A User-centred Design Framework for Context-aware Computing

Nicholas A. Bradley

Submitted for the degree of Doctor of Philosophy in the Department of Computer and Information Sciences at Strathclyde University

20 May 2005

DECLARATION OF RIGHTS

DECLARATION OF ORIGINALITY

The material presented in this thesis is entirely the result of my own independent research, under the supervision of Dr. Mark D. Dunlop, carried out in the Department of Computer and Information Sciences at the University of Strathclyde. The thesis is partly based on the following publications:

Bradley, N.A. & Dunlop, M.D. 'Towards a Multidisciplinary Model of 'Context' to Support Context-Aware Computing'. To Appear in *Journal of Human-Computer Interaction*. Vol. 20. Lawrence Erlbaum Associates. 2005.

Bradley, N.A. & Dunlop, M.D. 'An Experimental Investigation into Wayfinding Directions for Visually Impaired People'. To Appear in *Journal of Personal and Ubiquitous Computing*. 2005.

Bradley, N.A. & Dunlop, M.D. 'Navigation Assistive Technology: Context-aware computing'. To appear in M.A. Johnson & M. Hersh (eds.). *Assistive Technology for Vision Impaired and Blind People*. Springer Verlag, London. 2005.

Bradley, N.A. & Dunlop, M.D. 'Towards a User-centric and Multidisciplinary Framework for Designing Context-aware Applications'. *Proceedings of workshop on Advanced Context Modelling, Reasoning and Management at 6th International Conference on Ubiquitous Computing, UbiComp 2004*. Nottingham, UK. 7 September 2004.

Bradley, N.A. & Dunlop, M.D. 'Investigating design issues of context-aware mobile guides for people with visual impairments'. *Proceedings of workshop on HCI in Mobile Guides Workshop at International Symposium, Mobile HCI 04*. Glasgow, UK. 13 September 2004.

Bradley, N.A. & Dunlop, M.D. 'Towards a user-centric multidisciplinary design framework for context-aware applications'. *Proceedings of UbiNet workshop*. Imperial College, London. 25-26 September 2003.

Bradley, N.A. & Dunlop, M.D. 'A Pathway to Independence: Wayfinding Systems which Adapt to a Visually Impaired Person's Context'. *Proceedings of Symposium on Assistive Technology – Towards a better life*. Glasgow, UK. 30 April 2003, pp.23-27.

Bradley, N.A. & Dunlop, M.D. 'Investigating context-aware cues to assist navigation for visually impaired people'. *Proceedings* of *Workshop on Building Bridges: Interdisciplinary Context-Sensitive Computing*. University of Glasgow, UK. 9 September 2002. pp.5-10.

Bradley, N.A. & Dunlop, M.D. 'Understanding contextual interactions to design navigational context-aware applications'. *Proceedings of 4th International Symposium on Mobile HCI 02*. Pisa, Italy. 18-20 September 2002. pp.349-354.

Any published or unpublished material that is used by me has been given full acknowledgement in the text.

Signed: ______________________________ Date: ____________________

(Nicholas A. Bradley)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

A number of people kindly helped me throughout my PhD studentship. Without their support, this research would not have been possible.

I would like to give a special thanks to my supervisor and friend, Dr Mark Dunlop, for his invaluable, generous, and spirited guidance.

I would like to extend my gratitude to the RNIB, The Macular Disease Society, The Retinitis Pigmentosa Society, and Visibility (formerly the Glasgow and West of Scotland Society for the Blind) who all kindly assisted me with my user studies. Many thanks also to everyone who kindly participated in those studies.

The Department of Computer and Information Sciences at Strathclyde University has been a friendly and resourceful environment in which to conduct my research. I would therefore like to thank the Department for use of their facilities and for their generous funding.

Next I would like to thank Simon Sweeney, David Elsweiler, and Sheila Bradley for reviewing my thesis and for their priceless feedback.

Lastly, a final thanks to my family and Safaa Ammar for their moral support and encouragement.

ABSTRACT

Many exciting and promising application areas of mobile context-aware computing have emerged in recent years, such as tourist guides and navigation systems for visually impaired people. However, many researchers express grave concerns about the limited appreciation of human and social issues in design: usability issues remain unresolved particularly relating to mobile computer settings, and existing user-centred design approaches/frameworks are still in their infancy. This thesis proposes a framework to advance user-centred approaches to designing context-aware systems in order to help application developers (i) build richer descriptions or scenarios of mobile computer settings, and (ii) identify key human and social issues affecting the usability of their context-aware system. After a critical review of literature, a multidisciplinary model of context was developed in order to bring together theories, and proposed models, of context in Psychology, Linguistics, and Computer Science. This invaluable exercise illustrated the implications those theories have for context-aware computing. Three key perspectives of the multidisciplinary model were then used to investigate the issue of personalisation of context-aware services, focusing mainly on navigation services for visually impaired people. Firstly, the 'user's context' was investigated, where significant differences were found in the use of landmarks to navigate by people with a central vision loss, people with a peripheral vision loss, and registered blind people. Secondly, the 'application's context' involved designing context-aware services for transmission to participants within indoor and outdoor routes. Thirdly, the 'user-application's context', which brought together the first two perspectives, was investigated where it was found that certain groups were more effective at reaching landmarks when being given information that derived from people in the same visual impairment category. The multidisciplinary model, and the studies investigating its three key perspectives, were combined to form a user-centred framework for context-aware design. Key contributions included (i) richer modelling of user-interface interaction in mobile settings, and (ii) an augmentation to existing user-centred design approaches which includes not just meaningful activities of the user but also incidental and unpredictable activities that occur frequently in mobile settings.

CHAPTER 1

INTRODUCTION

1.1 Motivation

When people talk to one another, the *context* influences how their words and phrases are constructed, spoken, and interpreted. The phrase 'look at those monkeys', for instance, would be spoken and interpreted differently when visiting a zoo as opposed to commenting on the standard of my local football team! Humans are, in fact, very well attuned to making fine judgements about their context; not just for forming and interpreting dialogue but also for carrying out physical actions or activities. Most of the time we are able to do this without much conscious decision, analysis, or discretion. But the extent of this ability becomes quite impressive when we look deeper into the dimensions of context that influence social interaction and human behaviour. During a conversation, for instance, dimensions may include the relationship of those participating in communication; the physical location in which dialogue occurs; the purpose or motivation of conversation; the people surrounding a conversation taking place; the mutual perception of each other's knowledge, experience, intelligence and abilities; the nature and content of past conversations; the interpretation of each other's expressions and emotions; and the current time of day, week, month, or year. Humans could therefore be described as being *context-aware* as they are able to adapt their dialogue and behaviour to, and interpret actions and dialogue within, a particular situation, circumstance, or context (some better than others of course!).

Unfortunately, most traditional desktop computers and mobile computers (e.g. laptops, mobile phones, palmtops, etc.) are unable to make similar judgements about context when they attempt to communicate information to people. Such interfaces are therefore context independent, since they are unaware of who or what is surrounding the user, and so are unable to adapt to the surrounding environment. Except for limited examples such as context-sensitive menus on right click, traditional user-interfaces rely mostly on explicit user input to determine what information to provide or services to execute. Only the user's command is supported resulting in an unnatural and forced pattern of behaviour (when we consider human dialogue) causing the user to be caught up in a loop. This style of interaction is not only inappropriate for many modern computer settings, but is also time-consuming, a demand on the user's attention, and likely to lead to frustration caused by a mismatch between what the computer is capable of doing, and what the user would like it to do given his/her current situation or context. Consider the following situation that I experienced recently:

My friend Luke, whom I had not spoken to for quite some time, called me unexpectedly on my mobile phone. During our conversation, I was interrupted by an alert on my mobile phone informing me of a reminder that I had set two weeks before. Momentarily interrupting Luke, I checked to see what was on the phone's display. Since I was given the option to either accept or reject viewing the reminder, I decided to reject so I could return quickly to my conversation. Unfortunately, a few minutes later the alert sounded once again and this time I accepted viewing the reminder in order to prevent being interrupted for a third time.

In this situation, I was forced into dealing with the reminder during my call since my mobile phone was unable to make any contextual analysis of my current situation; it was simply executing an explicit command given by me. A more appropriate response, using some limited contextual information such as call status and whom I was speaking to, would have been to alert me after I had finished my call. The procedure in setting a reminder may also need to include a setting asking me to attach a priority level, so that in the case of a high-priority reminder an interruption during my call may have been warranted.

The transition from desktop computing to mobile computing has, in recent years, become more prevalent, as is evident in the pervasive use of mobile phones, palmtops, and other mobile devices. People now want access to services, information, and technologies that are typically found on desktop computers, as well as integrated multimedia technologies such as photo and video capturing. Although many internet-based services on mobile devices move closer to the ideology of information *anytime* and *anywhere*, the user still needs to use techniques similar to desktop interfaces to retrieve information. Researchers have indicated that this style of interaction does not transfer well to mobile devices since people are moving through complex and dynamic environments involving a myriad of interactions with other people and objects. People are therefore unable to focus exclusively on one task and are frequently subjected to incidental, unpredictable, or unexpected events/interruptions. In addition, interaction with the mobile device may be a secondary task, or be of lesser importance than other tasks such as engaging in conversation. Many researchers believe that more research is needed to investigate user-computer interaction in mobile settings. Many researchers also believe that the task analysis techniques used for carrying out those investigations need to be augmented in order to account for the dynamic and unpredictable nature of users and environments. While these are challenging, complex, and largely unanswered, issues in usability research, this thesis aims to provide a significant contribution to research investigating mobile computer settings and to the techniques used to analyse those settings.

Adapting to changes in the environment is at the heart of context-aware computing where it is envisaged that, by adding context, computers could (i) provide more relevant and useful location- and task-specific feedback by using, say, the user's current location, the time of day, and the user's electronic personal diary, (ii) make user interaction more natural and personalised, thus increasing the richness of communication, and (iii) be more dynamic by adapting to the continuously changing situation of the user. Although still largely based on research prototypes, context-aware computing seeks to completely redefine the basic notions of interface and interaction by inferring user actions, thereby minimising traditional user-driven interaction. Accessing a wide variety of contextual information is also now viable partly due to the enhanced sensing capabilities that can be integrated into mobile applications. This trend is likely to continue in light of Weiser's (1991) vision of ubiquitous or pervasive computing, where computers could be embedded in everyday objects allowing vast amounts of contextual information to be exchanged in an interconnected environmental infrastructure.

Services based on location-awareness, which is often one facet of context-awareness, have become more widespread, particularly the use of integrated GPS technology for in-car and handheld navigation systems, both of which have been commercially available and successful for a number of years. Although the exploitation of location-aware services is still in its infancy, this is expected to change once the U.S.A. enhanced emergency mobile phone legislation (E911) takes affect requiring 95% of mobile phones to provide an accurate location whenever an emergency call is made (similar initiatives are underway for 112 calls within the E.U.; see http://www.fcc.gov/911/enhanced/). Research initiatives exploring location-aware services on mobile devices include applications that provide information on nearby amenities (e.g. 'where's the closest...') and applications that adjust their state, services, and feedback depending on its location (e.g. mobile phones that automatically mute when in the cinema or in a meeting). Other location-aware systems include applications which aim to minimise call-out times of the police, and emergency and breakdown services, by matching an incident to the closest ambulance, police car, or breakdown van.

Context-aware services are very similar to location-aware services, except that a wider variety of information about the user's context is used to infer and support the user's mobile activities. Context-aware services have also been exploited for many promising applications and good examples, which are discussed in more detail later, include (i) context-aware mobile tourist guides that recommend places to visit based upon, for instance, the current location, the tourist's personal preferences, and the opening times of attractions, (ii) context-aware computing for medical work in hospitals, such as a context-aware pill container and a context-aware hospital bed, both of which adapt to what is happening in their context, and (iii) context-aware systems that offer navigation and orientation assistance to visually impaired people; the topic of which is a major focus of the work presented in this thesis. The latter example illustrates some obvious benefits, which include (i) augmenting visually impaired people's spatial orientation and contextual knowledge of the environment beyond what can be sensed from traditional mobility aids such as white canes and guide dogs, and (ii) minimising user-driven interaction in order to allow visually impaired people to focus more on environmental learning and hazard identification.

Adaptive or intelligent systems have in fact been around for a while, and good examples can be seen in aircraft safety-critical systems (e.g. obstacle avoidance systems that automatically realign aircraft if entering an unsafe distance from another aircraft) and, on a smaller scale, central heating thermostats that switch on and off to maintain a specified air temperature. These examples are centred on very precise context triggering criteria (i.e. distance and temperature thresholds), and have been highly effective for their specific purpose. However, when multiple context triggering criteria is brought together (which is the premise of context-aware computing) it becomes far more complicated to infer a suitable course of action. There are plenty of examples of context prediction tools that have been ineffective, ranging from the pop-up help wizard in Microsoft Word asking if you want help writing a letter, to the pop-up dialogue box appearing after inserting a pen drive asking if you want to copy picture files to your computer even though the pen drive contains predominantly more files of other types. In such situations, the user ends up feeling frustrated and annoyed at having to deal with events that had not been requested in the first instance.

For context-aware systems to be successful, many researchers believe it is the human and social issues of design that need to be resolved. Other than the more publicised privacy and security issues of personal user information, there is a danger that too much of the user's context is inferred, resulting in intrusive services that bombard the user with ill-timed, irrelevant information. What assumptions, for instance, can be made or inferred about a user's situation from sensed data? How would the application adapt to evolutionary changes of users and environments? How would information be adapted or personalised for different users and user groups? With respect to visually impaired people, requirements and visual abilities change considerably, as described by Orientation and Mobility Specialists, and so many of these issues would be critical to their safety, especially in cognitively demanding or contextually rich mobile situations. Visually impaired people present a particularly challenging and varied research application of context-aware computing, and for this reason this topic was chosen to be a major focus of this thesis, which reports on a series of user studies investigating the differences between users and the environments in which they interact.

To address human and social issues in design requires a better understanding of what the notion of ‘context’ means, particularly the user’s context during different mobile activities and within different mobile settings. This gap in knowledge is noticeable when examining existing processes or frameworks for designing context-aware applications, which have been predominantly software-orientated and show a distinct lack of understanding and appreciation of the user. Although an active research area within many disciplines including psychology, linguistics, and more recently computer science, the notion of context is still not fully understood, which is evident in the contrasting interpretations across and within various disciplines. There is a strong case for tackling issues of context from a multidisciplinary perspective. Many computer scientists argue that experts in several technological domains such as software engineers, user interface experts and radio experts need to be brought together in order to draw upon cognitive science, user experience and situation into the computer system design process. For instance, an understanding of theories within linguistics provides an insight into how information given by the computer should be adjusted and communicated for different contexts and situations. Whereas, an understanding of psychology provides an insight into (i) the cognitive processes that underpin a user’s decisions and behaviour especially in response to incidental events, and (ii) how people acquire and use spatial information in the environment to orientate and navigate.

In order to make a significant contribution to the limited body of user-centred research in context-aware computing, much of this thesis brings together cross-disciplinary theories of context as a means to better understand and capture key human and social issues, such as those discussed in the last paragraph.

1.2 General aim

The primary aim of this thesis is to propose a user-centred and multidisciplinary design framework for context-aware computing. The purpose of this work is to help application developers (i) build richer descriptions and scenarios of how their context-aware system might be used in different mobile settings, and (ii) capture key human and social issues affecting the usability of their system. It is worth noting that this thesis will not contribute to the technological and software solutions to context-aware development, concerning for instance the actual process in sensing, storing, managing, and interpreting contextual information; areas of which are researched extensively in middleware design. A more detailed list of my research aims will be covered at the end of the literature review in section 2.9.

1.3 Thesis outline

This thesis proposes a user-centred framework for designing context-aware applications in order to address the limited appreciation of human and social issues in research and development. The reader is taken through various stages leading up to the proposed framework. In Chapter 2, an extensive literature review will be described focusing initially on application areas, usability issues, and design techniques of mobile context-aware computing research. Cross-disciplinary theories of 'context' will then be described in order to understand better the mobile settings in which a context-aware system might operate. This involved proposing single context models that were used to represent the views of researchers in each discipline. The last two sections of the review will discuss wayfinding and cognitive mapping research since the main application area of this thesis concerns the design of context-aware *navigation* services for visually impaired people. These areas of research provide an insight into how people navigate, particularly how contextual information in the environment is used to make decisions regarding spatial activity.

In Chapter 3, a multidisciplinary model of context will be proposed and described. This model brings together the single discipline context models from the last chapter and is used as a foundation on which to conduct a series of user studies investigating the prominent issue of personalisation of context-aware services. Three key design perspectives of the multidisciplinary model were investigated, each of which forms a separate chapter.

In Chapter 4, the 'user's context' was investigated with respect to the navigation-based activities carried out by sighted and visually impaired people and their use of landmarks and cues in the environment to navigate. In Chapter 5, the design of the 'application's context' will be described, focusing on the transmission of different context-aware services for indoor and outdoor environments. In Chapter 6, the investigations of the user's context in Chapter 4 and the design of the application's context in Chapter 5 are brought together to investigate the user-application's context. This concerned a large-scale user study investigating how effective different groups of visually impaired people were at reaching destinations when different conditions of context-aware information (the contents of which were designed using the results from Chapter 4) were transmitted to them (using the designed application's context in Chapter 5).

In Chapter 7, the user-centred framework is proposed and discussed. The framework brings together the multidisciplinary model of context and the studies investigating the user's context, application's context, and the user-application's context. A user study is also undertaken investigating how effective the framework is for identifying key human and social issues of design. In the eighth and final chapter, the work detailed in this thesis will be concluded and areas for further investigation will be discussed.

CHAPTER 2

CRITICAL REVIEW OF THE FIELD

In this chapter an extensive literature review will be described focusing initially on application areas, usability issues, and design techniques of mobile context-aware computing research. Cross-disciplinary theories of ‘context’ will then be described in order to understand better the mobile settings in which a context-aware system might operate. This involved proposing single context models that were used to represent the views of researchers in each discipline. The last two sections of the review will discuss wayfinding and cognitive mapping research since the main application area of this thesis concerns the design of context-aware *navigation* services for visually impaired people. These areas of research provide an insight into how people navigate, particularly how contextual information in the environment is used to make decisions regarding spatial activity.

2.1 Context-aware mobile computing

The original vision of ubiquitous computing (now often called pervasive computing) was propounded by Mark Weiser in 1991. He envisaged a world where computers could disappear into the environment by being embedded and enmeshed in everyday objects (Weiser, 1991). In a ubiquitous environment, computers locate and serve users, instead of the users having to adapt to the interface and capabilities of the computer (as in desktop computing environments). Rich flows of contextual information make computers more aware of the environment, enabling them to transmit more personalised and localised information to the user. It is therefore conceived that users could become more responsive and attentive to their more meaningful and significant needs and activities.

Context-aware computing was therefore one of the early concepts introduced in some of the pioneering work on the ubiquitous computing paradigm and has since been an area of widespread research, partly due to availability of low cost and low budget sensors. It was first discussed by Schilit & Thiemer (1994) who defined it to be software that ‘adapts according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time'. Since then many other definitions have emerged, which include 'the ability of a computing service to collect information or context about the user, and then use that context to provide some services or functionality in support of the user and his/her task' (Dey, 2001a) and 'systems that sense or remember information about the person and the emotional or physical situation in order to reduce computer-user communication and effort' (Selker & Burleson, 2000).

Making a computer more aware of the user's context unravels new and potentially enhanced levels of user support, which have been categorised by a number of researchers. Schilit *et al.* (1994) propose four types of context-aware applications:

– *Proximate selection*: a user-interface technique where the objects located nearby (e.g. a printer) are emphasized or otherwise made easier to choose.
– *Automatic contextual reconfiguration*: a process of adding new components, removing existing components, or altering the connections between components.
– *Contextual information and commands*: adjusting results according to the situation in which they are issued.
– *Context-triggered actions*: simple IF-THEN rules used to specify how context-aware systems should adapt.

In another categorisation, Pascoe (1998) proposes a taxonomy of context-aware capabilities in terms of (i) *contextual sensing* - environmental states are sensed and presented to the user, (ii) *contextual adaptation* - contextual knowledge is used to adapt the application's behaviour to integrate more seamlessly with the user's environment, (iii) *contextual resource discovery* - the application discovers other resources and exploits these while the user remains in the same context, and (iv) *contextual augmentation* - application allows the user to augment the environment with information at a specific location for other users.

Although there is considerable overlap between both previous categorisations, there are slight differences too. Pascoe's categorisation, for instance, includes 'contextual augmentation' as a capability that is not included in Schilit *et al.*'s classes of applications. In an attempt to combine the principles from both categorisations, Dey (2000) proposes three general categories of context-aware features which include (i) presentation of information and services to the user, (ii) automatic execution of a service, and (iii) tagging of context to information for later retrieval. Chen & Kotz (2000) generalise context-aware features even more by stating that there are two ways in which a mobile application can take advantage of context. Firstly, *active context* is where an application automatically adapts to discovered context, by changing the application's behaviour, and secondly, *passive context* is where an application presents the new or updated context to an interested user or makes the context persistent for the user to retrieve later.

A commonality that exists across all categorisations of context-aware features is that their realisation is dependent on the ability of the application to sense relevant aspects of the user's context. This includes two separate issues concerning the ability of the application to sense the environment using various sensing technologies, and the ability of the application to recognise what is relevant about the user's context, which Schilit *et al* (1994) state is 'where you are, who you are with, and what resources are nearby' - other similar viewpoints include Dey (2001) who believes it is the user's location, identity, time and activity. Table 2.1. provides an illustration of potentially desirable user information (all of which have been used by context researchers at some point) and the technologies used to acquire it – for a more detailed discussion of sensing technologies, refer to Chen & Kotz (2000).

Information about the user's context	**Type of technology**
Indoor and outdoor location	GPS, Active badge, mobile phone cells
Nearby objects, e.g. printers, other mobile devices, etc	Ultrasonic transducers, Bluetooth and Infrared sensors
Local or surrounding environment	RF beacons
Speed of movement, e.g. walking vs. driving	Accelerometers sensors
Orientation of body, e.g. upright or lying down	Electronic compass
Outside temperature, light levels, and noise levels	Temperature sensors, photodiodes, omni-directional microphones
Heart rate, body temperature, blood pressure,	Physiological sensors
Time of day, week, month, season, and year	Built in clock
User preferences	Customised application settings
Social and business arrangements	Personal diaries
Available resources, e.g. weather forecasts, train and bus timetables, etc	Web-based servers
Surrounding people	Face recognition using camera technology & image processing

Table 2.1. Sensing technologies used to identify desirable features of the user's context.

One of the main design concerns about bringing together sensing technologies, such as those described in Table 2.1, is that the weight and size of the mobile device will be increased, thus impacting on the user's mobility. Although sensors have become smaller and more unobtrusive in recent years, there have been research initiatives investigating the deployment of sensors in the environment as public infrastructure that can be accessed by mobile devices through online centralised servers (Schilit *et al*., 1993; Bacon *et al*., 1997). Information from local weather stations, for instance, can be accessed instead of the device having to sense climatic conditions, resulting in a more efficient use of the battery.

However, perhaps the biggest challenge for context-aware computing research is to build applications that effectively deliver relevant and timely information to the user. From the perspective of software development, this challenge is to sense, store, consolidate, interpret, and transmit information. These areas are researched extensively in middleware design, which concerns the development of toolkits and services to facilitate the discovery and delivery of context data. Good examples are discussed in Dey (2000), Huang (2002), Coulouris *et al* (2001), and Sørensen *et al* (2004). Conversely, from the perspective of the user this challenge, which has received limited research by comparison, is to determine what is relevant to different users and user groups based upon contrasting requirements, mobile activities, and personal preferences. Researchers investigating this challenge include Bellotti & Edwards (2001) who highlight 'it is the human and social aspects of context that are crucial in making a context-aware system a benefit rather than a hindrance - or even worse – an annoyance', and Dourish (2001) who states that 'instances of interaction between people and systems are themselves features of broader social settings, and those settings are critical to any analysis of interaction'.

Whether tackling this challenge from the application or user's perspective, it is generally agreed by researchers in context-aware computing that more sophisticated models of the computer, user and task are needed (e.g. Selker & Burleson, 2000). It is also felt that there are considerable gaps in knowledge in modelling user-computer interaction in mobile settings. As illustrated in the next chapter, this thesis makes a significant contribution to these research areas, primarily though from the perspective of the user.

The remainder of this section illustrates examples of research application areas of context-aware computing. The focus is on mobile computing rather than desktop computing (or systems not involving mobile computers), since it is felt that analyses of context in mobile settings are far richer, arguably more challenging, and more under researched. There are, however, many good examples of non-mobile context-aware applications:

- Considered to be one of the first context-aware applications, the Active Badge System from the Olivetti Research Lab tracks the location of persons in an office and then uses it to forward calls to the closest phone (Want *et al.*, 1992).
- The In/Out board from the Georgia Institute of Technology gathers information about the participants who enter and leave the building and then displays that information to users depending on the identity of the user, the research group the user belongs to, and the information that would be interesting for that group (Salber *et al*., 1999).
- The context-aware office assistant is a system that interacts with visitors at the office door and manages the office owner's schedule (Yan & Selker, 2000).
- The active area of context-aware homes includes systems designed to support the daily activities of elderly people (e.g. Lines & Hone, 2002), and systems to support in-house context–aware communication by allowing family members to speak to one another as if they were in the same room (e.g. Hindus *et al*, 2001).
- There are research initiatives aimed at supporting the intensive and distributive nature of information management and communication in a hospital setting. The Intelligent Hospital project, for instance, concerns the development of an application that supports remote consultation, and tracking of patients and equipment (Mitchell *et al*., 2000). In other work, Bardram (2004) discusses a context-aware pill container and a context-aware hospital bed, both of which react and adapt according to what is happening in their context.

The mobile application areas chosen for discussion have been categorised under systems that support work activities, applications that support navigation of visually impaired people, applications that support tourists' activities, applications that allow users to augment the environment, mobile phones that adapt their behaviour, and applications that support leisure activities. In the last subsection key usability issues that remain insufficiently addressed in current research are discussed.

2.1.1 Supporting work activities

The palm-sized wireless ParcTab computers, developed at the Xerox Palo Alto Research Centre, were used for various context-aware experimentation in an office environment (Brown *et al*., 1997). Using an infrared communication system that links ParcTab computers to each other and to desktop computers through a Local Area Network (LAN), context-aware services included presenting information about the room the user was in, displaying information about UNIX directories associated with that room, and helping the user to find the most convenient local resource. In order to provide these services, the ParcTab applications used the user's location, the presence of other mobile devices, time, nearby non-mobile machines, and the state of the network file system. ParcTab computers were also used for another system called Forget-Me-Not, developed at the Rank Xerox Research Centre in Cambridge, UK. This system was designed to serve as a memory aid, helping people with everyday memory problems such as finding a lost document, remembering somebody's name, recalling how to operate a piece of machinery, etc. (Lamming & Flynn, 1994). The ParcTab collects information about selected aspects of the user's activities, such as the location of the user, who they are with, whom they phone, etc. This information is stored in a database and queried at a later date.

In another example, the Georgia Tech Laboratory developed a Conference Assistant that was designed to support attendees of a conference (Dey, Futakawa, Salber, & Abowd, 1999). After attendees register, indicating their research interests and contact details, the Conference Assistant is offered to each attendee, who can run it on his/her laptop or palmtop. Services offered include (i) highlighting timetable events of potential interest to the attendee, (ii) displaying information about presenters and their presentation material whenever a room is entered, and (iii) allowing the attendee to attribute notes to accessed presentation material – notes are time stamped and can be retrieved at a later stage. As context information, the application uses the location, the time, the activity in a certain situation, and the user's preferences.

2.1.2 Navigating visually impaired people

In recent years, a number of GPS-based systems have been designed to address the orientation and navigation needs of visually impaired people, as discussed in section 2.6.4. However, most of those systems provide the user with very limited contextual detail and, when considering Pascoe's (1998) categorisation, discussed in section 2.1, their capabilities are limited to contextual sensing. In order to move closer to the ideology of independent mobility, where visually impaired travellers can travel freely through the environment, a few researchers are attempting to draw upon other context-aware capabilities to augment the user's spatial awareness and knowledge of the surrounding and distant environment.

The Drishti wireless navigation system, which is being developed by researchers at University of Florida, transmits route information to visually impaired and disabled people in order to assist navigation through dynamic outdoor environments (Helal *et al.*, 2001). Drishti is designed to generate optimised routes based upon user preferences, temporal constraints such as traffic congestion, and dynamic obstacles such as ongoing ground work. For instance, routes involving fewer hazards may be chosen over the shortest route. Re-routing is supported if unexpected events occur, and travellers can also add notes about certain conditions or problems encountered as a reminder if the route is revisited (e.g. a pothole in the pavement).

Drishti integrates several hardware components including a wearable computer, an integrated GPS/Beacon/Satellite receiver, an electronic compass, and components for various wireless networks. Software components include a spatial database called ArcSDE to manage GIS datasets; a route store called NetEngine to define, traverse and analyse complex geographic networks; and a mapserver called ArcIMS to serve the GIS datasets over the Internet. Communication between the user and interface is accomplished using ViaVoice, which transmits detailed explanatory cues using text-speech software and also executes verbal commands of the user using voice recognition.

2.1.3 Supporting mobile activities of tourists

One of the most popular applications of context-aware computing is that of supporting the mobile needs of tourists. In the Cyberguide project, mobile tourist guides were designed at the Future Computing Environments (FCE) from the Georgia Institute of Technology (Adowd *et al.*, 1996). Developed for indoor and outdoor use, the Cyberguide prototypes provided information to a tourist about his/her location. Context-aware services include giving directions, offering personalised recommendations of places to visit, displaying background information, and allowing the user to leave comments on an interactive map. The system acquires outdoor location information from a GPS receiver and from an infrared (IR) positioning system indoors. The user's past experiences detailed in his/her travel diary are used to provide informed recommendations of places to visit.

In another system, a mobile tourist guide called GUIDE is being developed at the Distributed Multimedia Research Group from Lancaster University (Cheverst *et al.*, 2000). The system adapts and transmits geographical information regarding points of interest in order to suit the personal and environmental contexts of the tourist. The context-sensitive application supports different tasks that include:

- acquiring context-specific information regarding the current location;
- navigating the city or local area using a map;
- generating tours of the city and navigation to landmarks – the application optimises tours based on opening and closing times, the likely busyness of the attraction, the distance between attractions, and the most aesthetic route;
- communicating with other visitors or with the tourist information centre by sending a text message.

The handheld GUIDE system operates on a Fujitsu TeamPad 7600 device, and its software was designed similar to an Internet browser for immediate familiarity. A cell-based wireless communication infrastructure is used to broadcast both location and dynamic information to mobile GUIDE units. Location positioning is determined from location messages that are received from strategically positioned base stations.

In more recent work, part of the Information Society Technologies (IST) Programme of the European Commission, the Ambiesense system is being developed to exploit user contexts in ambient computing (Göker & Myrhaug, 2002). The aim is to design and implement technology that is ambient, personalised to the users, and sensitive to their individual situation (i.e. context-sensitive). The Ambiesense project involves developing a new system architecture that will enable ambient information services to be delivered to mobile citizens, particularly business travellers and tourists. These services will be ubiquitous, personalised to the individual user, and appropriate to the user's current situation/context.

2.1.4 Allowing users to augment the environment

A concept called stick-e notes, the electronic equivalent of Post-It™ notes, has been researched at the University of Kent in Canterbury (Brown, 1996). Referring to Pascoe's (1998) categorisation of context-aware capabilities, this concept is centred on contextual augmentation. The stick-e document is a framework for incorporating this metaphor in the design of a wide variety of context-aware applications. It is described how the user, who would possess a location-aware mobile device, can leave stick-e notes at specific locations in space. When the user revisits this location, the message is triggered and displayed to the user. These notes can also be broadcast and exchanged to a wider audience if this is considered to be a desirable design feature. In this example only the location is used to determine when a note is triggered, though Brown (1996) also describes how other elements of context can be included to make the presentation of notes more useful. Triggering events could be dependent on (i) the adjacency of other objects or people, e.g. when the user is in the presence of a particular friend, (ii) critical states, such as temperature thresholds, and (iii) time ranges, e.g. only display a note about a tourist attraction during opening hours.

The exchange of notes between users would not normally be done singularly, i.e. one note at a time; rather, a stick-e document would be exchanged containing a group of notes that have a logical relationship, such as notes relating to a particular activity or tourist trial. The dissemination of documents could be (i) downloaded to the mobile device using web-based services, (ii) exchanged between two devices using beaming, such as Bluetooth, or (iii) loaded into the mobile device via a wireless link (by this method, notes within the document could be updated regularly in order to reflect environmental change).

In another example, E-graffiti is a context-aware application that was developed at Cornell University (Burrell & Gay, 2002). By detecting the location and identity of a student on the Cornell campus wireless network, the system displays a list of relevant text notes to the student based upon his/her location. It also allows the student to create notes about a specific location on a wireless network. These notes would be displayed to other students if they visited the same location. Notes can either be public (visible by all) or private (visible by users chosen by the note creator). The user's location is identified by querying the access points that make up the wireless network to determine which access point is currently closest to the user.

2.1.5 Mobile phones that adapt their behaviour

At Carnegie Mellon University, research is being undertaken into a context-aware mobile phone, called SenSay (Siewiorek *et al.*, 2002). By combining light, motion, and microphone sensors, the phone adapts to dynamically changing environments and physiological states using different operational states. The 'uninterruptible' state, for instance, is activated if the user is involved in a conversation or at a meeting. This situation is detected using a microphone sensor and the user's electronic diary. People attempting to call the SenSay user in this state would be sent a SMS informing them to call back within three minutes if their call is urgent. Urgent calls would override the SenSay user's state, causing the mobile phone to ring at a high volume. The uninterruptible state also contains two sub-states concerning 'light on' and 'light off'. When the phone is in the user's pocket (light off state), the vibrate mode is used to alert the user. Whereas if the phone was out of the user's pocket (e.g. on a table) the light on state is activated and vibrate mode would be turned off. In another state, the SenSay phone can be used to alert the user during environmental circumstances where it is difficult to communicate (i.e. the 'active' state). For instance, in situations where there are high-level ambient noise levels, SenSay can adjust the ringer and vibrate modes accordingly.

In a similar investigation, Schmidt *et al.* (1999) designed an experiment to demonstrate situational awareness of a personal digital assistant and mobile phone. In the PDA scenario, a notepad application was changed to adapt the font size to the user's activity (i.e. large font when the user is walking, small font when the user is stationary) and to environmental conditions (e.g. light level). In the phone scenario, the context is recognised and used to select automatically profiles of the mobile phone. Depending on whether the phone is in hand, on a table, in a suitcase, or outside, the phone chooses to ring, vibrate, adjust the ring volume, or keep silent.

2.1.6 Supporting leisure activities

At Carnegie Mellon University, a web environment for context-aware services is being researched and developed (Sadeh *et al.*, 2002). The environment is based on a growing collection of customizable agents capable of (semi-) automatic discovery and access of Intranet and Internet services as they assist their users in carrying out different tasks (e.g. planning an evening, looking for a place to eat, filtering incoming messages, etc.). As an illustration, the MyCampus agent called the 'restaurant concierge' provides suggestions to users on where to have lunch, depending on their food preferences, the time they have available before their next meeting or class, their location on campus, and the current weather conditions. Other agents include (i) context-sensitive message filtering agents that are used to filter push messages such as announcements about events on campus, and (ii) context-sensitive reminder agents that remind students of tasks detailed in their 'To Do' list when they are near the location in which the task would be performed (e.g. reminder to buy milk when close to a grocery store).

In other research, Pignotti *et al.* (2004) describe a multi-agent service delivery architecture, which is used as a platform for a context-aware recommendation system called RECO. Using the user's profile (e.g. preferences), past behaviour (e.g. services previously visited), location, and time of day, the mobile system provides a range of recommendation services giving details about pubs, cinemas, restaurants, seminars, etc. RECO integrates with popular Web browsers through a client application, and the researchers are investigating the implementation of a client for Microsoft Pocket PC.

2.2 Usability issues of context-aware design

The purpose of this section is to illustrate the key usability issues of context-aware design and also to link these issues to the application areas discussed in sections 2.1.1-2.2.6. The main issues that will be discussed are: (i) personalisation of information, (ii) coping with unexpected mobile situations, (iii) localising information and its delivery, (iv) styles of user-interface interaction, (v) privacy and security, and (vi) social issues.

2.2.1 Personalisation

Personalisation is a key concept within Human Computer Interaction (HCI) research that is beginning to generate significant interest throughout the world of mobile devices. The concept is centred on the ability of a mobile device to adapt to the needs, preferences, and interests of users, rather than the users being forced to conform to the interface and operations of their devices. In recent years, personalisation has been widely discussed as a key feature in the context-aware field. In an investigation of user needs of location-aware mobile services, Kaasinen (2003) found personal variations in preferences for both the content of information and on its presentation.

However, despite this interest, very few user studies have been undertaken with a view to investigating personalisation differences across user groups. This has been evident in the lack of personalisation capabilities of current mobile context-aware systems. For instance, although the DRISHTI system for visually impaired people offers many encouraging levels of user support (Helal *et al.*, 2001), the information transmitted by the system was the same for all users. People with different, and with varying severities of, visual impairments would therefore not be able to adjust information and its presentation for their personal needs. Bradley & Dunlop (2004b) believe that these are key usability issues that need to be resolved if such systems are to support and enrich/enhance the lifestyles of users in an unobtrusive and seamless manner. Similarly, in another example, a significant test for mobile tourist guides is whether they can be 'picked up and used' by tourists from different demographic and cultural backgrounds. Tourists visiting a city would have contrasting expectations of supported activities, levels of functionality, and methods of user-interface interaction.

Personalisation is not explicitly accounted for in the design of ParcTab computers (Brown *et al*., 1997), of the SenSay mobile phone (Siewiorek *et al*., 2002), and of the PDA and mobile phone scenarios described by Schmidt *et al.* (1999). Displaying UNIX directories and information associated to a room on a ParcTab computer, for instance, might depend on the job roles and current activity of each person present in the room. Further, in the SenSay project, the ability of a phone to adapt its behaviour automatically (without user intervention) to changing environments might not be in keeping with the user's changing preferences and requirements, e.g. perhaps there may be situations during which I would want my phone to vibrate when on the table, or situations when I do not mind being interrupted in an informal meeting. More investigations need to be undertaken into the scenarios within which mobile phone states could be inferred.

While the premise of context-aware computing is to adapt to the needs and wishes of the user, no system (with the exception of DRISHTI system) explicitly accounted for the requirements of elderly and disabled people. It would appear that the researchers who have designed those systems make the assumption that users are able bodied. For instance, the PDA that adjusts its font size depending on the user's activity (Schmidt *et al.*, 1999) might not be desirable for elderly people with poor eyesight. With the exceptions of E-graffiti (Burrell & Gay, 2002) and GUIDE (Cheverst *et al.*, 2000), this could be due to the fact that no studies involving end-users were carried out. The motivation has mostly been a technological one and, as a result, most of the context-aware systems currently in development are at risk of being unusable by, and intrusive to, their end-users.

2.2.2 Designing for mobile computer settings

In comparison to desktop computer environments, mobile computer settings consist of richer, more frequent, more unpredictable, and more heterogeneous, contextual interactions with other people and objects. Since the user can rarely focus exclusively on one task, the extent to which the user-interface drains the attention of the user in a mobile setting normally provides a good indication of its effectiveness (Garlan *et al.*, 2002). Currently, the user-interfaces on most mobile devices are too intrusive since users have to use desktop-style techniques to retrieve information; techniques which Garlan *et al* consider to be too demanding on the user's attention particularly when preoccupied with walking, driving, or other real-world interactions. Not just that, but people make more unpredictable decisions about their activities when they respond to dynamic mobile environments (Dourish, 2001). This affects both the design of information content and delivery, issues of which present challenging topics for future usability research.

More investigations are needed into understanding individual and group differences in how people respond to mobile environments. The Cyberguide system (Abowd *et al.*, 1996), for instance, would need to support different cultural user groups making entirely different incidental decisions regarding their spatial activities (e.g. determining when a tourist might wander from a tourist trail). In another example, the stick-e notes system (Brown, 1996) would need to show evidence of the context triggering criteria working in practice with end-users. For instance, triggering a note when the user is in the presence of a particular person may not always be appropriate, such as in the situation of a work-related note being triggered when the user incidentally bumps into his work colleague at lunchtime. The suitability of notes is likely to be dependent on more than one or two context triggering features, and so more needs to be understood about the user's context in mobile settings.

2.2.3 Localising information and its delivery

Localising information and its delivery are key design features of context-aware computing. However, both of these issues are rarely given sufficient analysis or investigation when one considers the mobile settings through which a user is likely to travel. For instance, the Drishti system (Helal *et al.*, 2001) is limited to outdoor environments and was tested using a very precise task and scenario, i.e. through a university campus. Testing this system in a wider range of contexts, such as indoor, and for other mobile tasks would be more challenging and would involve acquiring far more contextual information. Similarly, the tourists aids, GUIDE & Cyberguide, would need to account for the wide-ranging activities of tourists who may pass through outdoor and indoor environments and may use different modes of transport too, e.g. touring a city by car, bus, tram, walking, or cycling. How would information be adjusted for each? Another key issue for DRISHTI, Cyberguide, and GUIDE is to what extent should information be filtered when routes are *revisited* – what assumptions can the application make about the user's acquired knowledge?

Certain techniques in presenting information to the user may also be more appropriate, when the user's task, activity, or situation is considered. Speech output, for instance, may be better for visually demanding tasks, whereas a visual display may be better for illustrating spatial relations. With respect to the delivery of tourist information, speech output may be preferred when viewing an attraction than a display (and vice versa if the user is wanting to acquire information before visiting an attraction). It also may be desirable to span contextual information across several sensory channels, such as through hearing and touch (Brewster *et al.*, 2003). Ross and Blasch (2000) argue that the best interface for visually impaired people is a combination of speech output and tactile cues using a tapping interface. More research, however, is needed to understand appropriate techniques for presenting information to different users within different environments (Bradley and Dunlop, 2002b).

2.2.4 Styles of acquiring contextual information

Cheverst *et al.* (2000) differentiated between two contrasting styles of how a user may wish to acquire context-aware information from an application. Information *push* is where information is pushed to the user in order to reflect a contextual change, such as an updated location. Using this approach, the user may be surprised by the timing of new information, which might also overwrite old information that the user had still been reading. In the other style, information *pull* is where the user decides when to acquire (or pull) new information. In this approach, the system would leave the currently displayed content unchanged, despite the fact that the content had become inconsistent with the user's current location.

The ability of the context-aware application to manage these two different styles of interaction appropriately will possibly determine its acceptance by the user. Information push in the wrong situation is likely to be highly intrusive to the user, and in some cases unsafe too. In the example of the DRISHTI system (Helal *et al.*, 2001), pushing information to visually impaired people when crossing the road would be highly inappropriate. In other systems, the GUIDE system (Cheverst, *et al.*, 2000) and Cyberguide system (Abowd *et al.*, 1996) would need to allow time for tourists to freely observe and experience an attraction without cognitively overloading them with pushed information.

2.2.5 Privacy and security issues

Since Weiser (1991) propounded his vision of ubiquitous computing, many researchers have been concerned about the privacy and security of the user (e.g. Jiang & Landay, 2002; Bellotti & Sellen, 1993). The push towards invisibility of embedded computing devices and ubiquitous sensing, has made it easier than ever to collect and use information about individuals without their knowledge. Sensitive private information might live indefinitely and appear anywhere at anytime (Jiang & Landay, 2002). Furthermore, the application areas described in sections 2.1.1 - 2.1.6 illustrate how many context-aware systems are inferring revealing information from loosely related personal data, which has even more troubling implications for individual privacy.

