating prototypes is missing in this design discipline.

Guidance

Asked for forms of guidance participants would like to see for auditory display design they provided a diversity of suggestions. Tested examples and approved standards were amongst the ones mentioned most often - *"Just a set of examples (concise) that show what has been done before."* (P80) or *"Standard interactive controls."* (P58). A main driving force behind these suggestions was expressed by P78: *"Approved standard of audio use that could be* *applied without extensive user testing and research."* It is the reduction of the effort for researching all the relevant background in various scientific fields and for conducting time consuming evaluations including iterative re-design stages. Another aspect connected to the term 'standard' is provided by P55: *"Successful strategies of tested / accepted designs."* Standards are not only tested solutions, but also accepted by users. Another related form of guidance incorporating examples are patterns which were mentioned twice - *"Design patterns are useful."* (P86). One participant addressed the problem of the accessibility of examples - P59: *"Given an interface problem, a similarity-rated list of inspiring successful interfaces for related situations."*

Context

Many participants stressed the importance of the context of use when designing auditory displays - P67: *"The appropriateness of using audio is very much dependent on the context of use."* and P61: *"Specific guidelines for different situations."* And P59 argues for using the context of use as an organising principle for examples: *"A well structured map of use cases / tasks / constraints & real-world examples."*

Examples

A more critical point of view about the value of examples is expressed by P37: *"Auditory displays people have fewer examples to build upon."* Thereby, the participant addresses the fact that auditory display design is, compared to other design disciplines, a very young field and goes on to say *"Until we have developed many successful auditory displays I believe we need to use design methods heavily based in theories of attention to develop new displays."* This proposes to develop guidance for auditory display design from theories in related fields (psychology in this case). It is, however, doubtful whether this approach can be successful when considering more relevant theories from other fields like information design or æsthetics. A unified theory that combines this manifold of theories is beyond reach.

An interesting statement in this context was made by P12: *"I'm not 100% convinced that guidance has helped us in other areas."* and he goes on *"Experience, and working with target audiences as much as possible, provides a much greater chance to do something that actually works."* He stresses the value of experience in the design process and is supported by other participants - *"Most guidelines come from own experience"* (P59). In this context it is the question of whether experience can be made available in any form of guidance.

Guiding whom?

Two participants were concerned about the particularities of the target group of guidance, the designers themselves - P1: *"...detailed and high level versions of the methodology to fit different levels of user expertise."* and P13: *"A more clear body of knowledge for beginning designers."* In an attempt to explain further the differences between levels of guidance for different levels of expertise, the participant also makes a remarkable statement about experienced designers: *"...but free the designer to use experience and creativity."* So while beginners may rely on more specific guidelines to create auditory displays an expert in the field appreciates the freedom in design choices to accommodate creativity and experience.

Attitudes

Finally, this survey also provoked expressions of all kinds of attitudes. This ranged from *"Stop asking me silly questions, PLEASE"* (P68 who nevertheless continued to fill out the questionnaire) to *"You have successfully made me think more innovatively this morning :)"* (P17). Either way, the 86 participants of this survey contributed greatly to a more detailed picture about the auditory design process, the needs of designers and the specific design problems when dealing with auditory displays. In the subsequent section the insights gained from above will be used to derive requirements for a methodological framework for auditory display design.

3.2.3 Summary

The results of this survey provide a number of interesting insights into the current practice of auditory display design and how the field is perceived by the HCI community at large. Although many of the participants have used audio in some of their designs (roughly two thirds), most of them reported to use it only in few of their designs with a strong preference for speech output. This reflects a general notion in which audio in HCI is reduced to speech and alarms with designers being unaware of alternative options in the design space and the potential benefits of using non-speech sound. The results also show that the design process is still largely attempted in an "ad-hoc", crafted way as illustrated by the vague reasoning for design decisions in the MP3-player example.

The context of use emerges as a central aspect in the design of auditory displays. Satisfying the requirements that arise from a specific context of use was given as the most important motivation to use audio. The context of use was ranked second for decisive factors in auditory display design and was also very prominent in answers regarding approaches. Participants also expressed the need for contextual solutions as part of a shared body of design knowledge. In contrast to these indicators the majority of guidance for auditory display design is focused on the physical mapping of information onto sound properties (see section 2.2.3). The concepts introduced in the following chapter are intended to address this issue and close the gap between contextual design and physical mapping.

The qualitative analysis of the responses revealed strong notions of scepticism, prejudices and emotions. Although participants generally expressed that they believed that audio could play a more important role in designing efficient human-computer interaction, the underlying tone in many of the responses showed surprisingly strong resentments. Annoyance and privacy issues were amongst the most commonly stated rational reasons while other views were more irrational like *"Untrained people don't like 'musical interfaces' "*. The number and intensity of emotional responses shows that audio in interaction design is a delicate matter and that current practices seem to be unsatisfactory and inapt to convince HCI practitioners to use audio in their designs.

3.3 Conclusion

This chapter analysed the current practice in auditory display design from two different perspectives: first from within by means of a literature study on recent proceedings of the ICAD conference, and second through an online survey amongst HCI academics and practitioners.

The results show that the design process for auditory display is largely unstructured and the way it is presented through papers provides limited support to re-use the design knowledge created. The common lack of consistent reasoning for design decisions make the design process appear mysterious to designers outside the field. Auditory display design therefore suffers from being perceived solely as a craft—at best—or being generally rejected. A synopsis of the two parts in this chapter reveals a significant gap between methods and approaches. While the proceedings provide a high level of detail in perceptual and technical issues, there is little sign of HCI methodology such as user research, ethnography or high-level prototyping techniques (e.g., storyboards, Wizard of Oz). At the other end of the spectrum, practitioners approach auditory design problems with familiar HCI methods causing the auditory display being designed by visual thinking and paradigms (e.g., *"just speak it out"*).

The generalisability of design knowledge also seems to be another significant problem. Existing guidance or methodologies are often tied to a specific context and adapting them to new problems remains difficult. Flowers et al. (2005) state in their comment on a previous ICAD paper: *"...it may prove impractical to establish design guidelines for auditory displays unless such guidelines are restricted to a quite narrow range of applications."* But this work argues that, unless we have succeeded in formulating more generic and high-level guidance for designing auditory display, there is little chance to bridge the gap between experts in auditory displays and human-technology interaction designers in general.

In summary, this chapter aims to make the case for demystifying the design process for auditory display design and to demonstrate the need to facilitate efficient knowledge transfer to establish the auditory channel as adequate means of interaction design.

Chapter 4

paco – a Methodological Design Framework

This chapter introduces **paco** – a methodological design framework that aims to facilitate the capture and transfer of design knowledge in the field of auditory display design. Although **paco**, short for **pa**ttern design in the **co**ntext space, was developed for the auditory domain, the underlying concepts are generic and applicable to any other designing discipline.

The first section of this chapter will derive a set of requirements for the development of **paco** stemming from the work presented in the previous chapters. Subsequently, section 4.2 introduces the approach chosen to meet these requirements in the methodological design framework. The context space, a core concept throughout the framework is introduced in section 4.3. Having these foundations in place, section 4.4 describes in detail the methods provided by **paco** before section 4.5 illustrates their usage in a case study. Finally, this chapter is concluded with a discussion on the benefits of **paco**.

4.1 Requirements

Section 2.2 discussed the current state of guidelines and principles for auditory displays. In practice, however, we see this guidance having only minor impact. The design process is largely seen as a craft informed by experience (see chapter 3 or Lumsden and Brewster (2001) and Arons and Mynatt (1994)). This section aims to derive specific requirements from these observations to develop a methodological framework that improves the knowledge transfer in the domain of auditory display design.

Five major categories of requirements can be identified as shown in table 4.1. Firstly, for auditory displays to play a bigger role in HCI, a design framework needs to fit into the 'bigger picture' of current practices in interaction design. It has to tie in with established HCI methods and provide the potential to bridge different modalities. Awareness of the design space[1] also appears to be an issue. As perceived by many HCI designers, the design space for auditory displays consists almost exclusively of speech, not considering non-speech sounds as a powerful means to convey information. A design framework must therefore make the full range of options explicit and assist designers to conceptualise the design space (also compare to Benyon et al., 2005, p. 247, on envisionment in design).

A key feature of the design framework is its ability to capture and transfer design knowledge effectively. Crucial to this process is how well the design rationale of previous solutions is conveyed to support informed design decisions to solve future design problems.

Audio is widely regarded as less efficient than vision and potentially annoying. Such prejudices are often founded in the disappointing, personal experiences that designers have had with the current quality of sounds in user interfaces. To address these concerns effectively, a design framework has to be able to communicate æsthetic aspects and values of good practice (see also Leplâtre and McGregor, 2004). Compelling, well designed examples are the best way to overcome prejudices and disbelief.

Simplicity, experience & creativity covers a wide range of requirements. Myers et al. (2000) highlight the importance of a low threshold and high ceiling[2] for successful software tools in user interface design. Although not strictly a software tool, these themes are adopted and define 'easy access' and 'high potential' as requirements for this framework. The survey presented in section 3.2 showed how high designers value experience, but also dislike rigid templates in a field that demands creativity. The design framework has to enable designers

[1] In this context, *design space* reflects the range of possible solutions to interaction design problems.

[2] *"The threshold is how difficult it is to learn how to use the system, and the ceiling is how much can be done using the system."* (Myers et al., 2000, p. 6)

to capture and re-use experience without restricting creativity.

Auditory display design is a highly multi-disciplinary endeavour. Efficient collaboration of experts from fields as diverse as computing, acoustics, psychology, and musical arts is key to successful auditory design. Interdisciplinary collaboration can be supported by developing common languages, sharing knowledge resources and design tools that allow designers to express their ideas and visions.

> *"Tools that support articulation of creative ideas and allow for better exchange between different disciplines can eliminate some of the barriers in interdisciplinary collaboration."* (Mamykina et al., 2002)

In the auditory domain, simple visual sketches are less suitable to express or exchange ideas. A fact also observed in Science by Ear[3] (de Campo et al., 2006), where humming was the most common way of exchanging ideas about sounds amongst an interdisciplinary team working on sonification tasks. A design framework for auditory displays has to recognise these difficulties and enable designers to describe and transfer auditory solutions effectively. Table 4.1 summarises the requirements.

Themes	Requirements
Bigger Picture	Blend in with established methods in HCI. Extendable for multi-modal designs. Conceptualising the design space.
Opinion	Appealing to overcome prejudices and common disbelief in audio. Incorporate æsthetics.
Transfer	Effectively capture design rational. Make it easy to apply design knowledge to different problems.
Simplicity, Experience & Creativity	Easy access and high potential (low threshold, high ceiling). Support experts to capture their experience. Allow designers to exercise their creativity rather than being restricted by templates.
Collaboration & Tools	Support for interdisciplinary collaboration. Design tools for expressing ideas and visions

Table 4.1: Requirements for the methodological framework **paco**

[3]A design workshop held as part of the SonEnvir project http://sonenvir.at

4.2 Approach

The design framework proposed is built around the concept of design patterns. The following paragraphs argue for this choice and highlight how design patterns satisfy the requirements specified above:

Bigger picture Design patterns have already been employed successfully in software engineering (e.g. Gamma et al., 1994) and in the domain of human-computer interaction (e.g. Tidwell, 2005). The number of non-computer related disciplines they have been applied to prove the flexibility of the concept (e.g. Alexander et al., 1977; Fincher and Utting, 2002). The possible range of levels of abstraction allows solutions in interaction design to be described close to the implementation or highly abstract and mode-independent (Frauenberger et al., 2004). Therefore, design patterns are suitable to span across interaction modalities and application domains.

Pattern languages (i.e., patterns linked through appropriate organising principles, see section 2.4) also possess generative power—just as generative grammars (Alexander, 1979, p. 187). This suggests that pattern languages are able to assist designers in conceptualising the design space. A similar argument is made by Beck and Johnson (1994) by promoting patterns to build 'architectures'—*"the way the parts work together to make the whole."* (see also Dearden and Finlay, 2006, p. 21).

Transfer The concept of design patterns was developed from the beginning with the aim of capturing and re-using design knowledge (Alexander, 1979). Their potential to inform the design process has been shown (e.g. Chung et al., 2004) and they promote the explicit capture of design rationale after the fact (see also Beck and Johnson, 1994)

Opinion shaping Design patterns are grounded in implementations, emphasise examples and embed good practice and values (Fincher and Utting, 2002) and consequently, forms of æsthetics. Compelling examples showcasing the efficient application of audio in interaction design can contribute to overcome the prejudice about auditory display. As Benyon et al. (2005) states: *"Very often it is only when people see some sort of concrete representation ... and how it will fit (or not fit) with their lives that they are able to comment meaningfully."*

Simplicity, Experience & Creativity The textual format of patterns, combined with concrete examples, provides a low entry barrier which enables designers new to the field to get started quickly. At the same time, well written design patterns extract the core of solutions, explaining the 'why & how' rather than a particular instantiated solution. This leaves the designers great freedom to incorporate experience and exercise their creativity (see also Thomas et al., 2002). *"A pattern language gives each person who uses it the power to create an infinite number of new and unique buildings."* (Alexander, 1979, p. xi).

Collaboration & Tools One of the key concepts in Alexander's patterns was the inclusion of all stake-holders in the process of design (Alexander, 1979, p. 42). This makes patterns particularly useful as a lingua franca between disciplines (Borchers, 2000a) or for including non-experts in the design process, e.g., in participatory design (Finlay et al., 2002). To support the design process by software tools is more difficult with patterns than with more formalised concepts such as model-based user interface design. So far, tool support has been focused on the representation or management of pattern collections (Deng et al., 2005). PLML, the pattern language meta-language, however, makes patterns more machine readable and opens up possibilities for extended tool support (Fincher, 2003).

Because of these matches, we argue for patterns being particularly suitable for the domain of auditory display design. Dearden and Finlay (2006) contrasts design patterns with other forms of guidance such as guidelines, heuristics, standards, style guides, and claims. The main advantages of patterns over other forms for the domain at hand are the flexibility in the level of abstraction, the foundations in concrete examples, embedded values in design, and the easy access to design knowledge across multi-disciplinary teams. A young design discipline such as auditory display would benefit greatly from such explicit exposition of good practice—in similar ways as Chung et al. (2004) found patterns to *"...positively influence the design of emerging applications by helping designers find good solutions and avoid adopting poor standards"* in ubiquitous computing (see also section 2.4.3).

However, the comparatively small number of successful solutions in auditory display design is scattered in the design space making conventional pattern mining difficult. To identify the invariants in 'good' solutions implies the necessity of having multiple proven solutions for similar problems available. This is rarely the case in a young discipline such as auditory display and consequently would undermine the validity of patterns derived. These problems became evident in the efforts of Barrass (2003) and Adcock and Barrass (2004) to apply the concept of design patterns to the domain of auditory display design. They developed four patterns based on papers in the ICAD 2002 proceedings, six were added during the 2004 conference and further two emerged from papers published in the ICAD 2004 proceedings. All patterns were put online[4] alongside with other pattern collections. However, their development stalled (last edited 15 September 2006) and no publication in ICAD as of now stated to be based on or inspired by any of the patterns. The traditional methods for pattern mining, application and evaluation (e.g., The Rule Of Three, Bushmanns Law, Review Barrass, 2003) have not succeeded in this particular domain.

The proposed framework aims to take the domain specific properties into account and provides experts and novice designers with methods that allow them to capture, apply, and refine design knowledge on various levels of maturity and abstraction. Figure 4.1 illustrates the basic cycle in the **paco** framework.

Figure 4.1: The basic cycle of methods in **paco**

The **paco** framework provides a method for experts to capture their designs and describe them in a re-usable way through patterns. It supports novice designers to conceptualise the design space and select appropriate patterns for their problems. Finally, it allows to extend the design knowledge by refining patterns and create new ones from the experience

[4] http://c2.com/cgi-bin/wiki?SonificationDesignPatterns

gained by instantiating them.

With the introduction of the context space in the next section a key concept of the framework is provided around which the methods for the creation, application and refinement of design knowledge are constructed. It will facilitate the exploitation of the benefits of patterns in this domain, and circumvent the potential problems stated above.

4.3 The Context Space

The context space is the organising principle in the **paco** framework. It is a multi-dimensional space in which design problems, design solutions and design patterns can be classified according to the context in which they are situated. But it is not only a taxonomy. By being localised in the context space patterns, problems, and artefacts get meaningfully inter-linked. The context space provides the syntax to a pattern language and facilitates the methods to create, apply and refine the patterns it contains.

4.3.1 Motivation

Fincher and Windsor (2000) discuss the importance of an organising principle to pattern collections. They identify four required properties: taxonomise, proximate, evaluative, and generative. The first requirement allows patterns to be locatable in a larger corpus by categorisation. To provide the proximity of inter-linked patterns supports exploring related patterns and therefore contributes to the conceptualisation of the design space. An organising principle should also allow users to consider the solutions from different perspectives and hence, be evaluative regarding the approach chosen. Finally, an organising principle reveals the gaps between existing solutions and serves the scientific field as a map to explore and generate solutions for the white spots.

The context space organises patterns, artefacts and problems along their contextual properties. Basic questions about the who, the where, and the what are answered by the localisation in this space. Although patterns are intrinsically contextual, using these properties explicitly as the organising principle is in many ways appealing. The following paragraph makes the argument for the context space as the organising principle in **paco** from a different perspective.

Designing auditory displays can be seen as creating signs that are interpreted by users through which they can interact with the system. This semiological view on designing audio has recently gained increasing attention as it provides a generic framework that focuses on the communication of information in a contextually appropriate way (e.g. Jakosch, 2005; Mustonen, 2008; Pirhonen et al., 2006). From this perspective, the context space constitutes the sign-system in which the solutions provided make sense. Whatever the sign, its meaning is derived from the code the recipient is applying to decipher it. These codes are frameworks provided by our physical or social environment and help us to understand signs. The context space makes visible the semiotic code in the sign-system of interaction that allows users to interpret the design as intended by the designer. The semiotic 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.

All types of semiotic codes (as discussed in Chandler, 2006, p. 149) work on solutions for auditory display problems: perceptual codes allow us to conceptually shape what we perceive, textual codes tell us about the genre and the medium used, and social codes are conventions emerging from social structures and interaction. The dimensions of the context space intend to reflect these codes and allow designers getting to grip with the sign-systems in which patterns work, problems have to be solved, or prototypes were built for.

4.3.2 Implementation

In order to describe the contextual properties of patterns, problems, and artefacts, the context space is defined by six basic dimensions. Defining these dimensions is a trade-off between accuracy, flexibility, and extensibility. While ordinal dimensions allow the definition of accurate metrics for proximity and make representing the context space easier, they lack the flexibility needed to capture contextual features such as social codes. Although there exist more sophisticated models for contextual design (e.g. Eisenstein et al., 2001), the complexity of these models and their limited flexibility make them inappropriate for application in the context space.

The approach chosen for **paco** is focused on being as simple and versatile as possible without sacrificing the fundamental requirements outlined above. Therefore, all the dimensions are implemented as tagging categories. The tagging paradigm became popular for categorising web-content in online communities such as the bookmarking site `http://del.icio.us/`. In contrast to formal classification, the categories emerge from a mutual understanding of users. A common concern is the stability of tagging systems, meaning the robustness with which information is coherently categorised by unsupervised individuals. Recent studies show that consensus emerges given sufficient time and users, leading to stable categorisations (Halpin et al., 2007). It is stated that tagging is *"90% of the value of a proper taxonomy but 10 times simpler"*.

The ontology models used in Model-Based Interface Design (Thevenin et al., 2003) serve as a starting point to define the dimensions of the context space. They define the user, the environment and the device as fundamental properties of the context of use of an interface. The concept of model-based user interface aims to achieve rule-based and automated translation of interfaces for different contexts (Calvary et al., 2001). Because of the complexity of this task, the concept is limited in scope (Myers et al., 2000, p. 13). For the context space, the three dimensions bear the same meaning, but are implemented as tagging categories supported by nominal scope values. The tagging paradigm allows designers to freely associate properties of the user, the environment, and the device with the solution or the problem they are describing. The scope value aims to indicate the level of generalisation. The higher end of the scale indicates solutions or problems with a limited scope of applicability, e.g., a specific user group or a special device. Low values stand for vaguely specified problems or generic solutions, e.g., for changing environments or unknown user groups. Table 4.2 provides an example of scope values for the user dimension.

In addition to these basic contextual properties, three more dimensions are defined: application domain, user experience and social context. These dimensions extend classical

Value	User scope
1	everybody, mass market product
2	wide range of users, minor constraints
3	users with specific needs, but loosely defined in other properties
4	specific user groups, well known properties
5	a single specific user group

Table 4.2: Example of scope values and their assigned user scopes.

requirement specifications in HCI with the aim of capturing significant properties in the context that have direct impact on the design of auditory artefacts. The application domain conveys an overall genre such as 'chemistry' or 'advertising'. Designs for these domains may be specified with similar users, devices, and environments, but nonetheless demand different approaches. This dimension also defines a scope value, similar to the ones above. For the remaining two this scope value was omitted for being impractical. The desired user experience captures notions such as 'trust' or 'playful' that have direct implications for the æsthetics of sound design. Finally, the social context aims to reflect special social settings in which the users interact with technology. Implications of power-relationships such as employer-employee or tribal effects can be conveyed through this dimension. Table 4.3 summarises the dimensions and provides example tags to clarify their usage.

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	none
Social context	privacy, family, dating	none

Table 4.3: Dimensions of the context space

To 'localise' a pattern, a problem, or a prototype in the context space means to assign tags and values for each dimension—creating a unique descriptor. The context space plays a central role in the methods of the **paco** framework. It facilitates a structured pattern-mining process, assists designers to find relevant patterns for their design problems, and is the glue that turns the collection of patterns into an inter-linked pattern language.

4.4 The Methods in paco

The methods in the **paco** framework provide structured processes to create, apply and refine design patterns. It is particularly tailored towards young and emerging designing disciplines like auditory display design.

4.4.1 Creation

The process of creating design patterns is focused on finding the core of a solution to a recurring problem by identifying the invariant design features in successful implementations. This is often not feasible in small designing disciplines as the implementations are highly specialised and scattered in the design space. Little overlap prevents the creation of meaningful design patterns.

The **paco** framework tackles these issues by providing a pattern-mining process that develops the seeds for generic patterns from specific implementations. It aims to elicit expertise from authors that goes beyond established, common practice—which is a too conservative approach for fields like auditory display design. It allows experts to capture the full range of design knowledge: from well established, common practice to specific, but proven solutions. It encourages experts to go even further by providing a means to capture informed guesses about possible, but unproven solutions. This is facilitated by introducing a rating scheme that marks the different qualities of design knowledge captured by patterns. The following describes its role in the process of pattern-mining.