Jiang & Landay (2002) claim that even a few privacy violations could lead to user distrust and abandonment of context-aware systems and to lost opportunities for great enhancements. Ultimately, more investigations are needed to investigate thresholds of perceived levels of privacy and security amongst end-users, since it is likely that there will be differences in how accepting they are of having their location, activity, and identity disclosed to service providers, friends, family, or work colleagues. For instance, the ParcTab computers may need to restrict certain directories containing personal information of employees from some of those present in the room. Overall, each of the systems described in sections 2.1.1 – 2.1.6 are affected by privacy and security issues since they all use personal user details of some sort. Context-aware application developers need to make these issues more explicit in their development, especially in terms of how information about the user will be used and distributed.

2.2.6 Social issues

One of the ambitions of context-aware computing is to provide richer communication with others, and to broaden the communities within which people communicate. Context-aware computing uncovers new metaphors of communication such as the ability to augment the environment at specific locations in space. Bellotti & Edwards (2001), however, argue that mediation between people is an ambitious and potentially threatening aim for context-aware systems since we are currently unaware of the impact these new forms of communication might have on communities of people, e.g. how will we know when personal information is captured, accessed, and used? When and how is information shared and distributed to others? These questions remain unanswered and Dourish (2001) states that ‘instances of interaction between people and systems are themselves features of broader social settings, and those settings are critical to any analysis of interaction’.

In the stick-e document system (Brown 1996), for instance, large amounts of notes that need to be managed, some of which may be irrelevant, inappropriate, or out of date. Adequate controls would therefore need to be set in order to ensure notes are not displayed repeatedly if the user decides to revisit a location. Much of the triggering states may have to be customised by the user, requiring considerable time and knowledge of how the system is likely to respond. On another issue, what liberties should be given to other people when they attempt to send information of potential interest to the user? For instance, the user’s perception of what is useful and important may be entirely different to the sender. Sharing notes with others has the potential to become obtrusive and tedious, especially where there are conflicts of interest.

Bellotti & Edwards (2001) also report on their research on personal information management. With reference to the Conference Assistant that facilitates people in sharing notes (Dey, Futakawa, Salber, & Abowd, 1999), Bellotti & Edwards found that people are in fact not comfortable with sharing their personal notes. Context-aware research needs to address how people would wish to communicate and share information, and also what concerns they have about disclosing personal details.

2.3 Techniques for designing mobile context-aware applications

In recent years numerous design frameworks have been proposed to address the complex software and technological challenges facing context-aware computing, in particular to middleware design (e.g. Coulouris *et al.*, 2001; Huang, 2002) and more generally to the process of actually building context-aware applications (e.g. Jang *et al.*, 2001; DeVaul & Pentland, 2000; Dey *et al.*, 2001). In the first sub-section, an example, which is used to model the application’s context in Chapter 3, is discussed. It should be noted, however, that the purpose of this thesis is not to advance design issues of software development. Instead, this thesis is focused on providing a contribution to the limited existence of user-centred techniques for designing context-aware applications. Those identified in current literature are critically discussed in the second sub-section.

2.3.1 Frameworks for software design

Dey *et al.* (2001) propose a component-based conceptual framework for building context-aware applications. This framework was chosen for discussion since it represents a significant milestone in ubiquitous computing, and has been used as an anchor article for a special issue on context-aware computing (Moran & Dourish, 2001).

Their approach to system architecture is concerned with actually collecting, transforming and delivering contextual information, with a focus on design reuse. The following components are discussed:

- '*Context widgets*' represent sensor abstractions that conceal details of how sensing and interpretation of the environment occur. Widgets essentially wrap around underlying sensors and services, and provide an interface to automatically deliver information to interested components or services of the system.
- '*Aggregators*' store multiple pieces of low-level information (such as a person or location) that is logically related and stored in a common repository for relevant application entities.
- '*Interpreters*' are responsible for abstracting low-level context data to higher-level information (e.g. using location, time of day, and travel velocity to infer user is on the train home from work).
- '*Context services*' are the same as context widgets, except that the output is abstracted and the actuators, or change of environmental state information, are controlled.
- '*Discoverers*' are the final component and are responsible for maintaining a registry of what capabilities exist in the framework.

Dey *et al*'s framework provides an insightful foundation in which context-aware applications can be built. However, the framework was implemented for very primitive applications, namely an In/Out Board and the Context-Aware Mailing List. In these examples, only the user's location is used by the application to make an inferred decision, e.g. only mailing list members within the building receive an email. However, the extent to which this email will be of use will depend on a richer variety of contextual detail, including information about the user and his/her activity. Codifying this contextual detail is far more difficult, and requires more robust algorithms to manage inference, since context becomes more entangled and interrelated - an area not explored to any great detail in Dey *et al*'s framework. Additionally, when one considers users negotiating outdoor environments involving more dynamic interactions with other people and objects, Dey's framework would need to be expanded to capture the human and social elements of design. These issues will also be difficult to capture using a component-based approach as designers are largely restricted to creating application code that uses existing components. Bellotti & Edwards (2001) argue that people, unlike systems, make unpredictable and non-deterministic judgments about context, and so designers will need to reach beyond the application to refine or augment other components in order to deliver capabilities not anticipated by the original component builders.

2.3.2 Frameworks for user-centred design

There is currently a lack of user-centred frameworks for context-aware design. Existing frameworks are predominantly software orientated (e.g. Kim *et al.*, 2001; Huang, 2002; Dey, 2001) and so need to be expanded to handle human variability, as 'it is the human and social aspects of context which are crucial in making a context-aware system a benefit rather than a hindrance - or even worse – an annoyance' (Bellotti & Edwards, 2001). A greater emphasis must also be placed on the temporal context as 'actions and utterances gain their meaning and intelligibility from the way in which they figure as part of a larger pattern of activity' (Dourish, 2001). Meyer & Rakotonirainy (2003) describe how 'research into future computing technologies is often far removed from the needs of the user' and as a consequence 'the nature of such future systems is often too obtrusive'. Jang *et al.* (2001) state that current application development of context-aware systems is not user-friendly. For instance, despite the insightful design principles proposed within the Ektara framework, its development involved using an artificially created scenario (involving no user studies) to test and implement six critical features of context-aware wearable and ubiquitous computing applications (DeVaul & Pentland, 2000).

The user-centred frameworks that have been identified in context-aware research will be critically discussed in the first three sub-sections. The last sub-section discusses the extent to which current HCI techniques are equipped to investigate mobile computer settings.

2.3.2.1 Intelligibility and accountability

Due to the large amounts of sensing required to manage unpredictable users and operating environments, Bellotti & Edwards (2001) argue that there are human aspects of context that cannot be sensed or even inferred by technological means. Consequently, the authors believe that the system cannot remove human initiative. Instead, Bellotti & Edward's introduce a framework (or set of design guidelines) that 'enable users to reason for themselves about the nature of their systems and environments, empowering them to decide how best to proceed'. For this to be achieved, the notion of 'intelligibility' is introduced, where the system communicates to the user what is known, how it came to be known, and what the system is doing about it. In turn, the system must enforce user 'accountability' when the context is inferred, especially when the application attempts to mediate user actions that influence other people. Bellotti & Edward's design principles are based on:

- informing the user of current contextual system capabilities and understandings,
- providing action-outcome feedback and current and previous action feedback,
- enforcing identity and action disclosure,
- providing user control over system and other user actions.

These design principles, and the issues raised by the authors, are valuable, informative, and timely contribution to human and social investigations of context-aware design. However, their framework needs to be expanded to include a greater understanding of users, with respect to the decisions they make and actions they perform in different contexts. Although it is stated that users and environments are unpredictable, a systematic process for exploring spatial behaviour is not given. In order to develop more robust inference tools, application designers need to be provided with information about what is meaningful to different sets of users. This integration of the user and application's context is an important one, which is not sufficiently addressed by the authors.

2.3.2.2 Embodied interactions

In other work, Dourish (2001) presents a foundation on which context-aware design frameworks can be developed, drawing on the notion of embodied interaction as developed in phenomenological philosophy. It is argued that context-aware computing needs to extend beyond the awareness of spatial location, of user identity, of the proximity of people and devices, and more towards monitoring the sociologically-motivated explorations of interaction. Dourish addresses this issue by investigating the notion of embodiment, which is about establishing meaning and relates to anything that has presence and participation in the world (real-time and real space, here and now), whether it be physical objects, conversations, or actions. This thesis introduces a model and framework that build on Dourish's work by providing a procedure or structure for which these design and usability issues can be captured.

2.3.2.3 Activity/attention framework

Smailagic *et al*. (2001) introduce an activity/attention framework for context-aware computing, which is centred on the extent to which a user is distracted away from his/her primary task. A distraction matrix is introduced as a means by which this issue can be conceptualised. Within the matrix, three types of distraction activities are discussed: (i) 'Information' involves the user being either actively distracted (e.g. snap: email arrival) or passively distracted (e.g. pause: looking at diary) by surrounding information, (ii) 'Communication' which involves the user being distracted by artificial, informal, or formal communication (e.g. chatting to a friend), and (iii) 'Creation' which involves the user being distracted by creative work activities (e.g. adding information to existing projects, add a ToDo item to your calendar, etc).

The second part of the matrix categorises each of the activity types from before by the amount of distraction they introduce in units of increasing time. Four categories are discussed: (i) *Snap* duration: an activity completed in a few seconds that should not interrupt the user's primary activity, e.g. checking your watch, (ii) *Pause* action: the user stops his/her current activity, switches to the new but related activity, and then returns to the original task within a few minutes, e.g. pulling over to the side of the road to check directions, (iii) *Tangent* action: a medium length task that is unrelated to the action that the user is engaged in, e.g. receiving an unrelated phone call, and (iv) *Extended* action: the user deliberately switches his/her task, beginning an entirely new long-term activity, e.g. when travelling to the gym, deciding to visit friends in the pub instead.

The activity/attention framework, or Distraction Matrix, proposed by Smailagic *et al*. (2001) would help context-aware application developers to identify situations where users may become distracted from their primary task. However, the matrix neglects some key issues that would require deeper investigation. For instance, for what reasons, and in what situations, do users become distracted? What aspects of context could have influenced distracted moments or situations? Inferring future user activities and better supporting those activities would require a detailed investigation of those questions. For instance, the user perhaps will prioritise their current activity to a possible distraction – deciding whether to stop your current work to join an informal conversation with two work colleagues. The model and framework presented in Chapters 3 and 7 provide a foundation on which application developers can include these types of issues in design.

2.3.2.4 Augmenting HCI techniques

In this section, the extent to which Human-Computer Interaction (HCI) is equipped to support the design and development of mobile systems is discussed. Over the years, HCI has traditionally built a solid understanding of how to design and evaluate forms of HCI in *fixed* contexts of use, in a single domain, with the users always using the same computer to undertake tasks alone or in collaboration with others (Kjeldskov & Stage, 2004; Johnson, 1998). This is not the case for mobile computing, where computers move through several contexts of use, in several domains, with the users often using more than one computer to undertake tasks while being surrounded by richer groupings of people and physical objects.

Johnson (1998) highlights the new challenges that mobile computing presents to HCI researchers and practitioners. These include (i) the demands of designing for mobile users, their tasks and context, (ii) accommodating the diversity and integration of devices, network services and applications, (iii) the current inadequacy of HCI models to address the varied demands of mobile systems, and (iv) the demands of evaluating mobile systems. Johnson goes on to raise many other important and interesting points when he describes each of the challenges in more detail. For instance in challenge (iii), it is discussed how traditional HCI is well-equipped to model various aspects of the users environment, such as their cognitive world, their tasks, their domain, and various types of group working or collaboration.

However, the HCI world is often ill-equipped to sufficiently model the mobile world to such an extent where designers can determine the impact an interface would have on a user's ability to notice and interact with unpredictable and dynamic features of the environment (e.g. noticing a speeding car as they stepped out onto a street). Johnson (1998) goes as far as to saying that these HCI issues may in fact save or cost lives.

In challenge (iv), he discusses how conventional usability laboratories would be unable to simulate adequately the unpredictability of the mobile world, and thus would be unable to easily provide for the wide range of competing activities and demands on users that might arise in a natural setting. Although data collection methods or field evaluations, such as video recording and observations, would seem an appealing approach for evaluating the usability of a mobile system, many researchers stipulate that this would be very difficult (Kjeldskov & Stage, 2004; Johnson, 1998; Brewster, 2002; Nielson, 1998). Not only are field studies unrealistic for many mobile settings (Pascoe et al., 2000; Johnson, 1998), but they also complicate data collection and limit control since users are moving through a dynamic environment consisting of a number of unknown variables that may affect the set-up. Although these difficulties are considerably reduced in usability laboratory experiments, which are still the most prevalent methods of evaluating mobile systems (Kjeldskov and Graham, 2003), there is a lack of realism, making it difficult to adequately capture mobile environments (Kjeldskov & Stage, 2004). Johnson (1998) remarks that HCI methods, models, and techniques will need to be reconsidered or constructed if they are to address the concerns of interaction on the move.

In order to address those problems, this thesis provides an augmentation to traditional HCI models and techniques by including a structure for which unpredictable and dynamic mobile computer settings can be investigated. In order to determine how this might be done, the next section explores what is meant by the notion of context in order to understand mobile computer settings.

2.4 Notion of context across disciplines

The phenomenon of *context* has become an increasingly intriguing multidisciplinary talking point. Davies & Thomson (1988) remark that the main reason for context assuming a central role in various research areas is 'the acknowledgement, explicit or implicit, that organisms, objects and events are integral parts of the environment and cannot be understood in isolation of that environment'. Although context is frequently cited, and its importance repeatedly proclaimed, Dervin (1997) argues that it is rarely given a detailed philosophical and theoretical treatment, in particular to its multiple interdependencies, its dialectical relationships between product and process, and its temporal and spatial (i.e. here and now) confluence of people, settings, activities, and events.

The roots of its emergence also lie in the inconsistencies and ambivalent definitions *across* and *within* different research specialisations (e.g. philosophy, psychology, pragmatics, linguistics, and artificial intelligence). Benerecetti, Bouquet & Ghidini (2001) stipulate that a general and unifying theory or formalisation of context is still in its infancy, and that it is unclear whether each research area is addressing aspects of the same problem or different problems with the same name.

Chen & Kotz (2000) illustrate the discrepancies in the use of the word 'context' within different areas of computer science (e.g. context sensitive help, contextual search, multitasking context switch, etc). The advent of mobile context-aware computing, for instance, has stimulated broad and contrasting interpretations, due to the shift from traditional static desktop computing to heterogeneous mobile environments. This transition poses many challenging, complex and largely unanswered research issues relating to contextual interactions and usability.

In order for context-aware systems to seamlessly support and enrich a user's mobile activities, there is a need to understand context from a multidisciplinary viewpoint (Selker & Burleson, 2000; Bradley & Dunlop, 2003a; Mynatt, Essa & Rogers, 2000). Sato (2003) states that the 'complex nature of *contexts*, points out the need for multidisciplinary viewpoints in developing frameworks for understanding contexts and for developing coherent mechanisms to incorporate those frameworks in interactive systems development'. Current design frameworks, however, are predominantly software orientated (e.g. Kim, Yae & Ramakrishna, 2001; Huang, 2002) making it difficult to capture and effectively manage human variability. Bellotti & Edwards (2001) stated 'it is the human and social aspects of context which are crucial in making a context-aware system a benefit rather than a hindrance - or even worse – an annoyance'. Consequently, researchers argue that experts in several technological domains such as software engineers, user interface experts and radio experts need to be brought together (Floch, *et al.*, 2001) in order to draw upon cognitive science, user experience and situation into the computer system design process (Selker & Burleson, 2000).

Many researchers in computer science have illustrated the benefits of understanding context. Dey (2001) remarked that it can lead to improved usability of context-aware applications. Dey & Abowd (1999) state that 'by improving the computer's access to context, we increase the richness of communication in Human-Computer Interaction (HCI), making it possible to produce more useful computational services'. An understanding of context will also enable application designers to choose what context to use in their applications, thereby helping them to determine which context-aware behaviours to support. Brezillon and Abu-Hakima (1995) remark that context plays an important role in person/machine and machine/machine interactions and in the representation of knowledge-based systems.

Context is also analysed and discussed considerably within industry and is regarded as the key to unlocking the true value of business applications on handheld devices (Zetie, 2002b). For example, Sun Microsystems, Giga Information Group and US Bancorp Piper Jaffray have recently identified 'context' as a key enabling technology missing from today's mobile platform applications. It is therefore not surprising that next-generation applications and web services are increasingly taking into account the user's context in order to use contextual information to modify the application's business logic, presentation and navigation.

The primary aim of this section is to review theories of context within Linguistics, Computer Science, and Psychology, with a view to combining those theories in order to propose a multidisciplinary model of context in Chapter 3. The investigation focuses on these particular disciplines as their theories and principles were considered to be the most applicable to, and beneficial for, context-aware computing. The ultimate goal is to facilitate application developers in forming richer descriptions or scenarios of how a context-aware device may be used in various dynamic mobile settings. More specifically, the aim of this section is to investigate:

- different viewpoints of context within Linguistics, Computer Science and Psychology, in order to develop summary condensed models for each discipline;
- the impact of contrasting viewpoints on the usability of context-aware applications;
- the extent to which single discipline models can be merged, and analyse how beneficial and insightful a merged model would be for designing mobile computers;
- the extent to which a proposed multidisciplinary model can be applied to specific applications of context-aware computing.

The purpose of this section is not to advance the philosophical debates on context, such as the phenomenological or positivist accounts of action that are widely covered elsewhere (e.g. Dervin, 1997), but to draw upon theories of context within each discipline to illustrate their practical implications for designing mobile context-aware computers. This section is divided into the following key areas: (i) general definitions of context, (ii) linguistics and context, (iii) computer science and context, (iv) psychology and context, and (v) context within other research areas. Definitions and categorisations of context are provided within each of those sections, and within sections (ii)-(iv) a proposed model of context is presented, together with a subjective analysis of this model in relation to context-aware computing. The purpose of creating models was to:

- show conceptually how context is interpreted within each discipline;
- facilitate the visual and theoretical identification of similarities and links for creating a multidisciplinary model;
- illustrate how principles within other disciplines have direct implications for context-aware computing.

Two further sections, (vi) & (vii), concern my own definition of context, and a cross-analysis of the proposed models for each discipline, as well as a discussion of areas for further research.

2.4.1 General definitions of context

The Chambers 21st Century Dictionary (1999) and the Oxford Dictionary (1992) both define context as either (i) 'the pieces of writing in a passage which surround a particular word, phrase, paragraph, etc and which contribute to the full meaning of the word, phrase, etc in question', and (ii) 'the circumstances, background or setting'. Benerecetti *et al.* (2001) provide a more analytical perspective of context. As described in Table 2.2, three dimensions of context dependence[1] are identified, namely 'partiality', 'approximation', and 'perspective'.

Dimension	Definition
Partiality	A context dependent representation is partial when it describes only a subset of a more comprehensive state of affairs. There are two perspectives: (i) *metaphysical* – a representation is partial if it does not cover the entire universe, and (ii) *cognitive* – a representation is partial if it does not include the entirety of what a person can talk about.
Approximation	A context dependent representation is approximate when it abstracts away some aspects of a given state of affairs. The aspects abstracted away are taken into account in some other form of representation.
Perspective	A representation is perspectival when it encodes a spatio-temporal, logical, or cognitive point of view on a state of affairs. For example, the statement 'It's snowing' implies a spatial perspective (i.e. the location in which the statement is used) and a temporal perspective (i.e. it is snowing now). Additionally, some statements such as 'hot air rises' imply a logical perspective as they implicitly refer to this world.

Table 2.2. Dimensions of context dependence (Benerecetti et al.*, 2001).*

In relation to context-aware computing, the *approximation* dimension is closely tied to the notion of relevancy (discussed in section 2.4.7.2). Contextual information not required by the user must be abstracted away, making the remaining information *partial*. The *perspective* dimension, on the other hand, indicates how information must account for a spatial perspective (e.g. a user's location), temporal perspective (e.g. is information relating to past, present or future?), and logical perspective (e.g. does information match that of the surrounding environmental context?). Although these context dependence principles stimulate ruminative discussion, it is unclear how they can be used to develop techniques for capturing, measuring and assessing parameters of context within complex tasks and systems.

[1] 'Context dependence' implies that when some aspect of context is used explicitly or intrinsically in a given situation, that aspect of context is required for that situation to occur.

2.4.2 Linguistics and context

Researchers in the area of linguistics and communication have studied many aspects of context. These include: (i) the changes in utterance interpretation when spoken in different contexts, (ii) the production of a speaker's utterance in accordance with what he/she perceives is the current conversational context, and (iii) the method in which a hearer selects or constructs the context in order to comprehend the message (ECCS, 1997).

Fetzer (1997) defines context as a 'tripartite system of objective, social and subjective worlds, their sub-systems and presuppositions'. The objective world is measurable and consists of a true/false-paradigm. The subjective world is characterised by sincerity in that a speaker's conversational intention is spoken as intended, and the social world is represented by textual, interpersonal and interactional meaning. In other viewpoints, Ochs (1979) distinguishes between the social and psychological worlds. These include peoples' beliefs and assumptions about (i) temporal, spatial and social settings, (ii) prior, ongoing and future actions (both verbal and non-verbal), and (iii) the state of knowledge and attentiveness of those participating in the social interaction.

Categorisations of contextual information used within a communication act have been proposed. Bunt (1997) believes that the relevant factors of conversational context can be grouped into five categories:

- *Linguistic*: Properties of the surrounding linguistic material (textual or spoken).
- *Semantic*: Constructed by the underlying task and the task domain (the objects, properties and relations relevant to the task).
- *Physical*: The physical circumstances/environment in which the interaction occurs.
- *Social*: The type of interactive situation, combined with the participant's roles in that situation, as depicted in terms of their communicative rights and obligations.
- *Cognitive*: The participants' beliefs, intentions, plans and other attitudes, their states of processing relating to perception, production, interpretation, evaluation, execution, and their attentional states.

Connolly (2001) distinguishes between the ‘linguistic’ context and ‘non-linguistic’ context (or situational context). *Linguistic* context refers to the units that give meaning to words, phrases or sentences. Connolly identifies two types:

- *Co-text*: The text that surrounds a unit of language (words, phrases, etc) that gives its linguistic context. This is similar to the concept of anaphora, where the coreference of one expression is made with its antecedent. The antecedent provides the information necessary for the expression's interpretation – e.g. the name ‘David’ being replaced with ‘his’ for succeeding text.
- *Intertext (or intertextuality)*: The notion that in order to comprehend/interpret part of one text, information from some other text may be required.

Situational context refers to the pertinent aspects of the environment which are non-textual in nature (but where the text exists), e.g. the author’s cognitive decisions, ideas regarding the compilation of the text.

Researchers in linguistics have also investigated how people behave and interact with context. A theory of meaning and communication, called Situation Theory (ST), is used to depict various types of situation (Connolly, 2001). In one representation, a hierarchical formation is used to illustrate the ‘utterance situation’ (at the bottom of hierarchy) that consists of who is addressing whom, where and when, and what utterances are produced. The ‘discourse situation’ relates to the entire conversation, which is part of the ‘embedding situation’ (an accumulation of discourses). At the top of the hierarchy, the ‘world’ depicts the maximal situation in which all other situations occur. The meaning of language was also addressed extensively by Wittgenstein (1958), who believed that the meaning of sentences depends on the context of utterance. He describes how words do not have denotation in isolation, but only when used inside a language game consisting of a social environment of speech and action. The term ‘language game’ is used to illustrate that speaking of language is part of an activity. So if the sentence, for instance, is the basic move in the language game, a language game itself is taken to be the basic unit in linguistic activity. Words become meaningful only when we consider the ‘occasion and purpose’ for which they are said.

In other investigations, Bunt (1997) describes how human dialogue consists of two tasks simultaneously: (i) attempting to achieve the underlying non-communicative goal, and (ii) communicating in order to achieve the associated communicative goal. To illustrate, if visiting a car dealership with the intent of purchasing a car, the non-communicative goal (which will motivate a dialogue) may be to buy a car within a particular price range. However, although the communicative goal will be to verbalize this to the car salesman, the non-communicative goal will be reshaped as the salesman's feedback is being weighed and compared to the original non-communicative goal (thereby allowing the salesman to convince you that this more expensive car is justified!).

Lastly, Fetzer (1997) illustrates how speakers/hearers create and interpret their utterances in and through an already existing context. Therefore, speakers link and anchor their utterances to that context. Fetzer also points out that context represents both a process and a result as it is 'selected' and 'constructed' through an act of verbal and/or non-verbal communication. *Selected* in the sense that the speaker selects contextual information based upon previous communication acts and then accepts/rejects this information, and *constructed* in the sense that the speaker adds new contextual information to the already existing contextual information through his/her response.

2.4.2.1 Usability issues for context-aware applications

Bunt's (1997) research can be used to model the interaction of a user with a context-aware application, as illustrated in Figure 2.1.

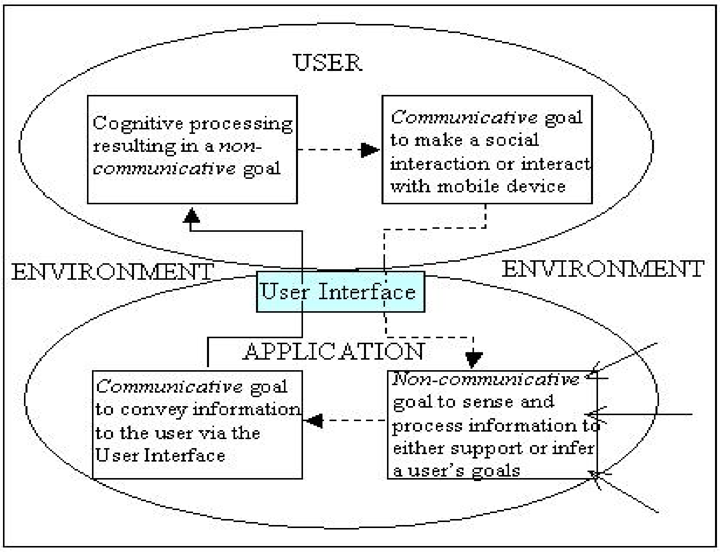


Figure 2.1. Modelling communicative and non-communicative goals of the user and application.

The upper oval circle in Figure 2.1 represents the user, the lower oval shape depicts the context-aware application, and the area surrounding the oval circles illustrates the environment. A scenario involving Alice travelling to the train station using her mobile computing travel aid will be used to illustrate the key principles of Figure 2.1.

Alice makes a non-communicative cognitive goal to travel to the train station in order to catch her last train home (i.e. a goal formed without communication with the mobile device). She may need to construct a communicative goal(s), or interactional goal, in which to solicit trip information (e.g. which actions are required to obtain travel directions via the user interface?). This would result in a non-communicative application goal(s) to sense and process information in which to support her query/instruction. However, prior to Alice realizing her communicative goal, the context-aware application may be able to infer her non-communicative goal from sensed information, such as the time of day and GPS location (thereby making the user's communicative goal unnecessary). In either situation, the application would need to execute a communicative goal in order to transmit travel details appropriately, comprehensibly and timely, with respect to Alice's personal preferences, situation, and environment. Other non-communicative application goals may be to check actively the status of the train, which is only communicated to her if a delay is encountered. As a result, this information would be given to Alice, who would cognitively process it, and then possibly form additional non-communicative goals (e.g. stop at nearest café for a drink).

The above scenario, in relation to Fetzer's (1997) research, also illustrates how a context-aware application must link and anchor information in accordance with the user's current context, as described below:

- 'Selected' application intelligibility: In order to make accurate inferred decisions regarding Alice's current and future intentions, the application may need to select previously captured information regarding her behavioural patterns. The application, for instance, may have tracked from previous train and bus delays that Alice visits cafés and bookshops to pass time – subsequently the application could automatically select, or make informed, recommendations.

– ‘Constructed’ application intelligibility: This is temporally driven as the application contributes to constructing present and future user contexts. The application must therefore intelligently filter, modify, or add to, information from past contexts to suitably construct Alice’s current context. So, in the above scenario, the application creates a context by informing her that the train is delayed. She is now aware of this, and may not require this information again unless the status of the train changes. A key issue would be: to what extent should the application construct Alice’s context - how much should be left to her own interpretation? If Alice is about to walk past a café after being told of a train delay, should the application assume she has spotted this, or should it provide an inferred recommendation regardless?

To illustrate this last point further, with respect to Connelly’s (2001) description of intertextuality and co-text, the application must be sensitive to Alice’s acquired knowledge and experience. The application, for instance, may not need to alert Alice of train departure times if she has already acquired this knowledge. In terms of intertextuality, she will be referring more to knowledge-based information than to application-based information. However, to what extent can assumptions be made relating to user knowledge, experience and memory capabilities when considering the diversity of human capabilities (and disabilities)?

2.4.2.2 Proposed summary Propeller model of linguistic context

Here, these viewpoints of linguistic context, have been captured and used to create my summary Propeller model of context, as illustrated in Figure 2.2.

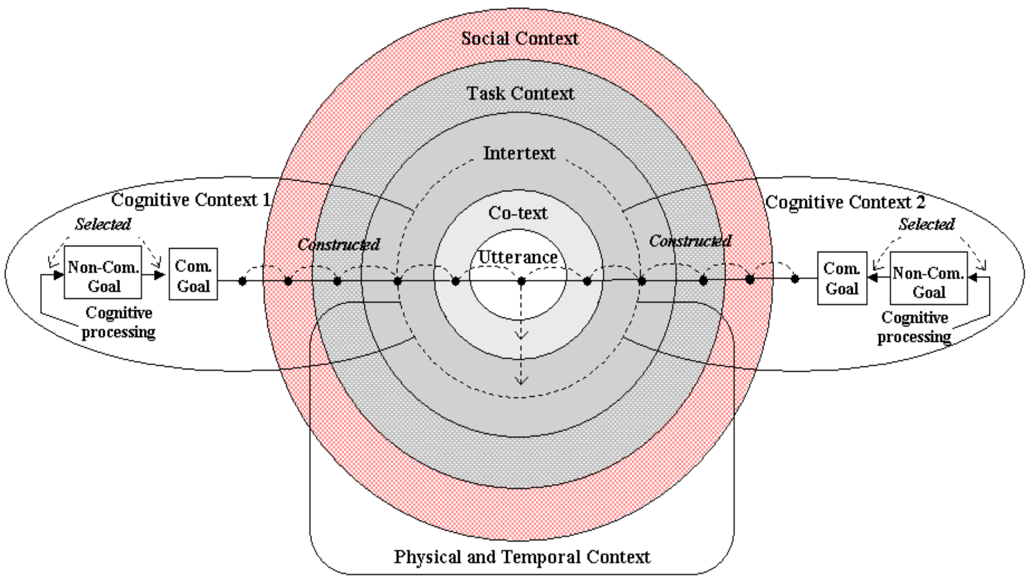


Figure 2.2. My proposed Propeller model of context within the linguistics domain.

The model represents how prior to an utterance, a person, represented by either cognitive context 1 or 2, firstly processes (i.e. rejects or accepts contextual information) and selects a non-communicative goal(s) which is then used to select a communicative goal(s). The communicative goal of verbalising the associated non-communicative goal, then shapes/constructs the social and task context, the intertext, and also the co-text. Whether it is an utterance or discourse, both the cognitive contexts will expand with more contextual information, which is used to process and select future goals.

After the utterance has occurred, this becomes the co-text to the next utterance. Similarly, after this discourse, the utterance will form the intertext to the next discourse. Lastly, all of this operates within a physical and temporal context (i.e. it has been influenced by previously occurring events).

2.4.3 Computer Science and context

The notion of context is a powerful and longstanding concept in HCI. Over the years, computer scientists have contributed to an expanding and varied list of definitions, categorizations and models, examples of which will now be described and contrasted, and used to propose a model of context for computer science.

2.4.3.1 Definitions of context

Computer scientists' definitions of context can be loosely placed into three distinct types. Those that describe the primary focus of context from the perspective of (i) the application, (iii) the user, and (iii) any entity of interest.

Primary focus as the application

Moran & Dourish (2001) define context as the 'physical and social situation in which computational devices are embedded'. Ward, Jones & Hopper (1997) view context as the state of the application's surroundings. Similarly, Brown (1996) defined context to be the elements of the user's environment that the user's computer knows about. Chen *et al.* (2000) define context as the 'set of environmental states and settings that either determines an application's behaviour or in which an application event occurs and is interesting to the user'.

Primary focus as the user

Dey, Abowd & Wood (1999) define context to be the user's physical, social, emotional or informational state. Whereas, Zetie (2002a) describes context in software applications as 'the knowledge about the goals, tasks, intentions, history and preferences of the user that a software application applies to optimizing the effectiveness of the application'. Zetie also identifies the key dimensions of context by asking questions about the user: who is the user (e.g. personal characteristics); what is the user doing (i.e. activity/task); where is the user; and how to contact the user (based on their location, time of day, preferences, priority of interaction, etc). Similarly, Schilit, Adams & Want (1994), treat the user as the primary entity in order to ask questions such as where you are, whom you are with, and what resources are nearby.

Primary focus as any entity of interest

Schmidt (2001) views context as facts that matter for an application/user/device, which are inherently connected to time and location. In more general definitions, Funk & Miller (1997) describe context as 'everything surrounding an item of interest, including the "mindset" of any humans involved in the context'. Similarly, Dey & Adowd (1999) define context as 'any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between the user and an application, including the user and application themselves.'

2.4.3.2 Categorisations of context

A variety of categorizations of context have also been proposed. Common categories include a user's location and environment; identities of nearby people and objects; and changes to those objects (Schilit & Theimer, 1994; Brown *et al.*, 1997; Ryan *et al.*, 1997; Dey, 1998), whereas, some use additional categories such as time of day (Brown *et al.*, 1997; Ryan *et al.*, 1997), user's emotional state and focus of attention (Dey, 1998).

Schilit & Theimer (1994) differentiate between three broad types of context: (i) 'computing environment' which includes available processors, devices accessible for user input and display, network capacity, connectivity, and computing costs; (ii) ‘user environment’ which depicts the location, collections of nearby people and social situation, and (iii) ‘physical environment’ which includes parameters such as lighting and noise level. Chen & Kotz (2000), however, stipulated that this categorisation neglects ‘time context’. Temporal recordings of user, computer and physical contexts provide useful sources for supporting applications.

2.4.3.3 Models of context

Coutaz & Rey (2002) propose a mathematical model, where the context of a situation is defined as the ‘set of periphic variables and relations between them’. The following formula represents how a series of situations (i.e. snapshots in time) are combined to give the context for a user (U), task (T) and time (t):

$$\text{Context (U, T, t)} = \text{Cumul(Situation (U, T, } t_0\text{)}\ldots\text{Situation (U, T, t))}$$

In the above formula, ‘cumul’ is a union operation that labels periphic variables and remaps relationships between variables as necessary. Coutaz & Rey also introduce the notion of contextor, which is a reflexive and hierarchically composable context sensor with data inputs and outputs plus control inputs and outputs.

In other models of context, Zetie (2000a) illustrates the interactions between an application and a user, as shown in Figure 2.3.

	Unknown to the user	Known to the user
Known to the application	**Inferred**	**Explicit**
Unknown to the application	**Hidden**	**Implicit**

Figure 2.3. Interactions of application and user (Zetie, 2000a).

As shown, the interactions of the application and user provide four possible combinations of what the user and the application know about the user’s current and/or future intentions: (i) *Explicit*: User’s intentions that are known to the user and application, (ii) *Inferred*: Information about intentions that the application infers but which are not explicitly part of the user’s intentions, (iii) *Implicit*: Intentions known to the user but not to the application, and (iv) *Hidden*: Intentions that are not known to either the application or to the user. Although a high-level depiction of user and application interactions, the four quadrants offer an insightful foundation with which to identify key design issues of context-aware services. The semantic representation of each of the quadrants has been captured in my proposed multidisciplinary model of context in Chapter 3.

2.4.3.4 Contrasting definitions, categorizations and models

Some definitions and categorizations of context are too specific, as they do not allow sufficient flexibility for different situations and applications (e.g. Schilit & Theimer, 1994; Coutaz & Rey, 2002). This view is also shared by Dey & Abowd (1999) who stipulate that 'context is about the whole situation relevant to an application and its set of users'. For all types of situations, it is impossible to stipulate what aspects will be pertinent. Using a mathematical model of context, for instance, may restrict the likelihood of being able to fully capture a user's complex interactions with other people and objects in their environment. This explanation also demonstrates why it is dangerous to use the application as the primary focus when defining context. In order to maximize usability, users and their heterogeneous interactions need to be placed at the centre of a design process, otherwise systems will become negligent of users' requirements making them obtrusive and frustrating to use.

Some definitions are also too general and non-specific (e.g. Dey & Adowd, 1999; Schmidt, 2001; Funk & Miller, 1997). They imply that context is *anything* that is relevant (or matters) to an entity or interaction of entities. Since it is not explicitly described how relevant dimensions of context can be identified and quantified, it would be very difficult to transfer or operationalise these definitions into a complex contextual scenario. It would also be uneconomical and tedious to identify from scratch which entities are germane for more than one situation. Midway points are required whereby generic categories (or reference points) of context can be applied to every situation. The content, importance level, interactions and influences of each category can be measured for each situational purpose.

A key issue that transpires from the previous two points is: how are dimensions of context identified, quantified and interrelated for each situational purpose? Zetie

(2002a) stipulates that in order to ensure the application adapts itself to the intentions of the user, Task Analysis is critical for a suitable and sufficient investigation.

2.4.3.5 Proposed summary model of context in computer science

The contrasting viewpoints, definitions and categorisations of context within the area of computer science, have been illustrated in my model shown in Figure 2.4. Whether the primary focus is from the perspective of the user, application or from any entity of interest, Figure 2.4 illustrates the key components and characteristics of context that are present during user-computer interaction (i.e. use context).

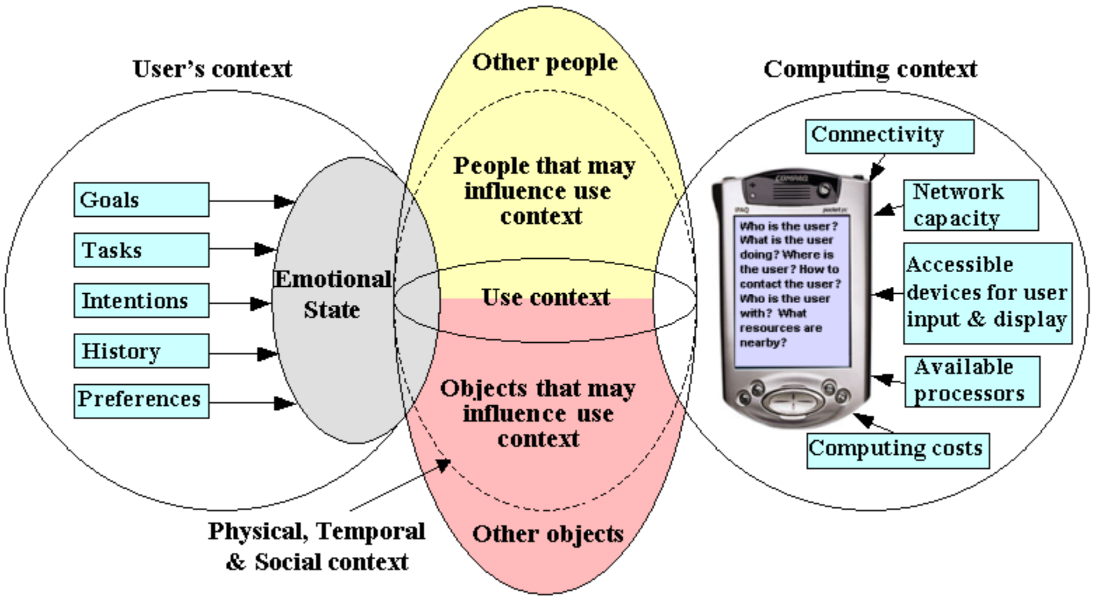


Figure 2.4. My proposed model of context in computer science.

As shown, surrounding people and objects may influence the user-computer interaction, making them intrinsic factors in shaping the use context. The broken line demonstrates how, as a result of temporal changes, other objects and people may pass from being relevant to irrelevant to the interaction taking place.

2.4.4 Psychology and context

Over the years, researchers in psychology have studied how changes in context can affect various cognitive processes, such as perception, language interpretation, reasoning, decision-making (framing effects), problem solving (fixedness and set effects), learning (lack of transfer from one context to another), and memory (priming effects) (ECCS, 1997).

Many psychologists have attempted to define and categorise context. In relation to context-dependent memory, Smith (1988) defines context as '…a concept that denotes a great variety of intrinsic or extrinsic characteristics of the presentation or test of an item'. Smith also contrasts two different conceptualisations of context based upon previous research:

- **Focal versus contextual**: Focal information is directly in the focus of attention (e.g. likened to foveal vision), whereas contextual information is processed outside the focus of attention (e.g. likened to peripheral vision).
- **Meaningful versus incidental**: Meaningful context refers to verbal/semantic material (e.g. accompanying words/text which may directly bias meaning selection processes). Incidental context is not meaningfully related in any implicit or explicit way (it just happens to be present). Kokinov & Grinberg (2001) demonstrate how perceiving some incidental objects from the environment may change the way in which we solve problems.

In other viewpoints of context, Ziemke (1997) states how context has been previously categorised into external (or objective) context and internal (or subjective/cognitive) context. External context would be the situation or environment the person is in, and the internal context would be the internal knowledge/mechanisms underlying the person's cognitive processes (e.g. mood, state-dependent effects). Bekerian & Conway (1988), however, add another dimension of context, namely, 'everyday context' which includes scripts or frames for action that prepare the person to expect subsequent events and to anticipate particular outcomes.

In relation to internal context, Ziemke (1997) distinguishes between two major paradigms in contemporary cognitive science. These are termed 'cognitivism' and 'enaction', which are described below:

- **Cognitivism**: In any specific situation not all knowledge about the world is applicable, useful or pertinent. The information solicited to make a cognitive process is therefore the subset of information that is available (e.g. despite being fluent in French and German, it is likely that only my knowledge of French would be useful to me during a visit to Paris).

- **Enaction**: Cognition is not considered an abstract human internal process; rather, it is an embodied process, which is the outcome of the constant human-environment interaction and their mutual relation during evolution/individual development. The cognitive processes required to effectively interact with a laptop, for instance, would have been influenced by previous computer interactions, during which skills, knowledge and experience would have been gained.

Lastly, Davies & Thomson (1988) provide an interesting insight into the impact of context on memory. Based upon investigations into Environmental Context (EC) dependent memory, two types of effects were evident. 'Long-term reinstatement effects' were the memories experienced when returning to a former residence after a long absence (e.g. often triggered by important lifestyle changes such as marriage, divorce, emigration, etc). 'Short-term EC effects' relate to the familiarity of people/objects in particular situations/environments. If encountered in another environment, it is common not to recognise this person/object in this new context.

2.4.4.1 Usability issues for context-aware applications

Combining the enaction paradigm (Ziemke, 1997) with Davies *et al*'s (1988) investigations into EC dependent memory, reveals an important issue for context-aware computing. The embodied mutual evolution of the human-environment process must be tracked by the application in order to provide information and services that are suited to the user's memories of past experiences. For instance, a tourist called Bob is visiting Rome for his second time. Since his previous trip, certain features of the EC may be familiar (i.e. long-term reinstatement effect). In order to provided tailored functionality of contextual detail, the application must determine from its own memory (i) the length of time since Bob's last visit, (ii) the information that was provided to him, and (iii) his previous activities. A key question would be: how does the application account for variabilities in human memory (e.g. a decline in cognitive function due to age)? A possible solution would be to use a memory triggering process involving snippets of information.