The process starts with a specific design, or aspect of the design, that was implemented and evaluated. Prototypes are developed to meet the requirements of a specific context. As a first step, the author 'localises' the design in the context space by assigning tags and values to the descriptor. This puts the design in context in the design space. Subsequently, the author describes the specific design through a pattern supported by examples, forces[5] and the rationale. The pattern format chosen is similar to the original used by Alexander (1979). In the strict sense, this is not a pattern as it does not describe a recurring problem,

[5]Forces are an essential part of design patterns. Two contradictory forces that work on a particular problem need to be resolved through a trade-off to be able develop a solution (Alexander, 1979).

but it is a specific solution described in a pattern format serving as the seed for generalised patterns. Consequently, the author of the pattern rates the pattern as a proven, but not generalised solution.

In iterative cycles the author now can generalise from the seed pattern. The context space allows the author of the pattern to conceptualise the generalisation as it is reflected by an extension of the descriptor. Each dimension of the context space provides an aspect of the generalisation, e.g., extended user group, multiple application domains. At each iteration, a new version of the pattern is derived. It is altered—i.e., generalised—to reflect the changes in the descriptor and rated according to what evidence supports the pattern. Low ratings can reflect informed guesses in which proven solutions are applied to different contexts without strong evidence that this is possible. Such patterns are also the natural end points of the iteration. High ratings are gained by multiple implementations or broad consensus between multiple authors. Figure 4.2 illustrates the process.

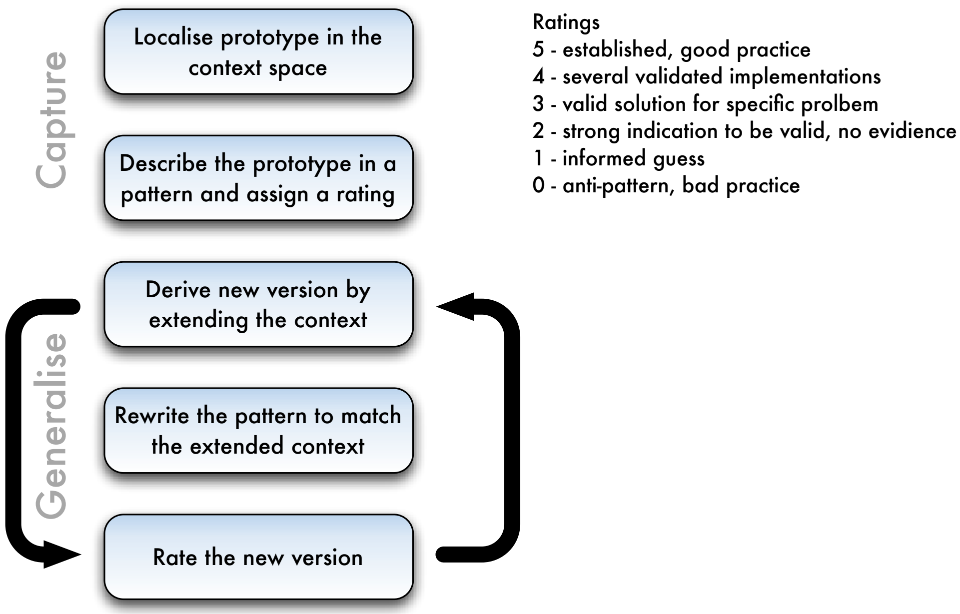


Figure 4.2: The creation process in **paco**

This process generates a range of patterns that are linked through their common seed pattern. The descriptors manifest these links in the context space and the ratings indicate the validity of the patterns. To summarise the pattern-mining process in **paco** has the following distinct features:

- It is based on specific implementations.
- It provides a structured process to generalise design knowledge.
- The rating mechanism allows the capture of a wide range of design knowledge.
- The concept space supports designers conceptualising the design space.

4.4.2 Application

The **paco** framework supports designers to transfer design knowledge from related design problems onto the problem at hand. At the beginning of each design process it is important to shape the problem and become aware of design options. Again the context space facilitates both aspects in this early phase of envisionment. It is not only home to solutions (i.e., design patterns) and specific artefacts (i.e., example implementations), but also to problems. Localising the problem in the context space means specifying the context in which the solution is required to operate. The dimensions of the context space and the tagging mechanism support designers in considering the problem from various perspectives and help them to specify contextual requirements. For designing auditory displays, we argue that the awareness of these contextual properties is key to create successful solutions.

In the same way as the context space links design patterns with each other, it links patterns with problems. The common organising principle in which both have their descriptors, enables the designer to match the problem with relevant design knowledge. The links between problems and solutions are manifested in common tags. An intrinsic feature of the tagging paradigm is that these links have a semantic value: the name of the tag. This allows designers to explore links to solutions in a differentiated way. For example, although a pattern generally serves a very different context, a specific aspect in dealing with a particular environmental constraint might be useful for a design problem. These exploratory features are intended to assist designers in conceptualising the design space and guide them in selecting relevant design knowledge to solve their problem. The rating scheme and the history of the relevant patterns also aid this selection process.

In the spirit of Alexander (1979), the implementation of the patterns selected can vary substantially and leaves the designer room for exercising their creativity. The semi-structured, textual format of patterns assists designers with examples, but does not enforce a certain kind of implementation. This loose concept also means that solutions derived from patterns need to undergo the usual iteration of evaluation and alteration to ensure the desired quality of the design. This is particularly important when using design patterns that are rated low and reflect non-validated design knowledge. Figure 4.3 summarises the process.

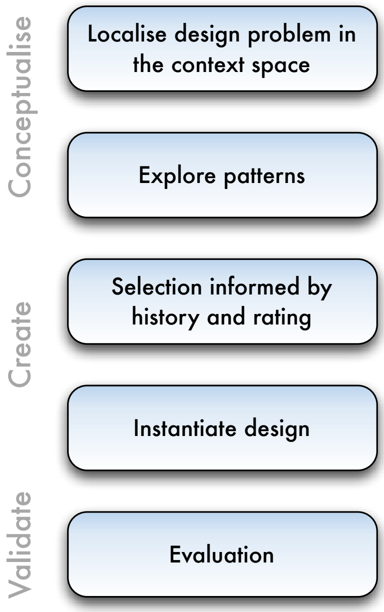


Figure 4.3: The application process in **paco**

4.4.3 Refinement

Any implementation, fully or partially based on patterns, produces new insights about the design knowledge promoted by the patterns. The last phase in the **paco** framework is intended to close the circle and bring to life a self-organising and community-driven process to create a shared body of design knowledge.

The work of Alexander (1979) has been criticised rightfully for its commanding notion, its promotion of subjective views of the author, and for favouring conservative—because proven—design (Saunders, 2002). By facilitating feedback and constant refinement the **paco** framework addresses these issues. Only the community has the natural authority to define common practice and ethical values in design. The rating system, however, also opens up design patterns for blue-sky ideas to prevent pattern languages from becoming static and conservative.

In **paco** there are two paths to feed back experiences made by implementing patterns. First, by altering the involved patterns directly and secondly, by starting a new creation process with the specific implementation which eventually connects to the patterns it was informed by. In both cases, patterns are never simply overwritten. In order to preserve their history, feeding back to a pattern in **paco** means to create a new version of it (as argued for by Deng et al., 2005).

The first path is straight forward. It means that patterns are augmented by new aspects found by an implementation and the corresponding evaluation. This could mean an extension in the context space if the pattern was successfully implemented for a different context, or any other change in the pattern itself. Implementations can support or undermine the validity of patterns changing their rating as a consequence. The second possibility is to start as with any other specific solution and create a seed pattern. The iterative generalisation in the creation process eventually leads to the patterns the solution was derived from. At this point, **paco** allows the designer to create a new version of them that stems from multiple implementations.

An evolving system like this facilitates the auto-validation of its content. Good design 'lives' and gets implemented – bad design 'dies' with low ratings. Although this is common practice for evaluating patterns, scientific rigour is only achieved by empirical evaluation. Borchers (2000b) argues that good patterns should have brief summaries of the results of relevant studies in the examples section. Another instrument of quality control common in the pattern community is to 'workshop' patterns. A pattern is critically reviewed by pattern authors in a writer's workshop. In conferences such as PLoP[6], writer's workshops have a long tradition and provide the opportunity to discuss patterns with pattern experts rather than domain experts, which often greatly adds to making them more accessible.

Any application of the **paco** framework to a specific discipline has to consider these community effects and support them. It depends on the structure of the community how

[6]Pattern Languages of Programmes, http://hillside.net/conferences/plop.htm

this could be facilitated, but an interactive online resource seems to be most suitable for distributed scientific communities such as the one for auditory display.

4.5 Case Study

This section aims to illustrate the workflow in the **paco** framework through a case study in the auditory domain. The designs being used as examples here were part of a body of research by the author that sought to exploit spatial audio techniques for non-visual menu navigation[7]. Although the iteration of designs has been created and evaluated prior to the development of **paco**, design patterns have been used throughout the design process which makes them particularly fitting for demonstrating how the methods of **paco** could be applied.

This case study spans across the entire cycle in **paco** and shows the creation, application, and refinement of design patterns. It illustrates how concrete prototypes can be used to create re-usable design knowledge.

4.5.1 Creation

An auditory version of a file-manager application was developed with the aim to explore spatial, non-visual interaction paradigms for the visually impaired (Frauenberger and Stockman, 2005). The design was based on a room metaphor that arranged the various components of the application on the walls of the virtual room. The pointer functionality was translated to the listener position, creating an immersed user experience. The user could move around the virtual environment and interact with auditory objects that represented objects in the application. Figure 4.4 illustrates the approach.

Several re-usable design elements were identified in this design, e.g., the container or the tree-structure. For the purpose of this case study, the menu navigation feature is extracted and serves as the starting point for the pattern-mining process. The prototype is localised in

[7]The results of this work have been reported repeatedly in ICAD and other forums and relevant references are given at appropriate places.

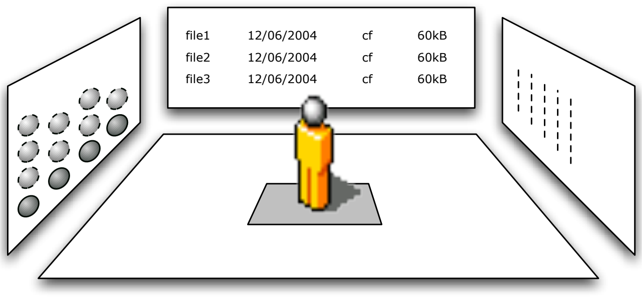


Figure 4.4: The design approach for the auditory explorer

the context space by specifying appropriate tags, for example "visually impaired", "desktop application", "office" etc. The design is described in pattern format and given the name "3D auditory menu" (see figure 4.5). The evaluation of the prototype showed that participants were able to access all elements in the menu with reasonable effort—the implementation proved to work. It is rated with 3 out of 5 indicating its status as proven, but not generalised solution to the design problem. Examples and a summary of the evaluation complete the pattern.

Subsequently, this seed pattern is used as the basis for generalising the design knowledge. The user base is extended to include sighted office workers, the design is amended to work for similar applications such as menus in mail clients. The new version of the pattern is saved under the same name, but with reduced rating (2) to indicate that there is strong indication that this will work, but no evidence. In a further iteration, the pattern is generalised to work with arbitrary hierarchical structures such as trees. This generalisation is not more than an informed guess by an expert and no evidence is backing it. The rating is set to 1 and this line of generalisation is ended. Figure 4.5 shows the evolution of the patterns. As these are illustrative examples only, they are not full patterns, but reduced to a sketch.

4.5.2 Application

A hypothetical project aims to build a note-taker application for visually impaired users. The application should be part of an office suite and allow visually impaired employees of a bank to make quick notes in a simple text editor. The design brief requires navigating

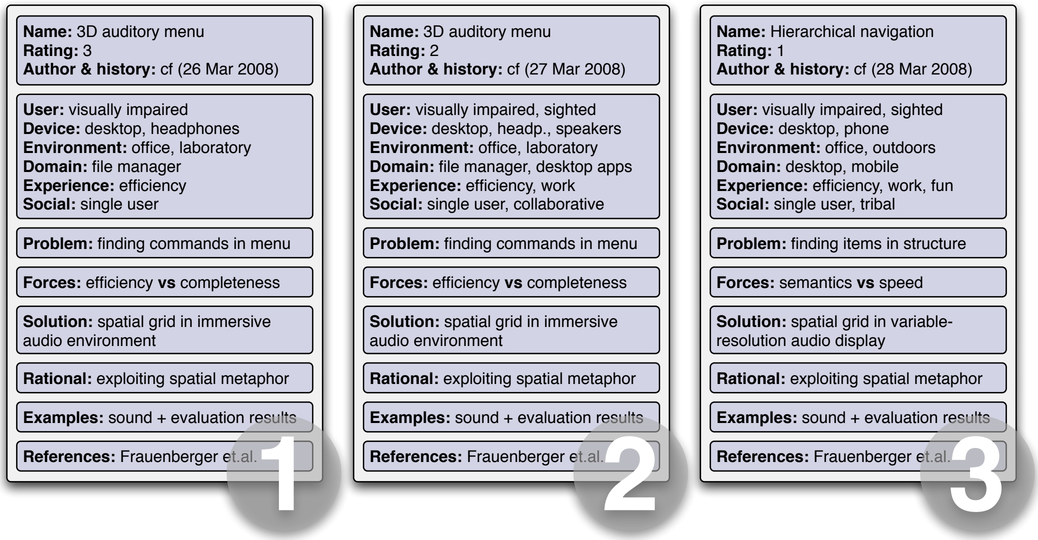


Figure 4.5: The evolution of the "3D auditory menu" pattern

the menu to be as efficient as possible.

As a first step, the problem is localised in the context space. The user group is well defined and the office setting imposes little restrictions. The device, a desktop computer, is powerful enough to create any type of auditory display and the desired user experience is also work orientated. The context space assists the designer to conceptualise the contextual implications imposed by the requirements by defining a unique descriptor for the problem.

The tags used to describe the problem context link it to various design patterns. The design space can now be explored by following common tags. In this hypothetical case, the auditory menu patterns are linked through the same environmental setting, the office, and user group, the visually impaired. The application domain is not a perfect match, but both are desktop applications. The solutions provided by the patterns suggest exploiting a spatial metaphor, but also state that the evaluation has found the static grid layout to be not ideal due to the limited spatial resolution of hearing (Frauenberger and Stockman, 2005).

It is decided to implement the "3D auditory menu" pattern for this application. The rating (3 out of 5) suggests that is not yet 'hard' design knowledge. Therefore, as indicated by the evaluation, a different spatial layout is employed. The research literature points to omitting vertical cues and relying solely on the horizontal plane in which localisation is the most accurate (Blauert, 1974). A flexible ring metaphor is proposed to further increase the number of items (Savidis et al., 1996). Finally, the system is implemented using a rotating-dial metaphor. In the virtual scene, a horizontal dial is located in front of the user. Spoken menu items are located on the edge of this dial and the user is able to rotate it to bring the desired items to the front. If the item is a submenu, a preview of its contents is given by making the first two entries audible at more distant locations. Figure 4.6 illustrates the metaphor, for a detailed description of the design see Frauenberger and Stockman (2006).

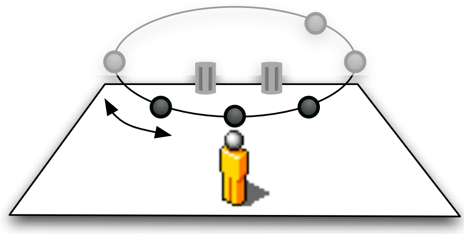


Figure 4.6: The rotating dial metaphor for 3D auditory menus

The evaluation of the prototype shows that users are able to navigate menu structures of desktop applications efficiently. Navigation was more robust in comparison to the static grid layout used in the first design and the approach is scaleable without compromising the spatial resolution of human hearing. Besides solving these issues, the evaluation also revealed an important, still unsolved, design problem: the transient manner of sound makes it difficult to make the user aware of the location of sound objects if the sound is not present continuously or repetitive. This, however, not only limits the maximum number of elements in a scene (i.e., concurrent streams), but also can be unpleasant and tiring (Frauenberger and Stockman, 2006).

4.5.3 Refinement

The implementation of the pattern "3D auditory menu" has produced new insights. An initial problem identified was successfully resolved and a more appropriate spatial metaphor has been developed. Additionally, an important design consideration has been revealed about the design of the sounds that make up the menu items (continuos sound versus location awareness). The refinement process in **paco** assists the designers in incorporating the knowledge gained into the existing pattern collection.

The most direct way is to create new versions of the existing patterns. The "3D auditory menu" pattern is derived and altered to use the new spatial metaphor. Examples are added to show the sound design in both prototypes and the additional backing in research literature justifies an increase in the rating. The pattern is now based on multiple implementations, has multiple references and is now also in the strict sense a complete design pattern[8].

Besides altering the patterns directly, the implementation could also be used as input to the creation process. The generalisation is finished when reaching the pattern the implementation is derived from. However, the new context of the implementation might also inspire authors to generalise in a different direction and create new blue-sky patterns.

4.6 Summary & Discussion

This chapter described the methods that make up the **paco** framework. They provide a structured process to pattern-mining, the application of patterns and their iterative refinement. The context space is the underlying organising principle that facilitates these methods. While being developed with the requirements for the auditory domain in mind, **paco** is a generic concept and can be applied to a variety of designing disciplines. The application of **paco** in the field of auditory display, was illustrated by a case study based on a body of research that investigates non-visual menu navigation in virtual audio environments.

The context space is a key concept in the framework that emphasises the importance of contextual requirements for design. Meaning making of signs—or in fact user interfaces or any information—can be argued for as being facilitated by the context in which the sign is embedded from a semiological perspective. The development of design patterns from concrete implementations anchored in the context space can consequently be interpreted

[8] As a result of this line of research and the additional input of experts during the evaluation of **paco**, this pattern has actually been developed fully and is available in appendix F

as syntactic reduction. Similar to the invariant roles in Russian folk tales found by Propp (1968)[9], patterns are the recurring solutions manifested in the semiotic codes described in the context.

In contrast to more formal approaches to link contextual attributes to patterns, the context space in the **paco** framework was developed for simplicity and flexibility. Javahery et al. (2006), for example, use a matrix of values from user and context models to facilitate a rule-based selection of patterns from a library. Although also addressing the gap between requirements and design knowledge, this approach is less flexible due to the underlying assumptions of the models. More importantly though, it does not allow designers to conceptualise the design space. The complex models and rules that link the problem with the patterns make it impossible to put the machine-selected patterns into the bigger picture. The simple tagging paradigm employed in **paco** supports this conceptualisation and enables designers to explore the space. This key feature of the context space plays an important role in the process of pattern-mining which is not addressed in Javahery et al. (2006).

The framework presented in this chapter is a collection of theoretical methods. To be integrated into a design process, the framework has to be implemented and supported by design tools. An online repository of design patterns that implements the methods of **paco** through a set of wizards is the most obvious choice. The enhanced multi media capabilities of web technologies provide new possibilities for authoring the content (e.g interactive examples in patterns) and ensure wide spread availability[10].

A crucial element of any implementation is the representation of the context space. It is the core of the framework and how well designers are able to conceptualise the space is not least dependent on the intuitiveness of its representation. Navigation, interactive exploration, and selection mechanisms must be implemented. The possibilities of visualising the context space, or in fact using sonification for that matter, are numerous. The visual information seeking mantra of Shneiderman (1996), *"overview first, zoom and filter,*

[9] Propp (1968) analysed Russian folk tales to identify their fundamental narrative elements and characters. He discovered that each single tale followed the same, invariable, basic structure and had the same functional characters.

[10] Many pattern collections are still exclusively available through books or other paper based publications and not accessible online (Henninger and Correa, 2007)

then details on demand", might be a natural starting point for a visualisation. Fortunately, the many software packages for data visualisation available allow for developing powerful implementations with comparatively little effort (for a recent overview see Prinz, 2006).

To conclude this chapter, the following enumeration highlights the main features of the methodological framework presented:

- **paco** enables designers to systematically create re-usable design knowledge from their expertise in the form of design patterns;
- Although developed for the design of auditory display, **paco** is a generic concept also applicable in other domains and potentially supporting multi-modal interface design;
- In **paco**, not multiple occurrences of similar solutions are the starting point for creating design patterns, but single, evaluated implementations. Hence, **paco** favours small or young scientific disciplines in which the small number of successful examples renders conventional approaches unfeasible;
- The rating scheme ensures that successful patterns 'live' and are ranked higher when multiple uses show the validity of the design knowledge, while others 'die' and serve as examples of bad practice;
- **paco** allows the expression of weak design knowledge through blue-sky patterns that are not supported by hard evidence. The rating scheme ensures the knowledge is flagged as such;
- The context space in **paco** allows for conceptualising the design space. This enables designers to systematically populate the design space reflecting their experience and expertise.

The following chapter sets out to evaluate the framework in the auditory domain. In a two-stage study the knowledge transfer from experts to novice designers and the impact of **paco** on this process are investigated.

Chapter 5

Evaluating paco

The previous chapters have made the case for a design framework that supports designers in creating auditory displays and described the development of **paco**, a methodological framework based on design patterns. This chapter aims to investigate how well the methods provided by **paco** meet the requirements when put in use with real-world design problems. In contrast to the exemplary case study in section 4.5, illustrating the workflow in **paco**, this evaluation focuses on investigating the efficiency of the process by involving experts and novices in auditory display design. This is a novel approach in auditory display design: design methodologies developed for this area have so far been evaluated in case studies, testing the results they produced (see Barrass, 1998; Mitsopoulos, 2000; Murphy, 2007). In contrast, this study approaches the evaluation of a design method for auditory displays by embracing the actual target groups: the designers.

The first section of this chapter will specify in more detail the hypothesises and the scope of the evaluation followed by an overview of the structure of the study. Subsequently, sections 5.3 and 5.4 describe the two phases and provide details of the experiments, the methods employed, and the results. Finally, section 5.5 provides a synopsis and refers back to the research question and hypothesises specified in section 5.1.

5.1 Hypothesises

The overall research question stated in section 1.2 asked whether a methodological framework could facilitate the efficient transfer of design knowledge from experts in the field of auditory display to novice designers. This chapter aims to investigate whether the methods provided by **paco** can achieve this aim. The two hypothesises to be targeted in this evaluation therefore are: The **paco** framework

(H1) enables experts in auditory display to capture design knowledge in the form of design patterns and

(H2) enables novice designers to re-use the design knowledge captured in new auditory display design problems.

In order to evaluate the above hypothesises, the following measures are defined:

H1	a)	completeness, quality and generalisation level of patterns created through **paco** compared to other patterns
	b)	added value of patterns compared to other sources of design knowledge (e.g., papers written by experts)
	c)	appropriateness of contextual attributes used to position a pattern in the context space
H2	a)	appropriateness, quality and diversity of auditory techniques used in a solution depending on the provided guidance
	b)	overall quality of a solution depending on the provided guidance
	c)	efficiency of the contextual matching process between design problem and design patterns
	d)	level of awareness for alternative solutions, i.e., the design space

The above defines the scope of this study. The **paco** framework suggests that designers who applied design patterns feed back their experience into the system and refine the patterns they used. This mechanism is essential to ensure the validity of the knowledge conveyed. Good patterns 'live', get used and are rated high, while bad patterns 'die' with low ratings and contradictory evaluations. However, while essential for the process, this community effect is outside the scope of this study. The intention is to focus on the effectiveness of the knowledge transfer first to prove the fundamental concept before a longitudinal study could investigate the aspect of automatic validation of design knowledge by usage.

The following section discusses the design of the study and the methodology chosen for finding answers to the questions stated above.

5.2 Overview

The study is designed along the life-cycle of a design pattern as described above. According to the user groups involved two phases can be distinguished:

Phase 1 Expert designers of auditory display use **paco** to create design patterns.

Phase 2 Novices in auditory display design use **paco** to create new designs.

In phase one expert designers describe two of their most successful designs using the **paco** framework. The workflow is implemented as an online system facilitating the creation of a series of design patterns and their localisation in the context space. Experts receive an information sheet, a pre-questionnaire and a custom link for the online system that allows them to work on their patterns independently. When finished, they are asked to complete a post-questionnaire.

Phase two investigates the application of the patterns created in phase one by novices to auditory display design. In a controlled experiment participants are given design problems and are asked to create concept design solutions. Two design problems were created that require the use of audio as a means of feedback in the user interface. Both problems match a subset of the patterns created in phase one and different conditions probe for the ability of participants to use the design knowledge provided to solve the problem. After a pre-questionnaire, participants have 40 minutes to create the design sketch followed by a five-minute presentation of their ideas.

The remainder of this chapter will present the experiments conducted and their results. A synopsis at the end of this chapter will summarise the findings.

5.3 Phase One: Creating Design Patterns

The goal of phase one was to investigate the creation of design patterns by experts in auditory display design using the **paco** framework. For the purpose of this study, 'experts' was defined as well-established members of the International Community of Auditory Display (ICAD) who authored more than five international and peer-reviewed publications in the field. Because the experts were physically distributed around the globe, it was necessary to facilitate this experiment remotely over the Internet. This imposed several restrictions upon the design of the study. Participants needed to be able to work on their patterns independently and according to their own time-plan. Hence, there was limited control over the process and no direct observation was possible. The subsequent section describe in detail the method and the results of this experiment.

5.3.1 The Method

Potential participants were approached in person during the annual conference of ICAD in 2007 in Montreal, Canada. The only selection criteria was the expert status and the likely availability of potential participants. They were provided with an information sheet (see appendix D.1) that explained the purpose and the background of the study. In a follow-up email they were asked if they would be interested in taking part. If they agreed, participants were sent the pre-questionnaire. Upon return, they were provided with a personalised link to the online system described below to create their patterns.

Pre-questionnaire

This questionnaire aimed to elicit basic information from the participants in three areas:

- Experience in designing auditory displays,
- current design practice of participants and
- their opinion about the state and future of the field.

The first part established the basic profile of the participant. The questionnaire asked for the earliest publication describing an auditory display and for their educational background. Two questions probed for their initial motivation to work in this field and whether this motivation had changed over the course of their work.

The second part aimed to capture the working process the experts use when approaching a design problem requiring audio. As there was no possibility to observe all experts and investigate their working process, this question in the pre-questionnaire was included to elicit a self-reflective view that could be compared with any account they provide as authors in their publications. Furthermore, this section asked for what made audio a requirement in most of their designs and what guidelines they used to inform their design decisions.

The last block of questions targeted the opinions of the participants about auditory display as a scientific field. The questionnaire explore whether participants thought that audio was underused in current commercial products and, if yes, why they thought this was the case. While the answer to the first question was predictable for this group of participants, the second part aimed to identify the issues that have to be addressed in future research. The subsequent questions had a similar goal and probed for the most promising application domains for audio and what the most difficult aspect is when designing with audio. One question addressed the re-usability of design knowledge and the final two asked for good and bad examples of audio in everyday technology. This set of questions was intended to provide a picture of the field and its future from the perspective of its most knowledgeable experts.

The exact wording of the pre-questionnaire is available in appendix D.2. When participants sent back the completed questionnaire, they received a personalised link to the **paco** online system and could start working on their design patterns.

The Online System

The **paco** online system implemented the workflow of the framework presented in chapter 4 in a series of web pages. Every participant received a personalised link that provided them with the starting point for creating design patterns.

The start page briefly explained the purpose of the study and described the task of the participants: To describe two of their most successful designs through design patterns using the **paco** framework. Subsequently the workflow in **paco** was explained and a link to the most recent publication on the topic was provided (Frauenberger et al., 2007b). This page also showed a list of all the patterns created by the participant. For each pattern the title and the descriptor into the context space was provided along with possible actions: 'New version' and 'Delete'. Figure 5.1 shows a screenshot of this page.

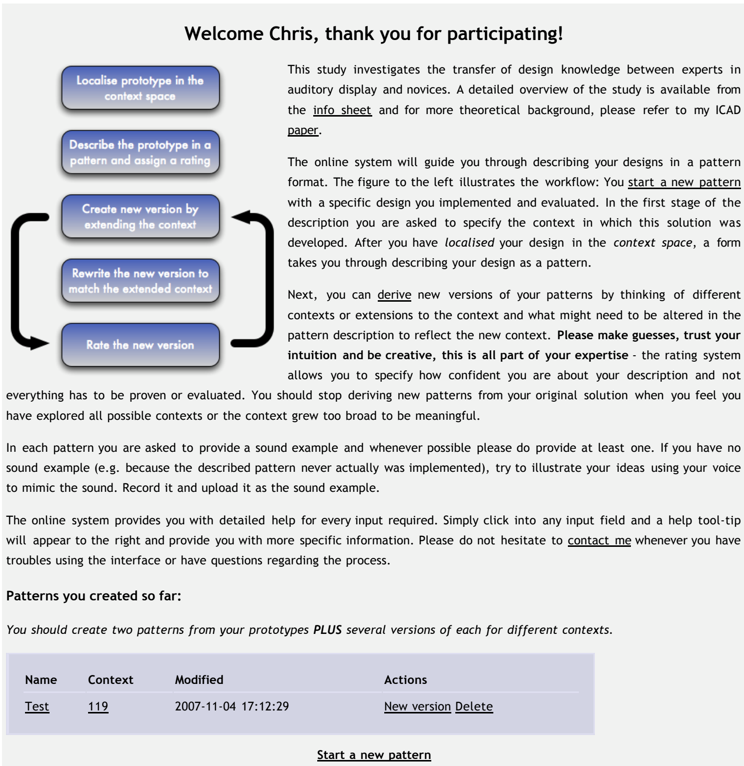


Figure 5.1: The start page for participants

The 'Start a new pattern' link would take participants to the second page allowing them to describe a new design in the context space, i.e., creating the descriptor for the pattern. The scope values could be defined by radio-buttons with help tool-tips describing the meaning of the values. Besides the scope values, users could also use tags to describe the context. All recently used tags were provided as a tag-cloud[1]. Figures 5.2 and 5.3 show the input fields and the pop-up windows for tags.

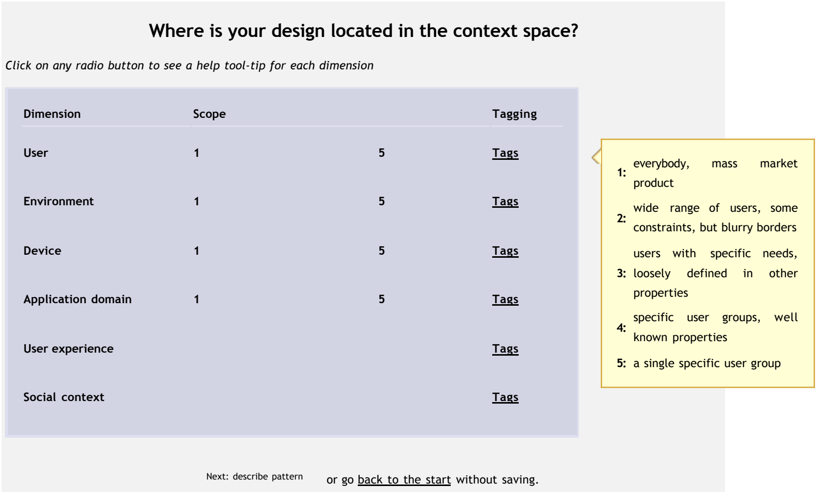


Figure 5.2: The input fields for describing the design in the context space

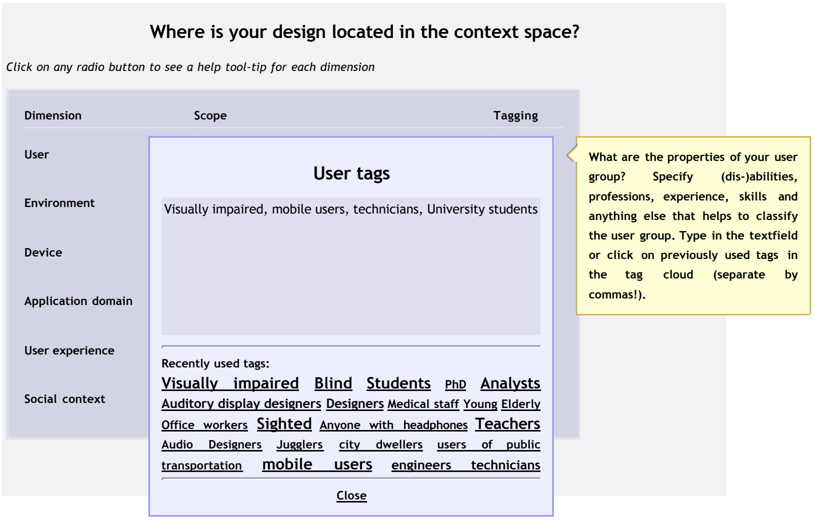


Figure 5.3: The input field for the user tags

The 'Next' button would take participants to a page at which they could localise their design. All input fields were supported by help tool-tips that would provide individual help texts and examples. Figure 5.4 shows an empty form with the help text for the problem description active.

Finally, after submitting the design pattern, the user was directed to a page that described the possible next steps in the process. There were three possibilities for participants: firstly,

[1]'Tag-cloud' is the common term used for lists of tags that use the font-size to indicate popularity or frequency of use.

Figure 5.4: The input fields for creating a design pattern in **paco** with a help tool-tip

to derive a new version of the pattern they just described. This option would take the user back to the context space and the pattern form with all the data of the previously defined pattern filled in. The users could then conveniently alter the description and the context and derive a new version of the pattern. Secondly, the users could start a new pattern with empty forms or, thirdly, they could go to their start page with the list of all their patterns and additional info. Figure 5.5 shows the screenshot of this page.

All pages had similar graphical design and were hosted on the departmental server at the Department of Computer Science at Queen Mary, University of London. They used a

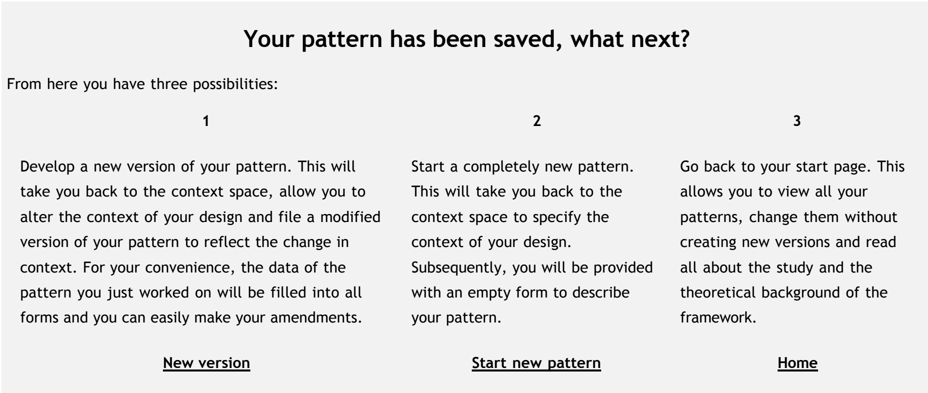


Figure 5.5: The final page providing participants with the possible next steps

MySQL[2] database as back-end and PHP scripting[3] to display dynamic content. Dynamic help texts were displayed using JavaScript[4]. Participants could work independently on their patterns, but had no access to any of the input provided by other participants. As soon as they reported back to be finished, they were sent a post-questionnaire.

Post-questionnaire

The post-questionnaire probed for information in five areas: Firstly, participants were asked to describe the **paco** framework in their own words and to provide an account for the workflow the participants adopted. This provided insight into how participants interpreted the instructions and whether they were able to follow the **paco** workflow. The questionnaire also asked for the most useful and least useful feature of **paco** to identify the most memorable aspects of the framework.

The second block of questions targeted the designs they described. Two aspects were investigated: what did participants learn about their designs through describing them as a pattern and how well did they think this knowledge was re-useable.

The following two blocks focused on two main features in **paco**, the context space and the pattern format. Firstly, questions focused on the appropriateness of the dimensions of the context space and their format (i.e., scales vs. tagging). Subsequently, the questions

[2] http://www.mysql.org
[3] http://www.php.net
[4] see e.g., http://developer.mozilla.org/en/docs/JavaScript

intended to reveal shortcomings of the pattern format used in this online system.

Finally, participants were asked to provide three pieces of research that are, in their opinion outstanding and should be regarded as cornerstones in the field. Similarly, they were asked to name three sounds they particularly like in everyday technology. This block aimed to elicit their view on the scientific field as a whole and to identify priorities and key-issues. It could also be compared to the similar set of questions from the pre-questionnaire to determine any impact this process had on people's opinions.

The post-questionnaire concluded with space for general comments and asked participants if they would agree to feed a publicly-available information resource with their input, provided their contributions were clearly attributed. The full text of the post-questionnaire is provided in appendix D.3.

5.3.2 Results

Thirteen experts in auditory display design, of 18 approached, agreed to participate in this study. All of them hold a degree in computer science (3 PhD, 10 MSc studying for a PhD in this field), two of them also hold a degree in music. Between them they have published 110 papers or articles about auditory displays, 40 of them in ICAD. Since work related to this thesis had been published in ICAD before this study took place, all participants had basic knowledge about the concepts and ideas behind this work. However, only one had previous experience with writing patterns and overall the group can be seen as sufficiently naïve with regards to developing design patterns, but highly experienced in the field of auditory display.

The Pre-questionnaire

Asked for the motivation for doing research in the field of auditory display, five out of 13 (38,5%) expressed their interest in music, four mentioned accessibility (30,8%), and three provided their general interest in sound (23,1%). Other reasons included the following-up of work done earlier, the direct influence of a renowned colleague and curiosity. For most, this motivation changed somehow since then (61,5%), reflected by either a change or a shift in scope of the work. All, however, remained focused on aspects of auditory display.

Asking for their designing practice, two participants did not answer the question about their approach to design problems that require audio; one wrote nothing, the other did not address the question. One referred to a design process that was developed by the participant. Most of the remaining answers highlighted the importance of specifying the requirements (six times) and researching for relevant work for advice (five times); only two mentioned both in the answer. Three times the user was explicitly mentioned in the description of the approach as well as the context of use and prototyping.

Interestingly, almost half of the participants answered the question about what made audio a requirement in their designs with the comment that it was simply the topic of their research (five or 38.5%). Three mentioned the nature of the data or the information that was to be presented and also three made a reference to the information overload in visual displays. For two participants it was accessibility issues and only one mentioned particular contexts of use such as eyes-free scenarios. The main source for guidelines or principles is related to auditory perception (for 38.5% of the participants). Three (or 23.1%) refer to general knowledge available in ICAD without being specific about the type of guidelines. General HCI guidelines and principles from the area of cognition were mentioned twice each. Two replied they would mainly trust their intuition or use no guidelines and another two were overly vague in their answers and could not be categorised.

Unsurprisingly, most experts (11 out of 13) agreed that audio is being underused in commercial products. However, six of them (54.5%) did not provide a reason, but went on emphasising the potential of audio. Two experts see the main reason for audio being underused as being the lack of guidance and the strong focus on the visual. One expert mentioned features of audio that are difficult to handle (privacy and æsthetics) as the possible cause and another one stated that one reason might be *"a relic of previous technological limitations on sound implementation"*. Remarkably, only two see the inappropriate use of audio in current technology as possible reason. One reflects critically on the quality of current design practice: *"Another reason is the fact that most instances of auditory display to date have been poorly informed and implemented [in] regard to basic human information processing limitations and capabilities"*.

There is relative agreement over what is the most promising application field for auditory display in the future: seven (or 54%) mentioned mobile computing while assistive technology, data exploration and monitoring, and alarms all received 38%. Asked for what they find most difficult when designing audio, evaluating the design and æsthetics were mentioned most often (three times). Interestingly, two participants also referred to the difficulty of getting started. One expert even stated: *"Similar to any creative process like writing or composing, it can be difficult to overcome the block at the beginning of the design process."* which indicates how much the process is seen as a craft. A similar notion was expressed when asked about the difficulties in re-using design knowledge. Five (or 38%) mentioned that the main difficulty is related to the creative nature of the design knowledge—the craft or skill needed is hard to capture or to communicate. One participant also reflects on the way design knowledge has been made available:

> *"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, thus the knowledge generated often seems trivial and small in scope".*

Expert designers of audio and sound in technology seem to be similarly annoyed by many of the sounds currently used. Two of them mentioned that they would not use any sounds provided by the technology they use on an everyday basis; one stated *"I aspire to silence (so I can listen to music if I want to, nature, or concentrate on my task)".* The ten participants who provided examples for bad and good designs had no difficulty in finding bad examples which were generally also more verbose than the good examples. Two participants provided bad examples, but no good ones.

The Patterns

From the 13 participants who returned the pre-questionnaire nine also created design patterns through the online system. The four experts who did not continue with the study, could not find the time. The remaining nine created 25 patterns with an average word count of 270. The standard deviation of 106.1 shows the variability in verbosity with the shortest being composed of 80 words, while the longest had 503 words. They uploaded 34 audio files as examples for their patterns (1.34 on average), but also one third of the patterns (eight) had no examples attached. Participants were essentially given as much time as they needed with links being sent out late July 2007 and the online system being shut down on 1 October. There was no email contact with the participants during this period, with the exception of periodic reminders.

Over half of the patterns (14) were seed patterns, i.e., patterns describing concrete implementations. The remaining 11 patterns were derived from seven of these seed patterns. Three participants (33%) did not derive patterns at all and created only seed patterns. The depth of inheritance varied from one to four. Figure 5.6 provides all patterns and their relationships. The numbers indicate that the experts did not use the **paco** workflow as

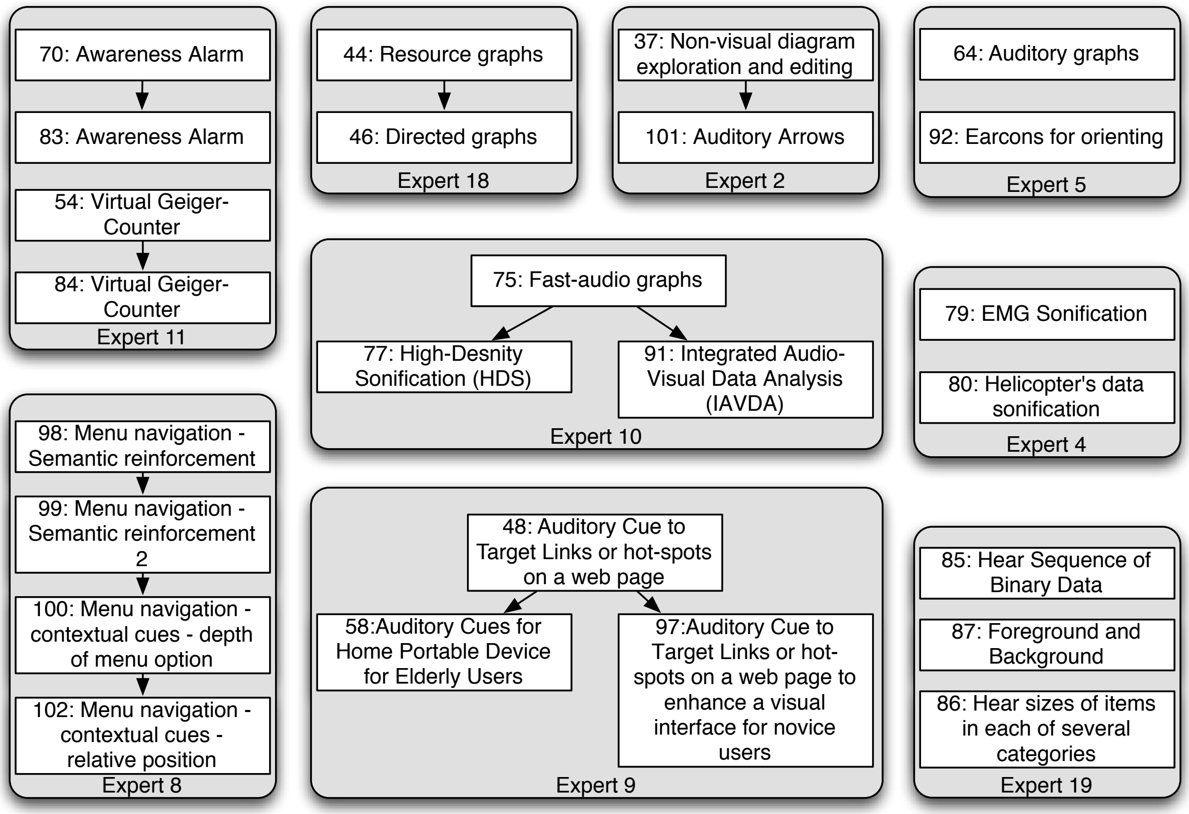


Figure 5.6: All patterns created by the experts and their relationships (The numbers preceding the titles are unique identifiers created by the system and used for reference below)

extensively as we hoped. Expert 8 was the only one who created a chain of inheritance with four patterns. Experts 9 and 10 derived two patterns from the same origin and experts 2, 11 and 18 each derived one pattern from one origin. However, a more detailed analysis of the changes in context and content of the patterns that were derived shows the impact of the workflow on the pattern mining process.