There may also be instances when it is useful to provide information about EC that has changed since a previous visit (e.g. buildings erected, shops and restaurants changed, etc.). If Bob was blind, for instance, and depended on building a comprehensive cognitive map or internal representation of the environment, the mobile device may need to inform him of EC modifications to ensure he does not become disorientated or confused in his surroundings as a result of information being conflicting to his memory (i.e. short-term reinstatement effect). This could be achieved by contrasting the geographic application database used during Bob's last visit with a new updated version. By providing such feedback enhances the development, evolution and mutual relation of humans with their environment.

The differentiation between incidental and meaningful context also has a major design implication for context-aware applications. If the application senses a nearby art gallery (unknown and incidental to Bob), whilst directing him to the train station (his meaningful task), how should this information be presented (if at all) and prioritized with respect to his current task and personal preferences? For the application to make those types of inferences, the following parameters may need to be accounted for: the time available before his train arrives, whether he has visited galleries before, etc.

2.4.4.2 Proposed summary model of context in psychology

Based upon the conceptualisations and theories of context within the psychologist's domain, the following summary model of context is proposed, shown in Figure 2.5.

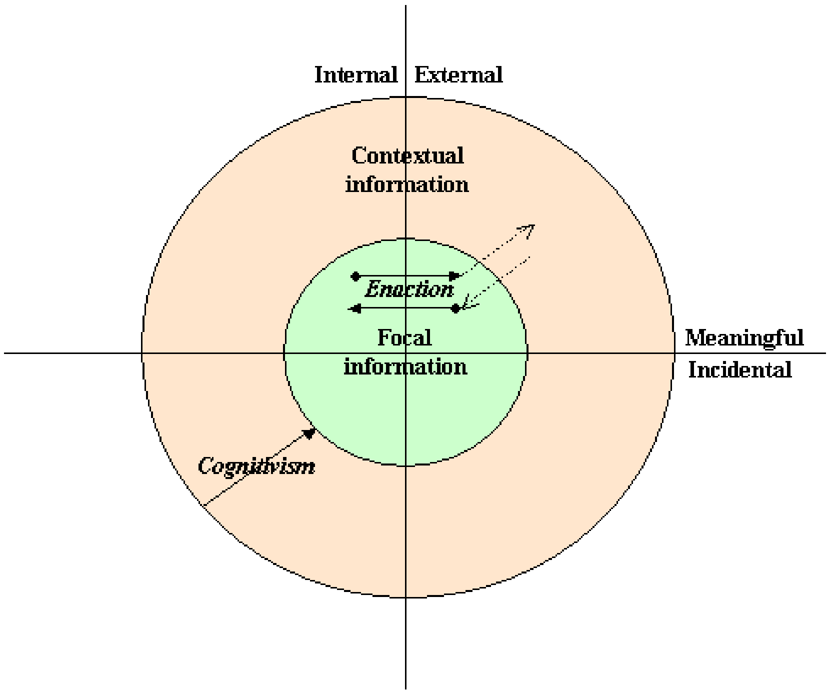


Figure 2.5. My proposed model of context in psychology.

The model is composed of an inner and outer circle forming the focal and contextual layers. One line splits the circles perpendicularly into internal and external contexts, while the other line splits the circles horizontally into meaningful and incidental contexts. As illustrated in Figure 2.6, the following scenario involving Bob en route to the Coliseum in Rome using his GPS enabled Palmtop for navigational assistance, is used to illustrate the eight possible combinations.

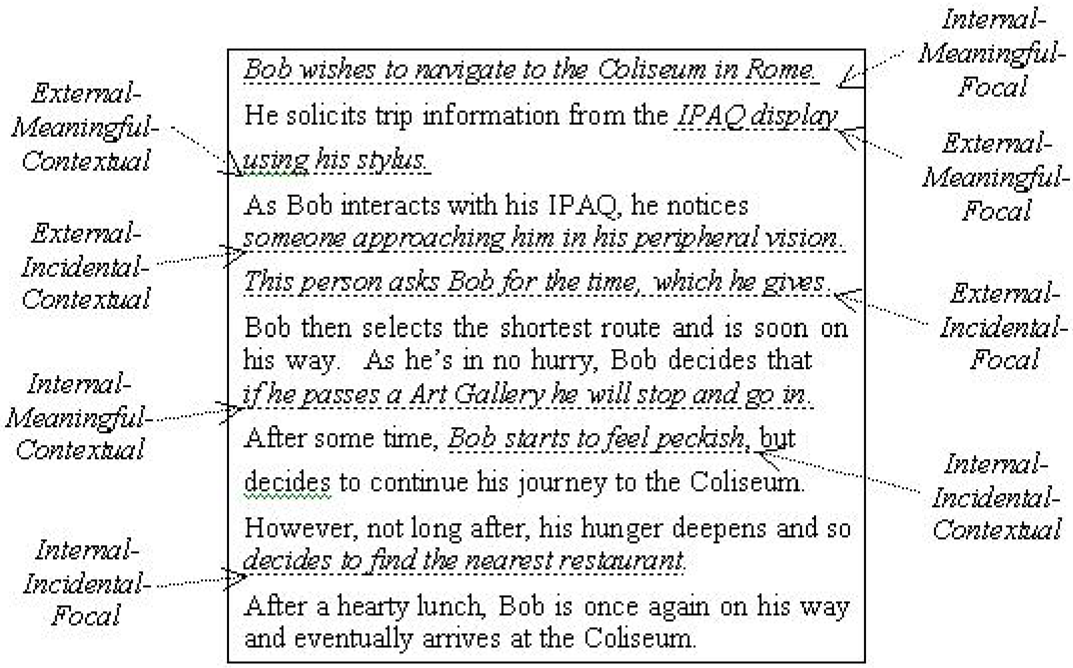


Figure 2.6. A scenario depicting eight possible combinations in psychology.

Bob‘s scenario above can be used to illustrate the enaction paradigm, shown in Figure 2.5. Within Bob’s internal context, decisions that are focal and meaningful are made prior to, and during, his trip. These decisions are influenced, changed and created by his interaction with focal and contextual information within his external context.

The cognitivism paradigm can also be illustrated using Bob’s scenario. If Bob had extensive knowledge of Spanish and Italian culture and history, only his Italian knowledge (a subset of his total knowledge) would influence his cognitive processes or imminent decisions. If Bob, however, had been in Madrid the opposite would have occurred.

2.4.5 Context within other research areas

The notion of context has also been investigated within many other areas of research, including Artificial Intelligence (AI), neuroscience, pragmatics, information science, sociology, management, and philosophy. Researchers in AI, for instance, have recently attempted to formalise context in order to model it in computer simulations (ECCS, 1997). They are predominantly interested in how context is connected to reasoning. For instance, how people change their perspective, their line of reasoning, how they think of and compare states of the world in different situations or moments in time. In another discipline, researchers in the area of Information Retrieval (IR) explore how context can be used to deliver more relevant documents and information to a user to satisfy their information need (Jones & Brown, 2004). Lastly, in the area of neuroscience, researchers have explored the differences between implicit and explicit memory and learning shedding light on the mechanisms which process information in the human brain. A number of differences have been discovered between explicitly and implicitly represented information and its processing and storage.

2.4.6 My definition of context

Based upon sections 2.4.1-2.4.5, the following multidisciplinary definition of context is proposed. In order to make the definition useful, context has been considered as a process, rather than a product. Context is:

> "a process whereby a person consciously or unconsciously compares an external environment with acquired personal experiences/knowledge (both of which may contain task, physical, social, and temporal dimensions) in order to form goals for undertaking concise actions, possible with other people and/or objects."

2.4.7 Cross-analysis of proposed models and areas for further investigation

The proposed models of context for linguistics, computer science, and psychology (Figures 2.2, 2.4, and 2.5) will now be critically analysed and compared, in order to propose a multidisciplinary model in Chapter 3. This assessment has been captured under three sub-headings relating to (i) contextual interactions, (ii) the notion of relevancy, and (iii) context in mobile computing.

2.4.7.1 Contextual interactions

'Contextual interactions' appear to be the quintessential cross-disciplinary component for understanding and utilising principles of context. From a high-level perspective, within linguistics it is the interaction between two people; within computer science it is the user-application interaction (combined with possible interactions with other people and objects); and within psychology it is the internal and external interactions.

Despite each discipline having contrasting viewpoints of context, their principles can be conceptualised across one another, which, although adding greater complexity, provides a deeper understanding of how people interact with the environment. A person speaking to a friend using their mobile phone, for instance, is both making an interaction with their mobile device at the same time as constructing dialogue which has been filtered through a cognitive, task, social, physical and temporal context. So, in this example, the linguists would be interested in how a speaker changes their utterances during phone-based dialogue in comparison to human-human dialogue. The computer scientists would be interested in how this context-driven communication influences the design of the user-interface, as well as to the services and information provided to them. Whereas, the psychologists would be interested in the cognitive processes by which knowledge is acquired, stored, selected and used to both interact with their phone, and converse with their friend. Each discipline has therefore implications for the other two disciplines.

To address an important comment in section 2.4, each discipline is tackling different representations of context, but at the same time can be considered as addressing similar, overlapping and complementary themes of the same problem; perhaps the most important of these being: how do people decide what aspects of their cognitive, task, social, physical and temporal context are *relevant* to them when undertaking, or planning for, future activities.

Lastly, contextual interactions should also be considered through the notion of embodiment, as described by Dourish (2001), where anything that provides a presence and participation in an activity or action (e.g. physical objects, conversations, actions, cognitive process, etc.) needs to be accounted for. This enables the social, cultural, organisational, and interactional context in which actions emerge to be explored.

2.4.7.2 The notion of relevancy

Issues of context and relevance are frequently cited in science and philosophy literature. Although they are normally treated separately as unrelated topics, Ekbia & Maguitman (2001) argue that context and relevance are inextricably linked and should be analysed together within a framework of logic. Dewey (1931) provides a pragmatic definition of context (in relation to relevancy) and differentiates between two components:

- *Background*: Includes spatial and temporal dimensions, and is ubiquitous in all thinking (e.g. ‘spatial’ in that it covers the entire environment in which a thought emerges). Background is considered to be that part of the context that ‘does not come into explicit purview, does not come into question; it is taken for granted’.
- *Selective interest*: Context is considered to dictate the person’s thought process. The notion of relevancy arises when the theory of selective interest occurs. There is evidence to suggest that humans take a selective interest in information (consciously/ unconsciously) that is considered to be of cognitive benefit, either to enhance their knowledge or to utilise this resource to carry out specific activities (Matsui, 2001).

As depicted in each of the proposed models for linguistics, computer science and psychology (Figures 2.2, 2.4, and 2.5), the notion of relevancy is of critical importance for all disciplines when attempting to understand human behaviour. So within a communication act, illustrated in the linguistics model, ‘background’ and ‘selective interest’ would refer to the process by which humans take selective interest in both their own background cognitive purview (selecting relevant aspects of previous experiences and knowledge) and their background environmental situation (involving the person their conversing with as well as their social and physical surroundings) in which to form communicative and non-communicative goals.

This concept can be extended when considering the model of context for psychology. The selective interest process (i.e. determining what is relevant) may have been meaningfully or incidentally motivated, possibly resulting in different conversations and levels of significance/relevance. For instance, a student who visits a lecturer at their office incidentally, in comparison to a student who pre-arranges a meeting, may have entirely different conversational and situational outcomes!

A user's interaction with a mobile device also illustrates these concepts. A person may take selective interest in surrounding people or objects (either meaningfully or incidentally) that may have been previously regarded as background context. This also nicely demonstrates one of the design challenges for context-aware computing: systems must, in a sense (i.e. from a physical interaction perspective), be pushed into the background (a notion propounded by Weiser, 1991) so that the user can focus and freely take selective interest in, and learn about, other people and objects in their environment.

2.4.7.3 Temporal and social issues of context

Throughout this cross-disciplinary review of context viewpoints there has been a common standpoint in the importance of understanding the temporal and social context, which are still under-researched, especially in user-interface design of context-aware systems. As Dourish (2001) states 'actions and utterances gain their meaning and intelligibility from the way in which they figure as part of a larger pattern of activity'. People and environments evolve, their relationships and conversations with people change, their knowledge of the world and cognitive interpretation expand and alter, and their patterns of behaviour with equipment and technology around them adapt. Context-aware computing is therefore an ambitious notion when one considers the extent of the temporal variability that would need to be considered.

Suchman (1987) provides an interesting viewpoint of sociological reasoning to problems of interaction, which has a direct relationship with issues of the temporal context. Despite being a fundamental component of many traditional task analysis techniques, she advocates that humans rarely function using *plans*, where a series of actions nicely fit together to accomplish a goal. Instead, Suchman draws on ethnomethodological work (i.e. an analytic approach to the organisation of social action) to argue that humans use 'situated actions' which are the outcome of moment-by-moment interactions with the environment. She states that social conduct is often improvised in order to adapt to the every day environment. This can be transferred to human-computer interaction, where it is argued that when people attempt to achieve goals, they are placed in situations that determine their actions. It is for this reason that the temporal context is imperative to any investigations of interaction, since users' goals and actions constantly adapt in accordance with the situations in which they are immersed.

Suchman's substantive work uncovers issues for designers of interactive computer systems and for cognitive scientists who seek to understand communication either between people or between people and machines. However, one issue that is not clear from her work is of the different scenarios within which situated actions would become more prevalent. For instance, referring back to the GUIDE system (Cheverst *et al*, 2000), situated actions are likely to be common for tourists who may wish to be spontaneous as they encounter new situations – in these situations the boundaries of plans and goals are less definitive. However, for the conference assistant system developed by Abowd *et al.* (1996), situated actions would be more restrictive and only occasionally might the user deviate from their initial plan or goal. The model and framework proposed in Chapters 3 & 4 will attempt to account for temporal issues of design, in order to facilitate developers in designing systems which adapt more seamlessly to a user's situated actions by continually adapting to an ever-changing and unpredictable environment. Also, the intention is to build on Suchman's work by providing a framework within which situated actions can be better understood with respect to the contextual factors that influence their spatial decisions in *different scenarios*.

2.5 Cognitive mapping

As discussed in earlier sections, there is a growing need to understand the user's context in order to support application developers in determining what aspects of context to use in their applications and which user behaviours to support. As shown in the last section, modelling the user's context is an extremely difficult task. Consideration of how people interact with their environment is essential in understanding and predicting spatial decisions and behaviour. This thesis focuses heavily on supporting navigation of visually impaired people and so it is envisaged that their interactions would be considerably different to that of sighted people. In this section (which is based on Bradley & Dunlop, 2005a), the area of 'cognitive mapping' is introduced as a means by which these issues can be analysed.

'Cognitive map' is a term which refers to 'an individual's knowledge of spatial and environmental relations, and the cognitive processes associated with the encoding and retrieval of the information from which it is composed' (Kitchen & Blades, 2002). Humans undertake many types of physical actions and activities in their daily lives. The cognitive decisions or choices underpinning these spatial behaviours are based upon previously acquired spatial understandings of the world and perceived external cues or references (such as maps or street signs). Cognitive mapping research focuses upon how individuals acquire, learn, develop, think about and store data relating to the everyday geographic environment, such as locations, attributes, and landmark orientations to navigate (Downs & Stea, 1997). The benefit to context-aware computing research is for (i) determining what types of landmarks people use to navigate and then integrating those personalised landmarks into Geographical Information Systems (ii) *understanding* and *predicting* spatial behaviour in order to design more useful and relevant context-aware services.

Over the years many researchers have attempted to conceptualise cognitive mapping. Several complex models and theories have been proposed, some of which originate from geographical research, others from psychological theories, and more recent theories that incorporate both geographical and psychological principles. Haken & Portugali (1996), for instance, propounded the inter-representational network (IRN) theory, which emphasises the interdependence of internal (cognitive) representations and external (environmental) representations. IRN embodies principles from:

- Gibson's (1979) perceptual theory where it is argued that environmental features are encoded directly from perception without additional cognitive processing;
- information processing theories (such as Golledge and Stimson, 1987) which concern the flow of information between the individual and environment; the perceptual filtering of information; the factors that influence the interpretation of, and decisions made regarding, perceived information; and the revealed spatial behaviours;

– *experiential realism* in that the patterns of cognitive processing are derived from the person's experience in the environment.

The remainder of this section will discuss the processes of, and the factors that influence, the acquisition of spatial information. The extent to which this area of research addresses the cognitive maps developed by visually impaired people will be discussed throughout.

2.5.1 Learning and acquiring spatial information

Strategies of learning spatial information can be considered from two different perspectives. Firstly, navigation-based learning is where spatial information is collected and processed directly from the individual's interaction with the environment. Kitchen & Blades (2002) outline three main theories about how people learn an environment from spatial interaction:

– Landmark theories, e.g. Golledge's (1978) anchor-point theory, are where environmental cues lay the foundation to which further information is added, such as the spatial relationship of landmarks in a path.

– Route theories, e.g. Gärling et al. (1981), are the opposite of landmark theories in that path-based information lay the foundation to which spatial positions of landmarks along this path are added.

– Theories concerning ordered views/scenes, e.g. Cornell & Hay (1984), suggest that wayfinding can be dependent on memorising ordered views or scenes rather than learning landmarks and paths.

The second form of spatial learning is resource-based where spatial information is collected and processed without having to directly experience the environment. Resource-based learning can be acquired from atlases, maps, television, newspapers/magazines, schooling, talking to others, and written and verbal directions. The process of acquiring this information, however, can be different for visually impaired people who use tactile maps, Braille newspapers, and embossed pictures to learn from resources that require sight. This type of learning is 'a useful supplement to direct experience, and is the only source of information about environments at scales that cannot be experienced directly, such as countries or continents' (Kitchen & Blades, 2002).

2.5.2 Factors that influence how knowledge is acquired

Navigation-based and resource-based learning are influenced by various factors, all of which can be classified under two separate headings relating to *environmental* and *individual* variability. Environmental variability is addressed by Jonsson (2002) who describes how spatial information can be encoded differently depending on (i) the time of day, e.g. landmarks can appear differently at night, (ii) the type of season, e.g. snow in winter vs. a summer's day, (iii) the weather conditions, e.g. rainy day vs. sunny day, and (iv) direction of travel, e.g. the appearance of landmarks change when travelling the same route forward and then back.

Individual variability is addressed by Kitchen & Blades (2002), who described how influencing factors may include gender, age, education, culture, emotion, beliefs, preferences, and abilities/disabilities. For some factors, there is contrasting evidence of an effect on learning, while for others more research is generally required. There is evidence, for instance, that elderly people have poorer spatial memory and spatial ability, i.e. the ability to process information about the relationships among objects in space and time. However, previous research has predominantly been devoted to the development of cognitive maps during childhood. Gender differences in spatial ability have also been found. In small-scale tasks involving mental rotation and spatial perception, males perform better than females (Allen, 1999). However, it is not known how important these abilities are in the development of cognitive maps.

The influence of disability on learning is a much needed area for further research. Of the limited studies that have been undertaken, most researchers have focused on visual impairments, while others have carried out studies with wheelchair users, and people with neuropsychological and learning impairments. People with severe visual impairments, for instance, rely on sequential learning using tactile, proprioceptive, and auditory senses to encode spatial information and construct spatial relationships (Bigelow, 1996). There is limited research, however, into the acquisition of spatial information by people with varying degrees and forms of visual impairment. These types of issues are illustrated in Figure 2.7 (parts a-d).

(a) Normal vision

(b) Loss of central vision (this can be caused by macular degeneration)

(c) Possible effect of advanced cataract

(d) One half of the field of vision lost (may be due to stroke or head injury)

Figure 2.7. Photographical representations of different visual impairments[2]

So key questions in relation to Figure 2.7 would include: how would people experiencing impairments similar to parts (a-d) encode spatial information, which types of sensory receptors would be used to acquire different types of spatial information, and with respect to navigational aids, what assistance or information could be provided to enhance their spatial orientation or cognitive map? For instance, someone experiencing the advanced cataract condition shown in part (c) may be more dependent on encoding auditory information than parts (b and d), as objects are less distinguishable. Further, a navigational aid would need to provide assistance on textual features in the environment (such as street signs) for someone experiencing a loss of central vision, shown in part (b), as reading text would be problematic.

[2] Representing human vision pictorially is difficult, as binocular vision is 3-dimensional and consists of focal and peripheral vision.

Some have argued that by improving the design of the built environment to be more accessible and memorable (Golledge & Stimson, 1997) would facilitate the development of visually impaired people's cognitive maps. However, this will not tackle the problem of macro-navigation, as discussed earlier. Overall, more cognitive mapping research is required in order to reveal what spatial information should be given to visually impaired pedestrians, in what form, and at which particular locations (Kitchen & Jacobson, 1997).

2.5.3 The structure and form of cognitive maps

Over the years there have been several theories proposed to account for (i) how cognitive maps are structured and composed, i.e. non-hierarchical, hierarchical, and schema theories, (ii) the form of, and mechanisms supporting, cognitive maps, such as images, dual coding, genetic coding, etc., (iii) the process by which spatial knowledge is accessed and utilised, and (iv) how spatial knowledge is expressed (Kitchen & Blades, 2002).

Jonsson (2002), for instance, differentiates between *active* and *passive* cognitive maps. Active maps contain spatial information that is always available and which can be described verbally, e.g. giving detailed directions to a disorientated tourist. In contrast, passive maps contain landmarks that are only recognised when the traveller sees them, e.g. revisiting landmarks after a long absence - returning to a former residence, holiday destination, etc.

Lovelace *et al* (1999) describes a study that explores the kinds and locations of landmarks used in instructions. Four groups can be distinguished: choice point landmarks (at decision points), potential choice point landmarks (at traversing intersections), en-route landmarks (along a path with no choice), and off-route landmarks (distant but visible from the route). A major conclusion of the study is that choice points and en-route landmarks were used more in route descriptions of unfamiliar environments.

In relation to (iv), there is evidence to suggest that people with visual impairments express their spatial knowledge differently to that of sighted people. Bradley and Dunlop (2002b) found that visually impaired people provide richer contextual descriptions (when describing a route) including information not used by sighted participants, such as sensory and motion-based information. In a further study by Bradley & Dunlop (2004b), significant differences were found between people with different visual impairments. For instance, when asked to walk to pre-determined outdoor and indoor landmarks, participants experiencing a central vision loss and total vision loss asked more questions relating to side streets, steps, distance, and temporary obstacles, than participants with a peripheral vision loss.

2.5.4 Methods for investigating cognitive maps

Kitchen and Blades (2002) provide a comprehensive literature study of cognitive mapping methods and categorise methods for individual studies as follows:

- *Unidimensional data generation*: Studies in this category involve studying cognitive models a single dimension at a time, focusing either on distance or angle. Various approaches to distance analysis can be used that attempt to overcome different problems in getting people to express what their internal model is. These include simple magnitude estimates, e.g. “if Glasgow – London is 100units, how far is Glasgow – Dublin?” and rating distances into different categories, e.g. very near, near, medium, far, very far, etc. Direction estimates usually involve either standing (or imagining oneself standing) at a location and pointing to another or drawing the direction from one location to another on paper.
- *Two-dimensional data generation*: Simple graphic approaches to 2D studies involve getting the experimental subject to draw maps of an area. Unfortunately, these drawings can be affected not only by the subject’s cognitive map but also by their ability to express this cognitive map through drawing – Kitchen and Blades discuss alternatives to try to reduce this problem. Completion tasks are one solution where subjects complete a partial map – either free hand drawing additional information on pre-prepared maps or filling in blank spaces on the map.
- *Recognition tasks*: Rather than relying on subjects descriptive abilities, recognition tasks simplify the subject’s task by asking them to select the correct map or map segment from a multiple-choice selection where the incorrect choices are variants of the correct map, e.g. skewed or rotated.
- *Qualitative approaches to studying cognitive maps*: The above methods are either inherently quantitative in nature or can be easily analysed quantitatively. As with HCI, cognitive mapping researchers have made use of think-aloud protocols among other techniques, to study, for example, how people learn spatial information from maps.

Kitchen and Blades also discuss other studies – particularly ones that attempt to verify models or test subjects' cognitive maps, e.g. comparing subjects ability to follow a route after previously following the route either in real-life or on video.

2.6 Wayfinding of visually impaired people

The main application area of this thesis is supporting orientation and navigation of visually impaired people. This is a hugely challenging task, both from a technical and usability perspective. The purpose of this section is to illustrate the current techniques and aids that visually impaired people use, the problems of those techniques and aids, and the technological solutions that have been designed to address those problems. The section describes levels of context that are currently used to address the mobility requirements of visually impaired people. This section is therefore divided into the following key areas: (i) orientation, mobility and navigation, (ii) traditional mobility aids, (iii) the limitations of traditional mobility aids, and (iv) technologies/ systems for distant navigation.

2.6.1 Orientation, mobility and navigation

The ability to orientate and navigate is an important skill that is used to experience and interact with the environment, to make social contact with other people, to undertake daily activities, and, ultimately, to maintain *independent* mobility. 'Orientation' refers to a person's awareness of his/her position in space. It has been defined as the 'process of utilising the remaining senses in establishing one's position and relationship to all other significant objects in one's environment' (Hill & Ponder, 1976). Orientation is therefore dependent upon the solicitation and interpretation of sensory information, which may be visual, auditory, kinaesthetic, tactile, thermal, and/or olfactory. Successful interpretation of sensory cues is dependent upon a known and predictable environment (LaGrow & Weessies, 1994).

Orientation and Mobility (O and M) specialists teach visually impaired travellers to recognise and anticipate the regularities of the environment. However, exceptions to those regularities become more informative than the regularities themselves, and become landmarks that a traveller can use to pinpoint their location in space (Hill & Ponder, 1976).

‘Mobility’ refers to the ability of a person to move safely and efficiently from one *point* to another within the physical environment. It has been defined as the ‘capacity, the readiness, and the facility to move’ (Hill & Ponder, 1976). This involves sensing and negotiating obstacles and hazards, establishing and maintaining a desired course, and recovery from veers and other unintended or unexpected changes in direction.

‘Navigation’ refers to the purposeful process involved in travelling from one *place* to another, using mobility skills, and orientation in the environment in relation to a desired course. Navigation therefore involves the traveller updating their orientation and position, which can be achieved using three methods classified on the basis of kinematic order (Loomis *et al.*, 2001):

(i) ‘Position-based navigation’ depends on external signals within the environment, such as landmarks, indicating the traveller’s position and orientation.

(ii) ‘Velocity-based navigation’ (normally referred to as ‘dead reckoning’) relies on external and internal signals indicating to the traveller their present position by projecting course and speed from a known past location, and predicting a future position by projecting course and speed from a known present position.

(iii) ‘Acceleration-based navigation’ (normally termed ‘inertial navigation’) involves both the traveller’s linear and rotary accelerations to acquire information on displacement and heading change from the origin.

With respect to these three methods, visually impaired people are at a huge disadvantage in unfamiliar routes, as they ‘lack much of the information needed for planning detours around obstacles and hazards, and have little information about distant landmarks, heading and self-velocity’ (Loomis *et al.*, 2001).

2.6.2 Traditional mobility aids

Traditional mobility aids have acted as an important and effective tool for helping visually impaired travellers detect objects in the local environment, negotiate narrow spaces, climb and descend stairways, enter and exit buildings, as well as many other mobility tasks. Three widely used traditional aids exist, and are described below:

- Human Guide: This is where a person with sight serves as a guide to a person who is visually impaired. The human guide is positioned slightly in front in order to ensure safety. At one time or another, most visually impaired travellers use a human guide, either as a primary aid or supplement to other aids.
- Long cane: Over the years, various types of canes have been developed for specific user needs and preferences. The long cane (also called the prescription cane or typhlo cane), however, is the most effective and efficient (Farmer, 1980). It enables visually impaired travellers to detect obstacles or drop-offs in the path approximately one metre in front of them. Information regarding the walking surface or texture can also be transmitted, while providing suitable lower-body protection. In the most common technique, the cane is extended and swung back and forth across the body in rhythm with the user's steps (LaGrow & Weessies, 1994).
- Dog Guide: Trained dogs are used as travel aids by less than 10% of vision impaired travellers. The dog responds to commands given by its handler, such as right, left and forward (commands are only disobeyed to avoid danger). The guide dog's job is not to find the way, but to guide its handler around obstacles or stop in front of them. Handler's must therefore know where they are going and make decisions about the proper time to begin a street crossing.

The requirements and abilities of visually impaired people vary considerable, and so an Orientation and Mobility specialist would advise on a mobility aid (along with techniques and instructional strategies) that reflects the uniqueness of each person. The traveller's quality of vision, for instance, is a key factor in identifying which mobility aid is most appropriate.

2.6.3 Limitations of traditional mobility aids

Long canes and guide dogs have been effective in helping visually impaired people with many mobility tasks, as described in the last section. However, Clark-Carter *et al.* (1986) state that at least one-third of people with visual impairment or blindness make no independent journeys outside their homes, and most of those who do venture outside independently often travel to *known* destinations along *familiar* routes, as exploration is considered stressful and can lead to disorientation. The inability of these aids to facilitate distant (or macro) navigation is considered the main reason for this (Petrie, 1995). The traveller, for instance, would remain unaware of a supermarket located at the other side of the street. Even for local (or micro) navigation these devices are limited as they only detect objects below waist height.

Very limited contextual detail of the environment can be acquired from traditional mobility aids. The focus of this thesis is therefore on assisting the visually impaired traveller for distant navigation by providing a greater spatial and contextual orientation beyond the immediate environment or what can be detected using a mobility aid. Visually impaired travellers will therefore not feel restricted to frequently travelled routes, as they will be supported in travelling to *unknown* destinations, along *unfamiliar* routes.

2.6.4 Technologies/systems for distant navigation

In the 1940s, the long cane was adopted as the primary mobility aid within the blind community in the 1940s (Farmer, 1980). Since then, electronic travels aids (ETAs) have been developed in order to provide more detailed feedback of the local or immediate environment, such as obstacle avoidance systems, e.g. Laser Cane and ultrasonic obstacle avoiders (Bradyn, 1985). However, in order to support independent mobility of visually impaired people to *unknown* destinations along *unfamiliar* routes, these devices will need to be complemented with distant navigation technologies.

Within the last decade, the development of ETAs has been used to support distant navigation. One approach is to use a network of location identifiers that can be remotely sensed by the visually impaired traveller within either indoor or outdoor environments. Some systems use infrared transmitters installed throughout the environment to transmit digital speech about the location, while others use Radio Frequency (RF) beacons to wireless transfer digitally coded and compressed speech (e.g. Kemmerling and Schliepkorte, 1998). The main drawback of this technology is the cost of installation. In addition, contextual information is limited, and generic for all users. Individual requirements such as those described in Section 2.5.2 would not be supported.

GPS-based mobile computer aids have been used by many researchers to assist the navigation of visually impaired people in outdoor environments. Here, signals picked up from satellites orbiting the earth's atmosphere are used by a mobile device to convert latitude and longitude coordinates to a geographical location using a digital map. Good examples of GPS-based systems include: (i) the MOBIC Travel Aid which integrates differential correction from ground base stations (DGPS) for greater location precision, a compass worn on the body for heading direction, and mobile telecommunication facility (Strothotte *et al.*, 1996), and (ii) a navigation system for the blind that uses a telephone connection to transmit the user's GPS coordinates to a central server, which sends back digitised speech to the visually impaired traveller (Makino *et al.*, 1997).

While GPS offers great potential, its accuracy and reliability is still not good enough to navigate visually impaired people safely and effectively through city-centre environments. DGPS is not available in many locations, and the signal from satellites can become blocked in narrow built up areas. The level of service offered by those systems is also very limited since they are solely based on location-awareness. Other important *contextual* information within the visually impaired person's context, which is necessary for independent mobility, has not been considered such as their personal requirements (e.g. adjusting information to the user's type of visual impairment). In support, Helal *et al.* (2001) describes how many GPS-systems 'lack dynamic query capabilities and support for dynamically changing environments' and that 'context-awareness is not well supported'.

Unfortunately, GPS is ineffective inside buildings and so most location-aware systems within indoor environments depend on relative positioning using various technologies. Active Badge, for instance, is a small wearable device which transmits a unique infrared signal every 10 seconds (Want *et al.*, 1992). These signals are detected by one or more networked sensors, which are used to determine the location of the badge on the basis of information provided by these sensors. There is also evidence to suggest that location can be inferred using other methods by integrating information from accelerometers, magnetometers, temperature and light sensors (Golding & Lesh, 1999) or using wireless networks.

2.7 Other related work

The purpose of this section is to highlight some related research. This has been divided up into 'user modelling', 'proactive systems', and 'relevance theory'.

2.7.1 User modelling

The area of 'user modelling' overlaps with much of the research discussed throughout the literature review, especially with the section describing the issue of personalisation in section 2.2.1. A user model is an explicit representation of properties of a particular user. A system that constructs and consults user models can adapt its performance to personalize information and services to individual users. In other words, personalised systems must be able to observe and collect information about the user's behaviour, and then make generalisations and predictions about the user based on those observations. Fink & Kobsa (2002), for instance, present a user modelling system that provides essential user modelling services for deployment to real-world environments. The open, standards-based, and platform-independent tool provides a set of core techniques for drawing assumptions about users.

2.7.2 Proactive systems

Similar to the capabilities of context-aware systems, 'proactive computing' refers to ubiquitous computers that take initiative on their own to work on the user's behalf. In contrast to 'reactive' systems that execute actions based on explicit input from users or changes in the sensed context, proactive computing is a subfield of ubiquitous computing that attempts to enhance the productivity of actions based on context inferences of sensor data (e.g. automation of actions, elimination of unnecessary effort, reduction of information overload, and optimisation of resources). The user's role is to monitor and receive its actions, and provide feedback and control the system. Salovaara & Oulasvirta (2004) provide a user-centred typology of proactivity from the viewpoint of *resource management*. It is described how 'a system can be advising on, preparing, optimizing, manipulating, inhibiting, or finalizing user's resources that can be computational artifacts, processes, or representations'. The authors believe that the typology can inspire designers to innovate new ideas of user assistance and of how proactivity may take its place in an application.

2.7.3 Relevance theory

The cross-analysis of single discipline models in section 2.4.7 revealed that the notion of relevancy is inextricably linked to investigations of context. An area of related work is 'relevance theory', which is seen as an attempt to work out in detail one of Grice's central claims that an essential feature of most human communication, both verbal and non-verbal, is the expression and recognition of intentions (Grice 1989: Essays 1-7, 14, 18; Retrospective Epilogue). For instance, one of the assumptions, outlined in Wilson & Sperber's (2004) extensive review of the current version of the theory, is that human cognition tends to be geared to the maximisation of relevance. Any external stimulus or internal representation which provides an input to cognitive processes may be relevant to an individual at sometime. The authors state that 'an input is relevant to an individual when, and only when, its processing yields positive cognitive effects'. While much of relevance theory is centred on human communication, its principles can also be applied for human navigation and the development of cognitive maps (discussed in section 2.5). Humans process inputs from external stimuli in the environment which are considered relevant for constructing a cognitive map of a particular area. A central aim of this thesis is to discover whether different groups of people find certain external stimuli more relevant for navigation than others.

2.8 Summary

In this chapter, various areas of research have been critically reviewed. At the start, context-aware computing was introduced as an exciting and promising area within which traditional human-computer interaction could be minimised, and become more seamless, naturalised, and task-specific. Good examples of application areas in mobile computing were discussed and then analysed with respect to key usability issues that remain insufficiently addressed in current research. As a means of investigating those issues further, a review of design frameworks, techniques, and processes (mostly user-centred) for designing context-aware systems was undertaken. It became apparent that many of those design practices or principles need to be expanded in order to capture and analyse the dynamic and contextually rich mobile computer settings within which people interact. This led to a cross-disciplinary analysis of the notion of context in order to draw upon contrasting viewpoints and theories. As part of this valuable exercise, models were constructed and used to cross-analyse those different viewpoints. Similarities and differences were identified, and it was felt that the most pressing areas for further investigation relate to contextual interactions, the notion of relevancy, and the temporal and social aspects of design. Cognitive mapping research was then introduced as an area for which these issues could be conceptualised and investigated. The main application area of the multidisciplinary model proposed in Chapter 3 is of supporting the navigation of visually impaired people, and so the last section discusses the extent to which traditional techniques and aids, and the plethora of distant navigation technologies (e.g. GPS-based systems, and intelligent canes) support the mobility requirements of visually impaired people.

2.9 Research goals and hypothesis

As described in section 1.2, the primary aim of this thesis is to propose a user-centred and multidisciplinary design framework for context-aware computing. The purpose is to facilitate application developers in building richer descriptions and scenarios of how a context-aware system might be used in various mobile environments. The more specific aims of this thesis, in light of the research reviewed in previous sections, are as follows:

- To combine single discipline models of context in Psychology, Linguistics, and computer Science (Figures 2.2, 2.4, and 2.5) in order to construct a multidisciplinary model of context. The underlying motives are to (i) capture key usability issues of context-aware design, including those issues already discussed in section 2.2, (ii) advance user and task/activity models in contextual rich mobile settings, (iii) augment traditional HCI techniques used for analysing those mobile settings, and (iv) provide a foundation on which to construct a design framework in Chapter 7.
- To apply the principles of the multidisciplinary model of context exclusively focusing on the substantive issue of personalisation discussed in 2.2.1. The issue of localisation (discussed in 2.2.3), however, is also addressed to a lesser extent in the last two studies, described in section 4.5 and in Chapter 6. The main application area will be of supporting navigation and orientation of visually impaired people since this area has not been adequately supported or investigated and generally represents a particularly challenging test for context-aware research. The aim is to use the model to design a series of user studies in order to investigate the issue of

personalisation of context-aware navigation services. This will involve three key stages involving (i) an investigation of the user's context, (ii) designing a prototype application to represent the application's context, and (iii) an investigation of the user-application context, or the integration of the user and application's worlds.

- To combine principles from the proposed multidisciplinary model of context with the results of the user studies in order to formulate a design framework, which would advance user-centred approaches and techniques for designing context-aware systems. The idea here is to provide a step-by-step process with which developers can use, firstly, to improve their awareness and understanding of complex mobile user scenarios, and, secondly, to improve their ability to assess, and account for, these key design issues during application development. The final aim is to evaluate the proposed design framework by comparing it to Bellotti & Edwards (2001) user-centred framework described in section 2.3.2.1.

This thesis is intended for a variety of readers, including mobile application developers and technologists who design location- or context-aware services; HCI researchers who advance user-centred design theories, models, or frameworks for designing usable context-aware systems; researchers and technologists who have a keen interest in assistive technologies for people with visual impairments, especially those for orientation and navigation; and cognitive mapping researchers who are interested in the development of cognitive maps by visually impaired people.

CHAPTER 3

MULTIDISCIPLINARY MODEL OF CONTEXT

In this chapter, cross-disciplinary theories of context described in section 2.4 are brought together in order to propose a multidisciplinary model of context. Much of the work described in this chapter is based on Bradley & Dunlop (2005b).

3.1 Aim and purpose

Two versions of my multidisciplinary model of context are presented: (i) an outline version (Figure 3.1) and (ii) a detailed version (Figure 3.2). The main aim of this chapter is to merge single discipline models of context in psychology, linguistics, and computer Science (Figures 2.2, 2.4, and 2.5) in order to construct a multidisciplinary model of context. More specifically, the aims of this chapter are to:

- capture key usability issues of context-aware design, including those issues already discussed in section 2.2;
- advance user and task/activity models in contextual rich mobile settings;
- augment traditional HCI techniques used for analysing those mobile settings;
- provide a foundation on which to construct a user-centred framework for designing mobile context-aware systems.

The key principles of the model will be described under three sub-headings, concerning the differentiation of the user and application's world, the separation of meaningful and incidental dimensions of context, and contextual processes and transitions. Two further sections concern a conceptual application of the model to two different areas of context-aware computing, and a section presenting conclusions of this chapter and the contribution of the model to research.

3.2 Differentiation of the user and application's world

The horizontal centre line, shown in my outline model in Figure 3.1, separates the 'user's world' from the 'application's world'.

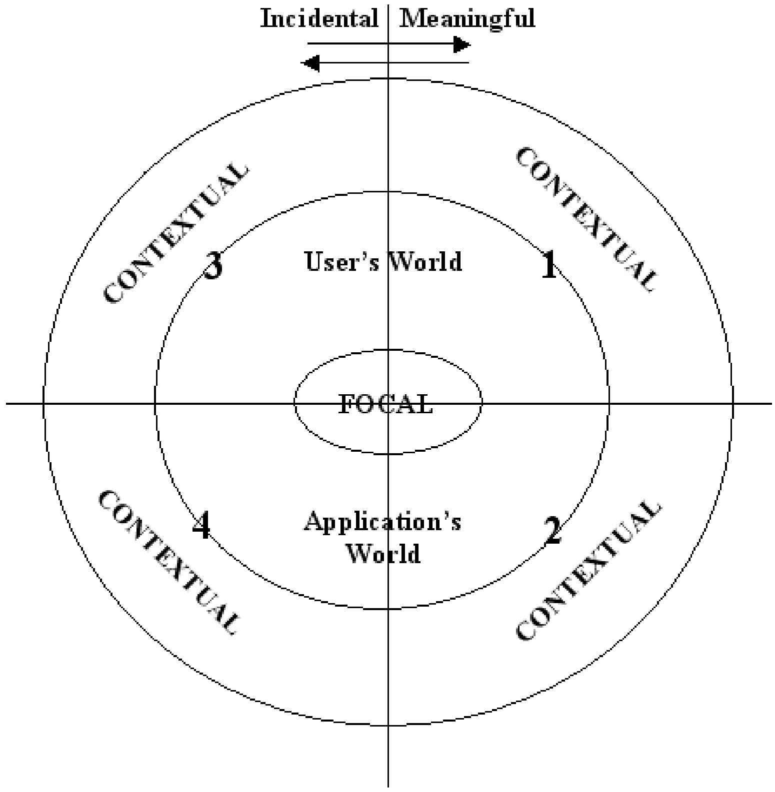


Figure 3.1. Proposed outline multidisciplinary model of context.

The oval shaped circle in the centre of Figure 3.1 represents what is 'focal' to:

- *the user* with respect to carrying out actions in an attempt to achieve goals (e.g. interact with Palmtop to find out the time of a train, interact with self service ticket machine to acquire train ticket). Goals and associated actions may be interrelated and form part of a higher-level structure or goal (e.g. to get home). Actions can also occur independently or simultaneously.
- *the application* with respect to transmitting contextual information and services to the user (e.g. alerting the user that their train home is delayed).

In contrast, the circular layer that surrounds the user and application's world represents anything in the 'contextual' world that (i) people are influenced by when attempting to carry out focal activities (e.g. influenced by surrounding people in the social context when using a cash machine), and (ii) an application senses, uses, or is influenced by when processing focal application services (e.g. sensing the physical location to infer the user's current activity). The contextual world can be broken down into several dimensions, four of which are common to both the user and application and are described below:

- *Task context*: The functional relationship of the user with other people and objects, and the benefits (e.g. resources available) or constraints (e.g. time pressure) this relationship places on the user achieving his/her goal.
- *Physical context*: The environmental location including its gradient and altitude, and consisting of surrounding physical objects, such as buildings, cars, trees, etc. This also includes the orientation, position, state, and purpose of those objects, and the types of information they transmit through audio, visual, odour, texture, temperature, and movement. Contrasting weather conditions (e.g. cloudy/sunny, cold/hot, etc.) and lighting conditions (e.g. daylight/ darkness) may also influence how objects are perceived.
- *Social context:* The relationship with, dialogue from, and the density, flow, noise, and behaviour of, surrounding people (e.g. sitting on a crowded train).
- *Temporal context:* The temporal context is embedded within everything (as illustrated in Figure 3.2), and is what gives a *current* situation meaning, based upon *past* situations/occurrences, expected *future* events, and the higher-level temporal context relating to the time of day, week, month, or season.