Participants used 21.8 tags on average to describe the context of their patterns (standard deviation 13.1). The use of tags was evenly distributed across the dimensions of the context space varying between 3.1 (social context) and 4.2 (application domain) tags on average. Participants created 18.9 new tags on average, but the standard deviation of 26.5 indicates that this varied significantly between the experts. Expert 11, for example, created 97 new tags (39% of all tags) while on the other end of the scale expert 5 created only a single new tag although he also used 17.5 tags on average to describe the patterns. Of all tags created, 36 (14.6%) are inappropriate for the associated category, i.e., clearly not describing a property of the dimension. The majority of these can be found in the "User experience" dimension (25) where most mismatched tags were describing the application domain (e.g., "Sports" or "Navigation"), but not the desired experience delivered to the user.

The changes to the context when deriving a new pattern reveal that in almost half of the cases participants did not change the tags in this process (five of 11 or 45%). Similarly, in six out of 11 cases (55%) the scope values were not altered and in seven cases (64%) the rating was not changed either. These numbers are strongly correlated to the authors: while expert 11 changed tags, scope values and ratings extensively, expert 8 did not change any of these in any of the patterns he derived. When deriving a new pattern those authors who changed the tags did not delete any old tags, but added 21 tags on average. Again this varied substantially between experts with the smallest change being five tags added and the biggest 54 tags added (standard deviation 21.5). These numbers indicate that the first step in the workflow for creating patterns—extending the context of an existing pattern—only worked partially. The minimal changes in rating also indicate that pattern authors did not push the process to its limits and were reluctant to make informed guesses about the applicability of their designs.

Analysing the content changes in the derived patterns shows that in seven of 11 cases (64%) there is a clear tendency towards generalisation. This shows that the concept of deriving patterns leads experts to abstracting their designs increasing their potential for re-usability. In two instances the derived patterns have little in common with their parent pattern and the remaining two cases could not be classified either way, because the patterns described a design method rather than a design itself. Table 5.1 shows an example of how the problem section changed in the process of derivation. While the parent pattern in this example describes the initial problem very accurately, the description of the derived pattern addresses a much wider field of problems. In five of the seven cases in which such generalisation was found, the author also altered the tags and scope values in the context space.

Virtual Geiger Counter (parent pattern)	**Virtual Geiger Counter** (child pattern)
In oil and gas exploration well-logs are large multi-attribute data-sets used to analyse lithography down a drill-path. ... , but the small screen size and much lower resolution ... Often a graphic zoom is provided to give full detail in a local region but this removes significant contextual information.	*Multivariate and time-varying data are hard to show and understand visually. There are masses of this data that are critical in many applications.*

Table 5.1: Example for the generalisation of a derived pattern (excerpts of the problem sections of pattern 54 and 84 by expert 11)

The tagging, however, produced a distinctive distribution of the patterns in the context space that shows topical clustering. Figure 5.7 shows a visualisation of the context space with all tags and patterns produced in this phase. The clusters produced by the force-driven layout separate the menu patters, sonification related patterns, alarm patterns and program auralisation patterns.

It remains difficult to formally assess the quality of design patterns as they are commonly evaluated in workshops or by their usage. Furthermore, the patterns produced here are not patterns in the strict sense of the definition. The **paco** framework aims to provide seeds for generic design patterns by describing specific solutions through a pattern format (see section 4.2). This makes formal criteria such as *The Rule of Three*, *Buschmann's Law* or *Review* (Barrass, 2003) not applicable. The "MetaPatterns: A Pattern Language for Pattern

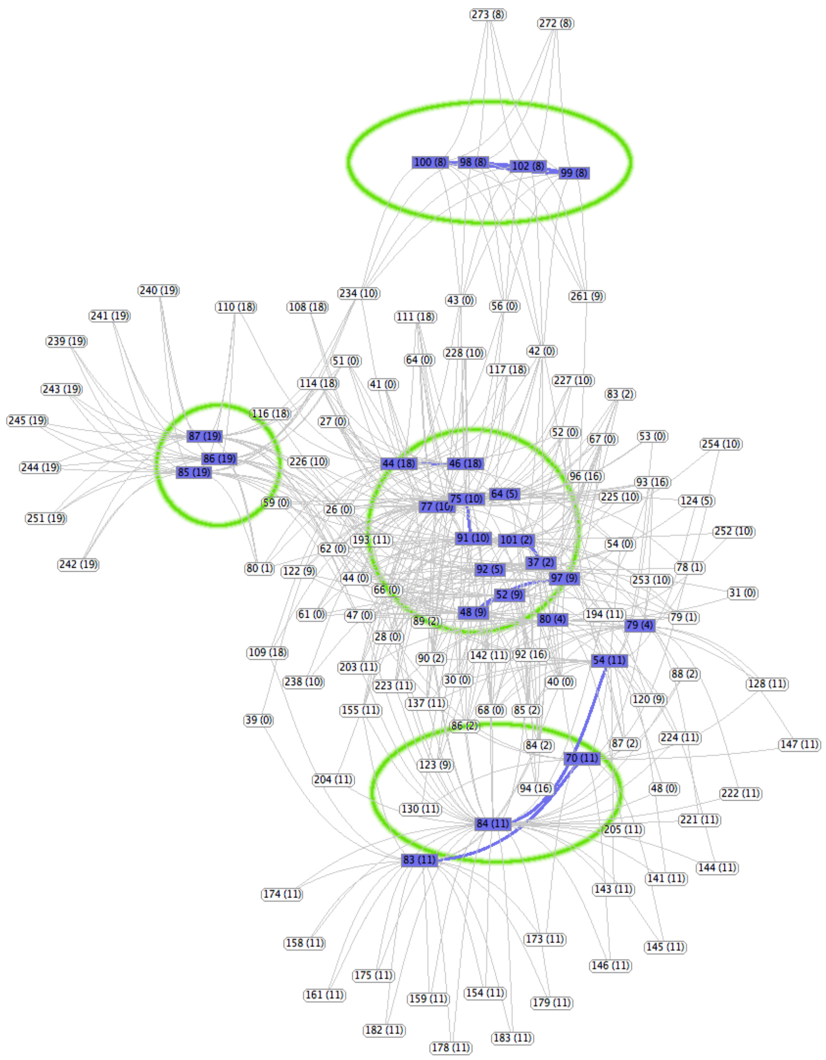


Figure 5.7: Tagging clusters, patterns in blue and tags in white with their unique identifier and the author in brackets

Writing" (Meszaros and Doble, 1996), however, provide a well established source for qualities of good pattern writing. The following paragraphs aim to investigate the patterns created from that perspective and create links back to the specified requirements (see section 4.1).

The mandatory elements of a pattern were enforced by the online form so that every pattern had a name, a problem description, a solution, forces and a rationale. Participants, however, sometimes confused elements and their purpose. Most commonly authors used the rationale section not only for providing the reasoning for their design decisions. For example, expert 10 stated *"An important aspect about this technique is that it really makes sense only when used interactively"* in the rationale section of pattern 77 without having mentioned interactivity in the solution. Expert 8 even wrote *"See solution"* in the rationale section of pattern 102. Another important quality of patterns is their accessibility for the user (see for example 'Single-Pass Readability', 'Skippable Sections' or 'Terminology Tailored to Audience' patterns in Meszaros and Doble, 1996). The patterns were heavily cluttered with field specific jargon: audio specific terminology was used on 110 occasions in the patterns (4.4 per pattern on average). While the most common ones like 'sonification', 'pitch' or 'timbre' might be familiar to most novices approaching the field, terms such as 'granular synthesis', 'envelope' or 'amplitude modulation' are less likely to be understood and hence make these patterns less accessible.

To be able to remember and refer to patterns easily the name (or title) of the pattern plays a central role. In order to create evocative names Meszaros and Doble (1996) suggest naming a pattern after the result it creates or to use a meaningful metaphor. The names chosen by the experts were five words long on average ($\sigma = 4$) with the longest being comprising 20 words and the shortest two words. Most were named after what they would provide (e.g., 'Menu navigation - Semantic reinforcement'), but some also took the name from the prototype they were based on (e.g., 'EMG sonification') or used metaphorical phrases (e.g., 'Virtual Geiger Counter'). Compared to the names of the patterns in the Welie collection (129 patterns, 1.9 words per name on average, three words maximum, van Welie, 2006) the names seem generally too verbose and sometimes not well linked to the actual content of the pattern or misleading (e.g., 'Virtual Geiger Counter'). The organisation of patterns in **paco** and their inter-relation through their location in the context space may make the names less important in the selection process of appropriate patterns for a given design problem. To which degree this organisation can overcome poorly chosen names will be shown in phase two of this study.

Although research papers naturally provide a much more detailed account of the work conducted by their authors, there are also bits of information that were evoked by the process of describing it through a pattern format that were not present in the literature. In the following example the rationale section of pattern 79 'EMG Sonification' (left) is compared to relevant sections of the corresponding research paper.

Pattern 79	**Literature**
The rational behind the use of AM was the constraint of needing to use the raw EMG data and needing to use a synthesis algorithm that produces a well known, and easily understandable, spectrum. Another possibility was to use Audification but this would have made more difficult to hear non-varying data or separate the channels in the frequency range.	*Our first experiments involved audification ... the EMG data sampling rate is rather slow compared to the data rate needed for sound ... when multiple sensors were used the resultant signal becomes very noisy. ... The final choice of sonification involved amplitude modulation;*

While the rationale for using AM (amplitude modulation) is clearly explained in the pattern it is much more vague in the paper. The paper describes how the authors arrived at the design, but the *"final choice"* is given with no explicit rationale. The fact that amplitude modulation was chosen because it *"produces a well known, and easily understandable, spectrum"* is not mentioned at all in the paper. This could be the result of the time authors had to reflect on their solutions since they had written the paper. Or they incorporated experiences which were not directly related to the specific solution, but were considered relevant for the generalisation. Another reason might be the target audience group: the explanation provided might be sufficient within the scientific community; i.e., everyone would know about the spectral properties of AM and hence be able to infer the reason for its use. This connection, however, is harder to make for novices to the field.

Another example illustrates how the 'forces' section of a pattern provokes authors to explicitly express trade-offs in the design that are not provided in their research literature:

Pattern 98	**Literature**
Keep sounds short to keep soundscape discreet while the user navigates the menu ***versus*** *Use longer sounds to widen the field of design options.*	*The constraints imposed on the design (temporal in particular: sounds have to be short) imply that only simple musical structures can be employed. ... Keeping the density and duration of a sonification small is a critical issue because the overall density of a menu sonification is a factor of annoyance.*

On the left a force provided in pattern 98 'Menu navigation - Semantic reinforcement' describes an important trade-off concerning the duration of sounds. In the corresponding publication no references to the length of sounds do convey the same information. While perhaps obvious to the experienced designer, this is valuable information for the novice. Similarly, the derived pattern 99 'Menu navigation - Semantic reinforcement 2' introduces the idea of themes or leitmotifs[5]. In the pattern the author raises three fundamental problems with using this concept:

Pattern 99

- *Themes are likely to be long, therefore inappropriate for fast menu navigation.*
- *Themes are likely to sound very distinct, thus undermining the homogeneity of the soundscape created.*
- *There is a risk of making the overall soundscape sound too cheesy.*

These issues could not be found in the related publication. Remarkably, the last item in the list also carries a very subjective and rather unscientific statement about the overall quality of the sound used. This is an example of how authors also express values in patterns which can play an important role in conveying good practice and is considered as being a strength of design patterns (see Dearden and Finlay, 2006).

The main added value of pattern 75 'Fast-audio graphs' can be seen as providing a synopsis of a series of publications that describe the design concepts and support them by detailed evaluation. The pattern provides the core of a solution in a very concise way:

Pattern 75

Keys to the solution:

- *Speed-up the generation of each auditory graph...*
- *Vary speed to control required level of detail...*
- *High temporal resolution...*
- *Rhythmic patterns...*
- *Dimensional reduction...*

None of these aspects in this pattern would not also be available in the papers. It would, however, be comparatively hard for a novice to extract the above *"Keys to the solution"* in

[5] A recurrent theme throughout a musical or literary composition, associated with a particular person, idea, or situation (New Oxford Dictionary).

the same way from a series of papers, especially because they are hardly ever flagged as such. The two patterns derived from 'Fast-audio graphs' provide different point of views on the same solution. While pattern 77 'High-density sonification (HDS)' is essentially a special case of its parent pattern, pattern 91 'Integrated Audio-Visual Data Analysis (IAVDA)' uses the previous patterns and puts them into a multi-modal context. This provides an excellent example of how patterns could eventually be used to bridge the gap between different interaction modalities towards a unified body of design knowledge.

Without doubt, papers provide more comprehensive insights into the work and patterns are no substitute for reading research papers for detailed information about a specific design. However, the patterns created in this evaluation indicate that describing designs through a pattern format can make certain aspects more accessible, most prominently:

Rationale Research papers in this field do not always reveal the rationale for design decisions. Through the existence of a rationale section in the pattern format authors are more likely to express their reasoning explicitly.

Trade-offs Many design decisions are trade-offs between forces that work on the problem. And many of those are not explicitly expressed in research literature because they are of no direct concern for the result, but crucial for adaptation and re-use.

Values Good practice also incorporates values being conveyed by expert designers that are not strictly scientifically proven or provable such as æsthetics. Patterns are more informal than research literature and therefore provide for including these values.

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.

The following section reviews the feedback the experts provided in the post-questionnaire before section 5.3.3 summarises the results of this phase.

The Post-questionnaire

Six of the 13 participants of this phase returned the post-questionnaire. The low return rate reflects a more general problem with experts in any scientific field: they are very busy. This was also shown in the long time it took them to finish their patterns in the online system (over two months) and the fact that four experts dropped out at this earlier stage. The following paragraphs analyse the feedback provided qualitatively only as the small number of answers does not allow for quantitative analysis.

The **paco** framework was described by participants as a *"system to aid designers in describing their design process"* (E9) with the aim of sharing solutions in the scientific community. It was emphasised that **paco** provides methods for solutions to be *"described in a structured manner"* (E10) and in a *"specific format (referred to as a pattern in the framework)"* (E2). All answers focused on re-usability and 3 out of 4 also referred to the context space.

The way people described their workflow revealed some of the problems participants had with following the instructions. Expert 19 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! Then I added the modified patterns."*

This illustrates that it might not have been entirely clear to participants how to generalise a pattern from a specific design within **paco**. Instead, some have started already with a generalised description. On the other hand expert 10 described:

> *"I started describing an auditory display that is already implemented. Then, I derived from it another auditory display that had also already been implemented. Finally, I derived from those two a third auditory display that has not yet been implemented."*

which fits well into the intended workflow of the **paco** framework.

Asked for what they liked about **paco** three participants made references to re-usability, e.g., that **paco** enabled them to break-down their designs into re-usable chunks (E2). Two participants emphasised the fact that **paco** made them think about all the aspects of the context of use and one mentioned to like *"the idea of thinking of conflicting design requirements"* (E9). On the negative side, one participant did not see the benefit of specifying the context and one did not like the tags. One was confused by the instructions given and one mentioned that the rating should not be left to the authors.

All but one participant said that they learned something new about their design by thinking about its re-usability, e.g., expert 19: *"I had not thought of them as patterns. However, when I formulated them, I went through a mental process that treated them like patterns. So they were patterns all along! It took Paco for me to realize that".* Most notably, expert 10 stated: *"I became more consciously-aware about their characteristics and the place they fill within the whole scope of users and applications".* This statement supports the hypothesis that the **paco** framework helps designers to conceptualise the design space. Expert 5 formulated a similar thought, but with a different conclusion: *"I learned that my designs, as stimuli for research, were more narrowly applicable (i.e., were narrower in context) than I might have considered before".* All participants, however, stated that they would re-use the patterns they created in future work.

Most participants did not answer the question about anything missing to describe designs in the context space. One mentioned that the existing dimensions would overlap and one would like to see more specific categories for some dimensions *"to have a more thorough check-list"* (E10). Besides the statement of expert 4 mentioned above, all expressed a preference for tagging versus scales at this stage.

Very little feedback was given about the pattern format. Notably, expert 19 made an argument for the limited ability of patterns to describe interaction: *"I can describe textually what goes on, but it would be better to have some visual way of showing it that can indicate the motion.".* Although we do not necessarily agree that it needs *"some visual way"* to express motion or interaction, the fundamental argument is highly justified and highlights a missing feature in the pattern format. Expert 10 argued for a more rigourous pattern format that would provide easier to follow guidance for authors: *"However, it would be* *helpful that the framework acted as a checklist of aspects that are often relevant, although not necessarily present".*

Asked for outstanding work that has shaped the scientific field, participants mentioned major techniques in auditory display design such as auditory icons, earcons or audification. In terms of applications of these techniques, assistive technology, medical diagnosis and mobile computing were mentioned as important. The list of sounds in technology that participants liked is dominated by alarm sounds (e.g., messaging notifiers, alarm for the lights in a car etc.). Exceptions included the trash-can auditory icon in Apple OS X, a signature sound for turning on/off a TV set and sound effects in films. Interestingly, the experts seem to have struggled with naming such sounds, or as expert 5 states: *"Wow - these were hard to come up with, which says something about how much of the knowledge in the field is actually implemented in devices on the market"* or more explicitly expert 4 says: *"I have to admit that I can't think of auditory displays that I truly like...".*

5.3.3 Conclusion and Interpretation

Phase one investigated the process of pattern creation by experts in auditory display design with the **paco** framework. Participation was decreasing during the course of this phase of the study; of the 13 participants who returned the pre-questionnaire, nine were creating patterns through the online system and six were returning the post-questionnaire. Nevertheless, 25 patterns were created that reflect substantial design knowledge.

The pre-questionnaire helped shaping the profile of the group of participants. Despite being experts in the field and having a considerable record of relevant publications, it was remarkable how much their skill was repeatedly referred to as a craft. While many reported that their low-level design decisions are informed by perceptual guidelines, their conceptual design seems to be mainly driven by intuition or experience. Interestingly, experts also struggled to find explanations for why audio is being underused in the commercial market. Only two blamed the quality of existing solutions; in both questionnaires, however, no participant found it difficult to find bad examples of audio in technology. Hence, there seems to be a gap between the functional abilities of sound and its æsthetic features that would allow audio to play a bigger role in human-technology interaction.

All but one participant found it easy to identify potential pattern material in their work. The one exception focused on a design method rather than a design solution. Although there is no reason why such processes could not be described in a pattern format[6] it was not the intention of **paco**. All other participants started with the description of a suitable, concrete design or design aspect and continued from there to create generalised design knowledge.

During the creation of the design patterns through the online system participants were only guided by the instructions given on the pages. This resulted in them following the **paco** workflow only partly. The numbers of derived patterns and the small changes to the rating indicate that participants did not push the process to its full extent. Although there was a clear tendency to generalise solutions as they were derived, there were few attempts to describe novel, non-implemented solutions. Experts were reluctant to leave the safe grounds of evaluated solutions and hardly dared to make informed guesses. This is supported by the fact that three of the nine authors did not derive any patterns from their initial descriptions. Also the changes made to the context space descriptors when deriving a pattern were only minor and seem not to have helped authors much with generalising their designs.

On the other side, the context space was credited for making the authors aware of contextual aspects of their designs. Furthermore, there is evidence that it helped designers to find *"the place [their designs] fill within the whole scope of users and applications"* (E10) i.e., to conceptualise the design space and to create conceptual relationships between solutions. Phase two of this evaluation study will show whether the context descriptions were appropriate for novices to match problems with the patterns. The number of tags used and created and the feedback given in the post-questionnaire indicate a preference for tags over scales.

The overall quality of the patterns is difficult to assess at this stage. How well these patterns work on different problems phase two will reveal. However, comparing them to carefully written patterns for collections such as Tidwell (2005) or van Welie (2006) is

[6]The Meta-Patterns by Meszaros and Doble (1996) are a good example

inappropriate as the authors are experts in auditory display design, but novices in writing patterns. Formally, the patterns created featured all the mandatory elements required although authors frequently confused sections and provided information in inappropriate parts of the pattern. The most important outcome of this phase is the evidence that these patterns were able to capture design knowledge that was not present in other sources. Especially regarding the rationale and reasoning the patterns reflected expertise that was difficult to grasp by, or not existent at all, in the relevant research literature.

There is evidently an added value in describing designs through the **paco** framework resulting in design patterns of various levels of abstractions from the specific solutions. Whether this added value can be transferred to novices trying to solve related, but different design problems will be investigated in the second phase: applying design patterns.

5.4 Phase Two: Applying Design Patterns

The goal of the second phase of this evaluation study is to test the design patterns created in phase one with novices to auditory display design. For the purpose of this study novices were defined as people with basic experience in designing user interfaces, but without knowledge about auditory displays or the design thereof. For example, a typical participant for this phase would be a computer science graduate student who attended standard HCI related courses or an HCI practitioner.

The design of the study was inspired by the one conducted by Chung et al. (2004) (as discussed in section 2.4.3). However, the conditions and measures applied in this study were adapted to specifically target the hypothesises defined above. The following sections introduce the design of the study, the methods and the results. At the end follows a discussion and interpretation of the results.

5.4.1 The Method

Participants were first given an information sheet that explained the context of the research and laid out the structure of the experiment. After signing a consent form, they filled in the pre-questionnaire and received their task. In the task description they were asked to create a design sketch—a concept design—for a given design problem and subsequently present their ideas to a fictional client. They had 40 minutes for creating a design and 5 minutes for their presentation.

Four different conditions determine the type of guidance they were given during the design process:

Condition A No guidance

Condition B Sub-set of the four most relevant design patterns as a list

Condition C List of all design patterns

Condition D **paco** online system

Condition A is the baseline and probes for spontaneous solutions to the design problem. Condition B provided a sub-set of four design patterns in a list to assist the participant in solving the design problem. These four design patterns were chosen to be the most relevant for the design problem given. A list of 16 patterns created in phase one was provided in condition C. Nine of the 25 patterns created in phase one were discharged to provide a balanced variety in terms of form and content. Condition D provided the **paco** online system and allowed participants to locate the design problem in the context space before an interactive visualisation of the context space showed their problem in relation to all design patterns and participants could explore the space and open any pattern.

The comparison of the baseline condition A to all other conditions (B, C, D) allows for measuring the overall impact of design patterns on the process. The available features in the solutions are the indicators for transferred design knowledge and the general awareness of design options. Contrasting condition B and C provides insights in the selection process. Both conditions provided the patterns as a simple list and the comparison will show if limiting the available range has an impact on the solution. Conditions C and D provided the same number of patterns, but presented them in different ways. This pair allows for measuring the impact of the method **paco** provides to apply design patterns. In particular, it shows if conceptualising the problem domain and exploring the context space is beneficial for the results. The performance of condition B in comparison with C and D could not easily predicted. One could argue that limiting the number of patterns to the most relevant ones should be beneficial, but equally, this reduction could mean the loss of the broader context, causing it to perform worse.

Participants in the pattern conditions were shown an example from Tidwell (2005) (Breadcrumbs, p. 78) and the concept of design patterns was briefly explained before they started the task. During the design process practical help was provided for using the online system, but no further advice was given. It was pointed out that they could make use of the patterns as much or as little as they wanted—participants could use all, none or any part of the patterns provided. Also, it was stressed that there is no single right way of solving the problem, but many possibilities and it would be up to the participant to decide which solution they would produce.

After 40 minutes the participants were asked to present their ideas to a fictional client. They were told to be as specific as possible within the five minutes they were given and focus on the design of the audio in their interfaces. They were asked not to refer to any pattern during this presentation, but only describe the solution they produced. The test facilitator could ask questions to clarify aspects of the design or probe for specific properties if participants were too vague or unclear about them.

After the presentation participants in the pattern conditions were asked to rate the patterns (0 for not read to 5 very useful for solving the problem). The following sections describe the various stages of the experiment in more detail.

The Pre-questionnaire

The background and experience of the participants is important for an experiment such as this. The pre-questionnaire aimed to capture the profile through two blocks of questions. The first block elicited demographic characteristics such as age, gender, education and profession. It also asked whether participants played an instrument and at which level. The second block aimed to determine the experience participants had with designing user interfaces, audio in HCI and the concept of design patterns.

The exact wording of the pre-questionnaire is available in appendix E.1. When participants were finished, they received the task and their design problem.

The Design Problems

In order to control for the variability in the design patterns two different design problems were created and assigned randomly to participants. Both design problems had in common that they forced participants to use audio in their designs as they restricted the use of visual means. It was stressed in the description that the problem is given as-is and that some aspects might be under-defined or unspecified. In these cases, the participants were free to assume whatever they thought was appropriate.

The problems were given as short design briefs (213 and 261 words) and incorporated information about the users and other aspects of the context of use. Neither was directly linked to any of the design patterns created by the experts, but some of the patterns described features that could be used to solve the problem.

The first problem was to design a next-generation MP3 player that had no visual screen. Similar to an iPod Shuffle, however, the player should also incorporate basic PDA functions such as access to calendars, shopping list etc. All information is synced from a base station so that participants needed not to worry about text entry. It was stressed that there was enough computational power available to incorporate more complex audio techniques. The context of use was described as highly mobile with users on-the-go and the device could be integrated into other physical objects such as handbags.

The second problem was set in a financial environment. The task was to design a system that would allow stock-market analysts to monitor multiple values of natural resources (e.g., gas, oil etc.). The specification did not allow the participants to use visual screens as it was argued that they were already overloaded with information, but to use sound to convey the information. Analysts should be able to react to certain patterns in the data and make important trading decisions. The brief described the stressful environment and the high demands of the target user group. Technically, everything was feasible and no constraints were restricting the use of sophisticated audio techniques.

MP3 player		Stock market	
100	Menu navigation - contextual cues - depth of menu option	70	Awareness Alarm
102	Menu navigation - contextual cues - relative position	79	EMG sonification
98	Menu navigation - Semantic reinforcement	80	Helicopter's data sonification
99	Menu navigation - Semantic reinforcement 2	54	Virtual Geiger-Counter

Table 5.2: Design patterns selected for condition B

Both design briefs ended with a paragraph re-stating the task, emphasising that in the following presentation they should describe their solution in the most possible detail and provide the rationale for the main design decisions. Participants then had 40 minutes to develop a concept design with or without the help of design patterns, depending on the condition. They were encouraged to make notes on paper and to ask questions if there was anything unclear about the task. Questions about the specification of the problem would not be answered unless it was a simple clarification of what was written. The exact wording of the design briefs is available in appendix E.2.

The Online System

In three conditions participants were provided with design patterns. In condition B a list of four design patterns was provided that would match closely with the problem given. The two lists for the two different problems did not overlap and were compiled according to the most relevant concepts they included. Table 5.2 shows the patterns selected for the problems. Condition C provided a list of all patterns alphabetically ordered. Figure 5.8 shows a screenshot of the page. All titles were linked to read-only versions of the patterns that would not allow participants to alter them, but they would still provide help tool-tips as in phase one to explain different sections in the pattern. The patterns for conditions B and C were also stripped of author, inheritance and descriptor information.

Condition D provided participants access to the patterns through the methods from the

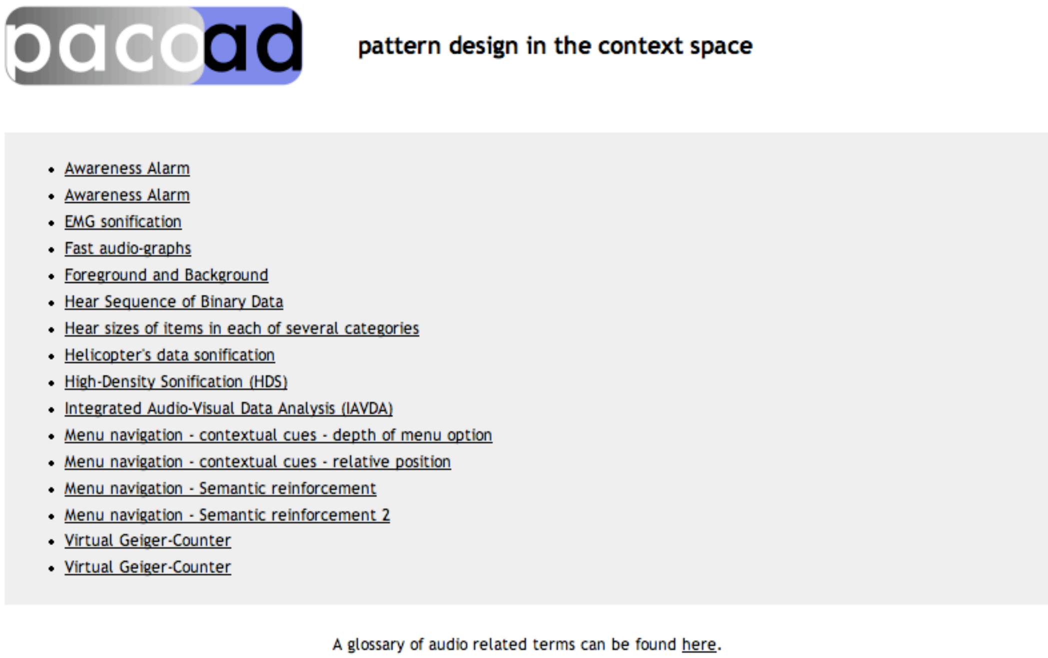


Figure 5.8: The list of patterns as provided in condition C

paco framework. The first step for participants was to localise the design problem in the context space. This was achieved through the same interface that experts used to localise their design patterns (see figure 5.2). Participants could use all tags created by the experts (more frequently used displayed in bigger fonts) and were asked to specify the scope values for each dimension. When finished the online system started a visualisation of the context space in which the design problem was linked to design patterns through common tags. The interactive visualisation allowed participants to explore the context space and open design patterns by double-clicking the blue pattern nodes. The visualisation could be zoomed and dragged using the mouse pointer. Figure 5.9 shows a screen-shot of the visualisation.

Data collection & analysis

The data collected during the experiments include:

- the pre-questionnaire,
- interaction logs for all pattern conditions (PHP logs on the web-server),

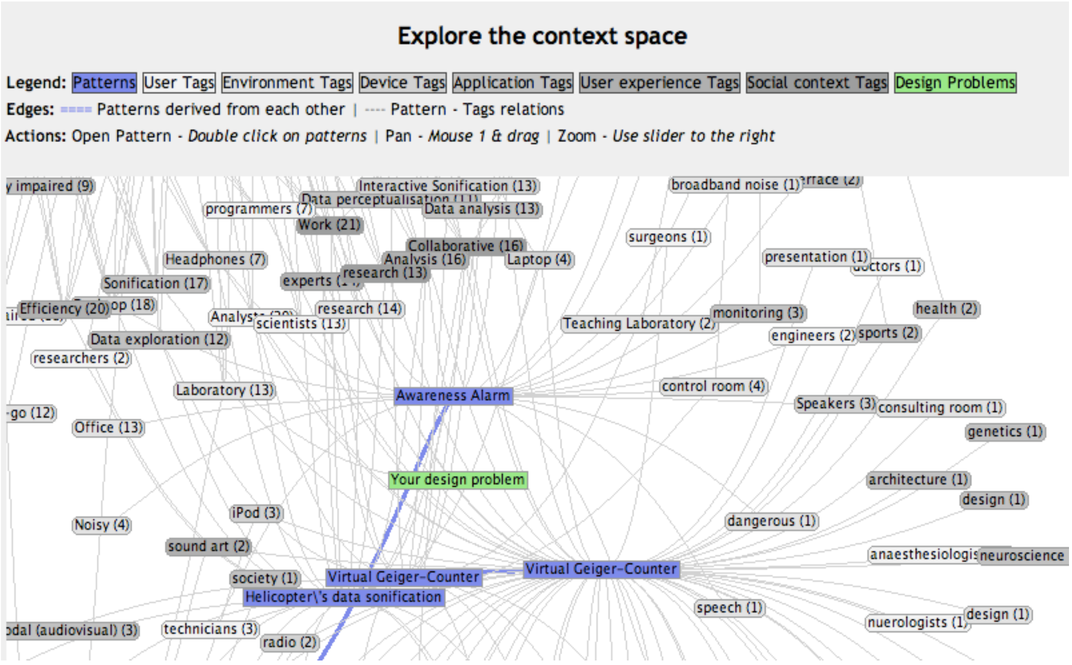


Figure 5.9: The visualisation of the context space as provided in condition D

- screen capture video[7],
- video footage of the process (40 minutes) and the presentation (5 minutes) and
- notes and other written material produced during the design phase.

The feedback given in the pre-questionnaire allows for drawing an accurate picture of the background of participants and ensures that their relevant levels of expertise is evenly distributed between the conditions. The logs, the written material, the screen capture and the video footage of the design process provide detailed information about how participants went about solving the task given. The analysis of this data focuses on the interaction with the design patterns and reveals which patterns were chosen during the process, which sound examples were played and at which patterns influenced the design solution.

The video footage of the presentation not only is key to extract the design features that were chosen by the participants, but also were used for anonymous judging. Six experts, blind to the conditions, were asked to rank the quality of the solution presented in these short videos. The criteria for this assessment were broadly defined as

[7]Screen capture videos were produced using iShowU (http://www.shinywhitebox.com/)

- How well did the participant meet the requirements of the brief?
- Which one is the better overall design?
- Imagine you are a user, how satisfied would you be with the solution described?

An online system provided the judges with two presentations for the same problem which they were asked to rank. The system would automatically choose two appropriate presentation videos to ensure each presentation is judged at least twice and that each condition is judged against every other condition. Judges could visit the web-page as often as they wanted. They were provided with the design brief, but no further information about the conditions was provided. To protect the identity of the participants, the videos were scrambled. Figure 5.10 shows a screenshot of the page.

Figure 5.10: The judging web-page for presentation videos

5.4.2 Results

The following sections present the results of the study. The first summarises the demographics of the participants elaborating on their background and other information elicited from the pre-questionnaire. Subsequently, a section shows results related to the design process i.e., the analysis of the video material captured while participants worked on their solutions, the analysis of the written material, and the interaction with the online system. Section 5.4.2 then investigates the presentations of the solutions before section 5.4.3 provides a summary and an interpretation of the results presented.

Demographics

After conducting an informal pilot study with colleagues 29 people participated in the main study. All but four were between 20 and 30 years old with all being under 40 years. Roughly one third of the participants were female (31.3%). 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. Figure 5.11 shows the overall distribution of participants by condition and the given problem.

Participants by condition

	MP3 Player	StockMarket	All
A	3	2	5
B	4	3	7
C	4	4	8
D	3	4	7
All	14	13	27

Figure 5.11: Participants by condition and problem group

All of the participants can be considered being novices to auditory displays, but having background in human-computer interaction or user-interface design. None of them had come across research literature related to the field or were introduced to the techniques of auditory display design as part of their education. All participants were students in computer science, two were in their third year of undergraduate studies, 11 were in a masters programme and 14 were PhD students. The different qualifications were as evenly distributed across the conditions as possible. Figure 5.12 shows the distributions of some of the key properties.

Almost a third (nine out of 27) played an instrument, but no one at a professional level. Slightly more (13 or 48.1%) were familiar with the concept of design patterns. However, only one had come across design patterns for user interfaces without having used any. The majority of them (10) knew design patterns only from software engineering, most commonly

PhD student Distribution

	MP3 Player	StockMarket	All
A	2	1	3
B	2	0	2
C	2	3	5
D	2	2	4
All	8	6	14

MSc student Distribution

	MP3 Player	StockMarket	All
A	1	1	2
B	2	1	3
C	2	1	3
D	1	2	3
All	6	5	11

BSc student Distribution

	MP3 Player	StockMarket	All
A	0	0	0
B	0	2	2
C	0	0	0
D	0	0	0
All	0	2	2

Figure 5.12: Distribution of groups of participants across conditions

through the Java programming language. The remaining two mentioned workflow patterns and project management patterns. This means that all participants can be considered as being sufficiently naïve regarding the use of design patterns as the format, the domain and the presentation were considerably different. The analysis of the performance below also showed that there seems to have been no advantage for this group of participants.

Asked for the use of audio in any of their designs over two thirds of the participants answered they had never used any sound. Five mentioned the use of background music for games, three used clicks for buttons and also three mentioned some other form of alarm. Notably, one participant reported to have designed a toaster with a beep to indicate that it is finished. One participant had experience with speech based user interfaces.

Participants described their usual design process mostly through single keywords. Over half of them mentioned some form of prototyping and slightly less referred to user requirements. Remarkably, only a quarter (or 26.9%) included an evaluation phase and only 19.2% provided the combination of prototyping, user requirements and evaluation. Other answers were centred around functional requirements (e.g., *"List interaction elements (user input, system output), group those by functionality"*), tool support or existing solutions. Figure 5.13 provides an overview of the answers.

The Design Process

Participants had approximately 40 minutes to develop a design for the design brief given. The time limit was not enforced strictly because the different conditions demanded varying efforts of reading and other sub-tasks like specifying the context through the online system. Participants were told they had 40 minutes in the beginning and were reminded of their

Design process

	#	%	
Prototyping	13	50.0%	
User requirements	13	50.0%	19.2%
Evaluation	7	26.9%	
Drawing on paper	5	19.2%	
Iteration	5	19.2%	
Functional req.	3	11.5%	
Tool support	3	11.5%	
Storyboard	2	7.7%	
Existing solutions	3	11.5%	
Task analysis	2	7.7%	
Advice by others	2	7.7%	

Figure 5.13: The design process as described in the pre-questionnaire

timing during the process, but could run longer if they needed to. Figure 5.14 shows the overall time used in each condition. As expected, conditions A and B were the shortest and participants finished the task in less than 40 minutes. The increase for condition C reflects the greater number of patterns available to the participants. Condition D ran the longest, but also demanded the most effort by the participants and the most interaction with the study facilitator. An extra effort for participants in condition D was to define the context of the problem which took them 7.5 minutes (σ 3.77) on average. Considering this, it is reasonable to argue that the effective differences in time were marginal and the practice in enforcing the time limit ensured that time constraints would have no impact on the quality of the solutions.

Process Time

	MP3 Player	StockMarket	All
A	38.50	38.90	38.66
B	38.53	38.00	38.30
C	41.83	40.88	41.35
D	45.97	42.88	44.20
All	41.06	40.52	40.80

Figure 5.14: The overall time participants used up for designing a solution by condition

All but two participants looked at all the patterns provided when in condition B (3.57 on average in a list of four patterns). When provided with the full range of patterns (conditions C and D), this number increased to over eight patterns on average. This is about half the patterns that were made available (16). The difference between condition C and D is marginal and statistically not relevant. Slightly less than three of these eight patterns were from the group of most relevant patterns as selected for condition B. For condition C, three patterns were within that group and 5.63 were outside; for condition D it was slightly less, 2.43 inside and 5.71 outside. Again, the differences between C and D were not statistically relevant. Figure 5.15 provides an overview of the numbers.

Average

	∑	On	On%	Off
B	3.57	3.57		
C	8.63	3	35%	5.63
D	8.14	2.43	30%	5.71

MP3 Player

	∑	On	On%	Off
B	3.25	3.25		
C	9	3.25	36%	5.75
D	9.33	2.67	29%	6.67

StockMarket

	∑	On	On%	Off
B	4	4		
C	8.25	2.75	33%	5.5
D	7.25	2.25	31%	5

Figure 5.15: Patterns looked at during the design process

The majority of participants also played sound examples from the patterns. Interestingly, the data suggests that participants in condition C played fewer sound examples than those in conditions B and D. Although the number of patterns that participants looked at was equal for conditions C and D, only half of the participants played sound examples in condition C while 71% did so in condition D. The difference, however, is made up entirely from participants with the MP3 player problem and might just be an anomaly. Figure 5.16 shows the distribution for all conditions.

Sound examples

	MP3 Player	StockMarket	All	(#	of)
B	100%	67%	86%	6	7
C	25%	75%	50%	4	8
D	67%	75%	71%	5	7
All	64%	72%	69%	15	22

Figure 5.16: Participants who played sound examples from the patterns

Participants in condition D were advised to use around two tags per dimension to describe the context of the problem in the online system. On average they used 11.71 tags for the six dimensions (σ 3.81). The majority of the tags chosen was appropriate for the given problem. Overall, only 7.3% (6 out of 82) of the tags were not in line with or inappropriate for the requirements stated in the design brief. On average, the tags connected the problem to 13 (σ 2.14) of the 16 patterns through an average of 28.86 (σ

9.87) links[8]. About one quarter of these links connected the problem to the group of the most relevant patterns (26.7% for the Stock Market problem, 21.3% for the MP3 Player problem). As the force-driven layout of the visualisation of the context space reflects this interconnectivity through tags, relevant patterns were not always spatially close to the problem.

A closer analysis of the tagging process reveals that this is mainly caused by the big variability in number of tags used in the patterns (see also section 5.3.2). Patterns with many tags associated were more easily linked with the problem than patterns with few tags. A ratio between the links to a pattern and its number of tags was therefore introduced as an additional metric to indicate the interconnectivity of a pattern with the problem (i.e., higher = better). Figure 5.17 shows the links and the link ratio by pattern. The background colour indicates the group of the most relevant patterns for each problem (yellow - Stock Market, green - MP3 Player). Numbers of links and the link ratio values are also provided for the two problem groups and show how well which patterns were connected to which problem. The averages by problem show that for the MP3 Player problem, the most relevant patterns were linked well with the problem (0.57) while the other patterns did less (0.36). For the Stock Market problem however, the MP3 Player patterns come top too. This might have been caused by the small, but very generic number of tags used in the MP3 Player patterns (e.g., "any" in the users dimension). While the patterns relevant to the Stock Market problem scored higher, they were hardly more linked than the patterns which were not in either of the groups. The bottom line of this analysis is that participants tended to used appropriate tags to connect to relevant patterns, but the variability in numbers of tags used in patterns caused these links to be less obvious and not well represented in the context space.

An important aspect of this analysis is that participants were able to explore the context space interactively. The most common strategy observed for navigating the context space was the use of the highlighting function to reveal stepping stones between the problem and patterns. Participants would move the mouse pointer over the problem to see the

[8] A link is defined as every occasion of a common tag between the description of the context of the problem and a design pattern.

Interconnectivity by Pattern

	54	70	77	75	79	80	83	84	85	86	87	91	98	99	100	102
# of tags in pattern	17	22	49	38	25	24	44	65	19	19	19	26	7	7	7	7
Links to the pattern	6	15	33	24	4	13	12	12	10	10	10	21	8	8	8	8
Overall Link ratio	0.35	0.68	0.67	0.63	0.16	0.54	0.27	0.18	0.53	0.53	0.53	0.81	1.14	1.14	1.14	1.14
Links StockMarket	5	13	18	14	3	10	2	9	8	8	8	13	4	4	4	4
Link ratio	0.29	0.59	0.37	0.37	0.12	0.42	0.05	0.14	0.42	0.42	0.42	0.5	0.57	0.57	0.57	0.57
Links Mp3 Player	1	2	15	10	1	3	10	3	2	2	2	8	4	4	4	4
Link ratio	0.06	0.09	0.31	0.26	0.04	0.13	0.23	0.05	0.11	0.11	0.11	0.31	0.57	0.57	0.57	0.57

Averages by problem

	StockMarket	Mp3 Player	Off
Links to the pattern	9.50	8	16.50
Overall Link ratio	0.43	1.14	0.52
Links StockMarket	7.75	4	10
Link ratio	0.36	0.57	0.34
Links Mp3 Player	1.75	4	6.50
Link ratio	0.08	0.57	0.18

Figure 5.17: Interconnectivity by pattern and averages by problems

tags they chose. When the mouse was moved over one of these tags, the linked patterns would be highlighted. This strategy enabled participants to find connections for particular aspects of their problem. A connection through a tag represents a special contextual aspect that the pattern and the problem have in common, for example a user group or an environment. This allowed participants to explore possible solutions with particular features of the problem in mind.

Although the context space provided additional cues that aimed to help participants to conceptualise the design space, a decisive aspect for opening a pattern remains the title. This is evidenced by observing participants not opening patterns close to the problem or opening patterns that are neither linked nor proximate depending on whether the title seemed relevant. This means that the title of the pattern can override the cues of the context space.

On average, participants produced slightly over two pages of written material during the process. Unsurprisingly, the most pages were produced by participants in condition A (3.7). The verbosity decreased slightly for condition B and dropped significantly for conditions C and D[9]; i.e., the more patterns were available, the less participants wrote on paper.

[9]Independent-samples t-test. A-C: $t = 4.1, p = 0.02$ A-D: $t = 5.31, p = 0.00$

This can be explained by the increasing efforts of reading (participants in conditions D and C looked at roughly twice as many patterns as in condition B, see above). Of all participants in pattern conditions (B, C, D – a total of 22), seven made no direct reference to a pattern in the written material[10]. While participants in condition B made less than two direct references to patterns (1.08), there was a significant increase for condition D (3.21)[11]. This difference can be explained by the reduced number of patterns in condition B. For condition C (1.88) this difference is less and not statistically significant[12]. However, this trend is difficult to explain as the same number of patterns were available to the participants. We argue that participants referred to patterns on the paper as they consider them being more worthy to solve the problem. This is supported by the data in such as only a third of the patterns participants looked at were in the group of the most relevant patterns, while over half of the patterns referred to in the notes were in this group[13]. This indicates that, despite having looked at the same number of patterns, people found more patterns worthy in condition D compared to condition C. Figure 5.18 provides the numbers.