Another contextual dimension affecting the user's world is the application's context, which to the user would concern transmitted information regarding focal application services, and his/her perception of the application's capabilities/limitations and of how the application operates. Although part of the user's world, the 'cognitive context' also affects focal actions, as described below.

- *Cognitive context:* A user's cognitive processing abilities; short- and long-term memory abilities; dislikes/preferences; opinions/beliefs; cultural interpretations; perceptual sensing abilities; perception of levels of privacy and security; cognitive mapping strategies, etc.

Within the application's world, another contextual dimension that could be sensed is the user's context. This may include information regarding (i) the user's personal diary, including planned activities, notes and reminders, as well as user-defined application settings and preferences (e.g. levels of privacy), (ii) physiological sensing such as heart rate to measure levels of anxiety, and (iii) monitored behavioral patterns of the user. Similarly, although part of the application's world, the 'application context' also affects how focal services are executed, as described below:

– *Application's context:* The capabilities and limitations of both the application (such as battery usage life, processor speed, memory capacity, sensors, input/output technologies, etc.) and the sources from which data is derived (such as the processing speed of a web-based server).

3.3 Separation between incidental and meaningful dimensions

The next separation to make is between *incidental* and *meaningful* context, as depicted by the centre vertical line in Figure 3.1. Generally speaking, 'meaningful' context relates to the user's primary high-level goal, whereas 'incidental' context concerns incidental occurrences that are normally unrelated to the user's primary high-level goal (e.g. bumping into a friend, being caught in a sudden downpour, etc). In order to illustrate in more detail, each of the four quadrants will be described separately.

Quadrant 1: In order to realize his/her primary high-level goal (e.g. locating a suitable restaurant to have dinner), the user is undertaking *meaningful focal* actions (e.g. reading either inferred recommendations from IPAQ or restaurant reviews in tourist guidebook) and is using, or being positively/negatively influenced by, *meaningful contextual* dimensions (e.g. currently raining, it's getting late, and the user is feeling hungry and tired). This quadrant is similar to the techniques of task analysis, which are aimed at eliciting the structured set of meaningful actions or activities people carry out in order to accomplish an explicit goal or task (see Preece *et al.*, 1994).

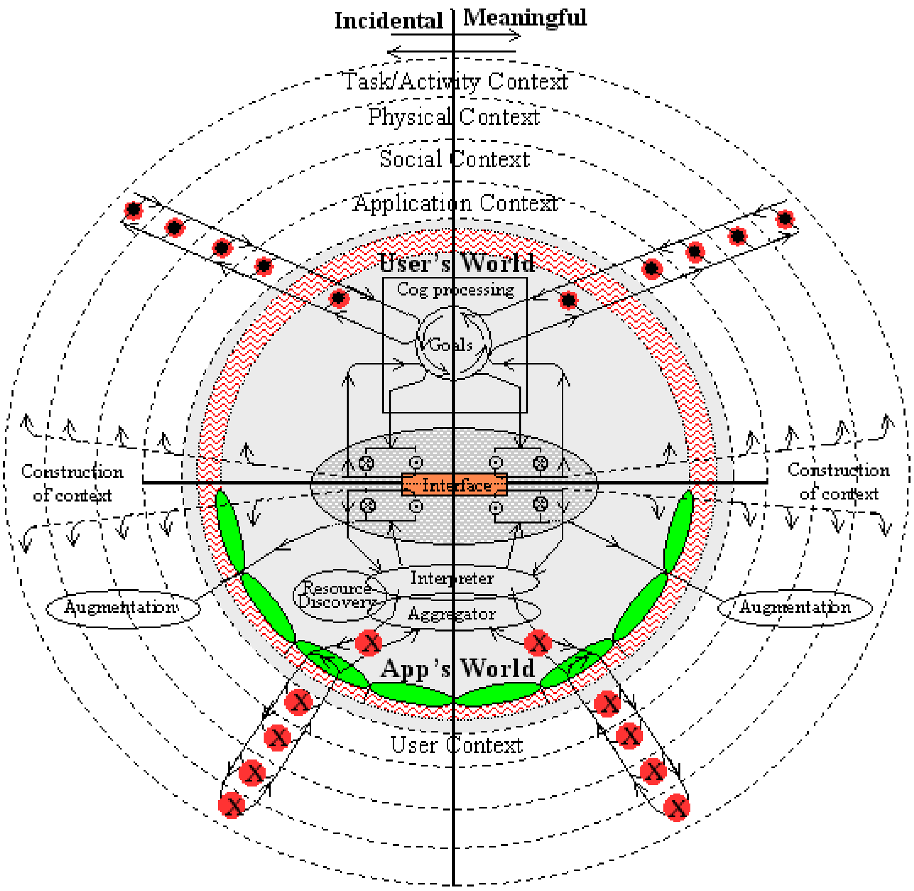
Quadrant 2: The application is aware of (or thinks it is aware of) the user's primary high-level goal (either inferred by the application or explicitly given by the user), and uses sensed data acquired from the *contextual* world to execute a *meaningfully focal* service (e.g. using the current time of day, the user's eating preferences, local weather reports, and the user's current location to recommend restaurants to the user).

Quadrant 3: Incidental occurrences in the contextual world are normally unrelated to the user's primary high-level goal. These events may either (i) remain *incidentally contextual* if they have no impact on the user's meaningful activities (e.g. other people walking past), (ii) become *incidentally focal* if the user needs to temporarily deviate away from their meaningful activities (e.g. having to cross the street to navigate past roadwork), (iii) become *meaningfully contextual* (e.g. decide to walk another route on subsequent days), or (iv) become *meaningfully focal* (e.g. if you badly injure yourself falling down the hole!). From another perspective, people may use incidental occurrences to determine their meaningful activity. For instance, people may use the busyness of a restaurant to decide which restaurant to eat at.

Quadrant 4: The application uses sensed *contextual* data, similar to Quadrant 2, to either support *incidental focal* events (as described in point (ii) of Quadrant 3), or infer future user intentions, which the user may be currently unaware of (e.g. informing the user of a friend in a nearby café). The application may also acquire sensed data and discover resources and tools in the environment, which, although possibly unrelated (and therefore incidental) to the present high-level goal, are considered of potential benefit to the user for future meaningful activities (e.g. a tool to provide a weather report whenever a new city is visited).

3.4 Contextual processes and transitions

The space between the centre focal circle and the inside perimeter of the contextual layer in Figure 3.1, concerns the user and application *processes* that link the contextual world to the focal world and differentiate between the incidental and meaningful worlds. This is illustrated in my detailed multidisciplinary model of context shown in Figure 3.2.



Key for user's world	Key for application's world
The confluence of context dimensions embedded in temporal context (depicted by outer red circle)	Sensed dimensions of context embedded in a temporal context (depicted by outer red circle)
Perceptual sensing (i.e. through 5 senses)	Application sensors
Focal user activities/actions	Widgets that wrap around sensors
Interact with user-interface	Focal application service
Interact with living organism(s) or natural/ synthetic object(s)	Information transmitted to the user via interface
	Communicate with other computers (on occasions undertaken without user intervention/knowledge)

Figure 3.2. Proposed detailed multidisciplinary model of context.

Generally, the depiction of the user's world in Figure 3.2 illustrates how cognitive goals of a user are continually shaped by their perception of the meaningful and incidental contextual worlds, consisting of task, physical, social, application, and cognitive dimensions, all of which are embedded in a temporal context. It should be noted that those dimensions represent an interleaving system and not a visual metaphor (e.g. task context does not encapsulate physical context).

The user's goals are then used to carry out concise focal actions, which may involve interactions with the application or surrounding people and objects. Focal interactions shape the context within which subsequent interactions take place and also contribute to the user's construction of future goals.

The depiction of the application's world illustrates how the application senses, stores and interprets contextual data. Focal services are then executed, which may be to transmit information to the user, leave information at a specific location in space (i.e. contextual augmentation), or communicate to other computers possibly without the user's knowledge or intervention. Similarly, these focal services construct the application's context and the context within which the application senses.

In order to explain in more detail the key concepts in Figure 3.2, the user and application processes will be explained separately.

3.4.1 User processes

Within the meaningful world, shown in the top right quadrant of Figure 3.2 (quadrant 1 of Figure 3.1), the user utilises, or is influenced by, dimensions of the *contextual* world. This process will now be described in more detail using a scenario illustrated in Figure 3.3.

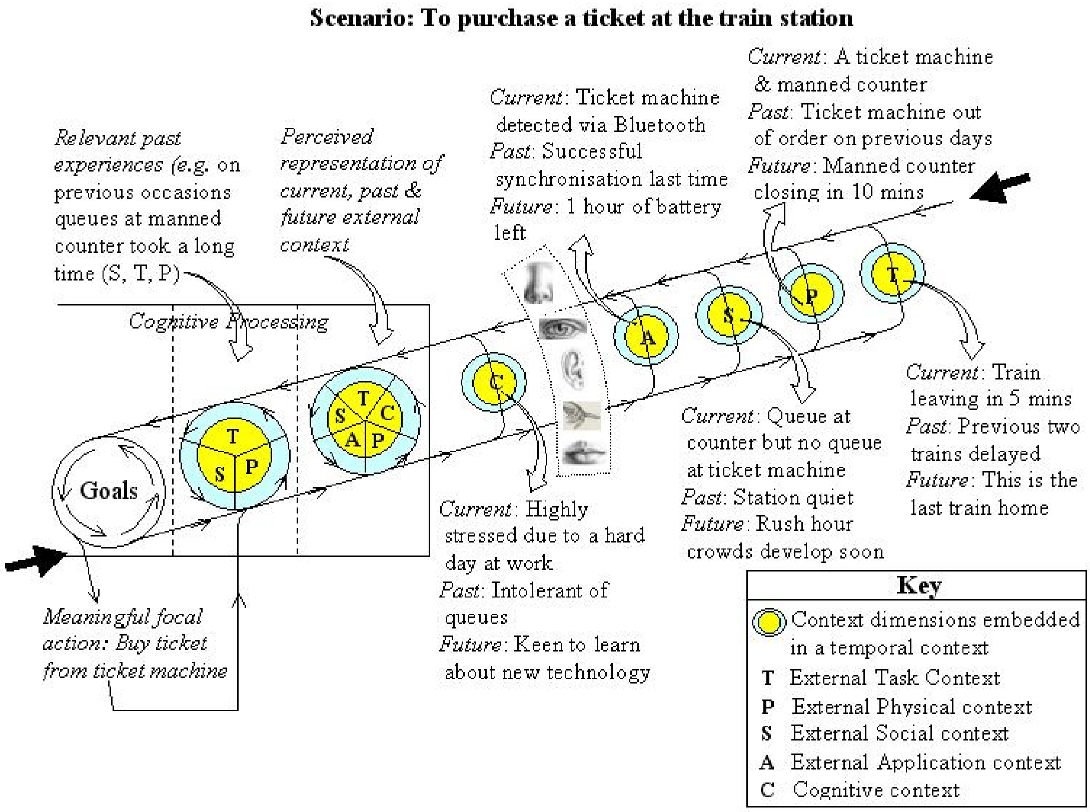


Figure 3.3. User processes that link the contextual world to the focal world.

Shown in the ‘goals’ circle on the far left, the user has a high-level goal of catching the last train home. This goal would be broken down into a series of low-level goals - the *current* one being to purchase a train ticket. This diagram can be considered from two perspectives, which is illustrated by the arrow on the left and the arrow on the right. When attempting to realize this goal (starting from the left arrow), the user is selecting meaningful and relevant aspects of the external contextual environment, such as the option of a manned counter or ticket machine. In contrast (starting from the right arrow), the user is also being influenced, either positively or negatively, by the external contextual environment (e.g. the manned counter closing in 10mins).

In either situation, meaningful aspects of the contextual environment, all of which are embedded in a current, past, and present temporal context, are perceived by the user through the five human senses, namely sight, hearing, smell, touch, and taste. The information is then interpreted through the user’s cognitive context (e.g. intolerant of queues and highly stressed) leaving a perceived meaningful representation of the external world that is compared against relevant past experiences or acquired knowledge. The user then makes a decision regarding the most appropriate goal(s) with which to undertake a concise meaningful focal action. After the user has executed a focal action, this (i) forms an experience with which future perceived cognitive representations of the external environment can be compared, and (ii) constructs the context within which future contextual interactions take place, as shown in Figure 3.2.

As shown in Figure 3.2, the user also contains an incidental world, where objects, people and/or thoughts occur incidentally and are normally unrelated to the high-level meaningful goal (e.g. passing a newsagents within the train station). Similar to the meaningful world, these incidental occurrences have an embedded temporal context and are perceived by the user through his/her cognitive context leaving an internal representation of the incidental world. Unlike the meaningful world, cognitive processing here involves a conscious or unconscious assessment of whether this information is a cognitive gain or necessity (e.g. to negotiate a particular hazard). This evaluation will be influenced by the user’s previous experiences or acquired knowledge (similar to the meaningful world), resulting in the user’s decision to either (i) discard this incidental occurrence altogether, (ii) form a goal to undertake an incidental focal action, or (iii) make the incidental occurrence a meaningful contextual influence (e.g. the newsagents is used to acquire change for the self-service ticket machine).

A feature not captured in the model is the way in which interactions of objects and people influence the context within which users interact and make decisions. For instance, if people over a period of time leave electronic reviews of the same restaurant, how do these combined reviews influence users' decisions on whether to eat there or not?

3.4.2 Application processes

Dey *et al*'s (2001) component-based conceptual framework for building context-aware applications is partially used to represent the application's world shown in Figure 3.2. As described in section 2.3.1, this framework was chosen since it represents a significant milestone in ubiquitous computing, and has been used as an anchor article for a special issue on context-aware computing (Moran & Dourish, 2001).

The context abstractions used were widgets, aggregators, and interpreters. The processes within the aggregator and interpreter, and the flow of context data, have also been represented slightly differently in order to illustrate the key principles of Figure 3.2. Essentially, 'widgets' represent sensor abstractions that conceal details of how sensing and interpretation of the environment occur. Widgets essentially wrap around underlying sensors and provide an interface to automatically deliver information to interested components or services of the system. 'Aggregators' store multiple pieces of low-level information (such as a person or location) that is logically related and stored in a common repository for relevant application entities. 'Interpreters' are responsible for abstracting low-level data to higher-level information (e.g. using the user's location, time of day, and travel velocity to infer he/she is on the train home from work). The two remaining context abstractions of Dey's framework, namely 'services' and 'discoverers' are not shown but would be included within the focal application service section of Figure 3.2. Discoverers are responsible for maintaining a registry of what capabilities exist in the framework, and services are the same as context widgets, except the output is abstracted and the actuators or change of environmental state information is controlled.

The processes of collecting, transforming and delivering contextual information will now be described in more detail, as illustrated in Figure 3.4.

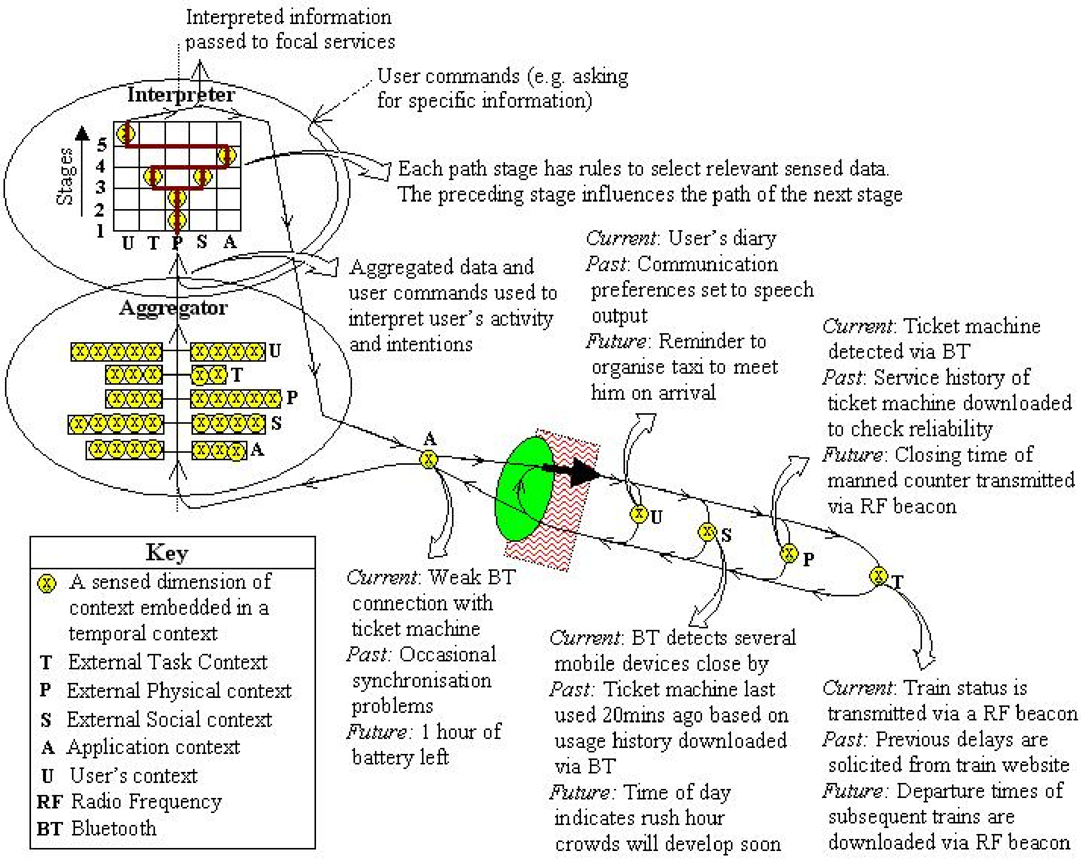


Figure 3.4. Processes of the application that link the contextual world to the focal world.

Starting from the dark arrow, Figure 3.4 illustrates how the context-aware system senses *meaningful* aspects of the *contextual world* - the dimensions of which are embedded within a past, current and future context. The availability and accuracy of sensed data, however, will be dependent on the application's context (i.e. the capabilities and limitations of the application, and the sources from which the information was derived).

My representation illustrates how data is then aggregated and logically stored under five common repositories relating to the user, task, physical, social, and application context. Aggregated sensed data contains past, current and future dimensions, and can be used to interpret meaningful and incidental activities of the user. The application's incidental world, shown in Figure 3.2, also contains a 'resource discovery'. Here, tools in the environment are discovered, and (if inferred to be relevant to the user) are downloaded to enhance its functionality and robustness. These tools may be used to either support incidental or meaningful application processes.

Within the interpreter, shown in Figure 3.4, my representation illustrates the conceptual process with which aggregated data could be abstracted (either driven by commands of the user or application). This has been depicted using a matrix consisting of the dimensions of aggregated sensed data on the horizontal axis, and the different levels/stages of abstraction on the vertical axis (note: the characteristics of the matrix are the same for both incidental and meaningful processes). The path through the matrix is governed by rules that are used to select relevant sensed aggregated data for each subsequent stage. Rules may be either fixed and pre-determined by the application (e.g. automatically contacting emergency services), or be more indefinite requiring some probabilistic modelling and inferential exploration of previous recorded paths (e.g. when the user enters the train station is he/she catching a train or meeting someone from the train?) – the reader is advised to read about *directed* probabilistic graphical models, also called Bayesian Networks or Belief Networks (Friedman & Goldszmidt, 1998), and *undirected* probabilistic graphical models, also called Markov models or Markov Random Fields (Rabiner, 1989). The following superficial example, as depicted in Figure 3.4, is described:

- **Stage 1**: Physical aggregated data - the user located in the train station. Rule: From previous matrix paths, the user typically decides to buy a train ticket when entering a bus or train station. Find out what objects are nearby.
- **Stage 2**: Physical aggregated data - a ticket machine and manned counter. Rule: From previous matrix paths involving stages 1 & 2, the user typically uses the counter to buy his ticket, though if there's a queue and time is pressing, he uses the ticket machine. Find out the status of train, and queues at counter and ticket machine.
- **Stage 3**: Task & social aggregated data – train leaves in 5mins, there is a queue at counter, and no queue at the ticket machine. Application infers user will wish to use the ticket machine. Rule: From previous matrix paths involving stages 1, 2 & 3, the

application has had Bluetooth connection problems with the ticket machine. Find out strength of Bluetooth signal.

– **Stage 4**: Application aggregated data – Bluetooth signal is strong. Rule: From previous matrix paths involving stages 1, 2, 3 & 4, the user pays for his ticket either by using hard cash or by direct debit using Bluetooth. Find out what payment preferences the user has set.

– **Stage 5**: User aggregated data – user has set his payment preference as direct debit. This path is sent to the focal application services section, which results in an executed action.

Once aggregated data has been abstracted or interpreted, the path through the matrix, along with the selected sensed data, is passed to the focal application service section, as shown in Figure 3.2. Focal services can take one of four forms: (i) task-specific information, either inferred by the application or requested by the user, is presented to the user via the User Interface (e.g. the application meaningfully infers the user is catching a train home, and informs him/her of a delay), (ii) information is not presented to the user, though the application executes a focal service as directed by the user (e.g. the user could *augment*, as shown in Figure 3.2, the environment at a precise location, informing friends of a good bookshop), (iii) the application meaningfully or incidentally infers a particular course of action without the user's intervention (e.g. automatically calling the user's doctor if he/she were to become ill), or (iv) an application service is executed in order to facilitate other application services (e.g. the application downloads a software tool for obtaining football scores, in order to infer more accurately a users likely course of action – to the pub to celebrate!).

3.5 Conceptual application of multidisciplinary model

The purpose of this section is to illustrate how the concepts and principles of the proposed multidisciplinary model of context might apply to different applications of context-aware computing. Those included are mobile tourist guides and devices to support mobile user communities. Also, an additional section at the end provides a superficial illustration of how an application developer might use my multidisciplinary model in practice.

3.5.1 Mobile tourist guides

One of the most popular application areas of context-aware computing is that of supporting the mobile information needs of tourists, as described in section 2.1.3. Using a scenario involving a tourist named Alice whose high-level goal is to experience and learn about the art and culture of Glasgow, the following observations can be made with respect to my multidisciplinary model of context in Figure 3.2 (along with Figures 3.3 & 3.4):

– *User's meaningful world*: Alice's lower level meaningful goal is to decide which attraction to visit. Her perceived cognitive representation of the environment includes a mixture of contextual information:

  - *Current physical context* – a bus stop is 30 metres away, positioned up a gradual incline. It is a cold day, and rain looks likely.
  - *Current task and application context* - her Palmtop ranks the Hunterian and Lighthouse Art Galleries as the top two nearby attractions. The Lighthouse Art Gallery would take 35 minutes to walk to (with no option of public transport), whilst the Hunterian Art Gallery could be reached in 15 minutes by bus, one of which is expected in 10 minutes.
  - *Current social context* – there is no queue at the bus stop.
  - *Past and current cognitive context* – dislikes walking, though would slightly prefer Lighthouse Art Gallery.

  Alice's representation is compared to her conversation with Bob (a relevant personal experience, as illustrated in Figure 3.3) who strongly recommended a visit to the Hunterian Art Gallery. Alice makes a decision and forms a goal to carry out concise meaningful focal actions to catch the bus to the Hunterian Art Gallery.

– *Application's meaningful world*: The following aggregated sensed data is used by the application to interpret and support Alice's high-level goal:

  - *Current physical context* - GPS location indicates that Alice is standing close to a bus stop in Glasgow. Temperature sensors indicate the current temperature is just above 0^{o}C. Rule: Check Alice's diary whenever she visits a new city.
  - *Current and past user context* – Alice's diary indicates she is on holiday. From previous holidays, Alice visits Art Galleries and likes to be reminded of weather reports. Rule: Find out weather reports and what galleries are nearby.

- *Current physical context* – a web-based geographical database indicates that the Hunterian and Lighthouse Art Galleries are nearby. A web-based weather report reveals that intermittent heavy downpours are expected. Rule: Discover timetables of public transport.
- *Future task context* – web-based public transport timetables indicate that the Hunterian Art Gallery can be reached in 15 minutes by bus, one of which is expected at the bus stop in 10 minutes. No mode of transport to the Lighthouse Art Gallery was found, though a distance calculation and Alice's average walking speed indicate it would take around 35 minutes to reach by foot. Rule: Check Alice's preferred mode of inner city travel, and check whether these preferences change in different weather conditions.
- *Past user context* – when it is a cold day, Alice prefers to travel by bus.

Based upon this interpreted information, the application executes a focal meaningful service to rank a set of tourist attractions (along with methods of transport) having the Hunterian Art Gallery at the top since Alice's preferred mode of inner city travel is by bus when it is a cold day.

– *Incidental world of the user and application*: There is a sudden downpour while Alice waits at the bus stop, which results in Alice taking cover under a tree 15 metres away (an incidental focal action). The application senses a change in Alice's location, which she has remained at for a couple of minutes. Using this information, combined with web-based weather reports, and the required walking distance after Alice's bus journey, the application infers that she may wish to take a taxi. The application therefore executes a focal incidental service asking Alice if it should call her a taxi.

– *Usability issues identified using model*: The application must prioritise which factors are likely to influence a user's decisions (transport convenience vs. attraction preference). The application must gauge or infer the likelihood of incidental events causing a change in a user's meaningful goal (e.g. if the incidental downpour had caused Alice to change her mind about visiting an art gallery).

3.5.2 Mobile user communities

Within the field of context-aware computing, some researchers investigate how communities of mobile users could be facilitated, as described in section 2.1.4. Using a scenario involving a blind person named Bob en route to catch a train to Stirling for his friend's birthday, the following observations can be made in relation to user communities when applying my multidisciplinary model of context.

– *User's meaningful world*: Bob's lower level meaningful goal is to purchase a talking book for his friend's birthday before catching the train to Stirling. Bob's perceived cognitive representation of the external context includes a mixture of contextual information:

  - *Current and future physical context* – Bob is in a bookshop just round the corner from the train station. Talking books are on special offer for three further days.
  - *Future task context* – Bob's train departs in 30 minutes.
  - *Current application context* – while in the bookshop, Bob's Palmtop transmits an automated verbal message asking him if he would like to leave a message for other blind people about this special offer.
  - *Future social context* – Bob feels this information might be of benefit to other visually impaired people.
  - *Current and future cognitive context* – Bob is in a good mood and is not feeling time pressured. He considers the bookshop to have a good selection of talking books.

  Bob's perceived representation of the external world is compared to his previous personal positive experiences of listening to talking books. He subsequently makes a decision and forms a goal to carry out concise meaningful focal actions to both buy a book for his friend's birthday and accept the application's inferred action to leave a message for other blind travellers.

– *Application's meaningful world*: The following aggregated sensed data is used by the application to interpret and support Bob's meaningful goal:

  - *Current physical context* - GPS location indicates that Bob is in a bookshop in Edinburgh. Rule: Check Bob's diary to find out what his plans are.
  - *Future and current user context* – Bob's diary indicates he is due to attend his friend's birthday in Stirling. Bob has also created a note reminding him to buy a present. Rule: Bob frequently likes to take advantage of special offers, so check to see whether any offers are available.
  - *Current task context* – a web-based server indicates that talking books are on special offer for three more days. Rule: Check the profiles of Bob's friend and other members of the web-based user community.

- *Current social context* – his friend's profile indicates that she likes talking books, particularly adventure stories. Other members also indicate a strong appreciation of talking books.

Based upon this interpreted information, two focal meaningful application services are executed; the first to provide an inferred ranked list of talking books on offer for his friend's present (having those relating to adventure stories at the top), and second service to provide an inferred inquiry asking Bob if he wishes to leave a message about this offer for other blind travellers.

– *Incidental world of the user and application*: Whilst walking to the train station, after having purchased his friend's present, Bob stumbles on a pothole that he was unable to detect in the pavement using his white cane. Bob undertakes an incidental focal activity to leave a verbal message warning other blind travellers of this hazard. The application asks Bob to specify a priority level to this message, in order to ascertain how much notice needs to be given (e.g. within a 5 or 10 metre boundary?). The application also identifies the word 'pothole' in Bob's message so it infers that Bob may wish to send an email to a local road maintenance authority at a later stage, so it stores the GPS location and executes a focal incidental service to remind Bob the next time he is checking his email.

– *Usability issues identified using model*: The application must enforce users to account for messages left for others (e.g. importance, usefulness, priority and applicability of messages). For instance, messages regarding environmental hazards may need to be pushed to other visually impaired people (meaningful augmentation, as depicted in Figure 3.2), whereas, messages regarding special offers may need to be presented less obtrusively, possibly deferring control of when information is viewed to the user (incidental augmentation, also illustrated in Figure 3.2).

3.5.3 Applying model in practice

The purpose of this section is to provide a superficial illustration of how an application developer might use my multidisciplinary model in practice. Although its true value is dependent on its application at an early stage of development, the model can also be used to re-interpret existing applications or application areas to identify more robust and user-centred levels of support. Essentially, the developer would need to ask questions regarding each quadrant of Figures 3.1 & 3.2, some of which have been listed in Table 3.1.

Quadrant	Questions about the user and application
1 (User's meaningful world)	(i) After identifying the user's high-level meaningful goal, task, or activity, what types of scenarios would the user encounter? (ii) Within each scenario, what meaningful aspects of the contextual world is the user being influenced by when making decisions about focal meaningful activities? (iii) After focal activity, how does this construct the contextual world and user's cognitive context? How does this influence the user's future focal activities?
2 (Application's meaningful world)	(i) What types of focal meaningful services could the application execute to support a user's meaningful activities? (ii) What information within the contextual world would the application need to acquire, and how would this be sensed, stored, managed, interpreted, and transmitted to the user? (iii) After meaningful services have been executed, how does this construct the contextual world and application's context? What impact would this have on the user, on the environment, and on other people?
3 (User's incidental world)	(i) What type of incidental events or scenarios might the user experience when undertaking his/her meaningful activity? (ii) What aspects of the contextual world is the user being influenced by when making decisions about incidental events? What type of focal activities might the user undertake? (iii) After focal activity, how does this construct the contextual world and user's cognitive context? How does this influence the user's future focal activities?
4 (Application's incidental world)	(i) What types of incidental focal services could the application execute to support a user's experience of incidental events? What additional incidental services could the application infer; information that the user may be unaware of? (ii) What information within the contextual world would the application need to acquire, and how would this be sensed, stored, managed, interpreted, and transmitted to the user? How would incidental services be prioritised with respect to meaningful user activities and meaningful application services? (iii) After incidental services have been executed, how does this construct the contextual world and application's context? What impact would this have on the user, on the environment, and on other people?

Table 3.1. Issues and questions to consider when applying my model in practice.

3.6 Contribution to research and conclusions

When applying my model to different areas of context-aware computing, the true value of my multidisciplinary endeavour becomes apparent. From a high-level or holistic perspective, it allows application developers to develop richer scenarios and descriptions of how the mobile system may be used within various dynamic mobile settings. The model provides an augmentation to traditional task analysis, as the incidental interactions and occurrences in the mobile world can be investigated, and not just the more predictable meaningful actions involved in accomplishing an explicit goal. As a result, more refined levels of user support can be mapped out; an exercise which will help application developers to design both meaningful and incidental services.

From a low-level perspective, the model can be used to investigate very specific issues of human behaviour and application development, both of which are represented dynamically (i.e. context is a *process*). Within the model of the user's world, this includes both the contextual factors that influence human decisions, spatial behaviour, and focal interactions, and the subsequent construction of context within which future interactions take place. The model also helps to address the issues of human variability in perception and cognition, and helps to tackle the unpredictable nature of users and the environments in which they interact. The value of the model of the application's world lies in the processes of identifying useful contextual information about the user, inferring human activity, delivering useful, relevant and timely services, and monitoring the evolution of users and environments.

Another benefit of the model is its focus on the integration of the user and application's world. Issues can be considered together or in parallel; an activity that does not occur often enough in current application development, and which can lead to more usable and unobtrusive systems. This helps developers to identify gaps and overlaps in knowledge, all of which can be used to draw out clearer and more seamless levels of support.

The more specific contributions to usability research, in terms of the unresolved usability issues discussed in section 2.1.7, are as follows:

Personalisation: From the user's world, the multidisciplinary model, depicted in Figure 3.2, illustrates that personalisation should not just be assessed simply from the user's cognitive context (e.g. adapting to a user's needs and preferences; the premise of most research on personalisation) but rather assessed in terms of how personalisation needs are influenced and shaped by, and processed along with, the contextual world (e.g. the influences of the social context on decision making – although not preferred by the user, making a group decision to eat at an Indian restaurant to satisfy the majority of people present). By doing so, more accurate predictions can be made regarding user activities, allowing context-aware applications to determine situations where conflicts of interest may occur (e.g. although I've expressed a desire to be guided walking back to my hotel, my device advises that this is potentially unsafe and so provides a taxi number). From the application's world, personalisation would therefore need to be weighed up against sensed contextual information, for example, recommending an Indian restaurant to suit the majority of people present rather than recommending a restaurant to suit the user's preference.

Localising information and its delivery: The contribution of the model to this issue lies in the separation of different layers of context and the illustration of how each is embedded in a temporal context that is constantly being constructed after contextual interactions take place (shown in Figure 3.3). Localisation of information is an integral part of this issue, since the application must sense those layers of context and monitor their evolutionary changes, such as a user's accumulation of experiences and knowledge, or a church that has been converted to a pub or restaurant, or a particular activity that has become fashionable. Essentially, the model would allow application developers to model different mobile task scenarios of the user, providing a structure within which information requirements could be ascertained. The contribution to the issue of information delivery is also clearly evident. The model would enable application developers to assess the suitability of different delivery techniques, which would depend on the user's current focal activity (driving vs. sitting in a café), and whether it was meaningful or incidental (e.g. acquiring background information prior to visiting a tourist attraction vs. negotiating an unexpected busy road). It would also depend on the meaningful contextual layers, shown in Figure 3.2, affecting those activities, such as the noise of nearby people, current lighting conditions, and the user's cognitive abilities (e.g. finds current activity mentally demanding and a drain on his/her attention).

Styles of acquiring contextual information: The contribution to the debates on information *push* vs. information *pull* can be also be captured and assessed by the multidisciplinary model. Similar to the other issues, the separation of the meaningful and incidental world, shown in Figure 3.2, provides a useful distinction for application developers. For instance, during high-priority meaningful tasks (e.g. giving a lecture, or attending a meeting), it is likely that users would be less tolerant of incidental information being pushed to them. Whereas during low-priority meaningful and incidental tasks, such as tourists visiting a new city, it is possible that incidental information may in fact be desirable as they may wish to be more spontaneous with their decisions and activities. In this situation perhaps pushing information to users may be more appropriate. So in essence, the model allows for such scenarios to be mapped out in terms of prioritising what is important to the user in a particular situation.

Social issues: The model nicely depicts different social influences to which the user is subjected. This provides application developers with a greater awareness and ability to adapt their systems behaviour to different social circumstances. As shown in the model in Figure 3.2, the user may be (i) focally interacting with other people either meaningfully or incidentally (speaking to work colleagues in a meeting, or speaking to friend who had called unexpectedly), (ii) contextually surrounded by people who are meaningfully influencing him/her during focal activity (e.g. interacting with a mobile phone whilst being influenced by surrounding people on a busy train), or (iii) contextual surrounded by people who have no impact at all on his/her focal activity, making them incidental (e.g. people passing by). Referring back to the issues discussed in section 2.1.7.6, the multidisciplinary model provides a valuable foundation and structure in which interactions of people and systems (discussed by Dourish, 2001) can be investigated. For instance, different social relationships, current focal activity and contextual situation, and types of meaningful or incidental information communicated by others, all have an influence on how best to inform the user.

Designing for mobile settings: The multidisciplinary model provides a considerable contribution to modelling mobile settings within which user-interface interactions takes place. This issue has already been extensively discussed throughout this chapter.

The main lesson that has been learnt from the construction of the model is centred on the difficulty in representing context as a single model to cover the exhaustive viewpoints and interpretations that exist across and within disciplines. While context is a complex subject that includes many wide-ranging issues, it is an extremely important area of research in mobile computing. Future mobile systems will be expected to operate in dynamic and contextually rich environments, and it is felt that my proposed multidisciplinary model is sufficiently detailed and versatile to at least identify and investigate these issues further.

CHAPTER 4

CAPTURING USER'S CONTEXT

This chapter, along with Chapters 5 & 6, provide an illustration of how the multidisciplinary model of context was used to investigate issues of context-aware design. This chapter therefore concerns capturing user context information using the top half of the multidisciplinary model illustrated in Figure 3.2 of Chapter 3 (or quadrants 1 & 3 of Figure 3.1). The bottom half of the model, or application's context, is described in Chapter 5. Chapter 6 investigates the issues arising from the interaction of the user and application's context.

The topic of 'personalisation of context-aware navigation systems for Visually Impaired People (VIP)' has been chosen as the main application area of this investigation. The next section discusses the reasons for choosing this topic.

4.1 Personalisation of context-aware navigation systems for VIP

The ability to orientate and navigate is an important skill that is used to experience and interact with the environment, to make social contact with other people, to undertake daily activities, and ultimately to maintain independent mobility. Despite there being a wide range of GPS based navigation aids on the market (e.g. GARMIN eTrex, PocketMap City Guide, etc.), these devices or applications not only take a very simple approach to guiding a user such as a 'you are here' indicator on a digital map, but also only transmit very simple information (e.g. turn right in 20m) which is the same for all users, environments, and modes of travel.

As described in Section 2.4, many factors influence people in how they use landmarks to orientate and navigate, such as personal requirements, current activity, and type of environment. One factor, which underlines the importance of environmental and situational context in the design of interactive systems, is visual impairment. This is a disability affecting approximately 45 million blind people and 145 million partially sighted people worldwide (Balliwalla, 2002). Without vision, those people have to gather and interpret other sensory information to navigate and orientate, such as auditory, kinaesthetic, tactile, thermal and/or olfactory (LaGrow & Weessies, 1994). It is therefore reasonable to assume that, when navigating, visually impaired people would use different landmarks than sighted people. Despite this difference, existing travel databases do not provide information that would be of use to visually impaired people, such as road widths, differences of road textures, direction of traffic flow, contrasting environmental smells and sounds, people identification, and temporary, unexpected features, e.g. overhanging branches (Maeda *et al*., 2002; May, 2000; Golledge *et al*., 1998; Sabelman *et al*., 1994; Helal *et al*., 2001). In addition, some researchers have stipulated that several levels of detail should also be made available in more realistic situations (Maeda *et al*., 2002; Strothotte *et al*., 1996; Golledge *et al*., 1998). For instance, Strothotte *et al*. (1996) differentiate between (i) 'basic information', which includes travel direction, nearest crossing, and any known obstacles, (ii) 'detailed information' which consists of pre-journey plans, and (iii) 'transport information' which includes nearest bus stops, stations, and taxi ranks. May (2000) also states that existing wayfinding systems do not differentiate between information required on foot versus information required in vehicles. Consequently, when travelling in vehicles, visually impaired people are deprived of information including road signs, landmarks, and identification of stations.

Visually impaired people are therefore a challenging test for context-aware research since the problems of designing for mobile settings are compounded by the navigation and orientation difficulties experienced by visually impaired people in unknown or unfamiliar environments. This area provides a challenging test for the model and provides an insightful foundation on which to construct the design framework in Chapter 7. Context-aware computing offers huge potential for those groups of users since the limitations of existing navigational devices, described in section 2.5.4, can be addressed. Visually impaired people would therefore be able to focus their attention on hazard identification and environmental learning and experience, rather than frequent interaction with the device or being restricted to familiar routes.

4.2 General aim and purpose

This chapter uses the multidisciplinary model of context to investigate the substantive issue of personalisation of context-aware information (discussed in section 2.1.7.1) for visually impaired people. Four studies are described, all of which make use of cognitive mapping principles discussed in section 2.6.1. A qualitative approach called think-aloud was used for all studies in order to investigate the use of landmarks by participants. However, in the first study this approach was also combined with written route descriptions. The other techniques of cognitive mapping are inherently quantitative in nature and would not have been suitable for identifying landmark use.

The aim of the first two studies, as well as part of the fourth study, is to investigate what people use or are influenced by in the *meaningful contextual* environment (outer layers of the multidisciplinary model of context shown in Figure 3.2) when undertaking focal activities to navigate. In other words, do people use different landmarks or cues in the environment to navigate? The first study concerns an investigation of differences between sighted people, and the second study concerns differences between sighted and visually impaired people. The aim of the third study was to use the results of the second study to investigate whether there are objective and subjective differences between sighted and visually impaired people when guided to pre-determined landmarks.

The aim of the fourth study, also using cognitive mapping principles, was (i) to investigate whether people with contrasting visual impairments use different landmarks or cues in the *meaningful contextual* environment to navigate, and (ii) to investigate how the *incidental contextual* environment affects different groups of visually impaired people. The issue of localisation discussed in section 2.1.7.3 is also investigated in this study with respect to indoor and outdoor environments. In the next chapter, the results of this study are used to design a java-based application, as well as a user study described in Chapter 6.

4.3 Investigating sighted people's use of landmarks to navigate

A preliminary study revealed that existing navigation aids (e.g. PocketMap City Guide) use very similar information and techniques to guide users. The aim of this study, which is also discussed in Bradley & Dunlop (2002a), was to investigate whether differences exist between sighted people in their use of landmarks or cues in the meaningful contextual environment to navigate. The study hypothesis is therefore that sighted *people vary individually and collectively in their use of landmarks or cues to orientate and navigate*.

4.3.1 Method

After an initial pilot study, the main interview study was carried out using 24 participants (12 males and 12 females). Four participants (2 males and 2 females) fell into each of the six age categories: 18 or under, 19-25, 26-35, 36-45, 46-65, and 66 or over. All participants were resident in Greater[3] Glasgow and their professions ranged from a school pupil to a retired lecturer. The interview study was comprised of three parts:

- *1. Pre-study questionnaire*: Information on participants' personal details, familiarity with Glasgow city centre, and experiences using navigation aids.
- *2. Route descriptions study*: Participants were asked to describe 4 different routes, two of which were to be described verbally and two written down.
- *3. Post-study questionnaire*: Information on participants' opinions of (i) the importance of different types of contextual information for navigation, (ii) usability design issues, and (iii) their mobile requirements.

The study sheets used for each part are shown in Appendix A-1. For part 2, a researcher in the department, who was unfamiliar with this research, was asked to choose a starting point and four well-known destinations in Glasgow city centre, all of which were in different directions from each other and would take approximately 10 minutes to walk to from the starting point. The destinations presented to participants were randomised, and the verbal/written order was alternated (with an equal balance between those who had to write first and those who had to verbalise first). Each interview was recorded in full.

[3] 'Greater' Glasgow covers the city of Glasgow, as well as the surrounding suburbs.

Verbal protocol analysis techniques (as described in Bainbridge (1991)) were used to categorise participants' descriptions from part 2. Nine contextual categories of information were identified:

– Directional (e.g. left/right, north/south),
– Structural (e.g. road, monument, church),
– Textual-structural (e.g. Border's bookshop, Greave Sports),
– Textual-area/street (e.g. Sauchiehall St., George Sq.),
– Environmental (e.g. hill, river, tree),
– Numerical (e.g. first, second, 100m),
– Descriptive (e.g. steep, tall),
– Temporal/distance (e.g. walk until you reach…or just before you get to…),
– Sensory such as smell/hearing/touch (e.g. sound of cars passing).

Tallies were recorded each time a participant mentioned/wrote a word or phrase relating to each of the listed contextual categories.

4.3.2 Results

The results of the interview study are represented in figures 4.1 – 4.6.