Pages written

	Mp3 Player	StockMarket	All
A	3.8	2.8	3.3
B	3.8	1.5	2.7
C	1.1	1.6	1.3
D	1.1	1.1	1.1
All	2.5	1.7	2.1

Patterns referred to

	Mp3 Player	StockMarket	All	% On
B	0.5	1.67	1.08	100%
C	1.25	2.5	1.88	53%
D	2.67	3.75	3.21	55%
All	1.47	2.64	2.06	62%

Figure 5.18: Analysis of the written material produced during the experiment

Presentations

After 40 minutes of designing, participants were asked to give a short presentation of the design they created. Although participants were told that they would have 5 minutes they would not be stopped if they had more to say about their solution. Questions by the

[10] A direct reference was accounted when the pattern name, full or partially, was given or an unambiguous reference to any part of a pattern was made.

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

[12] Independent-samples t-test. C-D: $t = -1.33, p = 0.205$

[13] This ratio is consistent for condition C and D, compare the numbers in figure 5.15 and 5.18

facilitator and clarifications also prolonged the presentations. With an average duration of 6.37 minutes however, the given limit was not greatly exceeded. The standard deviation of 2.2 minutes shows that the majority of the participants was in reasonable boundaries. The maximum length was 11.5 minutes, the minimum length 2.6 minutes. The distribution between the conditions and the design problems was inconspicuous, as shown in figure 5.19.

Duration [min]	MP3 Player	StockMarket	All
A	7.84	8.20	7.99
B	7.23	4.75	6.16
C	7.29	6.31	6.80
D	4.87	5.70	5.34
All	6.87	6.05	6.37

Figure 5.19: Average duration of the presentations by condition and design problem

The subsequent analysis of the content of the presentations aims to reveal links between features of the solutions created by the participants and the design knowledge provided by the patterns. In a first step, the following basic means of auditory interaction techniques can be distinguished in the solutions: text-to-speech output (TTS), non-speech sound output, speech recognition and non-speech input. TTS is the use of speech for conveying any information that also could be expressed by text on a visual display. Non-speech sound output covers the whole range of sounds including alarms, more complex sounds such as earcons or any type of background sound. Speech recognition provides input by human vocal commands and finally non-speech input is defined as any other human or non-human auditory input to the interface like humming or the recording of the background noise.

While every single participant considered TTS as an appropriate technique for the MP3 Player problem, around two thirds (nine out of 13) used it for the Stock Market problem. No noticeable correlation can be seen between the conditions for the use of TTS. The use of non-speech sounds however, showed a more clear trend. One out of five (20%) participants in condition A used non-speech sounds compared to 57% and 75% for conditions B and C respectively. Strikingly, every single participant in condition D (seven) used non-speech sound in their solutions which is a statistically significant difference to condition A[14]. The use of speech recognition follows an inverted trend: while four out of five (80%) of the participants in condition A incorporated speech recognition in their solution, only one did so in conditions B and C. None of the participants in condition D chose speech recognition as an input channel. This pattern of use is difficult to explain as there was no mention of speech recognition in either the design patterns, or the design briefs. A possible explanation is that participants in condition A were so focused on speech as the sole interaction channel that they considered it appropriate to match the input channel and the output channel. This point of view is supported by the notion found in the survey presented in 3.2.2 in which participants stated that *"...input and output modality should be the same."* Apparently, the increased awareness of alternatives to speech for the output channel had an impact on how much participants incorporated speech in the input channel. Figure 5.20 provides the numbers for this analysis.

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%

Figure 5.20: Basic auditory interaction techniques in the solutions presented

For all categories there is an observable difference regarding the design problem. The data suggest that the MP3 Player problem lends itself more towards speech related techniques while the Stock Market problem in general provoked more non-speech sounds in the solution. These differences are trends, but not statistically significant. A similar trend can be seen between the use of non-speech sound and whether participants played example sounds in patterns. In all pattern conditions, 13 out of the 15 participants (86.7%) who played an example sound used non-speech sound in their solution. Out of the seven who did not play a sound, only four were using non-speech sounds (57.1%). Only one of the participants, thought of non-speech input and suggested humming as a way to search the music catalogue in the MP3 Player.

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

The following analysis focuses on a more detailed level and aims to investigate any correlation of particular features in the solution with features provided by the patterns. For this purpose, a list of properties have been identified that are present in some of the solutions and are promoted through techniques described in the patterns.

Mapping The use of data or information to change properties of a sound, e.g., mapping stock values onto pitch of a particular sounds.

Events Non-speech sound events cover 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 awareness 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 the analysis, that is, this list represents a selection of techniques that were identifiable in the solutions participants developed. Figure 5.21 shows which patterns promoted each of the techniques in the list.

The presentations of all participants were coded according to these features. The chart in figure 5.22 shows how often on average a feature was implemented depending on the

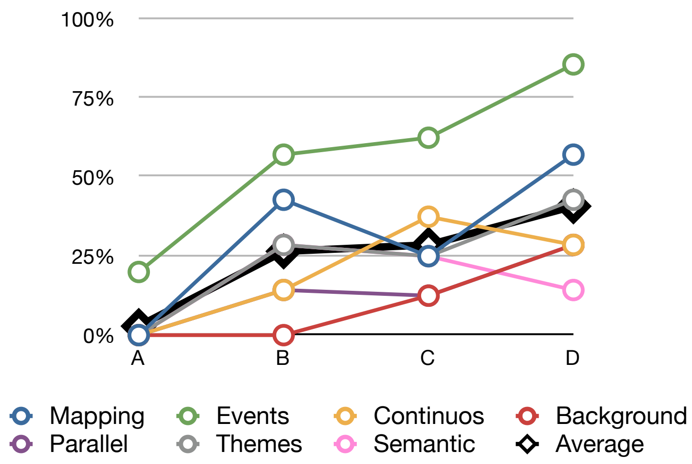
ID	Name	Mapping	Events	Continuous	Background	Parallel	Themes	Semantic
54	*Virtual Geiger-Counter*	☑	☑	☑	☑	☐	☐	☐
70	*Awareness Alarm*	☑	☐	☑	☑	☐	☐	☐
75	*Fast audio-graphs*	☑	☐	☑	☐	☐	☐	☐
77	*High-Density Sonification (HDS)*	☑	☑	☐	☐	☑	☐	☐
79	*EMG sonification*	☑	☐	☑	☐	☑	☐	☑
80	*Helicopter's data sonification*	☑	☐	☑	☐	☑	☐	☐
83	*Awareness Alarm*	☑	☑	☑	☐	☐	☐	☐
84	*Virtual Geiger-Counter*	☑	☐	☑	☑	☐	☐	☐
85	*Hear Sequence of Binary Data*	☑	☑	☐	☐	☐	☐	☐
86	*Hear sizes of items in each of several categories*	☑	☑	☐	☐	☑	☐	☐
87	*Foreground and Background*	☐	☑	☑	☑	☑	☐	☐
91	*Integrated Audio-Visual Data Analysis (IAVDA)*	☐	☐	☐	☐	☑	☐	☐
98	*Menu navigation - Semantic reinforcement*	☐	☑	☐	☐	☐	☑	☐
99	*Menu navigation - Semantic reinforcement 2*	☐	☑	☐	☐	☐	☑	☑
100	*Menu navigation - contextual cues - depth of menu option*	☑	☑	☐	☐	☐	☐	☐
102	*Menu navigation - contextual cues - relative position*	☑	☑	☐	☐	☐	☐	☑

Figure 5.21: Features promoted by each design pattern

condition. The table in the figure 5.22 shows the overall occurrences of features depending on condition and design problem. There is a clear trend visible towards condition D, but only the differences between the pattern conditions (B,C,D) and the baseline are statistically significant[15].

Looking more closely at the data (see figure 5.23) provides a number of valuable observations. The mapping feature was generally more often found in the Stock Market solutions (every second on average). For MP3 Player solutions, only condition D provoked some form of mapping (two out of three) while condition C saw none out of four. Only one solution in condition A implemented any non-speech sound events which should have been the most basic feature. The impact of design patterns is striking in this category as all pattern condition saw over 58%. Continuous sounds did not produce big differences while the use of background sounds was generally more favoured by participants with the Stock Market problem (three to one). Only one of the participants with the Stock Market problem used sounds concurrently and was referring to a mixed sound of all resource channels for pat-

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



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		
C	8	8	16	2.00	1.66	2.23	1.79
D	10	10	20	2.86	2.10		
All	25	25	50				
M	1.79	1.92					

Figure 5.22: Features identified in the solutions presented

tern recognition in the data. The concept of themes was considered more often for the MP3 Player problem as it was specifically promoted by the relevant patterns (99 and 102). The same effect can be seen for semantic value for the sounds used. Only one participant implemented this feature for the Stock Market problem.

To be able to link the design patterns to the features implemented in the solutions and therefore to assess their impact, figure 5.24 provides a matrix of features over participants. Each intersection can have one of the following four values: the participant read relevant patterns and implemented the feature in the solution (green), the participant did not read any relevant pattern but implemented the feature (yellow), the participant read a relevant pattern but did not implement the feature (blue) and finally, the participant did not read a relevant pattern and did not implement the feature (white). The patterns that emerge from this analysis show that on average participants in the pattern conditions (B, C, D) implemented 2.2 features that they read about. Condition D tops the list with 2.9 features followed by condition C (2.0) and condition B (1.6). Participants decided not to use 3.5

Mapping

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	1 of 4	2 of 3	43%
C	0 of 4	2 of 4	25%
D	2 of 3	2 of 4	57%
All	21%	46%	34%

Sound events

	MP3 Player	StockMarket	All
A	0 of 3	1 of 2	20%
B	2 of 4	2 of 3	57%
C	2 of 4	3 of 4	63%
D	2 of 3	4 of 4	86%
All	43%	77%	60%

Continuous sound

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	0 of 4	1 of 3	14%
C	2 of 4	1 of 4	38%
D	1 of 3	1 of 4	29%
All	21%	23%	22%

Background sound

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	0 of 4	0 of 3	0%
C	0 of 4	1 of 4	13%
D	1 of 3	1 of 4	29%
All	7%	15%	11%

Parallel sound events

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	1 of 4	0 of 3	14%
C	1 of 4	0 of 4	13%
D	1 of 3	1 of 4	29%
All	21%	8%	15%

Themes

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	1 of 4	1 of 3	29%
C	2 of 4	0 of 4	25%
D	2 of 3	1 of 4	43%
All	36%	15%	26%

Semantic

	MP3 Player	StockMarket	All
A	0 of 3	0 of 2	0%
B	2 of 4	0 of 3	29%
C	1 of 4	1 of 4	25%
D	1 of 3	0 of 4	14%
All	29%	8%	18%

Figure 5.23: Features in the solutions presented by conditions

features on average that were present in the patterns they looked at. The distribution in this case shows less variability (D: 3.3, C: 3.9, B: 3.3). For both aspects there were only marginal differences regarding the design problems. One participant in condition A and two participants in condition B implemented one feature each that they did not read any relevant pattern about.

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.

The anonymous judging of the presentations saw solutions from condition B being the

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

Figure 5.24: Features in the solutions presented correlated to patterns

rated highest. They won 11 of the 16 ratings (68.8%). Condition C and D came second winning eight of 16 ratings (50%) and condition A won four out of 14 (28.6%). A more detailed look comparing each condition with every other shows some interesting effects. Remarkably, conditions B and D both were consistently rated higher as condition A (four to zero and four to one), but condition A was favoured over condition C (three to two). The fact that condition C won over condition B in direct comparison (three to two) shows the variability of solutions.

Post Task Rating

All participants in one of the pattern conditions were asked to rate the design patterns after they had finished the presentation. The scale ranged from 0: *'I have not read it'* to 5: *'Very helpful to solve the problem'*. Figure 5.25 shows the distribution for all the patterns by condition and problem. In the left chart, a clear preference for the most relevant pattern group is visible when participants were working on the MP3 Player problem. For the Stock

Market problem this distribution is not quite as obvious and patterns outside of both of the relevant groups were rated high too. However, on average, there is a statistically significant difference between the ratings for patterns in the relevant group and the rest. For condition C averages are 2.5 for relevant patterns and 0.97[16], respectively 2.36 and 0.96 [17] for condition D. Participants in condition B rated the patterns 2.04 on average (standard deviation 1.74), and there was a significant difference between the problem groups (1.6 versus 2.4).

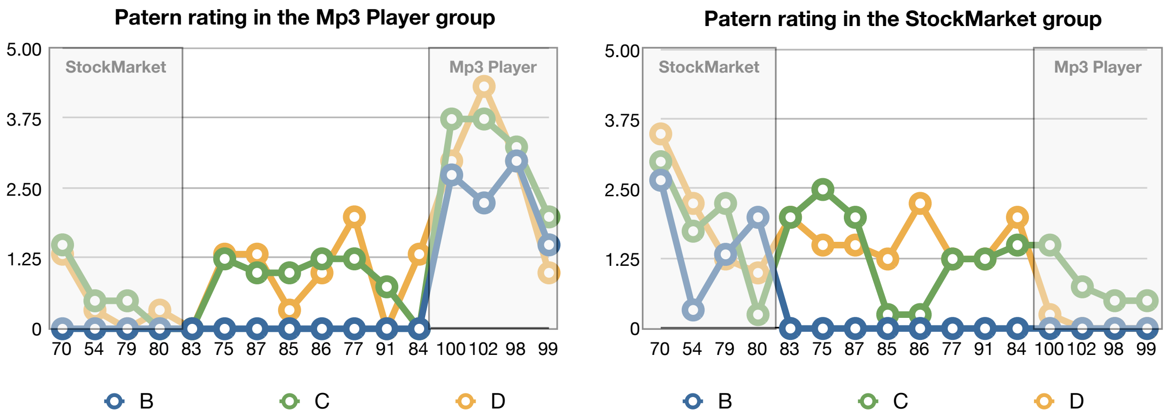


Figure 5.25: Post-task pattern ratings by condition and problem

5.4.3 Summary and Interpretation

In the second phase of this evaluation 29 novices to auditory display design participated and created concept solutions for two different design problems. The demographic variance between groups was controlled for by distributing the educational levels as evenly as possible. To control for the variance in the patterns and problems, two different design briefs were used, each drawing on different sets of relevant patterns. Participants were grouped into four conditions: A: the baseline without design patterns, B: selected list of the 4 most relevant design patterns, C: complete list of design patterns (16) and D: the **paco** online system including the same 16 patterns as in condition C.

Throughout this analysis there was a significant difference between condition A and the conditions with patterns (B, C, D). The five participants in this condition were the most

[16]Independent-samples t-test. A-D: $t = 2.23, p < 0.05$
[17]Independent-samples t-test. A-D: $t = 2.62, p < 0.05$

prolific in terms of written material and their presentations were amongst the longest. The most important differences, however, can be found in the features of their solutions: speech output and speech recognition were predominant in the designs and only one incorporated any form of non-speech sounds. In the anonymous judging condition A solutions were consistently rated lower as pattern solutions. This demonstrates clearly that there has been a knowledge transfer through the patterns.

Participants in condition B were provided with a list of four matching design patterns. The seven participants were the quickest on average and all but one looked at all patterns and played at least one example sound. The rating of the patterns was unexpectedly low and the data suggests that the MP3 Player patterns worked better then the patterns chosen for the Stock Market problem. Only slightly over half of the participants employed non-speech sound in their solution and on average and they also implemented the least advanced features within the pattern conditions. Overall it can be concluded that the access to fewer, but relevant patterns did not have more impact than the other pattern conditions.

Condition C provided the full list of patterns and the increased effort of reading twice as many patterns on average (they looked at 8.83 out of 16 on average) as in condition B is reflected by the increased time they took for solving the task. Participants identified relevant patterns well and on average read three out of the four most relevant patterns selected for the problem. Also the pattern rating shows a significant difference between relevant patterns and others. Only half of the participants played any sound example, which is the lowest amongst conditions. The use of non-speech sound increased to 75% compared to condition B, but is still less than in condition D. The same trend can be observed in terms of advanced features in the solutions: participants in condition C implemented more features that they read about in patterns than in condition B, but less than in condition D. However, the variability of the differences is too big to be statistically significant. Only one participant used speech recognition which is similar to condition B, but a significant drop from condition A.

The use of the online system implementing the **paco** framework as provided in condition D resulted in the longest times for the design process. This was caused by the extra effort of explicitly specifying the context of the problem and the increased need for further explanation by the facilitator. The tagging mechanism linked the problem with the patterns in the context space. The big variability in numbers of tags for the patterns however, caused the relations in the context space to be not represented well. The proximity of relevant patterns was often unsatisfactory. On the positive side, the 'stepping-stone' exploration technique, frequently observed in participants, allowed them to find patterns that were linked to the problem through a particular tag (i.e., aspect of the context). This and their frequent use of the zoom functionality demonstrate how participants were able to navigate the context space and indicate a conceptualisation of the design space. The title of a pattern, however, seems to be an overriding factor in judging how relevant it is to the problem at hand. Participants in this condition read as many patterns as the ones in condition C and equally there was no difference in the percentage regarding the most relevant pattern group. They also played as many sound examples as participants in the other pattern conditions. There is, however, a significant difference in how many direct references were made on paper: participants in condition D made significantly more references than participants in condition B. The difference to condition C is less and not statistically significant.

With no exception the solutions produced in condition D used non-speech sound and therefore show the most significant impact of design patterns. Also the reverse trend regarding speech-recognition is the most pronounced: it was not used in any of the solutions. This interesting side effect shows that design patterns are able to broaden the way people think about a solution not only in respect to what specific technique they promote, but also in other areas of the solution. As soon as the design patterns made participants think about different auditory means than speech for the output channel—they did not see the necessity of using speech for the input channel. As figure 5.22 shows there is a trend in favour of condition D for advanced auditory techniques implemented. However, the variability and differences between the pattern groups does not allow to call it statistically significant. The ranking of patterns showed the same result as in condition C and clearly separated the relevant patterns from the others.

5.5 Synopsis

The study as a whole investigated the knowledge transfer from experts to novices through the use of the **paco** framework and design patterns. The following will review the results and put them next to the hypothesises stated at the beginning of this chapter.

The two hypothesises under investigation were: The **paco** framework

(H1) enables experts in auditory display to capture design knowledge in the form of design patterns and

(H2) enables novice designers to re-use the design knowledge captured in new auditory display design problems.

To evaluate these hypothesises, the following measures were defined:

H1.a) *completeness, quality and generalisation level of patterns created through* ***paco*** *compared to other patterns*

The analysis shows that the method for developing patterns provided by **paco** enabled experts to extract valuable design knowledge from their work. They have based their initial patterns on concrete prototypes and promoted important auditory display design techniques through their patterns. The patterns were complete and usable, although they exhibited deficits compared to carefully crafted patterns published by pattern-writing experts such as Tidwell (2005) or van Welie (2006). For example, participants frequently confused the rational and solution section, the patterns contained much jargon and the titles chosen are too long and sometimes inappropriate. This demonstrates the need for additional support in these areas for domain experts in writing high quality patterns.

The results show the key role of sound examples for knowledge transfer. In future versions of the pattern format for auditory display design the importance of sound should be emphasised. For example, an illustration, absent in the current format, could provide an auditory sketch that illustrates the promoted features while leaving out as much detail as possible. A more general deficit was raised by one expert who made the point that the means of describing interaction are not sufficient. In many occasions describing interaction is far less effective than providing interactive examples. Future research has to show how this feature could be married with the textual nature of design patterns.

Although the iterative process for generating generalised patterns from concrete examples was only followed partially, there were clear signs that the method supported generalisations where applied. The framework had limited success, however, in provoking experts to develop blue-sky patterns and leave the safe grounds of evaluated design knowledge.

H1.b) *added value of patterns compared to other sources of design knowledge (e.g., papers written by experts)*
The comparative analysis of the patterns and corresponding publications by the authors presented above shows that the patterns clearly have added features. The most prominent are: explicit availability of the rationale for design decisions, highlighted trade-offs to make informed compromises, incorporated values of good practice and a synoptical overview of a potentially large body of work. Although research literature is certainly more comprehensive in general, these features tend to be underrepresented. They are, without doubt though, an important part of an informed, creative design process.

H1.c) *appropriateness of contextual attributes used to position a pattern in the context space*
The expert designers have used over 20 tags on average to describe the context of their patterns with less than 15% being inappropriate. The tags were evenly distributed between the dimensions of the context space indicating that each of the dimensions has been recognised in its own right. However, the "User experience" dimension saw the most tags not fitting into the category. The fact that most of the mismatched tags were describing an application domain suggests that the experts thought of desired user experience as an implication of the domain, but they struggled to explicitly express these experiences. While the same argument could be made for the "Social context", the experts were much better in creating meaningful tags for this dimension. All experts expressed a preference for the tagging over the nominal scales.

These results show that the tagging paradigm provided an appropriate means to describe the context of designs. A bigger number of pre-defined tags and upper and lower limits of tags per dimension would address the issue of the big variability and improve the capability of the context space to link patterns with problems. The nominal dimensions should be dropped and the "User experience" dimension should be incorporated into the "Application domain".

The **paco** workflow for creating design patterns was followed only to a limited extent. Two thirds did derive patterns, but only in half of these any changes were made to the descriptor. This data suggests that, at least in the context of this experiment, the **paco** workflow did not achieve the desired effect to open up a design space in which the context space would be the organising principle for design knowledge. In the post-questionnaire, however, experts credited the context space for making them aware of the contextual properties of their designs and helping them to find the place their designs would fill in the whole scope of contexts of use.

H2.a) *appropriateness, quality and diversity of auditory techniques used in a solution depending on the provided guidance*

The second phase of the experiment clearly demonstrated the positive impact of patterns on initial designs by novice designers. Solutions produced with the aid of design patterns implemented significantly more advanced features than solutions produced without patterns. The effect was demonstrated in this study despite the fact that the patterns were created by inexperienced pattern-writers. Participants with access to the **paco** framework used advanced, non-speech techniques without exception and the impact of the patterns is the most pronounced. The difference, however, to the other pattern conditions is not statistically significant.

H2.b) *overall quality of a solution depending on the provided guidance*

Solutions produced with the aid of design patterns were rated higher than those without. Six expert judges, blind to the conditions rated solutions in the pattern conditions highest regarding the quality of the overall design, potential user satisfaction and how well participants met the design brief. Differences between the pattern conditions were inconclusive.

H2.c) *efficiency of the contextual matching process between design problem and design patterns*

Over 92% of the tags chosen by the novices were highly appropriate for the context of use described in the design brief. The links these tags created to design patterns in the context space were less convincing however. Only a quarter of the links connected the problem with the group of highly relevant patterns (as provided in condition B). As further analysis showed this is mainly caused by the variability in tags that experts chose for their patterns.

However, novices with access to the **paco** online system read relevant patterns, rated them significantly higher than other patterns and made the most references to relevant patterns on paper. However, although the data shows a trend in favour of this condition, there was not significant difference to the other pattern conditions. The context space provided navigational aids such as zooming and participants developed strategies to find relevant patterns (tags as stepping-stones), but the title of patterns seems to be an overriding factor in the decision to read a pattern.