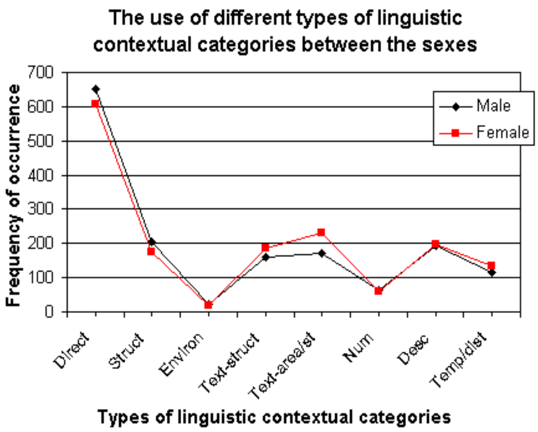


Figure 4.1. Use of contextual information between the sexes.

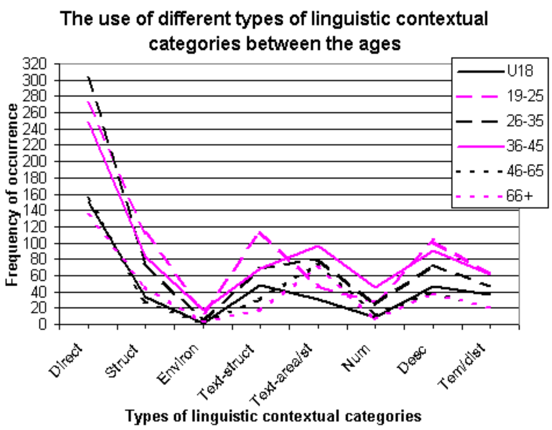


Figure 4.2. Use of contextual information between the ages.

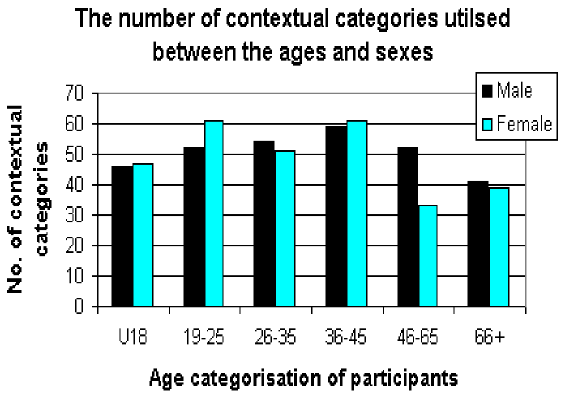


Figure 4.3. Number of contextual categories in total for each group by age and sex.

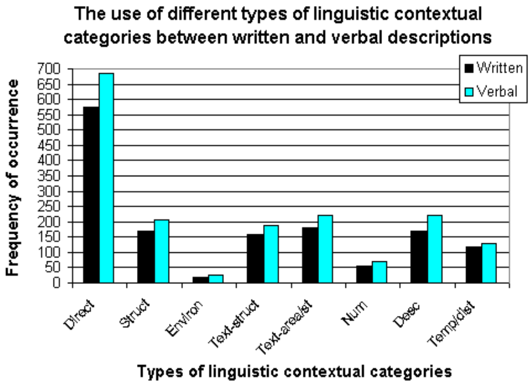


Figure 4.4. The use of contextual information for written and verbal descriptions.

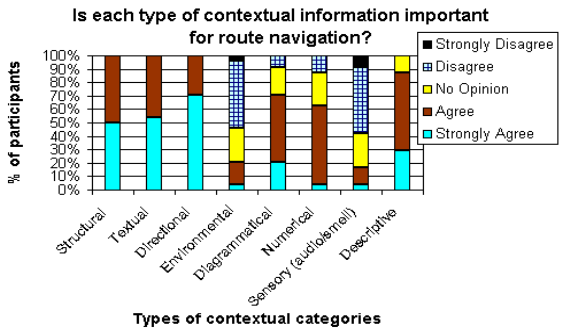


Figure 4.5. Participants' opinions on the importance of contextual information

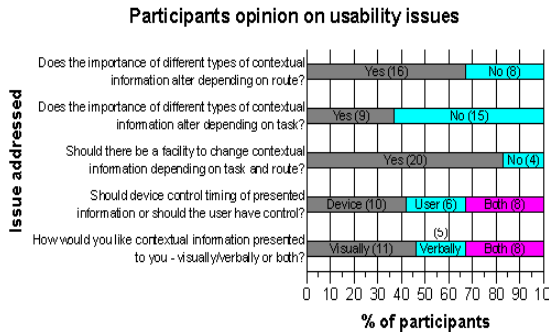


Figure 4.6. Participants' opinions on usability issues

The key findings from Figures 4.1 - 4.6 are:

– There is little difference between the sexes in the use of different types of contextual categories (Figure 4.1). Female participants, however, used slightly more textual-structural and textual-area/street information, whereas males used slightly more directional and structural information.

– The age groups 26-35, 36-45, 46-65 and 66+ all used more textual-area/street information than textual-structural information (Figure 4.2). This trend was reversed for age groups 18 and under, and 19-25.

– Figure 4.2 illustrates that participants between 19 to 45 used significantly more contextual information than those 46+ (1% sig-level on 2-tail independent t-test, t = 7.4, df = 38). This is further illustrated in Figure 4.3, where age groups 18 and under, 46-65, and 66+ used less contextual categories than the others. The 18 and under age group was not significantly different from the age groups 46-65 & 66+.

- Figure 4.4 shows that more words/phrases from each type of contextual category were used for verbal descriptions in comparison to written descriptions (1% sig-level, 2-tailed correlated t-test, t = 4.01, df = 23).
- Most participants either agreed or strongly agreed that structural (100%), textual (100%), directional (100%), diagrammatic (71%), numerical (63%) and descriptive (88%) information are important for navigation (Figure 4.5). Whereas most participants disagreed or strongly disagreed that environmental (54%) and sensory (58%) information are important.
- Most participants (83%) would desire a facility to change the type of presented contextual information (Figure 4.6). Most participants (42%) would prefer the device to dictate when new contextual information should be presented (Figure 6). Most participants (46%) would also wish for contextual information to be presented visually.

4.3.3 Discussion

The results support the original hypothesis that people vary individually and collectively in their use of landmarks or cues to orientate and navigate. Figure 4.2 illustrates significant differences between ages, the most noticeable being a greater use of textual-structural information than textual-area/street information by the younger age groups (under 26s). So, in other words, younger people used names of bars, shops, and restaurants as landmarks in the meaningful contextual environment, whereas older participants used more fixed landmarks such as street names. Therefore, what is meaningful to younger people when navigating is therefore incidental to older people, and vice versa. Possible reasons could be due to social behaviour – younger people perhaps visit bars, shops, and restaurants more frequently, and so these landmarks are more likely to be used to build their cognitive map. As a result younger people would also be more aware of pub or restaurant turnarounds. Older people perhaps would not, and so are more comfortable using fixed landmarks, such as street names. These issues, of course, would need further investigation.

The results demonstrate how each participant's descriptions are unique. This strongly indicates that navigation aids would need to personalise navigation information to suit different users; a view supported by 83% of participants (Figure

4.5). Structural, textual and directional were viewed to be important by all participants, but there were differences of opinion for other categories. While environmental and sensory information were rated low, there may be situations were this would change (e.g. people with visual impairments are likely to use other sensory information to orientate and navigate).

Participants also differed in their preferences for presentation styles (i.e. verbal vs. visual), and for controlling when new information is given. Context-aware systems must therefore personalise information in accordance to the user's task and situation. Some participants, for instance, described scenarios where speech output, consisting of concise information (i.e. directional, textual-area/street based and/or textual-structural based information), would be better for reaching a destination promptly in order to minimise visual checks. In this situation, information pushed to the user would be desirable. In contrast, visual presentation involving additional information (e.g. descriptive, numerical, etc) may be preferred (or used in conjunction with speech output) when touring a city for the first time in order to provide a greater spatial orientation and awareness of surrounding environmental landmarks. Lastly, in this situation, participants expressed that they may wish to have more control of when new information is read and updated.

4.4 Investigating the use of landmarks by sighted and VI people

In this section, the second and third studies are described. In the second study, which is also described in Bradley & Dunlop (2002b), a repeat of the first study is carried out but this time using visually impaired people. The results from both studies are then compared to investigate whether differences exist in how landmarks or cues are used to navigate. The third study involves guiding sighted and visually impaired people to different landmarks, using the results of the second study, in order to investigate objective and subjective differences between participants. This study is described in Bradley & Dunlop (2005c).

4.4.1 Comparison of the use of landmarks by sighted and VI people

For many visually impaired people, known destinations along familiar routes can be reached with the aid of white canes or guide dogs. By contrast, for new or unknown destinations along unfamiliar routes the limitations of these aids become apparent (e.g. white canes are ineffective for detecting obstacles beyond 3-6 feet – see section 2.5.3 for a more detailed discussion). While many technologies have been developed to address local navigation (e.g. obstacle avoidance systems) and distant navigation (e.g. GPS-based systems), there are still many usability issues that need to be resolved before visually impaired people can achieve independent mobility. For those issues to be addressed more emphasise needs to be placed on usability principles and techniques, since currently there is a predominance of technology-driven development (e.g. Shoval, 2000; Loomis *et al*., 2001). For instance, while Dodson *et al*. (1999) make the assumption that a speech user-interface should be used to guide blind users, Franklin (1995) illustrates the difficulties of interpreting spatial relations from common speech (natural language), and Strothotte *et al.* (1996) stipulate that many visually impaired people express concerns about using headphones as vital environmental sounds can be blocked out.

Zetie (2002a) illustrates how there is a need to understand the notion of contextual interactions, especially how people interact with, and use, information in the environment. Dey & Abowd (1999) state that context can 'increase the richness of communication in human-computer interaction making it possible to produce more useful computational services'. These issues are particularly important and more complex when one considers visually impaired people since their interactions are more complex, possibly involving more than one mobility aid (i.e. navigational system and guide dog/white cane). Information needs to therefore be managed and displayed appropriately in accordance with their personal requirements, task, situation and environment. Sabelman et al. (1994), for instance, describe how using other senses, like the smell of a bookstore or restaurant, would be beneficial for orientating in a new place.

This study involved a small-scale investigation into how visually impaired people use landmarks or environmental cues in the meaningful contextual environment to orientate and navigate. As discussed earlier, the purpose is to compare the results with the results obtained from the study described in section 4.3. The study hypothesis is that *visually impaired people will vary individually and collectively, in comparison to sighted participants, in their use of landmarks or environmental cues to navigate.*

4.4.1.1 Method

In order to compare the data from the previous study, the structure of this study was the same, as shown in Appendix B-1. However, some questions were changed to address the unique requirements of visually impaired people. This study also involved a smaller sample of participants due to the difficulty in locating visually impaired people who are willing to take part in experiments. In total, six participants (3 males and 3 females) aged between 36 to 65 were interviewed via the Glasgow & West of Scotland Society for the Blind (GWSSB), 2 Queens Crescent, Glasgow, UK (this organisation is now called Visibility). All participants were resident in Greater Glasgow and their professions ranged from a BBC reporter to a retired minister of religion. Participants' vision ranged from only light perception to total blindness. Four have been visually impaired since birth and two have been blind for 16 and 32 years respectively.

The interview study was recorded in full and comprised of the same three parts described in section 4.3.1, except within part 2 the visually impaired participants were asked to select their own starting point and destinations since many of them were unfamiliar with the routes used from the last study. They were also asked to verbalise all routes and describe them as if they were guiding another visually impaired person with a similar visual impairment as themselves. The same nine contextual categories were also used from before, and tallies were recorded each time a participant mentioned a word/phrase relating to each of the contextual categories. However, for this study a further two categories were added[4]: *motion* (e.g. cars passing, doors opening), and *social contact* (e.g. asking people or using a guide dog for help).

4.4.1.2 Results

The results from part 2 are illustrated in Figures 4.7 and 4.8. Six out of eight participants aged between 36-65 were randomly selected from the previous study to form the sighted participants' results (see section 4.3 or Bradley & Dunlop, 2003a).

---

[4] Sighted participants' recordings were re-assessed to identify whether words/phrases were mentioned relating to those additional categories.

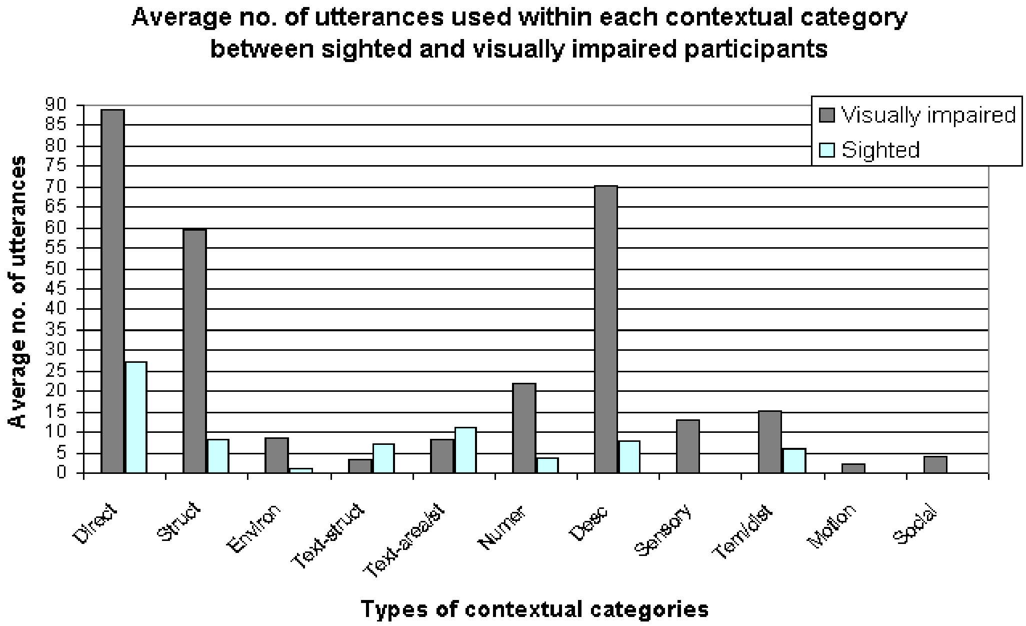


Figure 4.7. The average number of utterances used within in each contextual category between sighted and visually impaired participants.

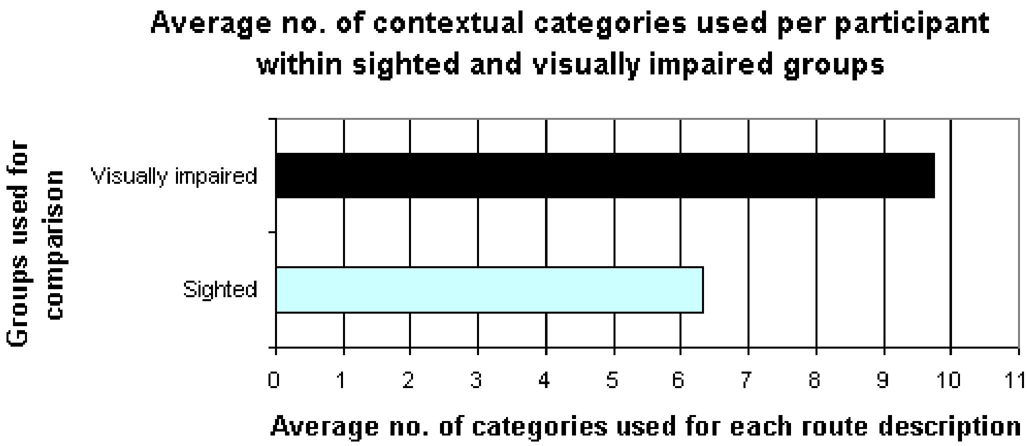


Figure 4.8. The average number of contextual categories used per participant within sighted and visually impaired groups.

The key findings from Figures 4.7 and 4.8 are as follows:

- Visually impaired participants on average used over 3 times more directional information, over 7 times more structural & environmental information, 6 times more numerical information (with additional types, such as using degrees for heading direction), almost 9 times more descriptive information and over 2 times more temporal/distance based information than sighted participants.
- No words/phrases relating to the sensory, motion or social contact contextual categories were used by sighted participants.

- Sighted participants on average used over double the amount of textual-structural information and almost half more textual-area/street information.
- Visually impaired participants mentioned words/phrases within a greater number of contextual categories on average (9.75) than sighted participants (6.33).

Part 3 of the interview revealed the following issues:

- Many expressed limitations of guide dogs and white canes. One participant found using a guide dog difficult within busy environments since the dog becomes tired and is less effective when navigating to unfamiliar destinations. White canes can become tiring to use (due to their repetitive nature) and also require specialist training from mobility or rehabilitation officers.
- All participants regarded sensory information as paramount for navigation, though many stated that each type (i.e. hearing, smell, touch) was additional confirmation for orientation/navigation and so relying solely on one type would be impossible. Audio cues included the (i) sound of hospital machinery, (ii) squeaking of doors opening, (iii) sound of escalators and ATMs, and (iv) sound of wind exiting a tunnel. Olfaction cues in the environment include the smell of bakeries, pet shops, chemists, newsagents, chip shops, etc. Lastly, the sense of touch is used to sense sun location for orientation, the difference in ground textures (e.g. concrete paving and metal drainage grill), the edge of buildings, etc.
- Other types of information desired included (i) the width of roads, (ii) whether the edge of the pavement was a down or up curb, and (iii) the number of crossings before a left/right turn.

Table 4.1 reveals participants' opinions on the most appropriate method of presenting contextual information for their needs.

Methods for presenting information	**% Participants**
Non-speech output, speech output and vibration alerts	50% (3)
Non-speech and speech output	33% (2)
Braille display	17% (1)

Table 4.1. Participants' opinions of how contextual information should be presented.

As shown in table 4.1, the most popular method of presenting contextual information is by using a combination of non-speech and speech output with vibration alerts.

However, 50% (3) of the participants thought using earphones would mask/distort important environmental cues used for navigation/avoiding hazards.

Additional comments provided are as follows:

– The most prevalent problem experienced is the unexpected/non-fixed/temporary features in the environment (e.g. temporary road signs, road sweepers, people, lampposts, overhanging branches/baskets, excavation work, etc.). These are more difficult to detect and provide the greatest hazards for journeys on foot.

– Context-aware mobile navigation aids should allow users to adjust the level of detail (e.g. beginner/intermediate/advanced). It is described how visually impaired people typically use the same routes frequently and thus would require less detailed information for future trips. This would minimise possible feelings of intrusiveness and frustration.

4.4.1.3 Discussion

The results do support the original hypothesis that visually impaired participants would vary individually and collectively in their use of landmarks or cues in the meaningful contextual environment to orientate and navigate. Each participant's route descriptions were unique, which strongly supports the need to personalise information. The explanation for those differences may be due to the fact that participants had different visual impairments, and also had been visually impaired for different lengths of time. Someone blind since birth, for instance, may rely more on identifying environmental cues using olfaction and hearing than someone who has restricted peripheral vision as a result of glaucoma. Further investigation of those issues is addressed in Section 4.5.

There were also major differences between visually impaired and sighted participants. The greater use of directional, structural, environmental, numerical and descriptive information, as well as of information within additional categories relating to sensory, motion and social contact, suggests that visually impaired people require richer contextual information, making them more contextually dependent. It is worth observing that most current navigation systems, which are designed for sighted users, are based heavily on giving directional, numerical and textual information and give very little (if any) structural or descriptive information. Furthermore, the results illustrate that sighted participants rely more on using information on distant landmarks such as names of buildings and streets, rather than more local landmarks used by visually impaired people such as the location and number of steps.

The individual and collective differences found in the study strongly support the need to personalise information transmitted by context-aware mobile navigation aids. More research is needed to investigate the landmarks used by people with different visual impairments. Many other usability issues also require further work. For instance, participants' preferences for presentation styles differed, and one participant described how information should be filtered to account for revisited routes.

4.4.2 Investigating workload when guiding sighted and VI people

This study is based on the results of the first two studies (described in sections 4.3 and 4.4.1) that involved investigating differences in how sighted people and visually impaired people use landmarks to navigate. Route descriptions from both studies were categorized, resulting in the eleven classes of contextual information shown in Table 4.2. The proportion of words/phrases used across the route descriptions of sighted and visually impaired participants is shown for each contextual category.

Class of contextual information	Example	% Used Sighted	% Used Vis Imp
1. Directional	Left/right, north/south	37.4	30.1
2. Structural	Road, monument, church	11.5	20.1
3. Environmental	Hill, river, tree	1.6	2.9
4. Textual-structural	Border's bookshop, Greaves Sports	9.9	1.2
5. Textual-area/street	Sauchiehall St., George Sq.	15.6	2.7
6. Numerical	First, second, 100m	5.0	7.5
7. Descriptive	Steep, tall, red	10.8	23.8
8. Temporal/distance	Walk until you reach…or just before you get to…	8.2	5.1
9. Sensory	Sound of cars passing or smelling a bakery	0	4.4
10. Motion	Cars passing, doors opening	0	0.8
11. Social contact	Asking people or using a guide dog for help	0	1.4

Table 4.2. Classes of contextual information used by sighted and visually impaired participants.

The results revealed that sighted and visually people vary individually and collectively within and across groups. When comparing groups, visually impaired participants used (i) information within three additional categories of information relating to sensory, motion, and social contact, (ii) considerably less textual-structural and textual-area/street information, and (iii) considerably more contextual information generally, especially in structural and descriptive classes. Within the sighted group, younger participants used significantly more textual-structural landmarks than older participants who used more textual area/street based landmarks. There was also variation within the visually impaired group.

The aim and purpose of this study was, firstly, to design two sets of proportioned verbal directions based upon table 4.2, and, secondly, to use these verbal directions to guide different groups of visually impaired and sighted participants to pre-determined landmarks. The purpose was to investigate whether participants experience differences in perceived workload. The hypothesis is therefore that *there will be a difference in workload between sighted and visually impaired groups, when given proportioned verbal instructions from sighted people's route descriptions versus proportioned instructions from visually impaired people's route descriptions*. The overall purpose of this study was to continue my investigation of the issue of personalisation, which remains insufficiently addressed in context-aware research and development.

4.4.2.1 Method

After a pilot study, 16 participants (8 sighted people and 8 visually impaired people – both groups were also gender balanced) who were resident in Greater Glasgow and aged between 23 to 73 were recruited for the study. The GWSSB (now called Visibility) was used again in locating participants[5]. Types of visual impairment experienced by participants included advanced glaucoma, macular degeneration (loss of central vision), and blindness (or only some light perception). Three participants had been visually impaired since birth, while five have been impaired for 4 - 35 years respectively. All participants used either a guide dog or white cane.

[5] The Data Protection Act 1998 precludes this organisation giving me contact details of their members. Therefore the GWSSB was asked to contact their members either by calling them directly or by sending a letter written by me. It was then left to members to contact me if they were willing to participate in the study. This explains the low number of participants for this study.

The experiment involved asking participants to walk to four pre-determined landmarks, all of which were situated in Glasgow city centre in order to simulate a typical contextually rich city-centre environment. Accompanied by a researcher, participants were given pre-recorded verbal directions via a Minidisk to navigate to each landmark, all of which took approximately 10 minutes to reach. Verbal directions designed from sighted participants' route descriptions from the last study were used to guide participants to two of the landmarks (condition 1), while verbal directions designed from visually impaired participants' route descriptions were used to guide participants to the other two landmarks (condition 2). The order of when each condition was given was randomised. By using 'Wizard of Oz' style techniques, the researcher controlled the timing of verbal messages. Subsequently, there may have been minor differences in message timing between each experiment though this method was still considered to be more accurate than current technological alternatives (e.g. poor accuracy of GPS in built-up city-centre environments). It should also be noted that despite the problems of using speech output as described in Section 1, the purpose of this study was to investigate information content rather than the process of transmitting information.

The time taken to reach landmarks and the number of deviations (i.e. minor - slight veering; and major deviations - wrong direction) provided the objective assessment. The timer was stopped when deviations occurred and whilst waiting at traffic lights, and then re-started once re-routed or when crossing the road was initiated – by doing so more accurate data was acquired. Questions about deviations as they occurred and post-trip questionnaires formed the subjective assessment.

The design of verbal messages was a complex task. Firstly, a researcher in the department who knew nothing about the experiment was asked to walk to each of the landmarks and while doing so verbally describe the environment in relation to the eleven contextual categories. This information was then loosely attributed to each of the conditions by using the proportions in Table 2. For each landmark, an equal number of messages was used for condition one and condition two (on average, this amounted to 15 messages). Messages were also structured in accordance with Pitt & Edwards (1996) principles of speech-based interfaces.

4.4.2.2 Results

The study involved two conditions: condition 1 consisted of verbal directions designed from the sighted participants' route descriptions, whereas condition 2 consisted of verbal directions designed from visually impaired participants' route descriptions. The time taken by participants to reach each landmark (Lan) when given either condition 1 or 2 is illustrated in the first subsection. Following this, the number of, and explanation given for, minor and major deviations are presented and described. Participants' feedback after the study is described in the last subsection.

Mean stage time for each condition

The results presented in Figures 4.9 and 4.10 illustrate the comparison between condition 1 and condition 2 mean times for both sighted and visually impaired participants. Figure 4.11 illustrates the differences between condition 1 and condition 2 mean times for both groups.

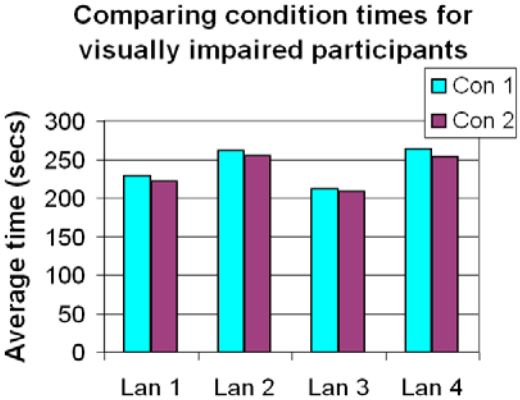


Figure 4.9. Comparing mean times for conditions 1 & 2 for visually impaired.

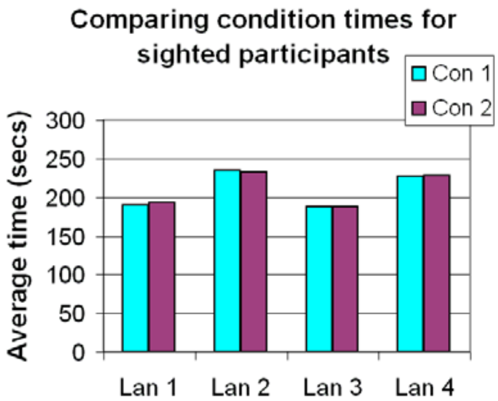


Figure 4.10. Comparing mean times for conditions 1 & 2 for sighted participants.

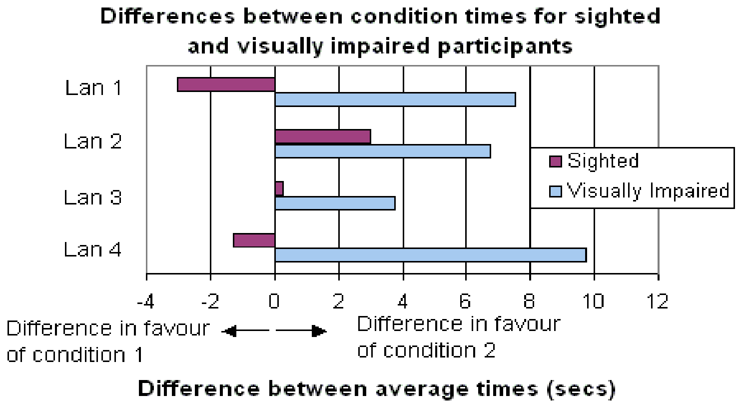


Figure 4.11. Differences between condition times for both sighted and visually impaired participants.

The key findings of Figures 4.9, 4.10 and 4.11 are as follows:

- Visually impaired participants reached landmarks significantly quicker when given information from condition two (using a two-tailed parametric related t-test, t = 5.599>3.182, at p = 0.05). In other words, messages which contained a reduced amount of textual-structural and textual area/street information, and which incorporated sensory, motion and social contact information, resulted in visually impaired participants reaching landmarks quicker than if they used messages which consisted of an increased amount of textual-structural and textual area/street information. There was not a significant difference between mean condition times of sighted participants (using a two-tailed parametric related t-test, t = -0.196<3.182, at p = 0.05).
- Figure 4.11 shows that the difference of mean times for each landmark were all in favour of condition 2 for the visually impaired group, and for two of the landmarks for the sighted group.
- Visually impaired participants took longer to reach all landmarks for both conditions than sighted participants. Using a two-tailed parametric independent t-test, this result was significant (t = 2.482>2.145, at p = 0.05).

Deviations from route

No minor deviations were made by sighted participants in either condition, whereas, visually impaired participants made 17 in condition 1 and 13 in condition 2. Explanations for those minor deviations included: (i) ‘slight curvatures in the road made it difficult to remain correctly positioned, and (ii) ‘when I crossed the street there were less surrounding features that I could use to stay aligned’.

With respect to major deviations, sighted participants made 2 major deviations in condition 1, and 1 in condition 2. Visually impaired participants, on the other hand, made 1 major deviation in condition 1, and none in condition 2. The explanation given by both sighted and visually impaired participants were that instructions had been misunderstood.

Post experiment feedback

The post-trip questionnaire provided an opportunity for participants to reveal any issues regarding the experiment, the information they received, or wayfinding in general. The main issues that were raised are described in Table 4.3.

Visually impaired participants' comments	Sighted participants' comments
(i) Five participants expressed how not enough detail in the immediate and temporary surrounding environment was given to them in condition 1. (ii) Four remarked how information on sounds and smells within condition 2 provided them with a better orientation of the environment.	(iii) Four participants found condition 2 messages too detailed, especially when crossing at traffic lights, and consisting of information that was not of use to them (such as sounds, smells, etc.). (iv) Two participants described how there were situations where controlling the level of detail would have been advantageous.

Table 4.3. Post-trip comments given by sighted and visually impaired participants

4.4.2.3 Workload assessment

Once participants had reached each landmark they were asked to complete a NASA-TLX (Task Load Index) questionnaire (Hart & Staveland, 1988). This was to assess their perceived level of workload using six dimensions:

- Mental Demands (MD): The mental and perceptual activity required (e.g. thinking, calculating, deciding, remembering, looking, etc).
- Physical Demands (PD): The physical activity required (e.g. pulling, pushing, turning, controlling, etc.)
- Temporal Demands (TD): The time pressure perceived due to the rate or pace at which tasks or task elements occurred.
- Own Performance (OP): The estimation of the success by which task goals were accomplished.
- Effort (EF): The level of physical and mental work required to accomplish a level of performance.
- Frustration (FR): The level of discouragement, irritation and annoyance versus gratification, contentment, and complacency felt during the task.

Mental, Physical, and Temporal Demands concern the demands on the participant, whereas the other three concern the demands on participant-task interaction.

The initial step involved listing every paired combination of workload dimensions in order to carry out a pair-wise comparison. Participants were asked to indicate which member of each pair provided the most significant source of workload variation, thereby providing a tally (or weighting) for each dimension.

Next, participants were asked to provide a magnitude rating using a five-point scale for each dimension, which was multiplied with the corresponding weighting. This provided a weighted score for each dimension. Figures 4.12 and 4.13 illustrate the average weighted scores for each condition for sighted and visually impaired participants. Whereas, Figures 4.14 and 4.15 show the comparison between both groups for each condition.

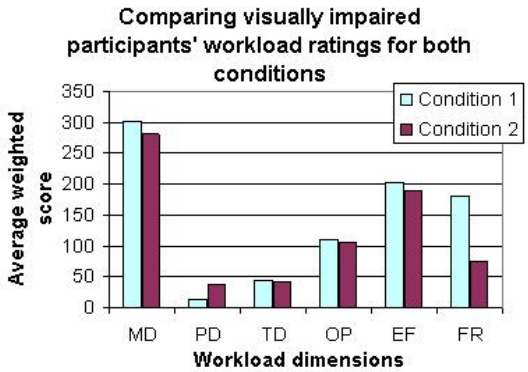


Figure 4.12. Comparing visually impaired participants' workload ratings after receiving conditions 1 and 2

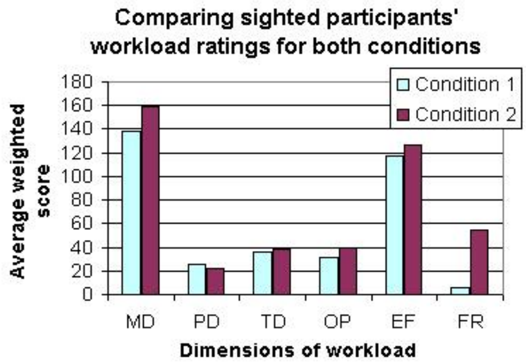


Figure 4.13. Comparing sighted participants' workload ratings after receiving conditions 1 and 2

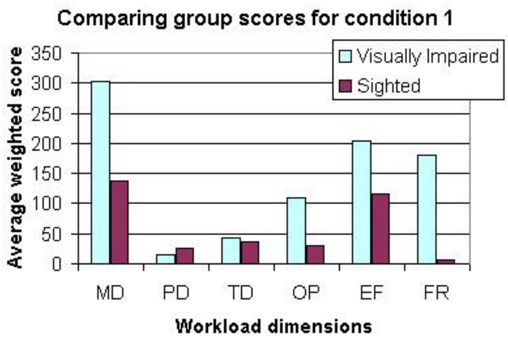


Figure 4.14. Comparing the workload scores of sighted and visually impaired participants after receiving condition 1.

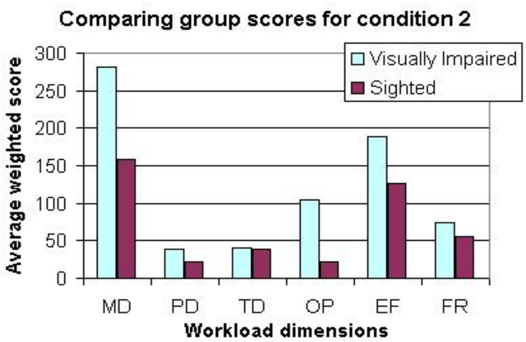


Figure 4.15. Comparing the workload scores of sighted and visually impaired participants after receiving condition 2.

Figure 4.12 illustrates that visually impaired participants found condition one to (i) be more demanding mentally and temporally, (ii) require a higher level of effort, and (iii) cause a higher level of frustration and lower sense of performance success. Whereas, Figure 4.13 illustrates how sighted participants found condition two to (i) be more demanding mentally and temporally, (ii) require a higher level of effort, and (iii) cause a higher level of frustration and lower sense of performance success.

To support this finding, visually impaired participants' mean Weighted Workload (WWL) score (the sum of weighted scores across all workload dimensions divided by sum of weights) was '56.7' for condition 1 and '49' for condition 2, whereas, sighted participants was '23.6' for condition 1 and '28.2' for condition 2. These results also reveal that the visually impaired group had higher WWL scores for both condition 1 and 2 than the sighted group. This corresponds to the results presented in Figures 4.14 and 4.15, which show how visually impaired participants have a higher weighted score for all workload dimensions (except PD in condition 1). The last finding is that MD and EF provide the greatest source of workload within both conditions and for both groups - whereas, PD provides the least.

4.4.2.4 Discussion

Two previous studies involved using cognitive mapping research (discussed in section 1.2) to investigate differences in how sighted people and visually impaired people use landmarks to navigate. The results of these studies were used to design proportioned verbal instructions from sighted people's route descriptions (condition 1) and proportioned instructions from visually impaired people's route descriptions (condition 2). In this study different sets of visually impaired and sighted participants were asked to walk to pre-determined landmarks while being given either condition.

The results support the original hypothesis that there would be a difference in workload between groups. Visually impaired participants were less frustrated, and required less mental and overall effort when being guided by condition 2 directions consisting of a reduced amount of textual-structural and textual area/street information, and incorporated sensory, motion, and social contact information. This finding is consistent with the objective assessment, which showed that visually impaired people reached landmarks significantly quicker when given condition 2 directions. The sighted group, on the other hand, displayed little evidence of being faster for either condition, but did demonstrate a greater mental workload within condition 2, especially for Frustration, Mental Demands, and Effort.

Since condition 1 contained messages predominantly consisting of building/street names, the explanation for these results could be due to the fact that there was insufficient information for visually impaired people to navigate through the immediate or local environment (a view supported by more than half of the visually impaired group). This would explain why the visually impaired group made more minor deviations when being given condition 1 directions. Existing travel databases need to be augmented for visually impaired travellers in order to incorporate more meaningful information. These results further support the need to personalise information for different users since what is meaningful to one user is often incidental to another.

The results of this study have contributed to cognitive mapping research in terms of the use of landmarks by people with visual impairments. However, more research is needed to investigate possible differences between visual impairments since the results also show that, although significantly less than condition 1, the workload value for condition 2 was also quite high. This is the topic of the next study.

4.5 Investigating differences between visual impairments

As discussed in section 2.5.4, a variety of mobile wayfinding GPS-based systems have been developed in the last decade in order to address the distant navigation requirements of visually impaired people. These include the MOBIC Travel Aid (Petrie, 1995), (ii) the Personal Guidance System (Golledge *et al*., 1998), and (iii) the Navigation System for the Blind (Makino *et al*., 1997).

'Independent mobility', which is described in section 2.5.1, is an ideology where visually impaired people can travel freely through the environment, without being constrained to familiar routes or known destinations. While mobile wayfinding systems offer huge potential to visually impaired people, most fall short of this ideology for four main reasons:

(i) Contextual information that would be of use to visually impaired people (such as road widths, differences in ground textures, people identification, traffic direction, etc) is not provided by existing travel databases (LaGrow & Weesies, 1994).

(ii) All systems have not considered the extreme diversity of the severity and form of visual impairments. Wayfinding systems, until now, either have been designed for totally blind people who form a small proportion of the visually impaired community, or have been designed to transmit the same information to all visually impaired travellers. Referring back to Figure 2.7, people with a central vision loss, shown in part (b), may have difficulty reading text on street signs, whereas people with peripheral vision loss, shown in part (c), may have difficulty sensing movement.

(iii) Multi-context navigation is not well supported. Information is rarely adapted to support both indoor and outdoor navigation, as well as different modes of travel (e.g. walking, bus, train).

(iv) 'Context-awareness is not well supported' (Helal *et al*., 2001) - the level of service is mostly centred on location-awareness. In order to provide more useful and relevant information/services, mobile guides need to draw upon richer context databases containing information about people and traffic flows, nearby excavation work, expected weather conditions, etc. Further, unexpected events or dynamically changing environments are not well supported (LaGrow & Weesies, 1994), such as cars parked on pavement, overhanging branches, etc.

The notion of context-awareness moves closer to this ideology of independent mobility by combining sensing technologies to discover more about the user's context. While most wayfinding systems use just contextual sensing, context-awareness extends the capabilities that could be made available through contextual augmentation, adaptation, and resource discovery (Pascoe, 1998).

The aim of the fourth study of this chapter, focusing mainly on points (ii) and (iii), is to investigate whether people with different visual impairments use different landmarks or cues in the *meaningful contextual* environment to navigate through indoor and outdoor environments. The study hypothesis is that *there will be, firstly, differences between how people with different visual impairments encode spatial information to orientate and navigate, and, secondly, differences between how visually impaired people encode spatial information in different contexts*.

4.5.1 Method

A total of 15 participants (8 male and 7 female) between the ages of 27 to 74 were recruited, all of whom are resident in Greater Glasgow. Participants were contacted through the RNIB, the Macular Disease Society, and the Retinitis

Pigmentosa Society[6]. Contacts from the RNIB and Low Vision Unit at Caledonian University suggested that 3 groups of visually impaired participants should be used: (i) people with a loss of central vision (e.g. macular degeneration), (ii) people with a loss of peripheral vision (e.g. retinitis pigmentosa, glaucoma), and (iii) people who are registered blind (e.g. optic nerve hypoplasia).

It should be noted that the 5 participants making up each group all experience different severities of visual impairment. Within the registered blind group, 3 participants still have slight light/dark perception, whereas the other 2 experience total vision loss. This, unfortunately, will always be a difficult parameter to control when involving visually impaired people in experiments. The length of time each participant had been visually impaired and the type of mobility aid used are shown in Table 4.4.

	Length of time impaired (years)					**Mobility Aid**		
Group	**Under 2**	**3-7**	**8-15**	**Over 16**	**Birth**	**Cane**	**Guide Dog**	**None**
Loss of central vision	0	3	2	0	0	4	0	1
Loss of peripheral vision	1	3	1	0	0	2	0	3
Registered blind	0	1	1	2	1	2	3	0

Table 4.4. Length of time impaired and mobility aid used

The study involved asking each participant to walk to three predetermined outdoor and indoor landmarks, all of which took around five minutes to reach. Participants encountered a typical contextually rich city-centre urban environment whilst walking to outdoor landmarks, and experienced a typical indoor setting through one of the main buildings of Strathclyde University.

Whilst en route to each landmark, participants were encouraged to ask questions about the environment that would enable them to reach each landmark safely,

[6] The Data Protection Act 1998 precludes those organisations giving me contact details of their members. Each of the groups were therefore asked to contact their members either by calling them directly or by sending a letter written by me. It was then left to members to contact me if they were willing to participate in the study.

efficiently and effectively. The content and frequency of questions were investigated by videoing the journey using a digital camcorder.

High-level instructions were read to them before setting off to each landmark. An example is provided below:

> *"Continue down towards George square and turn first right. Walk uphill passing the Student Union until you meet Cathedral Street. On your right will be the Department of Chemistry, the second landmark."*

On arriving at each landmark, participants were asked to comment on the environmental cues they were using to orientate and navigate. Additionally, using a list of incidental services, participants were asked to select two services that would have been useful to them when navigating to the current landmark (note: this procedure was only carried out for the first two outdoor and indoor landmarks, and participants were allowed to select the same service twice for each landmark). The list of incidental services was compiled using feedback from a previous study involving interviews with visually impaired people (Bradley & Dunlop, 2003b). The distinction is made between (i) incidental information on *task-affecting* events, which concern features of the environment that change, are unpredictable, and directly influence the participant navigating to landmarks, and (ii) incidental information for *task-augmentation*, which concerns features of the environment that are not necessary for effective navigation but which participants might take interest in whilst walking to each landmark.

For outdoor landmarks, incidental information on task-affecting events concerns information on: (i) crowd density/flow (e.g. queue at bus stop), (ii) traffic density/flow (e.g. often a busy street where traffic travels in one direction from left to right), (iii), weather forecasts (e.g. heavy rain expected in the afternoon), (iv) excavation work or other temporary obstacles (e.g. cars parked on pavement), and (v) traffic lights state (e.g. green man has appeared). Incidental information for task-augmentation concerns any feature of the environment that participants take selective interest in, such as the names of buildings.

For indoor landmarks, incidental information on task-affecting events concerns information on: (i) crowd density and flows (e.g. stairway becomes busy at a particular time), (ii) temporary obstacles (e.g. ladders, scaffolding, signs, portacabins, etc), and (iii) lighting conditions (e.g. about to walk into a poorly lit area). Similar to outdoor landmarks, incidental information for task-augmentation concerns any feature of the environment participants are passing that may be of interest to them, such as the name of departments.

4.5.2 Results

Three groups consisting of participants with a loss of central vision (CV), participants with a loss of peripheral vision (PV), and participants who are registered blind walked to three landmarks outside and then three landmarks inside. The results of each route are illustrated in the first two sections, and then compared in the third section.

4.5.2.1 Outdoor route

The outdoor landmarks, which were walked to by each participant, are illustrated in Figure 4.16, and as an example the questions and mistakes made by blind participants are represented. The number lying next to each question and mistake indicates its type, which can be discovered from Figure 4.17.

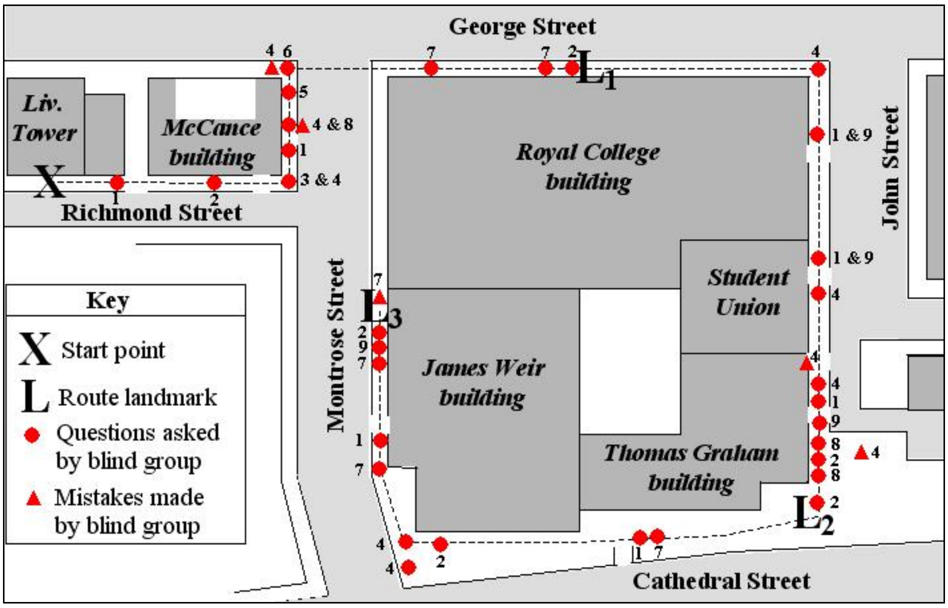


Figure 4.16. Questions asked, and mistakes made, by blind participants when navigating to outdoor landmarks.

The mean number of questions asked relating to each category is illustrated in Figure 4.17 for each group of participants.

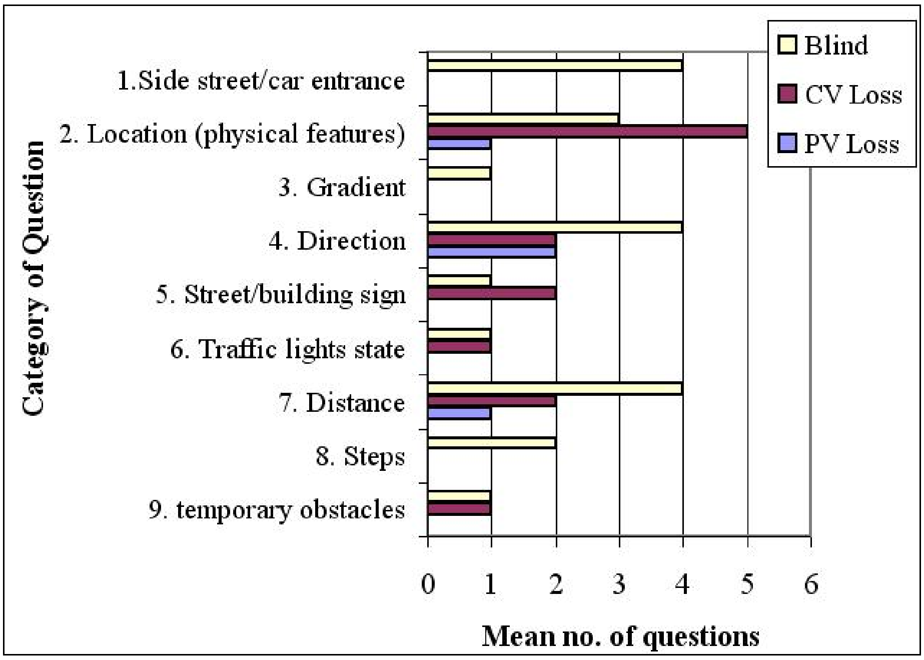


Figure 4.17. Mean number of questions asked relating to each category for each group.

The key results from Figure 4.17, together with statistical data in Table 4.5 from a one factor independent measures ANOVA test [where F (2, 12) = 6.93 at p<0.01] and Tukey's test [where q has a value of 5.05 at p<0.01], are as follows:

- Blind participants asked questions regarding side streets and steps (1), which were not asked by the other two groups. This result is highly significant (F = 80>6.93).
- The mean number of questions regarding location (2) and street/building signs (5) asked by participants with a CV loss was greater than participants with a PV loss. This difference between the means is slightly significant for both categories (3.8>HSD, 2>HSD).
- Blind participants and participants with a CV loss asked questions regarding the state of traffic lights (6) which were not asked by participants with a PV loss. This is a highly significant result (F =65535>6.93).
- The mean number of questions regarding distance (7) asked by blind participants is twice as much as the mean number of questions asked by participants with a CV loss, and four times greater than participants with a PV loss. This difference between the blind group's mean with the other two groups is significant (2.2>HSD, 3>HSD).

- Blind participants asked questions regarding steps (8), which were not asked by the other two groups. This result is highly significant (F = 26>6.93).
- The PV loss group did not ask any questions relating to temporary obstacles (9) in the environment.
- The most common category of question asked across all groups were location (2), direction (4), and distance (7). Questions were asked within all categories by the blind group, within 6 categories by the CV loss group, and within 3 categories by the PV loss group.

	ANOVA	Tukey test			
Category Q No.	**Variance ratio (F)**	**HSD**	**B & CV**	**B & PV**	**CV & PV**
			Val	**Val**	**Val**
1	80	1.30	4	4	0
2	9.76	3.14	1.2	2.6	3.8
3	2.8				
4	5.14				
5	12.15	1.49	1.4	0.6	2
6	65535	0	0	1	1
7	21.29	1.70	2.2	3	0.8
8	26	1.09	1.8	2	0.2
9	2.92				

Table 4.5. Testing for significance (shaded cells show a significant result).

The blind group made a total of 8 mistakes outside, the CV loss group made 3 mistakes, and the PV loss group made no mistakes.

On arriving at each landmark, participants commented on what type of environmental cues they used to orientate and navigate to walk to each landmark. Figure 4.18 illustrates the percentage of participants within each group who use each type of environmental cue.

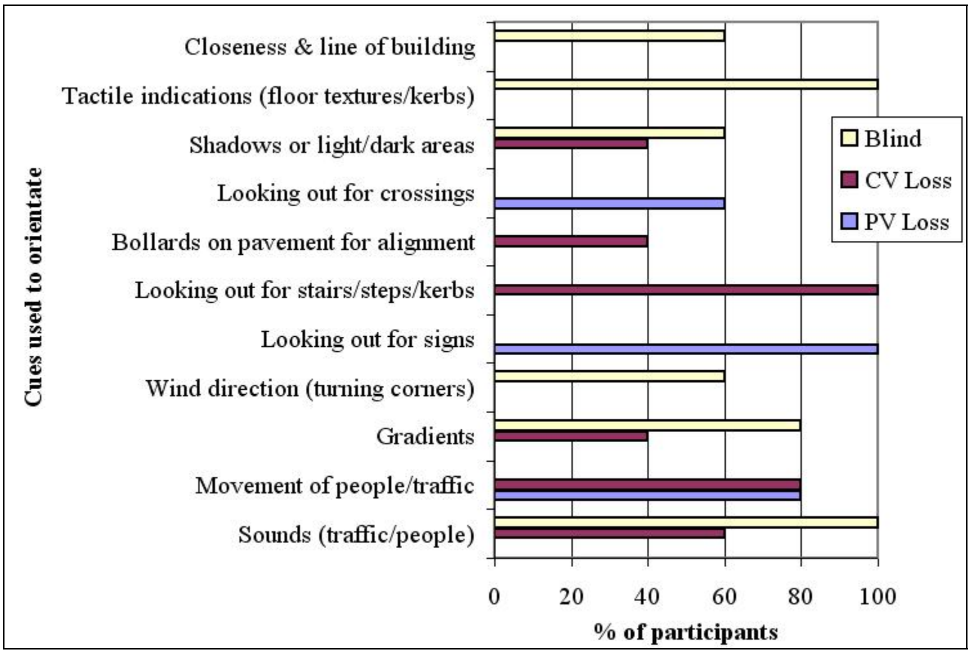


Figure 4.18. Percentage of participants within each group who use each type of cue to orientate and navigate.

As illustrated in Figure 4.18, only the blind group used the closeness of buildings (60%), tactile markings (100%), and wind direction (60%). Signs (100%) and crossings (60%) were only used by the PV loss group, whereas pavement bollards (40%) and stairs (100%) were only used by the CV loss group.

Shadows, gradients, and sounds were all used by the blind and CV loss group but not by the PV loss group. Whereas, people/traffic movement was used by the CV and PV loss groups but not by the blind group.

4.5.2.2 Indoor route

The indoor landmarks are illustrated in Figure 4.19, and as an example the questions and mistakes made by blind participants are represented. Similarly, the type of questions and mistakes made can be seen in Figure 4.20.

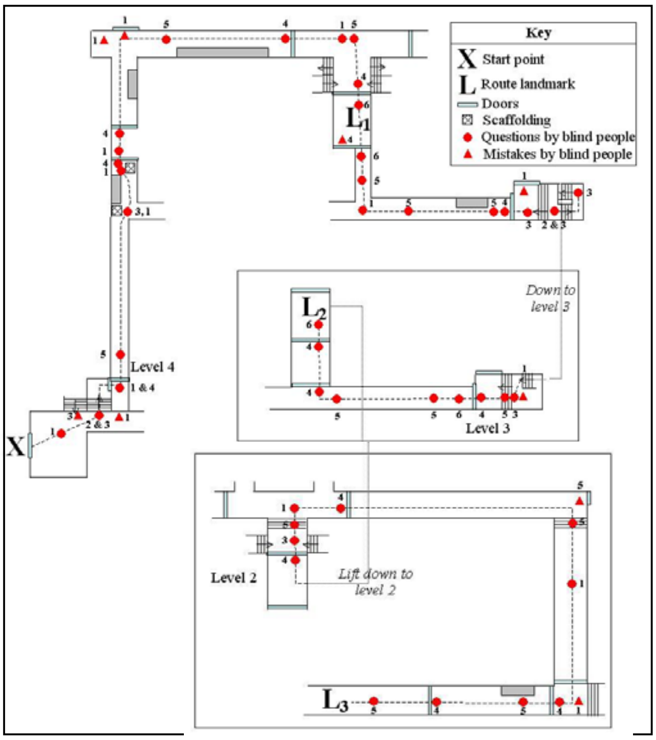


Figure 4.19. Questions asked, and mistakes made, by blind participants when navigating to indoor landmarks.

The mean number of questions asked relating to each category is illustrated in Figure 4.20 for each group of participants.

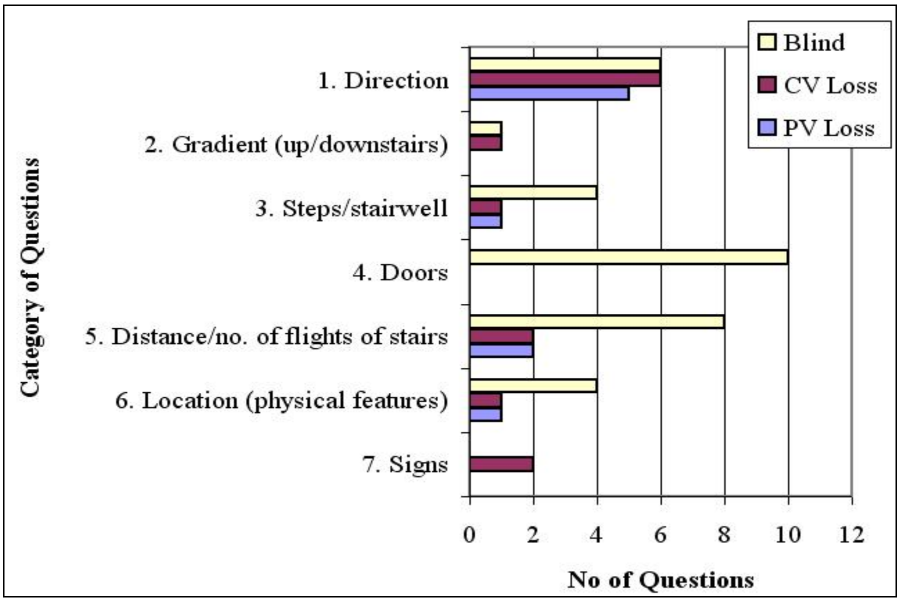


Figure 4.20. Mean number of questions asked relating to each category for each group.

The key results Figure 4.20, together with statistical data in Table 4.6 from a one factor independent measures ANOVA test [where $F(2, 12) = 6.93$ at $p<0.01$] and Tukey's test [where *q* has a value of 5.05 at $p<0.01$], are as follows:

- The mean number of questions regarding stairs (3) and distance (5) asked by blind participants is approximately 3 times greater for both categories than the mean number of questions asked by CV loss and PV loss participants. For the distance category, there is a significant difference between the blind group mean and the CV loss group mean (6.8>HSD) and PV group mean (6.8>HSD). For the stairs category, only the difference between the blind group mean and PV loss group mean is slightly significant (3.6>HSD).
- Blind participants asked many questions regarding doors – a category of question not used by either of the other groups. Also, the mean (10) was higher than for any other category across all groups. This result is highly significant (F = 38.6>6.93).
- Participants with a CV loss asked questions regarding signs (8), which were not asked by the other two groups. This result is highly significant (F = 12.52>6.93).
- The most commonly asked questions across all groups were direction (1), and distance (5). Questions were asked within six out of seven categories by the blind and CV loss groups, and within 4 categories by the PV loss group.

	ANOVA	Tukey test			
Category Q No.	**Variance ratio (F)**	**HSD**	**B & CV**	**B & PV**	**CV & PV**
			Val	**Val**	**Val**
1	0.72				
2	3.13				
3	8.34	3.45	3.2	3.6	0.4
4	38.60	4.65	9.8	10	0.2
5	42.81	3.03	6.8	6.8	0
6	6.78				
7	12.52	1.98	2.4	0	2.4

Table 4.6. Testing for significance (shaded cells show a significant result).

The blind group made a total of 20 mistakes indoor, the CV loss group made 7 mistakes, and PV loss group made 1 mistake.

The percentage of participants within each group who use each type of environmental cue to orientate and navigate inside is illustrated in Figure 4.21.

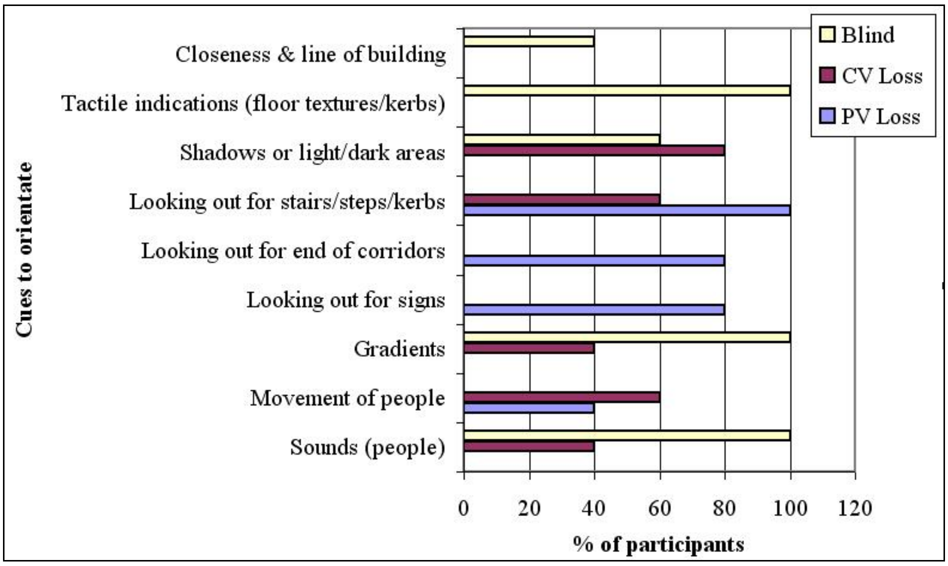


Figure 4.21. Percentage of participants within each group who use each type of cue to orientate and navigate.

Figure 4.21 illustrates that only the blind group used the closeness of buildings (40%) and tactile markings (100%), whereas looking for signs (80%) and the end of corridors (80%) were only used by the PV loss group. All blind participants and 2 people within the CV loss group used gradients and sounds. The PV loss group used neither, and also did not use shadows, which were used by the other two groups. The PV loss and CV loss groups, however, used the movement of people (40%, 60%) and stairs (100%, 60%), neither of which were used by blind participants.

4.5.2.3 Asking participants to prioritise incidental information

In the last two sections, the questions asked by participants revealed the type of information they require to reach landmarks efficiently and effectively. This included not only meaningful information but also incidental information regarding task-affecting events, such as cars parked on pavements. In order to explore incidental services further for both indoor and outdoor routes, participants were asked to select two incidental services that would have been useful to them when travelling to each landmark (note: only the first two outdoor and indoor landmarks were used). The list of incidental services is detailed in section 4.5.1, where the distinction is made between incidental information on task-affecting events and incidental information for task-augmentation. Table 4.6 illustrates the results from each visually impaired group for both landmarks indoor and outdoor.

		Group		
Context	**Lan**	**Registered Blind**	**Loss of CV**	**Loss of PV**
Outdoor	1	Temporary obstacles (i.e. cars parked on pavement)	Crowd density (i.e. students at the entrance to McCance building)	Structural info (i.e. the McCance building)
		Traffic lights state (i.e. green man)	Traffic lights state (i.e. green man)	Structural info (i.e. indoor car park)
	2	Crowd density (i.e. queue at bus stop)	Crowd density (i.e. queue at bus stop)	Structural info (i.e. Royal College building)
		Temporary obstacles (i.e. cars parked on pavement)	Crowd density (i.e. busyness of Student Union entrance)	Structural info (i.e. Student Union)
Indoor	1	Temporary obstacles (i.e. portacabin narrowing corridor and scaffolding)	Temporary obstacles (i.e. portacabin narrowing corridor and scaffolding)	Structural info (i.e. passing the department of bioscience)
		Crowd density (i.e. stairway busy with students)	Lighting conditions (i.e. about to enter a brightly lit area)	Lighting conditions (i.e. areas that are poorly lit)
	2	Temporary obstacles (i.e. portacabin narrowing corridor)	Crowd density (i.e. stairway busy with students)	Structural info (i.e. passing the department of power engineering)
		Crowd density (i.e. stairway busy with students)	Lighting conditions (i.e. about to enter a brightly lit area)	Lighting conditions (i.e. areas that are poorly lit area)

Table 4.7. The most popular incidental services chosen by visually impaired participants.

4.5.2.4 Contrasting contexts

When comparing the results for outdoor and indoor routes it can be seen that more categories of questions were asked outside (9 vs. 7). However, participants asked far more questions indoor than they did outdoor (61.5% more within the blind group, 14.5% more in the CV loss group, 131.6% more in the PV loss group).

Different types of questions were also asked in each context, and some of those categories that are the same are proportionately greater or lesser in one context. Blind participants, for instance, asked a proportionately greater amount of questions about distance inside.

Similarly, this trend is further evident in the environmental cues participants used to orientate. Light/dark cues were proportionately higher indoor for the CV loss group, gradients were higher indoor for the blind group, and sounds were lower for the CV loss group indoor.

4.5.3 Discussion

The results of this study support the hypothesis that there are differences between people with different visual impairments, and differences between indoor and outdoor contexts.

Blind people asked categories of questions and used environmental cues not used by the other two groups. Questions were asked about side streets, steps, and doors, while tactile markings and wind direction were used for environmental cues. The blind group also asked significantly more questions regarding distance, and a greater percentage used sounds to orientate. Blind people therefore require a richer variety of contextual information possibly due to their more restricted level of vision, making them more dependent on other sensory cues, such as sound and touch.

There were also differences between the CV loss and PV loss groups. The CV loss group asked far more questions generally and within additional categories relating to signs and traffic lights. Expressed difficulties in reading text and directly viewing or fixating on objects without central vision may explain this finding. In contrast, people with a PV loss were able to fixate on more distant landmarks, such as signs, crossings, distance to turnings, etc. Interestingly, people with a CV loss used light-dark contrasts to orientate, indicating a greater dependency on peripheral vision, which is used for light sensitivity. This in turn explains why people with a PV loss experience a high degree of usable vision during the day, but at night experience night blindness.

There were also differences in the most popular incidental services chosen by visually impaired participants within each group. For instance, information on temporary obstacles was the most popular service for the registered blind group, information on crowd flow the most popular for the loss of CV group, and information on structural information the most popular for the loss of PV group. This could be explained by the extent to which participants could see through their central vision (in other words, whether they could fixate on, or detect, objects in front of them). Participants with PV loss, for instance, can detect obstacles and people in their path and so are not as dependent on receiving this information (however this is likely to change at night time due to the reasons mentioned at the end of the last paragraph).

Differences between contexts were also found. More questions were asked inside than outside (the greatest increase by the PV loss group). For some categories, the number of questions asked became proportionately greater, such as distance for the blind group. Some environmental cues were used by a greater percentage of participants indoor, such as light-dark areas for the CV loss group. These differences may be due to participants having to negotiate a richer and more rapidly occurring contextual environment whilst navigating indoors. The CV loss group, for instance, used the light shining through windows to indicate the side or end of corridors. More research is required in order to investigate these differences in more contextual environments (e.g. urban vs. rural).

With respect to the multidisciplinary model of context illustrated in Figure 3.2, the differences reported illustrate how some cues in the environment are meaningful to one form of visual impairment but incidental to another, meaning that people will form different cognitive maps of the environment. In other words, people with different visual impairments use different landmarks and cues in the meaningful contextual environment to navigate. Further, incidental occurrences, such as a gust of wind turning a corner (i.e. part of the physical context in the contextual layer) may remain incidental and contextual to some but may be used as a meaningful contextual cue by others. These findings make a considerable contribution to the area of personalisation of navigation information for visually impaired people.

Overall, the results offer valuable guidance for application designers. When distance vision becomes more restrictive (PV loss to CV loss to blind), it would suggest that other or additional sensory input becomes more meaningful, and information regarding the immediate and incidental environment becomes more significant. Blind and CV loss people therefore require more contextual information in order to confirm, or orientate in, the environment than PV loss people. So, for instance, information regarding traffic flow may need to be given, since traffic noise is often used by blind people to indicate their direction and position on the pavement.

To conclude, information transmitted by mobile wayfinding systems needs to be personalised for people with different visual impairments, and adjusted for the different contexts through which visually impaired people travel. Context-aware research needs to draw upon these results in order to design more useful and relevant information and services. The study described in Chapter 6 involves using the information acquired within each visually impaired group in this study in order to design three conditions of meaningful and incidental verbal messages. These messages will be used to guide visually impaired participants to landmarks using a GPS-assisted laptop. The purpose will be to see whether participants are more effective and efficient using information derived from participants with the same category of visual impairment as themselves.

4.6 Conclusions

The general aim of this chapter was to investigate the user's world within the multidisciplinary model of context, specifically in the area of navigation. The aim of the first two studies, described in sections 4.3 & 4.4.1, was to investigate whether sighted and visually impaired people use different landmarks or cues in the meaningful contextual environment (outer layers of the multidisciplinary model of context) in order to carry out focal activities to orientate and navigate. Using a qualitative approach called think-aloud used by cognitive mapping and HCI researchers, sighted and visually impaired participants were asked to describe routes. The words/phrases used within those descriptions were categorised into 11 classes, and the frequency with which words/phrases in those classes were uttered or written was monitored. This provided an indication of the proportion of information used within and across groups.

The results revealed that within the sighted group, younger participants used more textual-structural information (names of bars, restaurants, shops) than textual-area/street information (names of streets/areas) in comparison to older participants. When comparing sighted and visually impaired peoples' route descriptions, visually impaired people used more directional, structural, environmental, numerical and descriptive information. They also used information within additional categories relating to sensory, motion and social contact. In the third study, described in 4.4.2, verbal messages based on those route descriptions of sighted people (condition 1) and visually impaired people (condition 2) were used to guide different groups of sighted and visually impaired people to landmarks. The results revealed that visually impaired participants reached landmarks quicker, were less frustrated, and required less mental and overall effort when given information derived from other visually impaired people in condition 2. Sighted people, on the other hand, thought this condition was more mentally demanding and frustrating, and required more effort.

The fourth study of this chapter, described in section 4.5, involved investigating whether people with contrasting visual impairments require different information about the meaningful contextual environment (e.g. steps, doors, distance, etc.) and incidental contextual environment (e.g. cars parked on the pavement, crowd and traffic flows, etc.) when they orientate and navigate through indoor and outdoor environments. A slightly different technique was used to investigate cognitive maps. Instead of route descriptions, three groups of visually impaired participants, namely, CV loss group, PV loss group, and registered blind group, walked to pre-determined destinations and were encouraged to ask questions about the meaningful and incidental contextual environment in order to navigate to those destinations effectively and safely. The type of questions asked were categorised and used to determine whether differences existed between visually impaired groups. Once participants arrived at landmarks they were also asked to choose, from a list, two incidental services that would have been useful to them when navigating to the current landmark. Incidental services consisted of information about the incidental contextual environment.

The results revealed that blind people asked categories of question and used environmental cues not used by the other two groups. Questions about the meaningful contextual environment concerned side streets, steps, and doors, while tactile markings and wind direction were used for environmental cues. The blind group also asked significantly more questions regarding distance, and a greater percentage used sounds to orientate. The blind and CV group also asked questions not asked by PV loss group about cars parked on the pavement in the incidental contextual environment. In another comparison, the CV loss group asked far more questions generally than the PV loss group and within additional categories relating to signs and traffic lights. There were also differences in the most popular incidental services chosen across each group. Information on temporary obstacles (e.g. cars parked on pavement) was the most popular service for the registered blind group, information on crowd flow the most popular for the loss of CV group (e.g. queues of people at bus stop), and information on structural information the most popular for the loss of PV group (e.g. passing Royal College Building). Differences between contexts were also found. More questions were asked inside than outside (the greatest increase by the PV loss group). For some categories, the number of questions asked became proportionately greater, such as distance for the blind group. Some environmental cues were used by a greater percentage of participants indoor, such as light-dark areas for the CV loss group.

With respect to the multidisciplinary model of context in Figure 3.2, the types of landmarks used by participants can be linked to the outer layers of the contextual world. Sighted participants and PV loss groups used landmarks or cues exclusively in the physical context (e.g. Border's bookshop, Queens Street, etc) and task context (e.g. left/right). Whereas, in addition to those context dimensions, the registered blind and CV loss groups also used and were influenced by cues in the social context (e.g. sound of people at traffic lights to indicate when it was safe to cross a street). With respect to Figure 3.3, the latter two groups were *influenced* (starting from the right arrow) by more in the incidental contextual environment - for instance, by cars parked on the pavement (physical context), by traffic flows (physical context), and by flows of people (social context). The sighted and PV loss group, on the other hand, exclusively *used* (i.e. starting from the left arrow) fixed and meaningful landmarks as reference points to navigate to landmarks, and thus were less affected by incidental events occurring around them.

To conclude, this chapter investigated the user's context of the multidisciplinary model of context, specifically in the area of navigation. The user studies undertaken have illustrated that differences exist between what people use or require in the meaningful and incidental contextual environment when orientating and navigating. However, this chapter has identified only some of the differences, which contribute to the issue of personalisation of context-aware mobile devices. Future studies or research, for instance, may involve investigating (i) cross-cultural differences in the use of landmarks, (ii) differences in the use of landmarks when driving, and (iii) differences in the use of landmarks when navigating through urban vs. rural environments.

CHAPTER 5

DESIGNING APPLICATION'S CONTEXT

This chapter provides an illustration of how the multidisciplinary model of context was used to design the application's context, i.e. the bottom half of the multidisciplinary model illustrated in Figure 3.2 of Chapter 3 (or quadrants 2 & 4 of Figure 3.1). In Chapter 6 the interaction of the user and application's context is investigated.

5.1 Aim and purpose

The aim of this chapter is to use the multidisciplinary model of context in order to design the application's context. The purpose is to design an application for use in the final user study described in Chapter 6. It was highlighted earlier that the motivation of this thesis is to advance human and social aspects of design and not to advance software development of context-aware design. The design of the application's context in this chapter is therefore fairly primitive. However, the characteristics of, and the components used to represent, the application's context provide an invaluable insight into how an application might better support the user's mobile activities. As illustrated in the multidisciplinary model of context, the distinction is made between meaningful focal application services, and incidental focal context-aware services.

5.2 Transmitting meaningful focal context-aware services

The outer layers of the multidisciplinary model of context illustrate how the application can sense and use information from the meaningful contextual environment, which for this study included sensing the user's location in the physical context (only outdoor however) and using the user's type of visual impairment in the user's context. This acquired information from the meaningful contextual environment was then used to adjust the content of information given to the user (this will discussed in more detail in the next chapter).

Meaningful focal context-aware services provide the user with the necessary information to undertake his/her primary meaningful focal activity, which for this study is to reach indoor and outdoor landmarks effectively, efficiently, and safely (e.g. information on steps, side streets, doors, etc.).

5.2.1 Components used to transmit meaningful information

In order to transmit meaningful information to participants during outdoor navigation, the following components were used:

- *java application* – based on work by two people within the Department of Computer and Information Sciences at Strathclyde University, but was extended for the purposes of this study. Firstly, code extracted from Johnston Stewart's MSc thesis (Stewart, 2001) was used by Dr Mark Dunlop to convert a raw GPS data string into a format interpretable by the user (i.e. the longitude and latitude coordinates, number of visible satellites, time of day, etc.). The application monitors GPS data every second, and updates the user's display when a change occurs. Secondly, Dr Dunlop extended the functionality, as part of a EU funded project called GLOSS, in order to allow the user to record textual messages at specific locations along a route. Messages could be retrieved by the user when re-entering a specified distance from recorded message locations. The main additions that were made for this study were to have a list of pre-specified locations that, when compared to the current location, played an audio file (consisting of a verbal direction or instruction) if the user entered within a 20 metre radius.
- *Sony Vaio laptop* – this was used to run the java application. Running the application on a GPS enabled Compaq IPAQ had previously been attempted but this platform was ruled out due to problems playing multiple audio files (possibly caused by limited memory). The laptop case was used to transport the laptop, which was carried by the researcher.
- *Garmin eTrex GPS mobile device* – this was connected via a USB cable to the laptop and provided raw GPS data for the java-based application. During the study this was held out in front by the researcher to obtain the strongest signal.
- *Headphones* – these were connected to the laptop and were used to transmit verbal directions to participants.

For travel through indoor environments, the Compaq IPAQ was used instead of the laptop due to the problems of obtaining a GPS signal. Using indoor sensors to acquire location-aware information (or any other methods) was also not possible due to financial and technological constraints. The researcher controlled the timing of messages, which were played to the participant by selecting audio files using a stylus.

5.3 Transmitting incidental focal context-aware services

The outer layers of the multidisciplinary model of context, illustrate how information could be sensed or used from the incidental contextual environment, which involved for this study (i) using the user's type of visual impairment in the user's context to adjust the content of incidental information given to them (discussed in more detail in the next chapter), (ii) artificially determining crowd flows in the social context, and (iii) artificially determining traffic flows, temporary obstacles, traffic lights state, lighting conditions, and structural information in the physical context. By 'artificially' it is meant that the application did not sense this information; rather the researcher controlled the incidental information that was transmitted for each experimental condition.

Incidental focal context-aware services provide the user with information about (i) *task-affecting* events, which concern features of the environment that change, are unpredictable, and directly influence the participant navigating to landmarks (e.g. cars parked on the pavement, green man at traffic lights, queue of people at bus stop, etc.), and (ii) *task-augmentation,* which concerns features of the environment that are not necessary for effective navigation but which participants might take interest in whilst walking to each landmark (e.g. passing the Royal College Building). Once again, the type of incidental information transmitted was different for each condition, which is described in more detail in the next chapter.

5.3.1 Technique used to transmit incidental information

Incidental information was verbally transmitted to participants by the researcher for both indoor and outdoor routes. These messages had to be coordinated with meaningful messages in order to ensure that no overlap occurred. Acquiring information technologically from the incidental contextual environment was not possible due to financial and time restrictions. In addition, human measurements were of greater interest for this study and so the technique used was still considered to offer a greater accuracy and sense of realism than what can be currently achieved technologically. Though it is felt that, with the advancement of wireless mobile web-based services and sensing technologies, investigations regarding incidental focal context-aware services will be easier to undertake in the future.

5.4 Problems experienced

Obtaining consistently accurate GPS data was the biggest problem throughout the study. Due to restricted visibility of satellites in built up areas, the GPS signal is often weak (giving inaccurate readings) and sometimes totally lost. When this occurred, considerable time was spent trying to re-establish a connection, which required a signal from 3 satellites or more. This occasionally required the researcher to open the laptop in order to re-run the application. This proved time-consuming and problematic, especially during busy periods or situations involving adverse weather conditions (which for a study in Scotland was quite common!). The number of components required for the study (described in section 5.2.1) also made the researcher's task quite tedious. This was particularly evident during situations where the participant's behaviour was being observed.

A consequence of inaccurate GPS data was that on occasions more than one pre-specified location was within the distance threshold of 20 metres. For those situations, the application was designed to select the closest pre-specified location from the current location. Although this worked for most situations, there were occasions when the wrong message was played. The timing of messages generally is difficult to design for and control since it is necessary to record the location 20 metres in front of where the participant receives the message. This took considerable time to get right and also meant that messages could not be too close together since this resulted in an increased rate of wrong verbal messages being played.

5.5 Conclusions

The aim of this chapter was to use the multidisciplinary model of context in order to design the application's context. It was highlighted earlier that the motivation of this thesis was not to advance software development of context-aware design. As a result, the design of the application's context was fairly primitive. However, the characteristics of, and the components used to represent, the application's context provide an invaluable insight into how an application might better support the user's mobile activities. As illustrated in the multidisciplinary model of context, the distinction is made between meaningful focal application services (e.g. cross two curbed side streets), and incidental focal context-aware services (e.g. cars parked on the pavement).

The outer layers of the multidisciplinary model of context illustrate how information can be sensed or used from (i) the meaningful contextual environment, which for the study included sensing the user's location in the physical context (only outdoor however) and using the user's type of visual impairment in the user's context – this information was used to adjust the content of information given to the user, or (ii) the incidental contextual environment, which included artificially determining crowd flows in the social context; traffic flows, temporary obstacles, traffic lights state, lighting conditions, and structural information in the physical context; and also using the user's type of visual impairment in the user's context - all of this information was used to adjust incidental information given to the user. To transmit meaningful information outdoor, the application ran on a laptop connected to a GPS device and, based upon the user's current location and type of visual impairment, audio files were transmitted to the participant via a set of headphones. For indoor routes, the researcher controlled when meaningful verbal messages were played using a Compaq IPAQ. To transmit incidental information, the researcher, who accompanied participants, verbally transmitted messages for both indoor and outdoor routes. The main problem experienced technologically was of weak, lost or inaccurate GPS data. The built up environment through which participants walked was responsible for this difficulty.

The next chapter provides a more detailed insight into the meaningful and incidental information transmitted for each condition. The plan is to test the application, described in the next chapter, in order to investigate whether people with different visual impairments are more effective at reaching indoor and outdoor destinations when being guided by information derived from people with the same visual impairment category as themselves.

CHAPTER 6

INVESTIGATING USER-APPLICATION CONTEXT

In Chapter 4 the top half of the multidisciplinary model of context, shown in Figures 3.1 and 3.2, was used to investigate the use of landmarks to orientate and navigate by different people or groups of people. Significant differences were found across and within groups of sighted and visually impaired participants. These results and the bottom half of the multidisciplinary model of context were then used to design an application that provides both meaningful and incidental focal services, as described in Chapter 5. This chapter involves investigating the issues arising from the integration of the user and application's world.

6.1 Aim and purpose

The aim of this chapter is to investigate whether visually impaired people are more effective and efficient at navigating to landmarks when being given meaningful and incidental information derived from people with the same category of visual impairment as themselves (i.e. information derived from section 4.5). The study hypothesis is therefore that, *when given different conditions of meaningful and incidental information for navigating to indoor and outdoor landmarks, there will be subjective, objective, and physiological differences within a group of participants experiencing a central vision loss, within a group of participants experiencing a peripheral vision loss, and within a group of registered blind participants.*

This overall purpose of this study, which is the main study of this thesis, is to use the study results, combined with Chapters 3, 4, 5, in order to propose a user-centred design framework for designing context-aware applications described in Chapter 7. The results of this study will contribute to the research areas of *human wayfinding* with respect to the development of cognitive maps by visually impaired people, and *context-aware mobile computing* with respect to the issue of personalising information and services for different users and contexts.

6.2 Method

A total of 24 participants (11 males and 13 females) aged between 29 to 71 were recruited, all of whom were resident in Greater Glasgow. Continuing the structure of the previous study, described in section 4.5, visually impaired participants fell into one of three groups: (i) loss of Central Vision (CV) group (e.g. people experiencing macular degeneration), (ii) loss of Peripheral Vision (PV) group (e.g. people experiencing retinitis pigmentosa, glaucoma, etc.), and (iii) registered blind group (e.g. people experiencing optic nerve hypoplasia). Some participants who participated in the last study were used again for this study – this was considered appropriate since the route was reversed and considerable time had passed since the previous study. The RNIB, the Macular Disease Society, and the Retinitis Pigmentosa Society helped again in locating more participants. The length of time each participant had been visually impaired and the type of mobility aid they used are shown in Table 6.1.

	Length of time impaired (years)					**Mobility Aid**		
Group	**Under 2**	**3-7**	**8-15**	**Over 16**	**Birth**	**Cane**	**Guide Dog**	**None**
Loss of central vision	1	5	2	0	0	5	0	3
Loss of peripheral vision	2	4	2	0	0	3	0	5
Registered blind	0	2	2	2	2	3	5	0

Table 6.1. Length of time impaired and mobility aid used

The study involved guiding visually impaired participants to two indoor landmarks through one of the main buildings of Strathclyde University shown in Figure 6.1, and to two outdoor landmarks through a contextually rich urban environment shown in Figure 6.2. Of the 24 participants who participated, 83% of participants stated they were unfamiliar with the outdoor route, whilst 17% stated they were familiar. All participants were unfamiliar with the indoor route. A copy of the experimental documentation used for the study is shown in Appendix C-1.

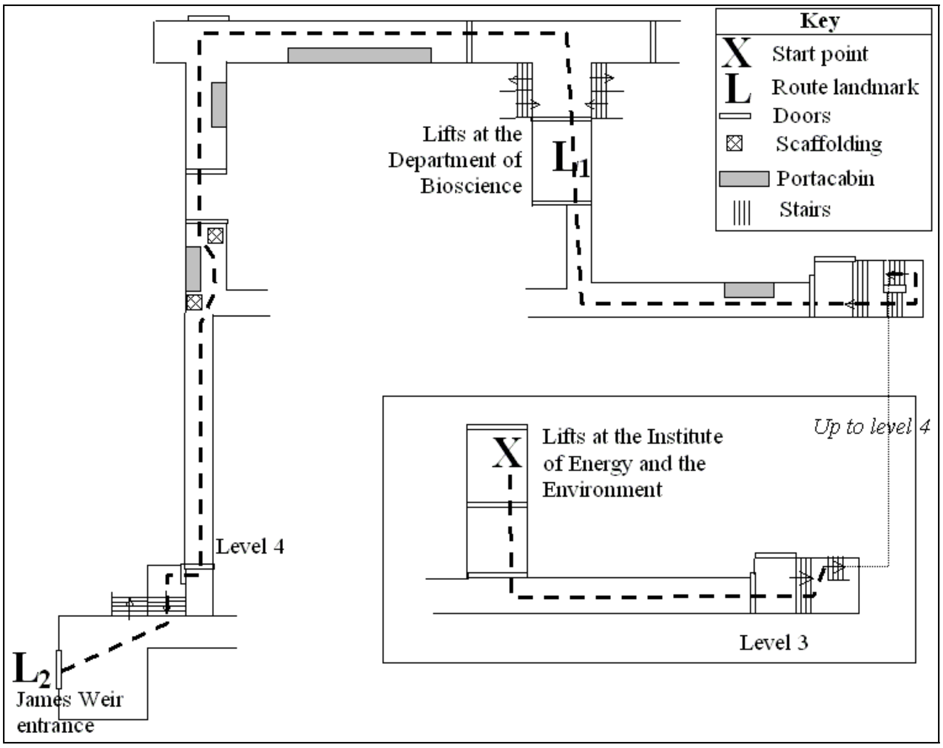


Figure 6.1. The indoor route.

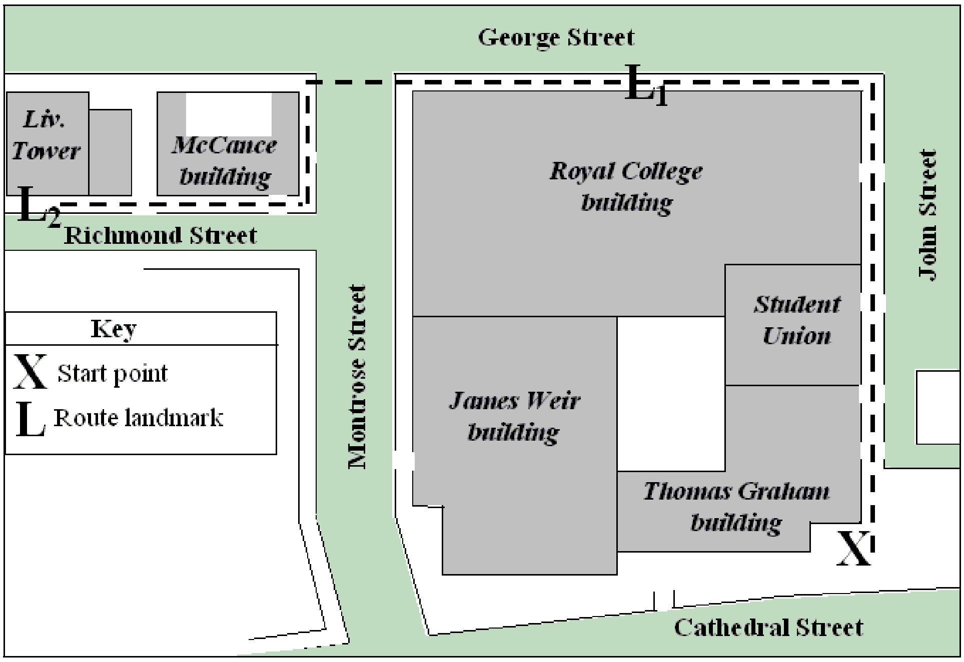


Figure 6.2. The outdoor route.

The information used to guide visually impaired participants fell into one of three conditions. These conditions were designed using the results of the previous study, described in section 4.5, which involved asking three groups of visually impaired participants to (i) ask navigation-based questions about their environment whilst walking to pre-determined landmarks, and (ii) select two incidental services that would have been useful to them when navigating to the current landmark. The three conditions that were used for this study are as follows:

- **Condition 1** – *meaningful* directions based on the navigation-based questions asked by participants who are registered blind, as well as *incidental* information that was chosen by them to be useful for navigating to a particular landmark.
- **Condition 2** – *meaningful* directions based on the navigation-based questions asked by participants with a PV loss, as well as *incidental* information that was chosen by them to be useful for navigating to a particular landmark.
- **Condition 3** - *meaningful* directions based on the navigation-based questions asked by participants with a CV loss, as well as *incidental* information that was chosen by them to be useful for navigating to a particular landmark.

The two sections that follow explain in more detail the content of those meaningful directions and incidental services.

6.2.1 Designing meaningful verbal directions

Taken from the previous study described in section 4.5, the average number of questions asked within each category by each visually impaired group when navigating to the first two landmarks outdoor and indoor are shown in Table 6.2. (Note: two categories of outdoor questions are missing from the results, namely, 'traffic lights' and 'temporary obstacles' – these are covered in the next section on designing incidental services.)