The visualisation of the context space has not proven to be beneficial to the process of selecting relevant patterns. With the small number of patterns used in this study, the selection is less problematic, but if pattern collections grow bigger efficient means to navigate these collections and conceptualising the design space they cover is of greater importance.

H2.d) *level of awareness for alternative solutions, i.e., the design space*
The study has not produced any proof for this to be case. The observed side effect of novices using less speech-recognition when being primed for using non-speech sound through the patterns, however, indicates that the patterns changed the overall conception of the design space. We argue that this can be interpreted as being a beneficial effect of design patterns on the design process.

On the basis of these findings, both hypothesises can be supported. The paco framework and its methods have enabled experts to capture significant design knowledge which was effectively transferred to solutions developed by novice designers.

Chapter 6

Conclusion

The work presented in this thesis investigated the design process of auditory displays in human-computer interaction and proposed a methodological framework to aid the transfer of design knowledge through design patterns. The introduction chapter motivated the work and set out the aims, defining the scope and the potential contributions. The subsequent chapter reviewed relevant work, ranging from available guidance in auditory display design to methodologies in HCI. The concept of design patterns, a key element in this work, was reviewed in more detail. Chapter 3 set out to investigate the current practice in auditory display design and presented two studies: a survey amongst designers and practitioners and a literature study of research papers presented in ICAD 2007, Montreal, Canada. Based on the findings, requirements for a methodological design framework were derived which led to the development of **paco**. Chapter 4 argued for the design choices made, introduced the concepts and methods in **paco** and illustrated the workflow in a case study. Finally, chapter 5 reports on an extensive evaluation study to investigate the usefulness of **paco**. Expert and novice auditory display designers participated in this study and the results provided valuable insights into various aspects of knowledge transfer and design practice.

The three intended audiences for this thesis are the auditory display community, the broader HCI research and practitioner community and the design pattern community. The work contributes to each of these disciplines in different ways. To our knowledge this is the first in-depth investigation of design practice in the field of auditory display. The **paco** framework has been specifically designed to provide this community with the means of creating a shared body of design knowledge to effectively build on prior work. To this end, the evaluation of **paco** represents the first comparative study involving designers, demonstrating the impact of such a framework on the design process. The specification of requirements for **paco** has provided insights into how auditory display is perceived from a wider HCI perspective. It is hoped that this work will impact upon the dissemination of good practice and make effective auditory displays more common in everyday technology in the long term. Lastly, the contribution to the design pattern community stems from the insights we gained from adapting the concept of patterns into a new field—auditory displays. The context-centred, methodological approach to pattern-mining and the application of patterns proposed, however, is not tied to the specific domain and is potentially applicable to any designing discipline.

The remainder of this chapter is structured as follows. The next section aims to reflect critically on aspects of this work in the light of the results. Section 6.2, finally, provides concluding thoughts and prospects for future work.

6.1 Reflections

This work has produced a wealth of results that answered some of the questions it set put to investigate, but also left others open and produced new questions. The following is an attempt to highlight some of the key issues that surfaced from this work and reflect back critically as well as project future lines of research.

6.1.1 Design Practice

The analysis of the design practice within and outside the community has shown that it remains difficult to access and re-use existing design knowledge. Factors identified include:

- gaps in our practice in documenting work, specifically in terms of the reasoning behind design decisions,
- the creative and multi-disciplinary nature of the process,

- limited awareness of contextual properties, e.g., from user research and interaction design and
- the difficulty of generalising design knowledge in this field.

To improve supportive frameworks for designing auditory artefacts, would benefit from further investigating current practice to better understand the people who design audio and their environments. Of particular interest is the design process in major industrial companies, for example the ones Microsoft or Nokia adopt in designing audio for their products. This could be investigated through observation, interviews and other ethnographic techniques and allow us to develop more detailed requirements for improved tool-support to facilitate efficient integration in the overall design process.

6.1.2 Pattern Mining

This work has demonstrated that design patterns facilitate knowledge transfer in the field of auditory display. Design patterns specifically address the problems identified in the design process by providing a semi-formalised means to document work and capture generalised design knowledge. The method of pattern-mining proposed in **paco** intended to structure the process and help inexperienced authors to create patterns. The evaluation showed that this process had limited success. While participants were able to create usable design patterns, the iterative process of generalisation was followed only to a limited extent.

Despite efforts to simplify the process as much as possible, we hypothesise that it was still too complex and confusing. More guidance and tool-support will be needed to enable inexperienced authors to systematically develop design patterns. A key factor could be the further development of the pattern format. While the one used for the evaluation study followed the original Alexanderian format, formats defined less loosely could provide more guidance for inexperienced authors. An important pattern element was also omitted in our adaptation: an illustration. In architecture, a sketch is included after the title of the pattern to illustrate the problem (see Alexander et al., 1977), in graphical interaction design, a mock-up or simple screenshot serves the same purpose (e.g. Tidwell, 2005). For auditory design patterns, the concept of an illustration is harder to define. The availability of a low-fidelity sketching tool for auditory display would greatly support designers in communicating their design ideas—not only through “illustrations” in patterns, but also in collaborative design situations and rapid prototyping.

Another issue with patterns to be addressed more generally, is the efficient capture of interaction techniques. In the current format, textual accounts are the only means by which authors can describe a proposed interaction paradigm. Again, low-fidelity sketches could be extended to be interactive and rich in supportive media in order to provide readers of patterns a first-hand experience with the proposed solution.

6.1.3 Context Space

The context space increased the contextual awareness of experts and novice designers. With the exception of “User experience”, all dimensions have received appropriate tags producing a meaningful taxonomy for the design knowledge created. The nominal scales, however, were used scarcely and in general users preferred tags to describe the contextual properties.

The representation of the context space leaves room for improvement. While the force-directed layout of the interactive visualisation provided intuitive clustering and navigation, there was no significant improvement over simple lists in terms of identifying appropriate design knowledge. This might be different once there is a greater number of design patterns and artefacts available, but also the ease-of-use of the representation has to be improved. We envision a space that offers flexible sorting, filtering and navigation to improve the conceptualisation of the design space. An interaction paradigm that proved to be very useful in the evaluation, is the exploration of links through tags as stepping-stones. The semantic quality of these links allows for fine-grained explorations according to specific contextual properties.

The content types of such a space have to accommodate for design knowledge, design problems, artefacts and could be extended to hold simple sounds or complex interactions. The need of such a unifying organising principle has been recognised in the community and first efforts have been made to conceive such a space. The “Sonic Interaction Atlas” by Hermann (2008) has the goal of organising sonic interactions along a set of nominal dimensions describing specific features of the user, objects, actions or perceptual channels. Data mining methods have subsequently been applied to create an interactive 2D representation of the resulting multi-dimensional space. Although this work is in its early stages and focuses on sonic interactions only, there are similar forces driving this effort, most prominently the goal of guiding designers of auditory interaction. Future work will hopefully see these two strands of research being merged, as discussed in a meeting at ICAD 2008 and this work will hopefully make a significant contribution to such efforts by the insights and evidence it delivers (see report on the "Recycling Auditory Display" workshop Frauenberger and Barrass, 2009).

6.1.4 Going Multi-Modal

A key objective of this work has been to ensure auditory display design can be integrated into the over-arching discipline of interaction design. In our view, this aspect is crucial for auditory display finding its place in the overall design space of human-computer interaction. The **paco** framework has been designed with this in mind. All the concepts and methods have been developed to support auditory display design, but are open to extensions and flexible to be used in a broader context.

A promising direction would be to apply **paco** on multi-modal design. As the context space is qualified to accommodate any sorts of design, this could create a common design space and connect auditory display design with work in other modalities effectively. The possibility of varying levels of abstraction in design patterns would also allow to describe interactive designs in a mode-independent way with links to mode-specific designs implementing the interaction in different contexts. This follows an early idea of us (Frauenberger et al., 2004) and could be another way of fostering auditory display design as part of a greater design space.

6.1.5 Community Effect

Above all, the success of the concepts presented will depend on the support they can attract in the community. This thesis aimed to contribute to the means we have to capture and transfer design knowledge and the evaluation revealed promising features to this end. However, the real value is determined by how effective it will be over time in enabling designers to build on previous work.

Many of the problems identified in the evaluation are rooted in the isolated context of an experiment. The rating mechanism, for example, may still prove to be an appropriate measure to ensure quality and encourage blue-sky ideas to be captured. However, in the context of the evaluation presented in this thesis, the rating mechanism played no significant role and was mostly ignored. A similar observation can be made on the use of tags. Although tags proved to work well in terms of describing the contextual features of designs and problems, the resulting population of tags was unbalanced and partly overlapping or redundant. This caused negative effects in matching problems with relevant patterns in the application phase and hence diminished some of the positive effects of the context space we hoped for. However, it is likely that the population of tags will consolidate if a sufficient number of users collaborate over a sufficient period of time (see also Halpin et al., 2007).

Similarly, if **paco** aids the creation of a body of design knowledge, the credibility and scientific rigour of such a body can only be guaranteed by a broad consensus in the scientific community. Due to these necessary community effects, it is difficult to predict the impact of the work presented in this thesis. But it is hoped thoroughly that it will contribute to promoting auditory display design and enable designers and researchers to build on each other's work more efficiently.

6.2 Concluding Thoughts

In the introduction to this thesis the overall research question was defined as:

Can a methodological design framework be developed that facilitates the efficient transfer of design knowledge from experts in the field of auditory displays to novice designers?

The development and evaluation of **paco** described in this work has shown that such a methodological framework based on design patterns indeed has beneficial impact upon auditory display design. Besides having demonstrated its capability of knowledge transfer, this work also revealed important insights into the design process of auditory displays in the overall context of interaction design.

Design patterns have shown some great potential in the area of sound design. Further research can build on the initial findings presented in this work and improve the adaptation of this concept to this and other disciplines in need for capturing the diversity of good practice comprising design knowledge, research results, skill, craft, creativity, experience, æsthetics and expertise. The context space as an organising principle to the design space seems to be a promising concept too. Designing interaction with a strong focus on the contextual requirements and affordances becomes essential with the diversification of users, their environments and the roles technology adopts in society—thinking beyond the desktop requires thinking beyond beeps and screens. In this respect, the context space may provide researchers and designers with the tool needed to conceptualise the relationships between solutions and their applicability.

In the progress of this work a number of initial design patterns have been created by the author and the experts involved in the evaluation study. This raw material has been reworked and attached to the thesis in appendix F as a collection of design patterns that, hopefully, will serve as seeds for a larger, shared body of design knowledge for auditory display design[1].

[1]See also http://cfabric.net/patterns

Appendix A

Pattern Language Meta Language (PLML)

This is the latest version of the PLML schema, downloaded from http://www.hcipatterns.org (July 2008).

```
<?xml version="1.0" encoding="UTF-8"?>
<!ELEMENT pattern
  (name?, confidence?, alias*, synopsis?, illustration?, context?,
   problem?, forces?, evidence?, solution?, diagram?, implementation?,
   related-patterns?, pattern-link*, literature?, management?)
>
<!ATTLIST pattern
  patternID CDATA #REQUIRED
  collection CDATA #REQUIRED
>
<!ELEMENT name (#PCDATA)>
<!ELEMENT confidence (#PCDATA)>
<!ELEMENT alias (#PCDATA)>
<!ELEMENT synopsis (#PCDATA)>
<!ELEMENT illustration ANY>
<!ELEMENT context EMPTY>
<!ATTLIST context
  mylabel CDATA #IMPLIED
>
<!ELEMENT problem (#PCDATA)>
<!ELEMENT forces ANY>
<!ELEMENT evidence (example*, rationale?)>
<!ELEMENT example ANY>
<!ELEMENT rationale ANY>
<!ELEMENT solution ANY>
<!ELEMENT diagram ANY>
<!ELEMENT implementation ANY>
```

```
<!ELEMENT related-patterns ANY>
<!ELEMENT pattern-link EMPTY>
<!ATTLIST pattern-link
  type CDATA #REQUIRED
  patternID CDATA #REQUIRED
  collection CDATA #REQUIRED
  label CDATA #REQUIRED
>
<!ELEMENT management
  (author?, revision-number?, creation-date?, last-modified?,
   change-log?, credits?)
>
<!ELEMENT author (#PCDATA)>
<!ELEMENT creation-date (#PCDATA)>
<!ELEMENT credits (#PCDATA)>
<!ELEMENT revision-number (#PCDATA)>
<!ELEMENT last-modified (#PCDATA)>
<!ELEMENT literature ANY>
```

Appendix B

Selected Publications from ICAD 2007

Baier, G., Hermann, T., and Stephani, U. (2007). Multi-Channel Sonification of Human EEG. In *ICAD Proceedings*, pages 491–496, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Baldwin, C. L. (2007). Acoustic and Semantic Warning Parameters Impact Vehicle Crash Rates. In *ICAD Proceedings*, pages 143–145, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Brazil, E. and Fernström, M. (2007). Investigating Ambient Auditory Information Systems. In *ICAD Proceedings*, pages 326–333, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Brungart, D. S., Simpson, B. D., Dallman, R. C., Romigh, G., Yasky, R., and Raquet, J. (2007). A Comparison of Head-Tracked and Vehicle-Tracked Virtual Audio Cues in an Aircraft Navigation Task. In *ICAD Proceedings*, pages 32–37, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

de Campo, A., Höldrich, R., Eckel, G., and Wallisch, A. (2007). New Sonification Tools for EEG Data Screening and Monitoring. In *ICAD Proceedings*, pages 536–542, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Frauenberger, C. and de Campo, A. (2007). Analysing time series data. In *ICAD Proceedings*, pages 504–508, Montreal, Canada. International Community for Auditory Display, Schulich

School of Music, McGill University.

Grond, F. (2007). Organized Data for Organized Sound: Space Filling Curves in Sonification. In *ICAD Proceedings*, pages 476–482, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Horowitz, M. (2007). A Mouse With Ears Explores Maps. In *ICAD Proceedings*, pages 242–246, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Jung, R. and Schwartz, T. (2007). Peripheral Notification With Customized Embedded Audio Cues. In *ICAD Proceedings*, pages 221–228, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Kainulainen, A., Turunen, M., Hakulinen, J., and Melto, A. (2007). Soundmarks in Spoken Route Guidance. In *ICAD Proceedings*, pages 107–111, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Liljedahl, M., Papworth, N., and Lindberg, S. (2007). Beowulf: A Game Experience Built on Sound Effects. In *ICAD Proceedings*, pages 102–106, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

MacVeigh, R. and Jacobson, R. D. (2007). Increasing the Dimensionality of a Geographic Information System (GIS) Using Auditory Display. In *ICAD Proceedings*, pages 530–535, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

McCormick, C. M. and Flowers, J. H. (2007). Perceiving the Relationship Between Discrete and Continuous Data: A Comparison of Sonified Data Display Formats. In *ICAD Proceedings*, pages 293–298, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

McGee-Lennon, M. R., Wolters, M., and McBryan, T. (2007). Audio Reminders in the Home Environment. In *ICAD Proceedings*, pages 437–444, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Metatla, O., Bryan-Kinns, N., and Stockman, T. (2007). Auditory External Representations: Exploring and Evaluating the Design and Learnability of an Auditory UML Diagram. In

ICAD Proceedings, pages 411–418, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Murphy, E., Kuber, R., Strain, P., McAllister, G., and Yu, W. (2007). Developing Sounds for a Multimodal Interface: Conveying Spatial Information to Visually Impaired Web Users. In *ICAD Proceedings*, pages 348–355, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Nickerson, L. V., Stockman, T., and Thiebaut, J.-B. (2007). Sonifying the London Underground Real-Time Disruption Map. In *ICAD Proceedings*, pages 252–257, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Oren, M., Harding, C., and Bonebright, T. L. (2007). Speed Sonic Across the Span: A Platform Audio Game. In *ICAD Proceedings*, pages 247–251, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Rouben, A. and Terveen, L. (2007). Speech and Non-Speech Audio: Navigational Information and Cognitive Load. In *ICAD Proceedings*, pages 468–475, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Stockman, T., Rajgor, N., Metatla, O., and Harrar, L. (2007). The Design of Interactive Audio Soccer. In *ICAD Proceedings*, pages 526–529, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Visell, Y. and Cooperstock, J. R. (2007). Modeling and Continuous Sonification of Affordances for Gesture-Based Interfaces. In *ICAD Proceedings*, pages 423–429, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Vogt, K., Plessas, W., de Campo, A., Frauenberger, C., and Eckel, G. (2007). Sonification of Spin Models. Listen to phase transitions in the Ising and Potts-model . In *ICAD Proceedings*, pages 258–265, Montreal, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Wallis, I., Ingalls, T., Rikakis, T., Olsen, L., Chen, Y., Xu, W., and Sundaram, H. (2007). Real-Time Sonification of Movement for an Immersive Stroke Rehabilitation Environment. In *ICAD Proceedings*, pages 497–503, Montreal, Canada. International Community for Auditory

Display, Schulich School of Music, McGill University.

Appendix C

A Survey on Common Practice in Auditory Display Design

Personal Information	
Sex	Male, Female
Age	<20, 20-30, 30-40, 40-50, 50-60, >60
Profession	one line free form text field
Highest education	one line free form text field
Audio related experience / knowledge	
Do you play an instrument?	Yes, No
If yes, which one?	one line free form text field
If yes, please rate your level:	Expert (5) - Beginner (1)
Can you read sheet music?	Yes, No
Please rate your technical experience with audio (i.e., do you have experience with creating or editing sounds):	Expert (5) - Beginner (1)
General experience in human-computer interaction design	
Please rate your practical experience in designing user interfaces:	Expert (5) - Beginner (1)

Please rate your theoretical expertise in user interface design:	Expert (5) - Beginner (1)
Which modalities have you used in your designs?	visual, auditory, tactile, olfactory
In which contexts have you designed interfaces?	desktop,mobile, web, other
End page one	
Have you ever used any audio in your interface designs?	Yes, No
If yes:	
In how many of your interfaces you used audio?	100%, 80%, 60%, 40%, 20%, less then 10%
At which contexts were these interfaces been targeted?	desktop,mobile, web, other
Please describe one briefly in one sentence:	multi-line free form text field
Was audio used to support the GUI (i.e., complementary) or as alternative modality in most of the cases?	complementary, alternatively
What types of auditory cues did you use?	natural everyday sounds, abstract sounds, speech, otherÂă
What was the main motivation for you to use audio?	multi-line free form text field
End page two	
Have you ever worked in design teams in which other people were in charge of designing sounds for a user interface?	Yes, No
If yes:	
How closely have these colleagues been integrated into the overall design?	Very great extent, Great extent, Moderate extent, Slight Extent, Not at all

What was the profession of these colleagues?	HCI experts, sound engineers, sound designers, artists, other
End page three	
You are asked to design a user interface for an application using audio output only.	
What would be the first things you do?	multi-line free form text field
What are the main factors that would determine the sound design?	multi-line free form text field
How would you create initial prototypes of your design?	multi-line free form text field
How would you involve the user in your design?	multi-line free form text field
End page four	
You are asked to design a user interface for navigating the menu of an mp3-player that has no screen. The menu contains the playlists, various settings as well as a calendar and contacts. The users have a little joystick and 3 buttons to interact and wear ear-plugs. Computational power is no constraint, think out of the box.	
Please describe your first idea to solve this interaction problem?	multi-line free form text field
End page five	
Thinking of the mp3-player: Why did you choose this approach?	multi-line free form text field
Which audio techniques, audio programming languages and audio toolkits are you aware of?	multi-line free form text field
Are you aware of any guidelines or principles for the design of auditory displays?	Yes, No
If yes:	

Which are these guidelines (please indicate their source)?	multi-line free form text field
Did they have any influence on your design choices regarding the mp3 player example?	Yes, No
Have you used these guidelines in any other designs of yours?	Yes, No
Did you have any other guidelines or principles (i.e., not specifically addressing audio) in mind when thinking about the mp3 player design?	Yes, No
If yes:	
Which were these guidelines (please indicate their source)?	multi-line free form text field
How well did they adapt to the above design problem?	Very great extent, Great extent, Moderate extent, Slight Extent, Not at all
End page six	
To which extent you think audio can improve human-computer interaction?	Very great extent, Great extent, Moderate extent, Slight Extent, Not at all
What sort of guidance would you like to have for auditory display design?	multi-line free form text field
Do you have any other comments on the use of audio in human-computer interaction?	multi-line free form text field
End page seven - Finish	

Appendix D

Phase One: Creating Design Patterns

D.1 The Information Sheet

pacoad pattern design in the context space for designing auditory displays

Thank you for participating in this study!

The design of audio in the user interface lacks efficient guidance for designers outside the scientific field, which leads to audio being not used at all or used in an inappropriate or inefficient way in many commercial products. The motivation of this research is to develop a methodological framework that helps the field to build up a shared body of design knowledge and facilitates its communication to novices.

The purpose of the study is to evaluate the methodological framework paco (pattern design in the context space). The framework provides methods to create and apply design patterns in the area of auditory display. The research questions investigated in this study are the following:

1. Can expert designers use paco to efficiently capture design knowledge through design patterns?
2. Can design knowledge for auditory display be communicated efficiently through design patterns?
3. Can paco help to conceptualise the design space and support novices in creating better designs?

We ask experts in the field of auditory display design to create patterns from their most successful designs. Novices to auditory display design are then asked to comment on these patterns, use paco to find patterns for a certain design problem and apply them to a different problem.

Procedure & Tasks

This phase of the study has 3 parts:

First, we ask you to complete a short pre-questionnaire. This will probe for demographical information and aspects of your designing practice. Please complete this questionnaire before you proceed and send it back via email.

Second, you will use the paco online system to describe two of your most successful designs through patterns. This can be any part or the whole of a design you developed and evaluated - anything that is self-contained and you can think of being valuable for others to re-use (E.g. this could be the design of an auditory display for an Mp3 player or a method to alert users of incoming mail or a specific mapping of information onto sound). The online system will guide you through the steps of describing your design and provides extensive help for every input required. Please use the link given in your email.

"Each pattern describes a problem that occurs over and over again in our environment and then describes the core of the solution to that problem in such a way that you can use this solution a million times over without ever doing it the same way twice." (C. Alexander - A Pattern Language, p x).

You will be asked to derive new versions of your pattern by asking yourself: What does it need to make this work in a different or bigger context? Please use your intuition and your creativity - this is all part of your expertise that we try to capture in this study! A rating system allows you to express how confident you are about the solution you describe, ranging from pure guesses to backed by hard evidence - everything is allowed, in fact encouraged.

"Writing about music is like dancing about architecture - it's a really stupid thing to want to do." (Elvis Costello, Musician magazine No. 60, October 1983). Therefore, we encourage you to include as much sound as possible in every pattern description. If you do not have a sound example (for example, because the design was never actually implemented), try to illustrate your ideas using your voice to mimic the desired sound. Record it and include it as an example.