	Category of questions outdoor							**Category of questions indoor**							
Group	**Side streets**	**Local area**	**Gradient**	**Direction**	**Signs**	**Distance**	**Steps**	**Direction**	**Gradient**	**Stairs**	**Doors**	**Distance**	**Local area**	**Signs**
Blind group	8	6	2	8	2	8	4	12	2	8	20	16	8	0
PV loss group	0	2	0	4	0	2	0	10	0	2	0	4	3	0
CV loss group	0	10	0	4	4	4	1	12	2	2	0	4	2	4

Table 6.2. The average number of questions asked by each visually impaired group regarding indoor and outdoor meaningful features.

Using the average values from Table 6.2, meaningful verbal directions were formed for each condition, where condition 1 is based on the results of registered blind participants, condition 2 based on the results of participants with a PV loss, and condition 3 based on the results of participants with a CV loss. So for the outdoor route, information about side streets and gradients are included in condition 1 but not in condition 2 or 3. Information about the local area, direction/heading, and distance is included in all conditions - however, considerably more information on the local area is included in condition 3, and considerably more information on direction and distance is included in condition 1. Information about street/building signs and steps is included only in condition 1 and 3.

For the indoor route, information about direction/heading, stairs, distance, and the local area is included for all conditions - however, condition 1 contains almost four times more information on stairs, distance, and the local area than the other two conditions. Information about gradients is only included in conditions 2 and 3, information about doors is only included in condition 1 (a considerable amount), and information about department signs is only included in condition 3.

The type of information included under indoor and outdoor categories is illustrated in Table 6.3.

Context	Category	Example
Outdoor	Side streets	Cross three curbed side streets
	Local area	The entrance to the student union is on your left
	Gradient	…going downhill/uphill
	Direction	Turn first left, walk straight ahead
	Street/building names	…onto George street
	Distance	In approximately 30 metres
	Steps	Walk down four steps
Indoor	Direction	Walk straight ahead, turn first right
	Gradient	Walk upstairs/downstairs
	Stairs	A flight of stairs leading up is now in front of you
	Doors	Go through a set of pull doors
	Distance	In approximately 50 metres
	Local area	You will pass several large windows on your left
	Department signs	'The Institute for Energy and the Environment' is written on and above the doors in front of you.

Table 6.3. Examples of information included within each indoor and outdoor category.

It should be noted that there are differences within the 'local area' category across conditions for both indoor and outdoor routes. For instance, within condition 1 of the outdoor route, information on the local area included the location and direction of traffic (e.g. traffic is on your right and in one direction from right to left), whereas in condition 2 information on the local area included the name of structural features (e.g. passing student Union on your left). Additionally, within condition 3 of the indoor route, information on the local area included passing windows (since the light coming through can be used to orientate and align oneself), whereas in condition 2 information on the local area included the name of departments that were being passed.

It should be noted that all meaningful directions for each condition were verbalised by myself and were pre-recorded using a simple microphone connected to a laptop. Each verbal message was recorded using Windows Sound Recorder and saved in '.wav' format.

6.2.2 Designing incidental information

Table 6.4 in Chapter 4 illustrates the most popular incidental services chosen by each visually impaired group for the first two landmarks indoor and outdoor. The route for this study is reversed so using the results presented in Table 4.6, the incidental services that were provided for each landmark (Lan) for each condition (Con) is shown in Table 6.4. Incidental information for each condition was verbalised by myself in real-time.

		Incidental services			
Con	**Lan**	**Indoor**		**Outdoor**	
1	1	Crowd density (i.e. stairwell going up to level 4 may be busy with students)	Temporary obstacles (i.e. portacabin on right narrowing corridor)	Temporary obstacles (i.e. cars often parked on the pavement)	Crowd density (i.e. approaching a bus stop which is often busy)
	2	Temporary obstacles (i.e. portacabins on the left narrowing corridor)	Crowd density (i.e. stairway at James Weir entrance may be busy)	Traffic lights state (i.e. green man is showing – it is safe to cross)	Temporary obstacles (i.e. cars frequently enter and exit this side street)
2	1	Structural info (i.e. passing the Dep. of power engineering)	Lighting conditions (i.e. about to enter a poorly lit area)	Structural info (i.e. Student Union has a variety of shops)	Structural info (i.e. Royal College building is on your left)
	2	Lighting conditions (i.e. about to enter a poorly lit area)	Structural info (i.e. passing the Dep. of bioscience)	Structural info (i.e. an indoor car park is on your right)	Structural info (i.e. the McCance building is on your right)
3	1	Crowd density (i.e. stairwell going up to level 4 may be busy with students)	Lighting conditions (i.e. about to pass from a dimly lit area to a brightly lit area)	Crowd density (i.e. entrance to Student Union may be busy with students)	Crowd density (i.e. approaching a bus stop which is often busy)
	2	Lighting conditions (i.e. about to pass from a brightly lit area to a dimly lit area)	Crowd density (i.e. stairway at James Weir entrance may be busy)	Traffic lights state (i.e. green man is showing – it is safe to cross)	Crowd density (i.e. entrance to McCance building may be busy with students)

Table 6.4. The incidental services transmitted for each condition.

6.2.3 Technology used to transmit information indoor and outdoor

As described in Chapter 5, a laptop connected to a GPS device (both of which were carried by the researcher) was used to determine the outdoor location of the visually impaired participant. This location was used to select and transmit meaningful verbal instructions, via a set of headphones, in order to guide participants to outdoor landmarks (note: the earpads covering the headphones were sterilised after use by each participant). Since GPS is ineffective inside, an IPAQ was used to transmit meaningful verbal instructions for reaching indoor landmarks. This involved the researcher using the stylus to select audio files on the IPAQ's touchscreen in real-time. The researcher also verbally transmitted incidental information to participants in real-time for both landmarks indoor and outdoor. The timing of when this information should be given was ascertained prior to the study, and precautions were made to ensure that meaningful and incidental messages did not overlap, especially for the outdoor route.

Using different techniques to transmit meaningful information for indoor and outdoor routes was deemed appropriate since the results from the indoor and outdoor environments are not compared. In addition, when the participants commented on the meaningful and incidental information given to them once they had reached each landmark, they were asked to focus on the content of information rather than the timing of messages or any other technological issues that arose.

6.2.4 Types of measurements

The study involved taking objective, subjective, and physiological measurements in order to test the suitability of different conditions of meaningful and incidental information for each visually impaired group. These are as follows:

- *Objective*: A simple stopwatch was used to measure the time taken by participants to reach landmarks – during situations where occurrences in the environment prevented the participant from continuing on their path (e.g. traffic lights red) the timer was stopped and re-started once the participant was able to continue. The researcher also noted the number of mistakes made (e.g. wrong turning or direction).
- *Subjective*: Using a NASA TLX questionnaire (Hart & Staveland, 1988), participants were asked to rate their perceived level of workload once they had reached each landmark – information about what this questionnaire involved is described in section 4.4.2.3. In addition, using a simple 5-point scale (very helpful to very unhelpful) participants were asked to rate how useful the information was given to them through the headphones (meaningful information) and how useful the information was given to them by the researcher (incidental information).
- *Physiological*: In order to measure participants' level of stress for each condition, a combined heart rate monitor and wristwatch was used to measure participants' heart rates. Readings were taken at the start of the experiment and on arrival at each landmark. In order to obtain a reading, the participants placed their thumb and index finger on two sensors located on the watch's facia. After approximately 10 seconds, keeping both fingers pressed down, a reading would appear. Though occasionally this required more than one attempt, especially for blind participants who found it difficult to locate the sensors and to keep their fingers positioned correctly.

6.2.5 Experimental Design

As mentioned before, 8 participants were recruited for each of the three groups. A pairwise comparison of groups was used to design the study, which meant that participants within each group needed to be randomly allocated to two separate groups – for instance, participants who are registered blind (B) were either allocated to B_1 (4 participants) or B_2 (4 participants). This is illustrated in Table 6.5.

	Indoor		**Outdoor**	
Comparison	**Groups**	**Conditions**	**Groups**	**Conditions**
1	B_1 vs. PV_1	1 & 2	B_1 vs. CV_2	1 & 3
2	B_2 vs. CV_1	1 & 3	B_2 vs. PV_2	1 & 2
3	CV_2 vs. PV_2	2 & 3	CV_1 vs. PV_1	2 & 3

Table 6.5. Pairwise comparison of groups.

So, for instance, in the first indoor comparison, the B_1 Group and PV_1 Group received conditions 1 (based on registered blind participants' results) and 2 (based on PV loss participants' results). Half of the participants in each group received condition 1 to navigate to the first landmark and then condition 2 to navigate to the second landmark. Whereas, the other half in each group received condition 2 to navigate to the first landmark and then condition 1 for the second landmark.

6.3 Results

The results of the study are divided into three sub-sections, namely, the 'objective assessment' which includes the time taken to reach landmarks and the number of mistakes made; the 'subjective assessment' which includes the perceived level of workload of participants and their ratings of meaningful and incidental information; and the 'physiological assessment' which includes participants' heart rates on arrival at each landmark.

It should be noted that throughout the results, a two-tailed parametric related t-test was used to analyse the data instead of a one factor ANOVA analysis of data, which would test for differences across all three groups or conditions at the same time. This was due the fact that, described in the experimental design in the previous section, each participant only received 2 conditions. If each participant had been given all three conditions this would have increased the sample size by 12 participants, which was not possible due to the difficulties in locating visually impaired people.

6.3.1 Objective Assessment

The results of the objective assessment are divided into the time taken to reach landmarks and the average number of mistakes made by each group for each condition.

6.3.1.1 Time taken to reach landmarks

The average time taken by each visually impaired group to reach indoor and outdoor landmarks when given either condition 1, 2, or 3 is illustrated in Figures 6.3 and 6.4.

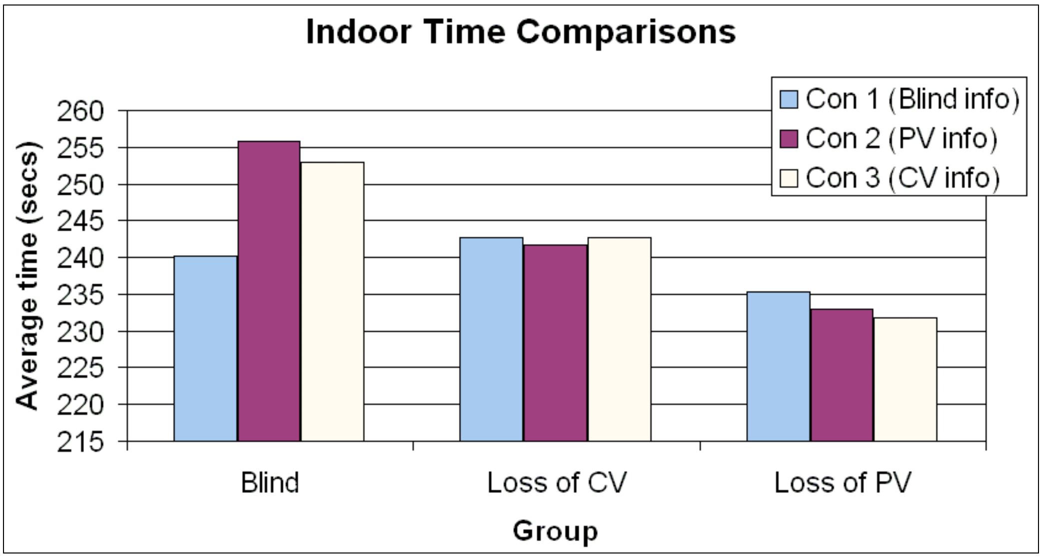


Figure 6.3. Comparing each group's average time to reach indoor landmarks when given different conditions.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings from Figures 6.3 are as follows:

- The registered blind group reached indoor landmarks significantly quicker when receiving condition 1 information in comparison to receiving condition 2 information (t = -2.889) or condition 3 information (t = -8.141). There was not a significant difference between condition 2 and 3.
- The loss of CV and PV groups did not show any statistical time differences when receiving all of the conditions.
- The loss of CV group was significantly faster than the Blind group when receiving information with condition 2 (t = 3.255) and condition 3 (t = 3.737), but not for condition 1. The loss of PV group were significantly quicker than the blind and CV loss groups when receiving all conditions.

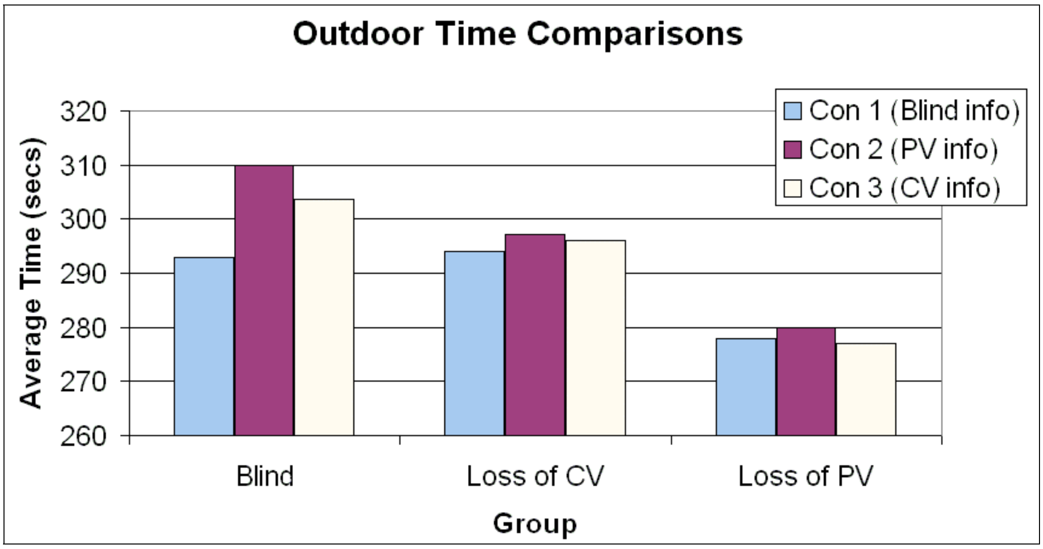


Figure 6.4. Comparing each group's average time to reach outdoor landmarks when given different conditions.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings from Figures 6.4 are as follows:

- The registered blind group reached outdoor landmarks significantly quicker when receiving condition 1 information in comparison to receiving condition 2 information (t = -4.012) or condition 3 information (t = -2.429). There was not a significant difference between conditions 2 and 3.
- The loss of CV and PV groups did not show any statistical time differences when receiving all of the conditions whilst navigating to outdoor landmarks.
- The loss of CV group was significantly faster than the blind group when receiving information with condition 2 (t = 2.870). The loss of CV group was also quicker in condition 2, though this difference was not significant. The loss of PV group was significantly quicker than the blind and CV loss groups when receiving all conditions.

6.3.1.2 Mistakes made

The average number of mistakes made by each visually impaired group for both indoor and outdoor routes is illustrated in Figures 6.5 and 6.6.

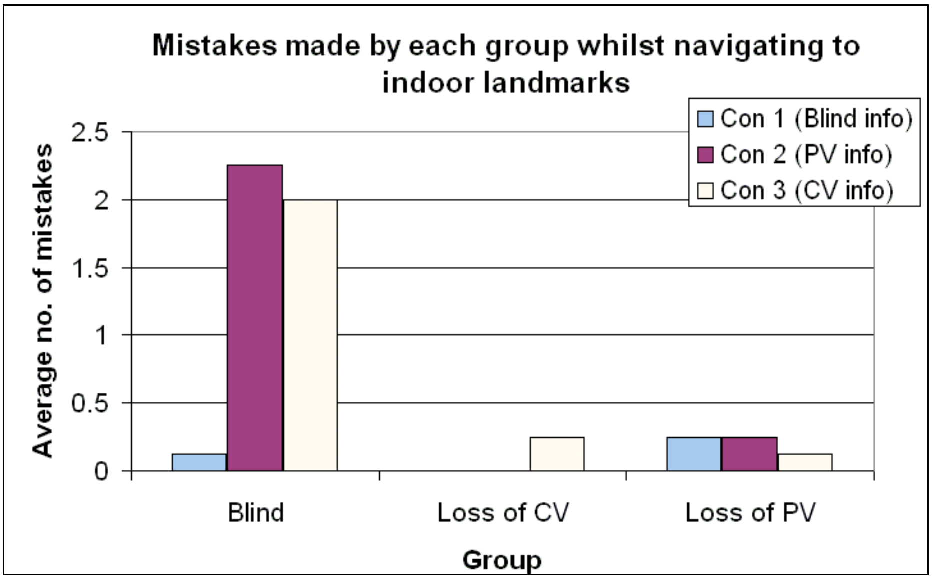


Figure 6.5. The average number of mistakes made by each group when receiving different conditions indoor.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings from Figure 6.5 are as follows:

- When travelling to indoor landmarks, the registered blind group made significantly less mistakes when given condition 1 information than when given condition 2 information (t = -3.461) and condition 3 information (t = -4.899).
- For the loss of CV and PV groups there were no significant differences between the conditions.
- Although the registered blind group made more mistakes overall than the other two groups, their average number of mistakes in condition 1 was similar to the average number of mistakes made in the corresponding conditions for the other two groups (e.g. the number of mistakes made by the loss of CV group when given condition 3 information).

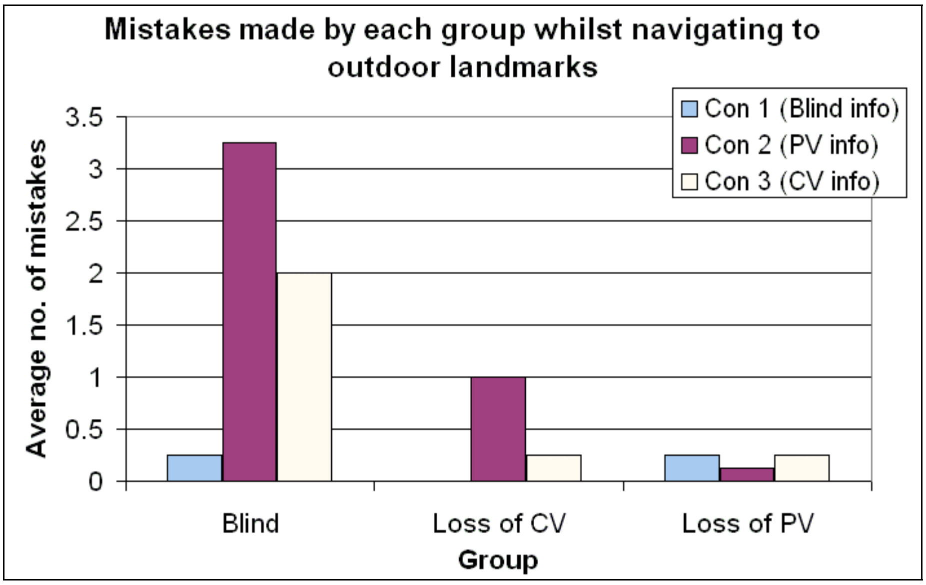


Figure 6.6. The average number of mistakes made by each group when receiving different conditions outdoor.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings from Figure 6.6 are as follows:

- When travelling to outdoor landmarks, the registered blind group made significantly less mistakes when given condition 1 information than when given condition 2 information (t = -7.348) and condition 3 information (t = -2.782). The blind group also made significantly less mistakes in condition 2 than condition 3 (t = -2.441).
- The loss of CV group made no mistakes in condition 1, and made significantly less mistakes when given condition 3 information as apposed to condition 2 information (t = -2.449).
- There were no significant differences in the loss of PV group.
- Although the registered blind group made more mistakes overall than the other two groups, their average number of mistakes in condition 1 was similar to the average number of mistakes made in the corresponding conditions for the other two groups (e.g. the number of mistakes made by the loss of CV group when given condition 3 information).

6.3.2 Subjective assessment

The results of the subjective assessment are divided into, firstly, the NASA TLX questionnaire which concerns participants' perceived level of workload, and, secondly, participants' ratings of meaningful and incidental information.

6.3.2.1 Workload assessment

The content of the NASA TLX questionnaire is described in Section 4.4.2.3. Each group's perceived level of workload for each condition indoor is illustrated in Figure 6.7. Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings are as follows:

- Registered blind participants found conditions 2 and 3 considerably mentally demanding (a source of workload not experienced in condition 1), required almost twice as much effort, caused considerable frustration (similarly a workload dimension not experienced in condition 1), and resulted in participants rating their own performance almost three times worse than in condition 1. This group also found condition 2 more demanding physically and temporally. To support this finding, when taking an average weighted score for all workload dimensions for each condition, there were significant differences between conditions 1 and 2 (t = -19.442) and conditions 1 and 3 (t = -4.706).
- Participants with a PV loss did not find any of the conditions mentally demanding. However, this group found condition 2 more physically demanding, and condition 1 more temporally demanding and frustrating. When taking an average weighted score for all workload dimensions for each condition, there were no significant differences between conditions.
- Participants with a CV loss found condition 2 twice as mentally demanding as conditions 1 and 3. Condition 2 also made participants more frustrated and resulted in them rating their own performance lower. Condition 1 however was found to be more physically demanding and required more effort than conditions 2 and 3. When taking an average weighted score for all workload dimensions for each condition, there were no significant differences between conditions.

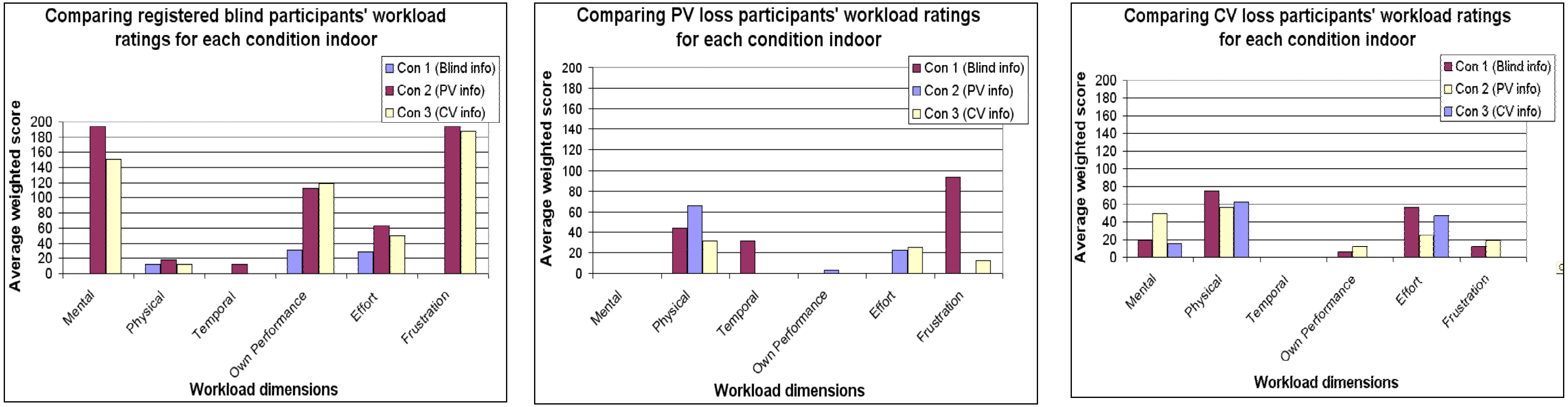


Figure 6.7. Each group's workload ratings for each condition when navigating to indoor landmarks.

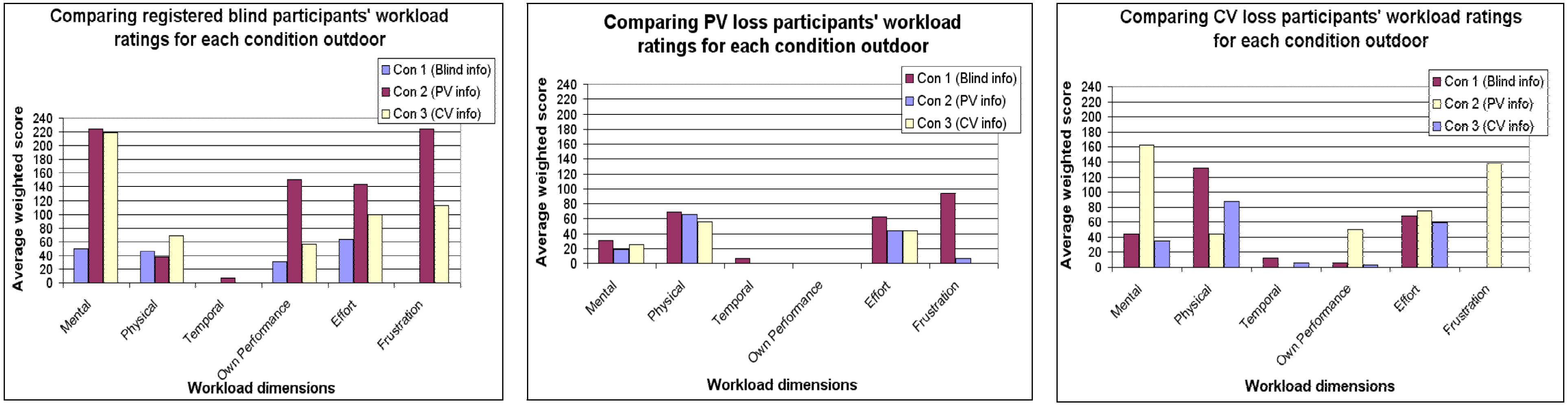


Figure 6.8. Each group's workload ratings for each condition when navigating to outdoor landmarks.

Each group's perceived level of workload for each condition outdoor is illustrated in Figures 6.8. Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings are as follows:

- Registered blind participants thought that conditions 2 and 3 was almost three times more mentally demanding, required considerably more effort, caused considerable frustration (a source of workload not experienced in condition 1), and resulted in them rating their own performance less. This group also found condition 3 more physically demanding and condition 2 more temporally demanding. To support this finding, when taking an average weighted score for all workload dimensions for each condition, there were significant differences between conditions 1 and 2 (t = -39.504) and conditions 1 and 3 (t = -3.302).
- PV loss participants thought that condition 1 was more mentally, physically and temporally demanding, required more effort, and caused considerable frustration. Noticeably, this group did not consider any of the conditions to affect their performance. There were significant differences between conditions 1 and 2 (t = 2.72) but not between conditions 2 and 3.
- CV loss participants thought that condition 2 was almost three times more mentally demanding, required more effort, and was considerably frustrating (a source of workload not experienced in conditions 1 and 3). This group also thought that condition 1 was more mentally, physically, and temporally demanding, required more effort, and resulted in them rating their own performance less. There were significant differences between conditions 1 and 3 (t = -3.302) and between conditions 2 and 3 (t = -9.192).

6.3.2.2 Rating meaningful and incidental information

Once participants had reached indoor and outdoor landmarks, they were asked to rate meaningful and incidental information given to them on a 5-point scale, where 5 represented very helpful and 1 represented very unhelpful. Figures 6.9 and 6.10 illustrate each group's rating of meaningful and incidental information for each condition indoor and outdoor.

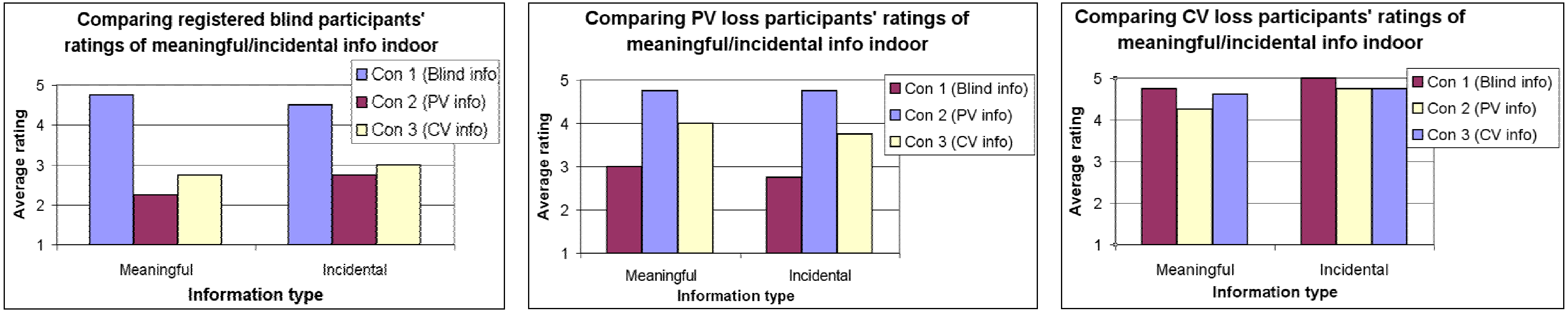


Figure 6.9. Each group's workload ratings for each condition when navigating to indoor landmarks.

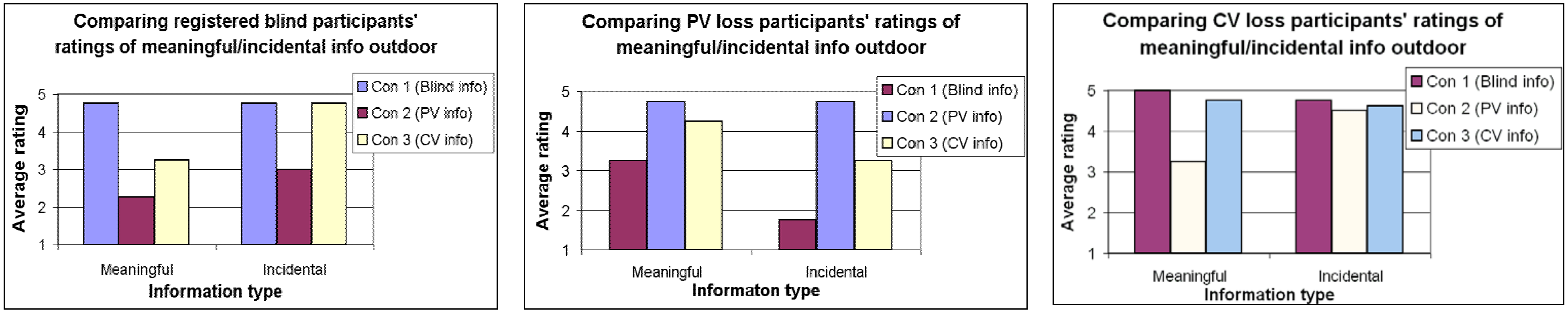


Figure 6.10. Each group's workload ratings for each condition when navigating to outdoor landmarks.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings are as follows:

- Registered blind participants found indoor and outdoor meaningful information from condition 1 significantly more helpful than in condition 2 (for indoor, t = 8.660; and for outdoor, t = 8.660) and condition 3 (for indoor, t = 4.899; for outdoor, t = 5.196). When rating incidental information indoor, blind participants similarly found condition 1 more helpful than condition 2 (t = 3.656) and condition 3 (t = 5.196). However, for incidental information outdoor, conditions 1 and 3 were considered very helpful – condition 1 was significantly more helpful than condition 2 (t = 3)
- The PV loss group found meaningful and incidental information in condition 2 for indoor and outdoor significantly more helpful than condition 1 (for indoor meaningful information, t = -2.782; for indoor incidental information, t = -7; for outdoor meaningful information, t = -5.196; and for outdoor incidental information, t = -7.348) and condition 2 (for indoor meaningful information, t = -3; for indoor incidental information, t = -5; for outdoor incidental information, t = -5.196; and for outdoor meaningful information – though this result was not significant) This group also found meaningful and incidental information in condition 3 more helpful than in condition 1.
- With the exception of meaningful information in condition 2 outdoor, the CV loss group found meaningful and incidental information in all other conditions indoor and outdoor helpful. This group did, however, rate meaningful and incidental information within condition 1 slightly more helpful than the other conditions for both indoor and outdoor routes (none of those differences were significant). The only significant result was for meaningful information between conditions 2 and 3 outdoor (t = 5.196).

6.3.3 Physiological assessment

The results of the physiological assessment are shown in Figures 6.11 and 6.12 for each visually impaired group for each condition indoor and outdoor.

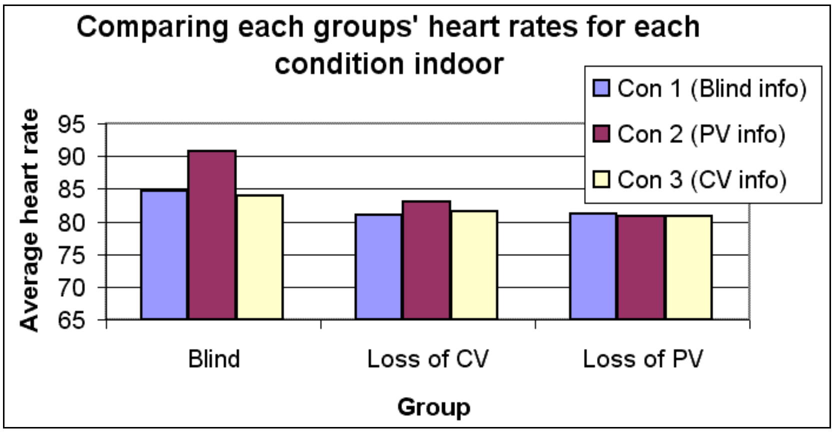


Figure 6.11. The average heart rate of each visually impaired group after receiving each condition indoor.

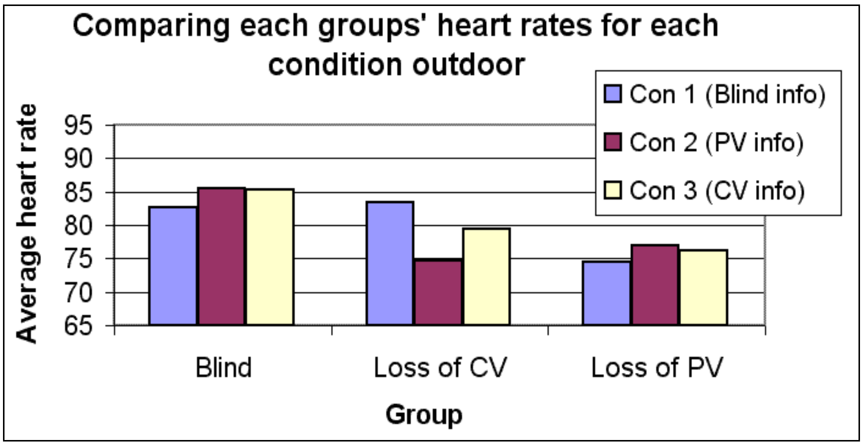


Figure 6.12. The average heart rate of each visually impaired group after receiving each condition outdoor.

Using a two-tailed parametric related t-test (critical value is 2.353, at p = 0.05), the key findings from Figures 6.11 and 6.12 are as follows:

- The blind participants' heart rates were higher when given condition 2 information as opposed to condition 1 information (for outdoors, this difference was significant, t = -3.674) and condition 3 information for both indoor and outdoor. There were no other significant differences.
- The heart rate of loss of CV participants was highest when given condition 2 information indoor and condition 1 information outdoor. However, there were no significant differences between the conditions.
- The heart rate of PV loss participants was not noticeably different across conditions and contexts. However, their heart rates were slightly higher for condition 1 indoor and condition 2 outdoor.

6.4 Discussion

The purpose of this study was to investigate whether different groups of visually impaired participants are more effective, are less stressed, and have a lower perceived level of workload when being guided to indoor and outdoor landmarks using meaningful and incidental information derived from people who experience a similar visual impairment as themselves. The results of a previous study were used to design three conditions: condition 1 concerned meaningful directions based on the navigation-based questions asked by participants who are registered blind, as well as incidental information that was chosen by them to be useful for navigating to a particular landmark. Using the same structure as condition 1, condition 2 was based on participants with a PV loss, and condition 3 based on participants with a CV loss.

Each participant walked to two landmarks indoor and two landmarks outdoor. Each group received all conditions. With regards to the original hypothesis, objective, subjective, and physiological differences between conditions were found though not across all three groups. When given meaningful and incidental information derived from other registered blind people, the blind group (i) were significantly faster indoor and outdoor, (ii) made significantly fewer mistakes, (iii) rated their perceived level of workload significantly less (particularly for mental demand and frustration), and (iv) rated information as being significantly more helpful. Their heart rates were also significantly less when compared to their heart rates after receiving information derived from PV loss people. This indicates that the content of information within the other two conditions did not support their cognitive mapping strategies (i.e. the landmarks used were not as meaningful). Blind people commented that conditions 2 and 3 were not sufficiently detailed enough, especially in describing the local environment, which would also explain this finding.

Within the PV loss group, no statistical differences were found between conditions in the objective assessment. However, this group rated information derived from PV loss people significantly more helpful, especially in comparison to information from blind people, which was found to be more unhelpful on average across all routes. This is supported in the workload assessment, which showed that this group were considerably more frustrated and time-pressured when using information derived from blind people for both indoor and outdoor routes. The physiological assessment, did not, however, show any noticeable differences, suggesting that, due to their ability to detect objects in their focal vision, they were less anxious when receiving information that was not useful to them. Participants commented that condition 1 contained too much detail which was not useful to them (e.g. information on doors indoors), which explains the finding here.

Within the CV loss group, no statistical differences were found between conditions in the objective assessment, apart from significantly more mistakes occurring when this group received information derived from PV loss people. In the subjective assessment, meaningful and incidental information was found to be helpful within all conditions. However, information derived from PV loss people was rated less helpful than the others, especially for meaningful information outdoors. These results are supported by the workload assessment, which reveals that this group found this condition more mentally demanding and frustrating than the other two conditions. However, despite this group rating meaningful and incidental information derived from blind people as the most helpful indoor and outdoor, the workload assessment revealed that this condition was slightly more mentally demanding, more physically demanding, and required more effort than information derived from CV loss people. It is hard to explain these results, though an explanation could be due to the severity of CV loss. In severe cases the participant's vision would be similar to someone who was blind. However, in less severe cases the participant would be able to detect considerably more in the local environment, such as the detection of an upcoming door. Another reason could be age-related since most people who experience CV loss are elderly (i.e. 75% over the age of 66). Therefore, in addition to their visual impairment, cognitive difficulties such as reduced short-term memory may be a factor. Richer information derived from blind people may have therefore been preferred in order to give them a greater confirmation or reassurance of the environment in which they were walking.

6.5 Conclusion

Three groups of visually impaired people (CV loss, PV loss, and registered blind) were guided to indoor and outdoor landmarks using three conditions of meaningful and incidental verbal messages. Each condition derived from a previous study consisting of people with corresponding categories of visual impairment. Significant objective, subjective, and physiological differences were found between conditions though not within each visually impaired group. Generally, the blind group and PV group rated information more helpful and rated their perceived level of workload less when given information derived from the same category of visual impairment. The blind group also reached landmarks quicker, made less mistakes, and had a lower pulse rate (in comparison to PV information). The CV Group, on the other, found information from registered blind people more helpful but rated their perceived level of workload less, on average, when given PV loss and CV loss information.

CHAPTER 7

USER-CENTRED DESIGN FRAMEWORK

This chapter proposes a user-centred design framework for context-aware computing that brings together the proposed multidisciplinary model of context described in Chapter 3 with the research investigating its key components, namely the user's context described in Chapter 4, the application's context described in Chapter 5, and the user-application context described in Chapter 6.

7.1 Aim and purpose

The aim is to propose a user-centred framework for designing context-aware systems that merges the principles of the multidisciplinary model of context (Chapter 3) with the research studies investigating its key components (Chapters 4-6).

Current research into context-aware computing has not sufficiently addressed the human and social issues of design, as discussed in 2.3. The purpose of this chapter is therefore to provide a step-by-step process that application developers can use, firstly, to identify key HCI issues affecting the usability of their context-aware system, and, secondly, to capture richer mobile scenarios or settings within which the context-aware system is likely to operate. The framework is also intended to augment traditional task analysis techniques in order to help HCI researchers to capture the incidental activities of users rather than just the meaningful activities carried out in order to achieve an explicit goal. In doing so, developers will be able to design more useful and relevant task-specific context-aware services that are in tune with the user's context and with their mobile needs and requirements.

The more general purpose of this chapter is to advance user-centred design frameworks for context-aware research and development; an area which is in its infancy. The proposed design framework has also been developed to complement, and to be used in parallel with, software approaches to context-aware development, such as Dey *et al.* (2001) component-based conceptual framework for building context-aware applications.

The final aim of this chapter is to evaluate the proposed design framework by comparing it to another user-centred framework, namely, Bellotti & Edwards (2001) framework concerning the notions of intelligibility and accountability. The framework and its evaluation are also described in Bradley & Dunlop (2004a).

7.2 User-centred design framework

The structure of the design framework is based on the three chapters investigating the key components of the multidisciplinary model (i.e. Chapters 4-6):

- Acquisition of user context data;
- Acquisition of application context data;
- Usability design considerations that address the issues arising from the integration of user and application worlds.

When applying this framework, the multidisciplinary model of context should be interpreted alongside Figure 3.2 in order to understand fully the concepts described.

7.2.1 Acquisition of user context data

1.1. Specify the user's primary goal, determine the mobile settings in which the user would need to travel, and investigate the types of *focal* meaningful activities that may be carried out. For example, in the study described in Chapter 6, the primary goal of visually impaired people was to navigate effectively, efficiently and safely to landmarks; the mobile settings included indoor and outdoor contexts; and *focal* meaningful activities included negotiating traffic lights, side streets, and stairs. Other activities may include interacting with people.

1.2. Investigate what aspects of the *contextual* meaningful environment (outer layers of multidisciplinary model) influence or are used by different groups of users when carrying out focal meaningful activities. For example, when blind people carry out the focal meaningful activity of crossing a street, they occasionally use other people in the social context and the sound of car engines in the physical context as indicators (or landmarks) of when it is safe to cross. People with a loss of PV use the green man indicator displayed on traffic lights and the busyness of traffic in the physical context as indicators. When investigating what aspects of the contextual environment influence users, consider the following dimensions:

- *Task context*: The functional relationship of the user with other people and objects, and the benefits (e.g. resources available) or constraints (e.g. time pressure) this relationship places on the user achieving his/her goal.
- *Physical context*: The environmental location including its gradient and altitude, and consisting of surrounding physical objects, such as buildings, cars, trees, etc. This also includes the orientation, position, state, and purpose of those objects, and the types of information they transmit through audio, visual, odour, texture, temperature, and movement. Contrasting weather conditions (e.g. cloudy/sunny, cold/hot, etc.) and lighting conditions (e.g. daylight/darkness) may also influence how objects are perceived.
- *Social context:* The relationship with, dialogue from, and the density, flow, noise, and behaviour of, surrounding people (e.g. sitting on a crowded train).
- *Temporal context:* The temporal context is embedded within everything (as illustrated in Figure 8), and is what gives a *current* situation meaning, based upon *past* situations/occurrences, expected *future* events, and the higher-level temporal context relating to the time of day, week, month, or season.
- *Application's context:* The application's context concerns any information that has been, or is being, displayed on the user-interface.
- *Cognitive context:* A user's cognitive processing abilities; short- and long-term memory abilities; dislikes/preferences; opinions/beliefs; cultural interpretations; perceptual sensing abilities; perception of levels of privacy and security; cognitive mapping strategies, etc.

1.3. Investigate incidental events that may cause users to deviate away from, often just temporally, their focal meaningful activities being carried out in the mobile settings investigated in 1.1. Determine the *focal* incidental activities that may need to be carried out. For example, in Chapter 4 it is described how incidental events included cars parked on the pavement blocking the path of pedestrians, and incidental activities included navigating around the parked car.

1.4. Repeat 1.2 in order to investigate what aspects of the *contextual* incidental environment influence or are used by different groups of users when carrying out focal incidental activities. For example, blind people preferred to stay on the pavement (physical context) when navigating around the car, whereas PV loss people preferred the shortest route around the car (task context), which involved stepping onto the road. The contextual incidental environment may also affect the user when undertaking focal meaningful activities. For instance, icy conditions (physical context) affecting the user when descending steps.