Finally, we ask you to complete the post-questionnaire that will be sent to you as soon as you notify us that you are finished with your input in the paco online system.

Notes

The subject under investigation is the paco framework, not you - we are not assessing levels of expertise. If you have problems using the interface or any other questions regarding the study or the procedure, please do not hesitate to contact me (frauenberger@dcs.qmul.ac.uk).

All your personal data is anonymised in the analysis of this study. When reporting on this study no information about you is revealed.

The copyright of all the written material you produce during this study remains with you. We will contact you after the study is finished and ask you if we may make your design patterns available to the public. If you agree to make your patterns available, they will contribute to a "open source" like library in which content will be licensed through an appropriate licence scheme[1] to protect authors and ensure access of the public.

For recruitment of volunteers for study ref (QMREC2007/41), approved by Queen Mary University of London Research Ethics Committee. This project contributes to the College's role in conducting research and teaching methods. You are under no obligation to reply to this email, however if you choose to, participation in this research is voluntary and you may withdraw at any time.

[1] Free documentation licence http://www.fsf.org/licensing/licenses/fdl.html or the Creative Commons http://creativecommons.org

D.2 Pre-questionnaire

1) Experience

When did you publish your first paper describing an auditory display and in which forum?

What is your original educational background (e.g., masters degree)?

What was your first motivation to work in the field of auditory display?

Has this motivation changed over the years?

2) Design practice

How do you usually approach design problems that require audio?

What made audio a requirement in the majority of your designs?

Which guidelines do you use when designing auditory displays?

3) Your opinion

Do you think audio is underused in commercial products? If yes, why?

What are the most promising application domains of audio in the future in your opinion?

What is the hardest thing when designing with audio?

Do you think it is difficult to re-use design knowledge for auditory display? If yes, why do you think so?

Think of the technology you use on an everyday-basis. Do they provide audio as part of their interface? Do you use it? Could you provide a good and a bad example?

What do you find most frustrating when designing auditory displays?

D.3 Post-questionnaire

1) The Framework

Please describe the paco framework off the top of your head in your own words in two sentences:

Please, describe your workflow using the paco system:

What do you think is the most important feature of paco?

What is the least useful feature of paco?

2) The designs

Thinking about the solutions you described, did you learn something new about your designs? If yes, what?

Do you think you will re-use the designs you described? If yes, in which context?

3) The context space

What dimensions are missing or of no use for describing the context of your solutions?

Was it easy to find the appropriate terms for tagging the context?

Tagging vs. Scales; what is the better way of describing the context of a design? Why?

4) The pattern format

Can you think of aspects of your designs that you could not express through the pattern format provided?

Provide a concrete example:

5) Things you like

Name three pieces of research in the area, that are, in your opinion, cornerstones for the field (i.e., outstanding, important work that shows the potential of auditory displays)?

Name three sounds you particularly like that were intentionally designed in technology:

6) General Comments

About the framework (methods and patterns)?

About the system (implementation)?

Anything else?

7) And finally...

We would like to use the data collected in this study as a starting point for a publicly available library of design patterns for auditory display. This means, that we will consolidate the patterns created, alter, merge or extend them and make them available as part of a web-page. Naturally, we will give full credits as soon as some of your input is used and we will keep you posted about the development. Please indicate here if you would like to make your data available:

Yes / No

Appendix E

Phase Two: Applying Design Patterns

E.1 Pre-questionnaire

1) About you

What is your age (<20, 20-30, 30-40, 40-50, 50-60, 60+) ?

Gender (M/F) ?

What is your profession?

What is the highest degree you hold?

Do you play an Instrument? If yes, which one and at which level (1=basic to 5=professional) ?

2) Experience

How much experience do you have in designing human-computer interaction (please provide approximate numbers of interfaces designed and years of related education) ?

Please describe briefly the process you use for creating user interfaces (i.e., what is your starting-point, how do you progress etc.):

Which guidance do you usually refer to when designing user interfaces (e.g., guidelines, principles, text-books etc. please give examples) ?

Are you familiar with the concept of design patterns? If yes, in which context?

Have you ever used audio in one of your designs? If yes, please describe the work briefly:

E.2 Design Briefs

pacoad
pattern design in the
context space for designing
auditory displays

DESIGN BRIEF - THE MP3 PLAYER

The following text describes a fictional design problem that you are assigned to. It specifies the requirements for the development of a user interface that should be met by your solution. The brief is given as-is, some aspects of the design may be under-defined or unspecified, but it is part of your challenge to work around this.

You have 40 minutes, you may make notes, drawings or audio recordings to capture your design ideas. After this time, you will be asked to present your design to the camera in no more than 5 as if you are presenting it to your client.

***

A well known computer manufacturer asks you to design the user interface of the next generation Mp3 player. The player will be too small to have a visual display, hence all interaction will be using the auditory and tactile channel. Besides playing music, it will also function as a simplified personal digital assistant, providing access to information such as personal calendars, to-do items, shopping lists, contact details or news feeds. Due to the highly mobile context of use, however, this information will be read-only and synced from a computer (laptop or desktop) at home or at work.

People will use this device everywhere they go. They will use it in any environment that allows for listening to music or where they need to access the other information stored on it. The target user group is clearly people who used devices like the iPod and / or PDAs before, but wished they were smaller and easier to carry around without much effort. The device does not try to do everything (no camera, no video, no keyboard etc.), but do the things it is designed for well.

The device will be very small and might be integrated into other objects like handbags or sunglasses or even in the fabric of cloths. The number of tactile controls (buttons etc.) should be kept as small as possible and they might not be attached physically to the device. Users wear wireless headphones and the computational power of the device is on the lower-end to save battery-power, but is capable of most audio processing.

Your task is to create a design sketch for the user interface of this device with the focus on easy, but fast navigation through the information. Describe your design as detailed as possible and provide the rational for your major design decisions. Particularly, describe the sound you will be using in much detail.

pattern design in the context space for designing auditory displays

DESIGN BRIEF - THE STOCK MARKET PROBLEM

The following text describes a fictional design problem that you are assigned to. It specifies the requirements for the development of a user interface that should be met by your solution. The brief is given as-is, some aspects of the design may be under-defined or unspecified, but it is part of your challenge to work around this.

You have 40 minutes, you may make notes, drawings or audio recordings to capture your design ideas. After this time, you will be asked to present your design to the camera in no more than 5 as if you are presenting it to your client.

***

A well known highstreet-bank asks you to design a user interface for analysts in the stock market. A particular set of stock data, the prices for oil, gas and other basic resources (around 6), is important for some of the analysts to make decisions regarding bidding for shares of companies. The recognition of patterns in this data may provide them the edge over competitors. However, because they have to keep an eye on many things on their screens at the same time, there is no way to present all this information visually. Hence, your task is to design a user interface that uses sound to present the analysts with the changes in stock values in these basic resources.

Once they recognise an important trend they would be able to switch the particular data onto their screens and analyse it more closely while the sound still provides them with information of the rest of the set.

Analysts are busy people, stress levels are high and distractions have to be kept to minimum. They usually sit in front of three screens and the environment is pretty hectic. However, they could have stereo speakers installed on their workplaces without distracting colleagues. Companies rely on their decisions and they are always provided with the newest equipment.

Your task is to create a design sketch for the user interface. Describe your design as detailed as possible and provide the rational for your major design decisions. Particularly, describe the sound you will be using in much detail.

Appendix F

Design Patterns

The patterns are presented here as text versions. It has to be noted, however, that these versions omit an essential part of the patterns: audio. Therefore this collection of design patterns is in the progress to be compiled as an online resource that allows users to access multi-media content in support of the patterns. Also, as the collaboration with other researchers progresses, we hope that we can improve on the representation of the patterns, their format and their organisation in an unified design space.

Title	Local context	
Context	*User*	analyst, researcher, teacher, pupil
	Environment	lab, office, classroom
	Device	workstation, headphones, multi-channel audio, mixed reality, multi-modal
	Application	science, data exploration, perceptualisation, education
	Social	single use, collaborative, work
Problem	When analysing multi-variant, very large or complex data, a representation that allows for exploring details while still being aware of the larger context is highly desirable. In purely visual solutions this is often achieved by implementing interactive zooming or filtering which, however, removes either context or details.	

Forces	fine detail in the data cognitive load focus on details interactive exploration	— — — —	high level context amount of detail distraction by contextual cues static representation
Solution	Details are presented by auditory means, while the overall context remains visual. The detail can be any part of the data, a small chunk or any sub-set of dimensions. Indicate the relationship between the data heard and the context seen, e.g., by highlighting the range of data the dimensions presented aurally. The type of sonification used will depend on the context and the nature of the data, but could be parameter mapping, audification or model-based sonification. When used interactively, provide controls for defining the range and granularity of details.		
Rationale	The split of context and detail between two modalities allows users to perceive both simultaneously rather then sequential. This reduces the cognitive effort of remembering the contextual information while exploring details.		
Examples	The Virtual Geiger Counter is an interactive tool to explore geological well-logs.		
References	S. Barrass and B. Zehner: Responsive sonification of well-logs, in Proceedings of the International Conference on Auditory Display ICAD 2000, Atlanta, April 2-5.		

Title	Ambient alarm	
Context	*User*	engineers, monitors, technicians, pilots
	Environment	control room, cockpit, hectic, overloaded, stressful, dangerous, long term
	Device	workstation, headphones, multi-channel audio, multi-modal
	Application	monitoring
	Social	single use, collaborative, work, stress, decision making
Problem	Operators in control rooms of complex systems such as power plants or aircraft, have to deal with an enormous amount of information. In critical situation it is key to convey urgent information reliably without overwhelming the human operator. When monitoring continuos data, the level of required attention might also vary and it is key to design feedback so that the perceived urgency reflects the real urgency and the necessary attention of operators is kept to the minimum.	

Forces	awareness long term fast reaction detailed information	— — — —	boredom and distraction short term over-reaction overwhelming information
Solution	The design of a pleasant, ambient auditory alarm system allows users to switch the sound into the background and attend to other tasks. The continuos sound demands very low attention as long as it is stable and everything is OK. Even subtle changes, however immediately attract the operators attention and indicate the status of the system monitored. Many mechanical machines provide this form of feedback naturally (cars, steam engines) and solutions can build on these common metaphors. Particularly useful are mappings on rhythmic patterns such as the Noordon gallop. Multiple variables of the system can be used to produce a common rhythmic stream which splits into multiple streams once a variable starts changing.		
Rationale	Human auditory perception is highly effective to mask stable, continuos sound. This results in very low active attention. However, especially with changes in the rhythmic patterns in the continuos feedback, users become aware and can attend the problem. Especially in long-term monitoring auditory feedback like this can reduce human error and reduce the tedious task of observing visual instruments.		
Examples	The sonification of four parameters of a steam-propulsion plant produces an ambient alarm that has a distinct galloping rhythm. If any of the variables raises, they clearly stand out, producing a separate stream, and allow the operator to react before they reach critical levels.		
References	M. Albers, S. Barrass, S. Brewster S, B. Mynatt: Dissonance on Audio Interfaces, IEEE Expert, September, 1997		

Title	Silent home	
Context	*User*	any
	Environment	any
	Device	any
	Application	any
	Social	any
Problem	Interaction design exploiting auditory means can impose increased cognitive effort on users. This results in users perceiving auditory displays as annoying or tiring.	
Forces	information — cognitive effort	
	awareness — relaxation	
Solution	Indicate clearly an interactional state in which there are as little sounds to be heard as possible. This should be a refugium for the user whenever the cognitive efforts imposed by the interface become to stressful. This implies that it should be easy to reach (e.g., shortcut), but equally easy to leave for the user to continue where they left. Another way of providing silent homes is to reduce audio feedback to immediate responses to interactional events. Thereby, the user can have a perceptual rest, by just doing nothing.	
Rationale	The transient manner of audio often makes designers using a lot of repetition. However, if not repeated, users have to put up with additional cognitive effort to remember. Both effects can make interaction more tiresome and demand for resting points in the interface.	
Examples	Bad: The 3D auditory menu system used repetitive speech to indicate the position of menu items. Even when users did not interact with the system, lots of information was presented resulting in users perceiving the interface as tiresome.	
References	Frauenberger, C., Stockman, T., Putz, V., and Höldrich, R. (2005). Interaction patterns for auditory user interfaces. In ICAD Proceedings, pages 154âĂŞ-160, Limerick, Ireland. International Conference on Auditory Display.	

Title	Variable speed
Context	*User*: researcher, analyst, engineer, teacher, pupil *Environment*: office, lab, classroom *Device*: workstation, headphones, multi-channel audio *Application*: data analysis, perceptualisation, science, education *Social*: single-use, collaboration, efficiency
Problem	Large and complex data sets, possibly multi-variant, need to be analysed. The user should have easy control over how much of the data's properties or inter-data relationships should be preserved in the representation and how long it takes to explore the data.
Forces	detail — time required detail — overview all information — cognitive overflow
Solution	Instead of looping through the chosen time-line in a data set at a constant rate, provide interactive control for the user to change the speed of the presentation. This allows users to explore the data value for value or skim through the data quickly omitting much of the detail, but gaining overview. At the extreme this technique can mean that the whole data set is represented by a single sound. This technique works with all basic sonification approaches, however, audification will distort the result more significantly due to a pitch shift when using variable speeds.
Rationale	By simply giving the user control over the speed at which data is presented, the user also gains control over the required level of detail and the necessary overview to detect structures. Different speeds respond to the rhythmic sensitivity of human hearing and can reveal different relationships. It also follows the Information Seeking Mantra by providing interactively overview and detail.
Examples	Interactive sonification of large data sets in tables.
References	Kildal and Brewster (2005), Explore the Matrix: Browsing Numerical Data Tables Using Sound, ICAD05 Kildal, J. and Brewster, S.A., Exploratory Strategies and Procedures to Obtain Non-Visual Overviews Using TableVis. International Journal on Disability and Human Development (2006), 5(3), pp 285–294

Title	Structured information
Context	*User*: visually impaired, eyes-free *Environment*: office, outdoors, mobile, sports, noisy, bright *Device*: desktop, mobile, PDA, headphones *Application*: user interface, navigation, exploration *Social*: single-use

Problem	Hierarchically structured, ordinal information such as a menu has to be presented auditorily. The representation has to allow users to navigate through the structure quickly while conveying as much information about the current position in the structure as possible.
Forces	additional information — information overflow maximising perceived differences — homogeneity of soundscape efficient navigation — additional information
Solution	Items in a structure often require speech to be represented, but brief navigation sounds before the item can make navigation significantly more efficient and reduce cognitive effort. Use themes to distinguish different branches of the data. Themes can be different instruments, abstract sounds with distinct timbres or sequential variations on musical motifs. The theme needs to leave sufficient room for variation to represent other information (e.g., content types or depth in menu), but also be recognisable as a coherent family. Long themes should be avoided as they prevent fast browsing, but too short themes often offer too little flexibility. When designing themes, also consider semantic relationships to the data and the homogeneity of the result. Within a theme, the depth of an item within the structure can be presented through density. Items closer to the root should have more dense sounds, while those further down have lighter sounds.
Rationale	Studies have shown that different themes or instruments can be reliably distinguished in brief sounds. The proposed approach allows for building complex structures with efficient browsing.
Examples	Various examples of menu navigation sounds.
References	Leplâtre, PhD Thesis, http://www.dcs.napier.ac.uk/~gregory/thesis/thesis.pdf

Title	Auditory arrows
Context	*User*: visually impaired, eyes-free, analyst, teacher, pupil *Environment*: office, lab, on-the-go *Device*: desktop, workstation, mobile, laptop, headphones, speakers *Application*: user interface, exploration, perceptualisation *Social*: single-use
Problem	A directional link between entities has to be expressed by auditory means. This could denote a structural relationship (e.g., inheritance) or an actual physical direction as in a street sign. Users need to be able to intuitively build a mental model of the relationship.
Forces	learnability — diversity of signs conventions — cultural ambiguities robust interpretation — diversity of contexts

Solution	The main mapping choice for indicating the direction of an auditory arrow is order. Each arrow consists of a long sound (stem) and a short sound (head) of the same sort. The directional information can be re-enforced by stereo panning and/or increase in pitch for the arrow head. Different timbres can be used to distinguish different types of arrows, the length of the long sound can indicate the length of an arrow.
Rationale	The design is inspired by the sound that is produced by drawing an arrow on a chalk-board. Also, the metaphor leaves enough room for accommodating other information in dimensions like direction, pitch, timbre etc.
Examples	An auditory arrow as used in an implementation for auditory UML graphs.
References	Metatla O., Bryan-kinns N., Stockman T., Auditory External Representation: Exploring and Evaluating the Design and Learnability of an Auditory UML Diagram. Proc. of ICAD2007

Title	Overviews of Graphs			
Context	*User*	visually impaired, eyes-free, analyst, teacher, pupil		
	Environment	office, lab, on-the-go		
	Device	desktop, workstation, mobile, laptop, headphones, speakers		
	Application	exploration, perceptualisation		
	Social	single-use		
Problem	A key feature of visual graphs is that they convey an overall structure quickly which is an important factor to efficiently access the more detailed information. When presenting graphs non-visually, this feature should be preserved to allow users a similar approach to information seeking.			
Forces	semantic structure	—	visual structure	
	amount of information	—	time to convey overview	
Solution	The first step to the create an overview is to identify what information is key to convey. Prioritise the information semantically and analyse what user elicit from graphical overviews of the data if available. The core of the solution is to represent this high-level information and design for interaction to allow access to details when necessary. For representing high-level information, psycho-acoustic effects can be exploited. For example by presenting multiple streams in parallel, allowing users to switch between streams perceptually. Or by speeding up a representation (see **Variable speed** pattern) until details are not perceptible anymore. Care should be taken, however, that the resulting overview is an abstraction of the information and not an artefact of the representation.			

Rationale	An overview of data is a semantic property that is often produced as an artefact of the graphical representation (e.g., the structure of an underground map). However, to be able to represent an overview in the auditory domain, it is key to understand what information constitutes an overview. Only when the semantics of the overview is determined, it becomes clear what needs to be represented. Features of auditory perception can be exploited to generate overviews by intentionally "overloading" the sense—i.e., presenting too much information too fast. Details are then automatically rejected and an abstract form of the information is conveyed. It depends on the nature of the data, however, if such an abstraction is semantically appropriate for providing an overview. Interaction is an important element in the information seeking mantra: overview first, detail on demand. Therefore, it is important to link the representation of the overview to the details through interaction.
Examples	The sonification of the London Underground disruption map uses multiple streams to represent each line and auditory markers for where they intersect. Sound features indicate the status of lines and stations. The auditory representation of UML diagrams detaches the semantic content from its visual representation. The interaction designed to explore a diagram is tailored towards an auditory representation.
References	Nickerson, L. V., Stockman, T., and Thiebaut, J.-B. (2007). Sonifying the london underground real-time disruption map. In Proceedings ICAD07, pages 252âĂŞ257, Montral, Canada. International Community for Auditory Display, Schulich School of Music, McGill University. Metatla, O., Bryan-Kinns, N., and Stockman, T. (2007). Auditory external representations: Exploring and evaluating the design and learnability of an auditory uml diagram. In Proceedings ICAD07, pages 411âĂŞ418, Montral, Canada. International Community for Auditory Display, Schulich School of Music, McGill University.

Title	Spatial Menu Navigation	
Context	*User*	visually impaired, eyes-free
	Environment	office, outdoors, mobile, sports, noisy, bright
	Device	desktop, mobile, PDA, headphones, multi-channel audio
	Application	user interface, menu navigation
	Social	single-use
Problem	A menu system of unknown complexity has to be conveyed auditorily. Users wear headphones and interact with the system through tactile elements. A typical application would be an MP3 player or Personal Digital Assistant (PDA). The user should be able to build up a mental model of the overall structure and be able to navigate the menu efficiently.	

Forces	efficient navigation	—	additional information
	semantics	—	speed

Solution The solution exploits a spatial metaphor to support user's ability to build a mental model of the menu system—much like in the graphical domain. However, the reduced spatial resolution of hearing does not allow static layout (e.g., a grid). Therefore, a dynamic arrangement is employed in a virtual audio environment. Menu items are laid out in a circle on the horizontal plane, in front or around the user's head position. The user can rotate this circle to explore the menu, bringing items of interest to the main focus area at the front. Multiple (less than 5) items are heard concurrently, but at different locations, and are moved when rotated. Any item in the front can be selected. If the item is a sub-menu, the user enters a new level and the content of the sub-menu is laid out on the circle.

Several techniques can provide additional information during interaction: a) indicate whether the item in the front (i.e., in the focus area) is a sub-menu with by providing a preview of its content, or by another sound property, b) use techniques from the **Structured information** pattern or ambient sound to indicate menu-level, branch etc. and c) support the spatial metaphor by non-speech sounds for rotation (e.g., a rolling sound) and selection (e.g., a bell).

The representation of the items itself depends on the content-type. Many menus will require text-to-speech systems, but by using non-speech sounds prior to the speech, navigation will be faster and other structural information can be conveyed too.

A common problem with virtual audio environments is the transient manner of audio cues. Once played, the user needs to remember the location of the item. The stronger the spatial metaphor is, the easier this becomes for users. Do not attempt to solve this by playing the items repetitively, it is very tiresome. Use the **Silent home** pattern and play cues only when the user navigates through the structure or on demand.

Rationale	Localisation of sound is most reliable in the horizontal plane, with the front being the most accurate. Therefore, this solution aims to bring important items dynamically into this focus area. The rotation of the items on a circle constrains the movement of sound objects and therefore makes it easier to locate or remember their locations. Additional sound cues can strengthen this metaphor. For many types of content, speech is needed to convey the full meaning. However, depending on learning effects users may be able to use only the brief non-speech cues prior to the full length speech to navigate to the desired item, greatly improving efficiency. These brief sounds can then convey additional information about the item and its location in the structure. A promising novel technique in this respect is also the use of **Spearcons**.
Examples	The menu system of a text editor has been implemented and tested with the solution proposed in this pattern. The example demonstrates 3 minutes of navigating through this menu.
References	Frauenberger, C. and Stockman, T. (2006). Patterns in auditory menu design. In ICAD Proceedings, pages 141âĂŞ147, London, UK. international Conference on Auditory Display. Savidis, A., Stephanidis, C., Korte, A., Crispien, K., and Fellbaum, K. (1996). A generic direct-manipulation 3d-auditory environment for hierarchical navigation in non-visual interaction. In Assets âĂŹ96: Proceedings of the second annual ACM conference on Assistive technologies, pages 117âĂŞ123, New York, NY, USA. ACM Press. Palladino, D. K. and Walker, B. N. (2008). Efficiency of spearcon-enhanced navigation of one dimensional electronic menus. In Proceedings of the 14th International Conference on Auditory Display, Paris, France.

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