1.5. Consider the impact those meaningful and incidental focal activities have on the user's context after they have taken place (i.e. how have they constructed the context for future activities?). For instance, after forming incidental focal activities to negotiate road works on the pavement, the visually impaired traveller may choose to walk a different route next time.

7.2.2 Acquisition of application context data

2.1. Use 1.1. and 1.2 to identify types of meaningful focal context-aware services that may be of use to different user groups, e.g. the application described in Chapter 5 transmitted directions that participants used to navigate to landmarks.

2.1.1. Using the context dimensions described in 1.2 (minus the cognitive context), investigate the types of *contextual* meaningful information in the environment (outer layers of multidisciplinary model) needed to infer or identify the user's context in order to provide those meaningful focal services. Also use the following contextual dimensions:

– *User's context*: Information regarding (i) the user's personal diary, including planned activities, notes and reminders, as well as user-defined application settings and preferences (e.g. possibly setting levels of privacy), (ii) physiological sensing such as heart rate to measure levels of anxiety, and (iii) monitored behavioural patterns of the user.

– *Application's context:* The capabilities and limitations of both the application (such as battery usage life, processor speed, memory capacity, sensors, input/output technologies, etc.) and the sources from which data is derived (such as the processing speed of a web-based server).

For instance, in Chapter 5, the application used the location of the user (physical context) and the user's type of visual impairment (user's context) to determine which verbal messages to transmit.

2.1.2. Explore different types of sensors, technologies, services, and networks from which contextual information could be derived. Also consider the high level structure within which the context-aware device will function – e.g. constraints placed on the availability of contextual information.

2.1.3. Evaluate how this information might be sensed, managed, interpreted, and presented to the user. Refer to middleware design, which is described in section 2.3.1 and, more extensively, in (Dey, 1999).

2.2. Use 1.3 and 1.4 to identify types of incidental focal context-aware services, either to support focal incidental activities of the user (e.g. negotiating road works), or to infer focal incidental activities unbeknown to the user (e.g. the location of nearby friends).

2.2.1. Repeat 2.1.1 – 2.1.3. For instance, supporting focal incidental activities may involve identifying, within the incidental contextual environment, the location of road works in the physical context and then re-routing the user in order to avoid the potentially hazardous event. Inferring focal incidental activities may involve sensing the location of nearby friends in the social context in order to inform the user of a nearby friend.

2.2.2. Prioritise incidental services with respect to meaningful services.

2.3. Consider the impact those meaningful and incidental focal context-aware services have on the application's context after they have taken place (i.e. how have they constructed the context for future context-aware services?). For instance, the application may need to reduce the amount of information transmitted if the user revisits a location.

7.2.3 Usability Design considerations

3.1. With respect to the issue of personalisation, investigate the suitability of different types of meaningful and incidental focal context-aware services for different groups of users. In Chapter 6, for instance, it was found that information derived from blind people was more suitable than information derived from PV and CV loss people for guiding blind users to landmarks.

3.2. Investigate how meaningful and incidental focal context-aware services might be transmitted to the user. Prioritise each service with respect to the user's current focal activity, as well as the influence of the contextual environment. In Chapter 6, for instance, focal application services were not transmitted to participants when they were crossing streets since visually impaired people need to use their sensory channels to identify potential hazards.

3.2.1. Based upon 2.1.2 & 2.1.3, evaluate which output technologies should be used to transmit meaningful and incidental focal context–aware services. Speech output, for instance, may be more appropriate when the user's task is visually demanding.

3.2.2. Investigate whether incidental and meaningful services should be pushed to the user (may be desired in safety-critical situations), or pulled by the user (may desired in '*do not disturb*' situations, such as in meetings, in a lecture, etc). Refer to section 2.2.4, which describes the research undertaken by Cheverst *et al.* (2000).

3.3. Investigate privacy and security issues relating to the application sensing personal user information and then communicating this information to external sources, such as service providers, friends, family or other people. How much of the user's context would the user be happy for the application to sense? How much would the user be willing to give away about their current activity and situation? How would the user control different levels of privacy in different situations?

3.4. Investigate the extent to which information transmitted by the context-aware device should be reduced once a user acquires knowledge and experience of particular contexts, activities, and situations (refer to the notion of intertextuality and co-text principles in Linguistics (Connolly, 2001)).

3.5. If the application supports contextual augmentation, explore the human and social implications of allowing users to disseminate incidental and meaningful messages for others. Consider 3.2.2 when exploring the retrieval of messages by others.

3.6. Investigate how the application should respond to situations where information or services are wrongfully inferred, inaccurate, or unknown. During conflicts of interest, control should be deferred to the user (Bellotti & Edwards, 2001). Also refer to the work of Bohnenberger & Jameson (2001) who address the uncertainty a system might have about whether a user will follow recommendations provided by the system. Decision-theoretic planning methods are used to select an optimal *policy* for the situation-dependent presentation of recommendations.

3.7. Investigate the likely impact of context-aware behaviour (e.g. adaptation, proactiveness, etc) on the user, e.g. was the information expected and understood. There is a need to maintain levels of predictability and a need to help maintain user control by designing the system to be comprehensible to the user. Hook (2000) notes that successful intelligent interfaces either perform very simple adaptations based on limited knowledge about the user or base adaptation on simple user actions rather than trying to infer complex user models. Unfortunately many user interfaces are still too complex, resulting in a need for tools that can filter information, make suggestions, or guide complex tasks that would reduce workload of the users. This can partly be achieved by making the interface sufficiently visible to help the user understand the reasoning behind some of the system's actions. This would be particularly important in safety critical situations, such as in the case of visually impaired people navigating in busy, hazardous environments.

7.3 Conceptual application of framework

This section provides a high-level illustration of how the design framework might be applied. The application area is of supporting orientation and navigation of visually impaired people.

– *User goal*: To navigate independently through outdoor environments efficiently, effectively, and safely. Requirements: Information regarding hazards, traffic lights state, likely busyness of people/traffic.
– *Meaningful user activities*: To negotiate crossings/ traffic lights, steps and kerbs, street signs, and poorly designed or maintained environmental features (e.g. potholes in the road, sloped kerbs).
– *Incidental user activities*: To negotiate flows of people/ traffic (e.g. queues at bus stops), temporary obstacles (e.g. overhanging branches, cars parked on pavement, etc.), and excavation work on pavement.

Whilst negotiating a crossing, for instance, a blind person may use or be influenced by the contextual information in the (i) physical context: listening for car engines to indicate that cars have stopped, and feeling for tactile markings (small bumps) for alignment, (ii) social context: awareness of other people waiting/ crossing, (iii) task context: beeping from traffic lights to indicate when it is safe to cross, and the time given to cross the road, (iv) temporal context: dense flows of traffic/people during rush hours, and (v) cognitive context: some blind people prefer to wait for others to cross the street with them, and based upon past experiences, some traffic lights do not provide audio feedback.

Table 7.1 illustrates examples of meaningful (M) and incidental (I) services, which may provide assistance.

Service	Acquisition of information
M: Traffic lights state	Radio Frequency beacons positioned on traffic lights could transmit information.
M: Width of streets (2/4 lanes to cross)	User's GPS location, and detailed geographical data could be downloaded either prior to journey or in real-time through web-based servers.
I: Busyness of traffic and people	User's GPS location, and web-based congestion reports, derived from web cams.
I: Nearby road works	User's GPS location, and web-based servers revealing the locations of roadwork.

Table 7.1. Possible application services.

7.4 Evaluation of Design Framework

In this section the proposed design framework, described in section 7.2, is evaluated. An outline version of the framework, shown in Appendix D-1 (Design Framework 1), was used to compare it with Bellotti & Edward's (2001) framework for context-aware computing. This is based on the notion of accountability and intelligibility and is described in section 2.3.2.1 and included in Appendix D-1 (Design Framework 2).

7.4.1 Method

An introductory lecture on context-aware computing was given to 25 postgraduate students (22 males and 3 females) from the Department of Computer and Information Sciences at Strathclyde University. After, they were set a task requiring them to design two different context-aware systems. Students worked in groups (11 pairs, and one group of three) and to design each system they were given either (i) my design framework or Bellotti & Edward's framework, and (ii) one of two scenarios – an example of one is given below:

"Bob is blind and has just arrived at Glasgow Airport. He is travelling to London for a school reunion dinner. He needs to fly to Stanstead and then catch a train to

King’s Cross Station. This should allow him time to walk to his hotel and check in before meeting his friends in the restaurant. Bob wishes to use his context-aware device to plan for, and facilitate, his mobile activities.”

The allocation of students to each group and the distribution of scenarios and design frameworks were randomised. All groups received both frameworks and scenarios. Groups were given 30 minutes to design each system.

7.4.2 Results

An independent examiner, who had considerable knowledge of context-aware design, marked the two designs provided by each group (see Appendix E). Marks out of 10 were awarded for each design, depending on how well:

- the user's context had been addressed (identification of user requirements, tasks, activities) (4 Marks),
- the application's context had been addressed (identification of useful contextual information and services, and the utilisation of different types of technologies) (3 Marks),
- usability issues had been identified and discussed (any human and social design issue) (3 Marks).

The overall results are illustrated in Figure 7.1, showing the differences in performance between my design framework (DeFr1) and Bellotti & Edward’s (DeFr2).

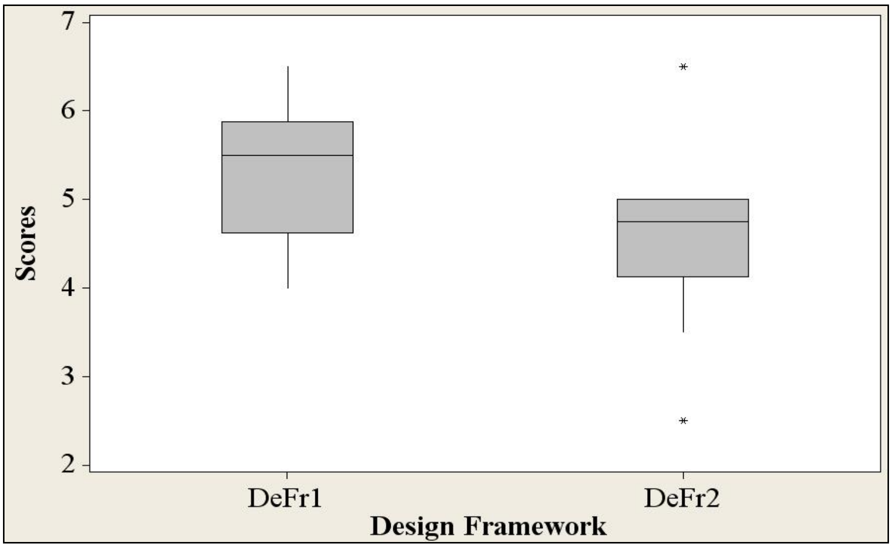


Figure 7.1. Overall performance using each framework.

The key findings of Figure 7.1, together with the statistical data in Table 7.2 from a two-tailed parametric related t-test, are as follows:

- When students used DeFr1 they performed significantly better overall, than when they used DeFr2 ($t = 2.026 > 1.796$, at $p = 0.10$). As shown in Figure 2, the median value for DeFr1 is far greater with most of the data values above the first quartile being greater than DeFr2's median value.
- Students addressed the user and application's context significantly better using DeFr1 ($t = 2.916, 2.862 > 2.201$, at $p = 0.05$).
- Students attained a higher mean value for the identification of usability issues when using DeFr2, though this result was not significant at $p = 0.05$.

Marking topic	Mean		St Dev		*t*-stat	Level of Sig
	Fr1	Fr2	Fr1	Fr2		
Overall	5.33	4.71	0.79	1.12	2.026	0.10
User	2.25	1.63	0.72	0.57	2.916	0.05
Application	2.08	1.54	0.70	0.40	2.862	0.05
Usability	1.08	1.54	0.70	0.62	-1.538	0.05

Table 7.2. Testing for significance (shaded cells show a significant result).

Post study feedback, derived using a simple questionnaire, revealed that students felt pressed for time when using DeFr1. This was evident in the results, as half of the groups received <= 1 mark for the last section concerning usability issues. Consequently, this influenced the overall significance strength of the study as shown in Table 7.2, which explains why a significance level of 0.10 was used.

7.5 Conclusions

A user-centred framework for designing context-aware systems has been proposed, bringing together the proposed multidisciplinary model of context described in Chapter 3 with the research investigating its key components, namely the user's context described in Chapter 4, the application's context described in Chapter 5, and the user-application context described in Chapter 6. It should be emphasised that the proposed framework is not a completed, static entity but is a framework that may adapt and evolve over time. For instance, the framework may need to be modified or updated from experience of using the framework or when new applications of context-aware computing emerge.

Potential users of the framework should also note that in applying the framework, other frameworks should also be considered, depending on the scenario being addressed, for both understanding the application domain and for informing the design. For example, consulting the Locales Framework, which concerns the exploration of a current social situation (or locale) in which people collaborate, communicate, and achieve work related goals (Fitzpatrick 1998), may be beneficial if the domain is more focused towards 'mobile' work based activities.

As personalisation is a central theme of the framework and thesis generally, it is worth raising the issue of tailorability (e.g. allowing the user to specify personal privacy requirements) versus complexity of the user interface. Arguably, the more flexibility and opportunity given to the user to tailor application services to individual requirements, the more complex the interface will become. This issue is likely to involve a trade-off in order to give adequate control to the user while at the same time ensuring the interface is suitably comprehensible to use.

The design framework provides two main contributions to research, each of which will be addressed in turn.

C.1 Richer modelling of user-interface interaction in mobile settings

Referring back to the multidisciplinary model of context in Chapter 3, user-interface interaction in mobile settings can be better understood when theories of context in different disciplines are brought together. Using psychology research, the framework helps application developers to not just explore meaningful user activities relating to his/her primary goal, but also to explore incidental, unpredictable, and dynamic user interactions with other people and objects, which occur frequently in mobile settings. The framework uses linguistics research to help application developers investigate what impact the contextual world (i.e. the dimensions of context) has on the user when undertaking focal activities, and on the computer when executing focal context-aware services.

Key human and social issues emerge when investigating these concepts, such as identifying how and when (if at all) to contact the user during situations where the demand on the user's attention is being spread across multiple contextual interactions. The framework indicates that often a prioritisation is needed between a user's current activity and the focal services available for transmission.

The framework also emphasises throughout the importance of investigating differences between users. The user studies involving visually impaired people revealed that what is meaningful to one person can be incidental to another, so the issue of personalisation is, and will continue to be, a significant area of research.

Adapting to temporal changes is also at the heart of the framework (1.5 and 2.3) since this is an important concept for user-interface modelling in mobile settings. Contextual interactions construct the context for future interactions and so application developers need to account for those in design.

C.2 Advanced user-centred design approaches to mobile context-aware computing

The proposed design framework has considerably advanced the limited body of research tackling user-centred design frameworks or approaches to mobile context-aware computing. With respect to the Bellotti & Edward's (2001) design framework described in Section 2.3.2.1, the framework forces application developers to investigate more deeply the contextual influences (i.e. dimensions of context) affecting a user's spatial decisions and behaviour, especially those that are unpredictable or incidental.

The framework also provides a *process* by which embodied interactions (Dourish, 2001), described in section 2.3.2.2, can be conceptualised by application developers. For instance, included in the framework's design is the distinction between various types of relevant focal activity that include not just the immediate interaction with the mobile device, but also the rich interactions with people and other physical objects. By assessing these interactions together also advances Smailagic *et al.* (2001) activity/attention framework, described in section 2.3.2.3 as it provides an insight into the reasons why people become distracted from their focal activity (point 1.3 in framework). These issues are hugely important to application developers since incidental distractions, which occur frequently in mobile settings, need to be identified and suitably supported by focal application services. The ability of an application to do this will determine its success. Users will become considerably frustrated if bombarded with information during distracted moments or moments of incidental focal activity. The proposed framework facilitates application developers in determining how the user should be supported in such situations, as described in point 2.2 in the framework.

The framework also provides an augmentation to traditional task analysis techniques. As discussed in section 2.3.2.4, many HCI techniques have been highly effective in assessing tasks, where the user operates in a single domain, works in a fixed context of use, and has an explicit meaningful or purposeful goal to carry out. Those techniques do not transfer well to mobile settings where people respond to unpredictable and incidental events that occur around them. The proposed framework augments task analysis techniques since both meaningful and incidental goals and focal activities of the user can be investigated.

From a general perspective, the framework helps application developers identify and explore scenarios. These scenarios are gauged at a level at which people understand and are highly useful for Scenario Based Design, which concerns designing systems centred on scenarios of interaction, as extensively discussed by Carroll (2000).

In support of both contributions (C.1 & C.2), the evaluation of the design framework revealed that students performed statistically better in identifying the context of the user and application. By enabling application designers to address this integration, usability is placed at the *centre of the design process*. Separation of concerns in software development therefore needs to be undertaken in conjunction with human and social analyses of context, enabling the application developer to build more useful and usable context-aware systems. This framework provides a valuable tool with which to conceptualise these issues.

CHAPTER 8

CONCLUSIONS

This thesis has proposed a user-centred framework for designing context-aware applications in order to address the limited appreciation of human and social issues within existing research and development. The purpose was to help application developers (i) build richer descriptions and scenarios of how their context-aware system might be used in different mobile settings, and (ii) capture key human and social issues affecting the usability of their system. The main application area was of supporting navigation and orientation of visually impaired people since this area generally represents a particularly challenging test for context-aware design and research.

The critical review of literature covered many areas of research. Context-aware computing was introduced as an exciting and promising area within which traditional human-computer interaction could be minimised, and become more seamless, naturalised, and task-specific. Good examples of application areas in mobile computing were discussed and then analysed with respect to key usability issues that remain insufficiently addressed in current research, namely, personalisation, designing for mobile environments, localising information and its delivery, styles of acquiring contextual information, privacy and security, and social issues.

As a means of investigating those issues further, a review of design frameworks, techniques, and processes (mostly user-centred) for designing context-aware systems was undertaken. This revealed that many of those design practices or principles need to be expanded in order to capture and analyse the dynamic and contextually rich mobile computer settings within which people interact. This led to a cross-disciplinary analysis of the notion of *context* in order to draw upon contrasting viewpoints and theories. As part of this valuable exercise, models were constructed and used to cross-analyse those different viewpoints. Similarities and differences were identified, and it was felt that the most pressing areas for further investigation related to contextual interactions, the notion of relevancy, and the temporal and social aspects of design.

Cognitive mapping research was then introduced as an area in which these issues could be conceptualised and investigated. The main application area of the framework was of supporting navigation of visually impaired people, and so the review included a discussion on the extent to which traditional techniques and aids, and the plethora of distant navigation technologies (e.g. GPS-based systems, and intelligent canes) support the mobility requirements of visually impaired people.

In light of the literature review, three detailed aims were specified, each of which will now be summarised. Using the review on the notion of context described in section 2.4, the *first aim* was to merge single discipline models of context in psychology, linguistics, and computer Science in order to construct a multidisciplinary model of context. The purpose was to use this model to (i) capture key usability issues of context-aware design, including those issues already discussed in sections 2.2, (ii) advance task/activity models in contextual rich mobile settings, (iii) augment traditional HCI techniques used for analysing those mobile settings, and (iv) provide a foundation on which to construct a design framework.

Capturing, defining and modelling the essence of context from a multidisciplinary perspective was an extremely beneficial and interesting endeavour. When each discipline was analysed individually, the usability implications were compelling. The differentiation between meaningful and incidental context in psychology, for instance, demonstrates how a user's decisions can diversify when other objects and people are encountered incidentally.

When disciplines are assessed collectively, it was found that each possesses similar, overlapping and complimentary characteristics that can be conceptualized across each other (despite tackling different representations of context). Further exploration is required in two particular areas:

(i) An investigation of which aspects of the task, social, physical, temporal and cognitive context are relevant to users when undertaking, or planning for, activities in various types of mobile scenarios. Procedures and techniques for tracking relevant *contextual interactions* need to be developed so that usability is placed at the centre of context-aware design and development. These techniques would need to establish links between a person's unique cognitive and perceptual processes (e.g. people with visual impairments) and the presence, state and purpose of static and dynamic objects in the environment.

(ii) An investigation of the *temporal context* with respect to its relationship with each dimension of context, and how this relationship influences the process with which people form goals and carry out focal actions. For instance, a user's relationships with other people and objects change and evolve over time. In order for context-aware systems to adapt to such changes, a greater emphasis must be placed on multidisciplinary investigations in order to provide a deeper understanding of human behaviour in mobile computer settings.

Summary models representing the opinions of researchers within each discipline were used to propose an outline and detailed multidisciplinary model of context (Figures 3.1 & 3.2). These are composed of four quadrants demonstrating (i) the differentiation of focal and contextual aspects of the user and application's world, (ii) the separation of meaningful and incidental dimensions, and (iii) the user's cognitive processes and the processes of the application. The proposed model provides a foundation on which complex mobile scenarios can be conceptualized and modelled. Its applicability, versatility, and effectiveness to different applications of context-aware computing were illustrated using examples including user communities and mobile tourist guides.

When applying my model to different areas of context-aware computing, the true value of my multidisciplinary endeavour becomes apparent. From a high-level or holistic perspective, it allows application developers to develop richer scenarios and descriptions of how the mobile system may be used within various dynamic mobile settings. The model provides an augmentation to traditional task analysis, as the incidental interactions and occurrences in the mobile world can be investigated, and not just the more predictable meaningful actions involved in accomplishing an explicit goal. As a result, more refined levels of user support can be mapped out; an exercise which will help application developers to design both meaningful and incidental services.

From a low-level perspective, the model can be used to investigate very specific issues of human behaviour and application development, both of which are represented dynamically (i.e. context is a *process*). Within the model of the user's world, this includes both the contextual factors that influence human decisions, spatial behaviour, and focal interactions, and the subsequent construction of context within which future interactions take place. The model also helps to address the issues of human variability in perception and cognition, and helps to tackle the unpredictable nature of users and the environments in which they interact. Within the model of the application's world, the value lies in the processes of identifying useful contextual information about the user, inferring human activity, delivering useful, relevant and timely services, and monitoring the evolution of users and environments.

Another benefit of the model is that it focuses on integrating the worlds of the user and application. Issues can be considered together or in parallel; an activity that does not occur often enough in current application development, and which can lead to more usable and unobtrusive systems. This helps developers to identify gaps and overlaps in knowledge, all of which can be used to draw out clearer and more seamless levels of support.

The more specific contributions to usability research, in terms of the unresolved usability issues discussed in section 2.1.7, are as follows:

Personalisation: In the user's world, the multidisciplinary model, depicted in Figure 3.2, illustrates that personalisation should not just be assessed simply from the user's cognitive context (e.g. adapting to a user's needs and preferences; the premise of most research on personalisation) but rather assessed in terms of how personalisation needs are influenced and shaped by, and processed along with, the contextual world (e.g. the influences of the social context on decision making – although not preferred by the user, making a group decision to eat at a Indian restaurant to satisfy the majority of people present). By doing so, more accurate predictions can be made regarding user activities, allowing context-aware applications to determine situations where conflicts of interest may occur (e.g. although I've expressed a desire to be guided walking back to my hotel, my device advises that this is potentially unsafe and so provides a taxi number). In the application's world, personalisation would therefore need to be weighed up against sensed contextual information, for example, recommending an Indian restaurant to suit the majority of people present rather than recommending a restaurant to suit the user's preference.

Localising information and its delivery: The contribution of the model to this issue concerns the separation of different layers of context and the illustration of how each is embedded in a temporal context that is constantly being constructed after contextual interactions take place (shown in Figure 3.3). Localisation of information is an integral part of this issue, since the application must sense those layers of context and monitor their evolutionary changes, such as a user's accumulation of experiences and knowledge, or a church that has been converted to a pub or restaurant, or a particular activity that has become fashionable. Essentially, the model would allow application developers to model different mobile task scenarios of the user, providing a structure within which information requirements could be ascertained. The contribution to the issue of information delivery is also clearly evident. The model would enable application developers to assess the suitability of different delivery techniques, which would depend on the user's current focal activity (driving vs. sitting in a café), and whether it was meaningful or incidental (e.g. acquiring background information prior to visiting a tourist attraction vs. negotiating an unexpectedly busy road). It would also depend on the meaningful contextual layers, shown in Figure 3.2, affecting those activities, such as the noise of nearby people, current lighting conditions, and the user's cognitive abilities (e.g. finds current activity mentally demanding and a drain on his/her attention).

Styles of acquiring contextual information: The contribution to the debates on information *push* vs. information *pull* can also be captured and assessed by the multidisciplinary model. Similar to the other issues, the separation of the meaningful and incidental worlds, shown in Figure 3.2, provides a useful distinction for application developers. For instance, during high-priority meaningful tasks (e.g. giving a lecture, or attending a meeting), it is likely that users would be less tolerant of incidental information being pushed to them. Whereas during low-priority meaningful and incidental tasks, such as tourists visiting a new city, it is possible that incidental information may in fact be desirable as they may wish to be more spontaneous with their decisions and activities. In these circumstances perhaps pushing information to users may be more appropriate. So, in essence, the model allows for such scenarios to be mapped out in terms of prioritising what is important to the user in a particular situation.

Social issues: The model nicely depicts different social influences to which the user is subjected. This provides application developers with a greater awareness and ability to adapt their systems' behaviour to different social circumstances. As shown in the model in Figure 3.2, the user may be focally interacting with other people either meaningfully or incidentally (speaking to work colleagues in a meeting, or speaking to friend who had called unexpectedly), or be contextually surrounded by people who may be meaningfully influencing the user (e.g. interacting with a mobile phone whilst being surrounded by people on a busy train), or have no impact at all, making them incidental (e.g. people passing by). Referring back to the issues discussed in section 2.1.7.6, the multidisciplinary model provides a valuable foundation and structure in which interactions of people and systems (discussed by Dourish, 2001) can be investigated. For instance, different social relationships, current focal activity and contextual situation, and types of meaningful or incidental information communicated by others, all have an influence on how best to inform the user.

The main lesson that has been learnt from the construction of my model is centred on the difficulty in representing context as a single model to cover the exhaustive viewpoints and interpretations that exist across and within disciplines. While context is a complex subject that includes many wide-ranging issues, it is an extremely important area of research in mobile computing. Future mobile systems will be expected to operate in dynamic and contextually rich environments, and it is felt that the proposed multidisciplinary model is sufficiently detailed and versatile to at least identify and investigate these issues further.

The *second aim* of this thesis was to apply the principles of the multidisciplinary model of context exclusively focusing on the substantive issue of personalisation discussed in 2.1.7.1. The issue of localisation (discussed in 2.1.7.3), however, is also addressed to a lesser extent in the last two studies described in section 4.5 and in Chapter 6. The aim was to use the model to design a series of user studies in order to investigate the issue of personalisation of context-aware navigation services. More specifically, this involved three key stages involving (i) an investigation of the user's context (upper two quadrants of the multidisciplinary model of context), (ii) designing a prototype application to represent the application's context (lower two quadrants of the model), and (iii) an investigation of the user-application context, or the integration of the user and application's worlds.

Four studies were undertaken to investigate the user's context of the multidisciplinary model of context. The aim of the first two studies (sections 4.3 & 4.4.1) was to investigate whether sighted and visually impaired people use different landmarks or cues in the meaningful contextual environment (outer layers of the multidisciplinary model of context) in order to carry out focal activities to orientate and navigate. Using a qualitative approach called think-aloud used by cognitive mapping and HCI researchers, sighted and visually impaired participants were asked to describe routes. The words/phrases used within those descriptions were categorised into 11 classes, and the frequency with which words/phrases in those classes were uttered or written was monitored. This provided an indication of the proportion of information used within and across groups.

The results revealed that within the sighted group, younger participants used more textual-structural information (names of bars, restaurants, shops) than textual-area/street information (names of streets/areas) in comparison to older participants. When comparing sighted and visually impaired peoples' route descriptions, visually impaired people used more directional, structural, environmental, numerical and descriptive information. They also used information within additional categories relating to sensory, motion and social contact. In the third study (section 4.4.2), verbal messages based on those route descriptions of sighted people (condition 1) and visually impaired people (condition 2) were used to guide different groups of sighted and visually impaired people to landmarks. The results revealed that visually impaired participants reached landmarks quicker, were less frustrated, and required less mental and overall effort when given information derived from other visually impaired people in condition 2. Sighted people, on the other hand, thought this condition was more mentally demanding and frustrating, and required more effort.

The fourth user study (section 4.5) involved investigating whether people with contrasting visual impairments require different information about the meaningful contextual environment (e.g. steps, doors, distance, etc.) and incidental contextual environment (e.g. cars parked on the pavement, crowd and traffic flows, etc.) when they orientate and navigate through indoor and outdoor environments. A slightly different technique was used to investigate cognitive maps. Instead of route descriptions, three groups of visually impaired participants, namely, CV loss group, PV loss group, and registered blind group, walked to pre-determined destinations and were encouraged to ask questions about the meaningful and incidental contextual environment in order to navigate to those destinations effectively and safely. The type of questions asked were categorised and used to determine whether differences existed between visually impaired groups. Once participants arrived at landmarks they were also asked to choose, from a list, two incidental services that would have been useful to them when navigating to the current landmark. Incidental services consisted of information about the incidental contextual environment.

The results revealed that blind people asked categories of question and used environmental cues not used by the other two groups. Questions about the meaningful contextual environment concerned side streets, steps, and doors, while tactile markings and wind direction were used for environmental cues. The blind group also asked significantly more questions regarding distance, and a greater percentage used sounds to orientate. The blind and CV group also asked questions not asked by PV loss group about cars parked on the pavement in the incidental contextual environment. In another comparison, the CV loss group asked far more questions generally than the PV loss group and within additional categories relating to signs and traffic lights. There were also differences in the most popular incidental services chosen across each group. Information on temporary obstacles (e.g. cars parked on pavement) was the most popular service for the registered blind group, information on crowd flow the most popular for the loss of CV group (e.g. queues of people at bus stop), and information on structural information the most popular for the loss of PV group (e.g. passing Royal College Building). Differences between contexts were also found. More questions were asked inside than outside (the greatest increase by the PV loss group). For some categories, the number of questions asked became proportionately greater, such as distance for the blind group (e.g. the distance to a turning). Some environmental cues were used by a greater percentage of participants indoor, such as light-dark areas for the CV loss group.

With respect to the multidisciplinary model of context in Figure 3.2, the types of landmarks used by participants can be linked to the outer layers of the contextual world. Sighted participants and PV loss groups used landmarks or cues exclusively in the physical context (e.g. Border's bookshop, Queens Street, etc) and task context (e.g. left/right). Whereas, in addition to those context dimensions, the registered blind and CV loss groups also used and were influenced by cues in the social context (e.g. sound of people at traffic lights to indicate when it was safe to cross a street). With respect to Figure 3.3, the latter two groups were *influenced* (starting from the right arrow) by more in the incidental contextual environment - for instance, by cars parked on the pavement (physical context), by traffic flows (physical context), and by flows of people (social context). The sighted and PV loss group, on the other hand, exclusively *used* (i.e. starting from the left arrow) fixed and meaningful landmarks as reference points to navigate to landmarks, and thus were less affected by incidental events occurring around them.

The investigation of the user's context of the multidisciplinary model revealed that differences exist between what people use or require in the meaningful and incidental contextual environment when orientating and navigating. However, this investigation has only identified some of the differences, which contribute to the issue of personalisation of context-aware mobile devices. Future studies or research, for instance, may involve investigating (i) cross-cultural differences in the use of landmarks, (ii) differences in the use of landmarks when driving, and (iii) differences in the use of landmarks when navigating through urban vs. rural environments.

The second stage of the second aim was to use the multidisciplinary model of context in order to design the application's context. It was highlighted earlier that the motivation of this thesis was not to advance software development of context-aware design. As a result, the design of the application's context was fairly primitive. However, the characteristics of, and the components used to represent, the application's context provide an invaluable insight into how an application might better support the user's mobile activities. As illustrated in the multidisciplinary model of context, the distinction is made between meaningful focal application services (e.g. cross two curbed side streets), and incidental focal context-aware services (e.g. cars parked on the pavement).

The outer layers of the multidisciplinary model of context illustrate how information can be sensed or used from (i) the meaningful contextual environment, which for the study included sensing the user's location in the physical context (only outdoor however) and using the user's type of visual impairment in the user's context – this information was used to adjust the content of information given to the user, or (ii) the incidental contextual environment, which included artificially determining crowd flows in the social context; traffic flows, temporary obstacles, traffic lights' state, lighting conditions, and structural information in the physical context; and also using the user's type of visual impairment in the user's context - all of this information was used to adjust incidental information given to the user. To transmit meaningful information outdoors, the application ran on a laptop connected to a GPS device and, based upon the current location and the user's type of visual impairment, audio files were transmitted to the participant via a set of headphones. For indoor routes, the researcher controlled the timing of when meaningful verbal messages were played using a Compaq IPAQ. To transmit incidental information, the researcher, who accompanied participants, verbally transmitted messages for both indoor and outdoor routes. The main problem experienced technologically was of weak, lost or inaccurate GPS data. The built-up environment through which participants walked was responsible for this difficulty.

The third and final stage of the second aim of the thesis was to investigate the user-application's context. Three groups of visually impaired people (CV loss, PV loss, and registered blind) were guided to indoor and outdoor landmarks using three conditions of meaningful and incidental verbal messages. Each condition derived from a previous study consisting of people with corresponding categories of visual impairment. Significant objective, subjective, and physiological differences were found between conditions though not within each visually impaired group.

Generally, the blind group and PV group rated information more helpful and rated their perceived level of workload less when given information derived from the same category of visual impairment. The blind group also reached landmarks quicker, made less mistakes, and had a lower pulse rate (in comparison to PV information). The CV group, on the other, found information from registered blind people more helpful but rated their perceived level of workload less, on average, when given PV loss and CV loss information.

The *third aim* of this thesis was to combine principles from the proposed multidisciplinary model of context with the results of the user studies in order to formulate a design framework, which would advance user-centred approaches and techniques for designing context-aware systems. The idea here is to provide a step-by-step process with which developers can use, firstly, to improve their awareness and understanding of complex mobile user scenarios, and, secondly, to improve their ability to assess, and account for, these key design issues during application development. The final aim is to evaluate the proposed design framework by comparing it to Bellotti & Edwards (2001) user-centred framework described in section 2.3.2.1.

A user-centred framework for designing context-aware systems was proposed, bringing together the proposed multidisciplinary model of context described in Chapter 3 with the research investigating its key components, namely the user's context described in Chapter 4, the application's context described in Chapter 5, and the user-application context described in Chapter 6. It should be emphasised that the proposed framework is not a completed, static entity but is a framework that may adapt and evolve over time. For instance, the framework may need to be modified or updated from experience of using the framework or when new applications of context-aware computing emerge.

Potential users of the framework should also note that in applying the framework, other frameworks should also be considered, depending on the scenario being addressed, for both understanding the application domain and for informing the design. For example, consulting the locales framework, which concerns the exploration of a current social situation (or locale) in which people collaborate, communicate, and achieve work related goals (Fitzpatrick 1998), may be beneficial if the domain is more focused towards 'mobile' work based activities.

As personalisation is a central theme of the framework and thesis generally, it is worth raising the issue of tailorability (e.g. allowing the user to specify personal privacy requirements) versus complexity of the user interface. Arguably, the more flexibility and opportunity given to the user to tailor application services to individual requirements, the more complex the interface will become. This issue is likely to involve a trade-off in order to give adequate control to the user while at the same time ensuring the interface is suitably comprehensible to use.

The design framework provides two main contributions to research:

C.1 Richer modelling of user-interface interaction in mobile settings

Referring back to the multidisciplinary model of context in Chapter 3, user-interface interaction in mobile settings can be better understood when theories of context in different disciplines are brought together. Using psychology research, the framework helps application developers not only to explore meaningful user activities relating to his/her primary goal, but also to explore incidental, unpredictable, and dynamic user interactions with other people and objects, which occur frequently in mobile settings. The framework uses linguistics research to help application developers to investigate what impact the contextual world (i.e. the dimensions of context) has on the user when undertaking focal activities, and on the computer when executing focal context-aware services.

Key human and social issues emerge when investigating these concepts, such as identifying how and when (if at all) to contact the user during situations where the demand on the user’s attention is being spread across multiple contextual interactions. The framework indicates that often a prioritisation is needed between a user’s current activity and the focal services available for transmission.

The framework also emphasises throughout the importance of investigating differences between users. The user studies involving visually impaired people revealed that what is meaningful to one person can be incidental to another, so the issue of personalisation is, and will continue to be, a significant area of research.

Adapting to temporal changes is also at the heart of the framework (1.5 and 2.3) since this is an important concept for user-interface modelling in mobile settings. Contextual interactions construct the context for future interactions and so application developers need to account for those in design.

C.2 Advanced user-centred design approaches to mobile context-aware computing

The proposed design framework has considerably advanced the limited body of research tackling user-centred design frameworks or approaches to mobile context-aware computing. With respect to the Bellotti & Edward's (2001) design framework described in Section 2.3.2.1, the framework forces application developers to investigate more deeply the contextual influences (i.e. dimensions of context) affecting a user's spatial decisions and behaviour, especially those that are unpredictable or incidental.

The framework also provides a *process* by which embodied interactions (Dourish, 2001), described in section 2.3.2.2, can be conceptualised by application developers. For instance, included in the framework's design is the distinction between various types of relevant focal activity that include not just the immediate interaction with the mobile device, but also the rich interactions with people and other physical objects. By assessing these interactions together also advances Smailagic *et al.* (2001) activity/attention framework, described in section 2.3.2.3 as it provides an insight into the reasons why people become distracted from their focal activity (point 1.3 in framework). These issues are hugely important to application developers since incidental distractions, which occur frequently in mobile settings, need to be identified and suitably supported by focal application services. The ability of an application to do this will determine its success. Users will become considerably frustrated if bombarded with information during distracted moments or moments of incidental focal activity. The proposed framework facilitates application developers in determining how the user should be supported in such situations, as described in point 2.2 of the framework.

The framework also provides an augmentation to traditional task analysis techniques. As discussed in section 2.3.2.4, many HCI techniques have been highly effective in assessing tasks, where the user operates in a single domain, in a fixed context of use, and has an explicit meaningful or purposeful goal to carry out. Those techniques do not transfer well to mobile settings where people respond to unpredictable and incidental events that occur around them. The proposed framework augments task analysis techniques since both meaningful and incidental goals and focal activities of the user can be investigated.

From a general perspective, the framework helps application developers identify and explore scenarios. These scenarios are gauged at a level at which people understand and are highly useful for Scenario Based Design, which concerns designing systems centred on scenarios of interaction, as extensively discussed by Carroll (2000).

In support of both contributions (C.1 & C.2), the evaluation of the design framework revealed that students performed statistically better in identifying the context of the user and application. By enabling application designers to address this integration, usability is placed at the centre of the design process. Separation of concerns in software development therefore needs to be undertaken in conjunction with human and social analyses of context, enabling the application developer to build more useful and usable context-aware systems. This framework provides a valuable tool with which these issues can be conceptualised.

REFERENCES

Abowd, G.D., Atkeson, C.G., Hong, J., Long, S., Kooper, R. & Pinkerton, M. (1996). 'Cyberguide: A mobile Context-Aware Tour Guide'. *Wireless Networks.* Vol. 3 (5). pp. 421-433.

Allen, G.L. (1999). 'Spatial abilities, cognitive maps, and wayfinding: Bases for individual differences in spatial cognition and behaviour'. In Golledge, R.G. (eds), *Wayfinding Behavior, Cognitive Mapping and Other Spatial Processes.* Baltimore: John Hopkins. pp. 301-321.

Bacon, J., Bates, J. & Halls, D. (1997). 'Location-orientated multimedia'. *IEEE Personal Communications.* Vol 4(5). October 1997. pp.48-57.

Bainbridge, L. (1991). 'Verbal Protocol Analysis'. In Wilson, J.R. & Corlett, E.N. (Eds.). *Evaluation of Human Work: A practical Ergonomics Methodology*. Taylor and Francis. London. pp.161-179.

Balliwalla, N.P. (2002). 'Low Vision - Assessment and Aids'. Bombay Hospital Journal. http://www.bhj.org/journal/2002_4403_jul/md_397.htm, 2002.

Bardram, J.E. (2004). 'Applications of context-aware computing in hospital work: examples and design principles'. *Proceedings of the 2004 ACM symposium on Applied computing*. Nicosia, Cyprus. pp.1574 - 1579.

Bekerian, D.A. & Conway, M.A. (1988). 'Everyday Contexts'. Chapter 14. In: Davies, G.M. & Thomson, D.M. *Memory in context; context in memory*. John Wiley & Sons. Chichester. pp.305-318.

Bellotti, V. & Sellen, A. (1993). 'Design for Privacy in Ubiquitous Computing Environments'. *Proceedings of 3rd European Conf. Computer Supported Cooperative Work (ECSCW 93)*. Kluwer, Dordrecht, Holland. pp. 77–92.

Bellotti, V. & Edwards, K. (2001). 'Intelligibility and Accountability: Human Considerations in Context-Aware Systems'. *Special issue on Human-Computer Interaction*. Vol. 16. pp. 193-212.

Benerecetti, M., Bouquet, P. & Ghidini, C. (2001). 'On the Dimensions of Context Dependence: Partiality, Approximation, and Perspective'. *Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001*. Dundee, Scotland. 27-30 July 2001. pp.59-72.

Bigelow, A.E. (1996). 'Blind and sighted children's spatial knowledge of their home environments'. *International Journal of Behavioural Development*. 19. pp. 797-816.

Bohnenberger, T. & Jameson, A. (2001). 'When Policies Are Better Than Plans: Decision-Theoretic Planning of Recommendation Sequences.' *Proceedings of International Conference on Intelligent User Interfaces, IUI 2001*. New York: ACM.

Bradley, N.A. & Dunlop, M.D. (2002a). 'Understanding contextual interactions to design navigational context-aware applications'. *Proceedings of 4th International Symposium on Mobile HCI 02*. Pisa, Italy. 18-20 September 2002. p.349-354.

Bradley, N.A. & Dunlop, M.D. (2002b). 'Investigating context-aware cues to assist navigation for visually impaired people'. *Proceedings* of *Workshop on Building Bridges: Interdisciplinary Context-Sensitive Computing*. University of Glasgow, UK. 9 September 2002. p.5-10.

Bradley, N.A. & Dunlop, M.D. (2003a). 'Towards a Multidisciplinary User-Centric Design Framework for Context-Aware Applications'. *Proceedings of 1st UK-UbiNet Workshop*. Imperial College, London. 25-26 September 2003.

Bradley, N.A. & Dunlop, M.D. (2003b). 'A Pathway to Independence: Wayfinding Systems which Adapt to a Visually Impaired Person's Context'. *Proceedings of Symposium on Assistive Technology – Towards a better life*. Glasgow. 30 April 2003. pp. 23 – 27.

Bradley, N.A. & Dunlop, M.D. (2004a). 'Towards a User-centric and Multidisciplinary Framework for Designing Context-aware Applications'. *Proceedings of workshop on Advanced Context Modelling, Reasoning and Management at 6th International Conference on Ubiquitous Computing, UbiComp 2004*. Nottingham, UK. 7 September 2004.

Bradley, N.A. & Dunlop, M.D. (2004b). 'Investigating design issues of context-aware mobile guides for people with visual impairments'. *Proceedings of workshop on HCI in Mobile Guides.* Mobile HCI04. Glasgow, UK. 13th September 2004.

Bradley, N.A. & Dunlop, M.D. (2005a). 'Navigation Assistive Technology: Context-aware computing'. To appear in M.A. Johnson & M. Hersh (eds.). *Assistive Technology for Vision Impaired and Blind People*. Springer Verlag, London.

Bradley, N.A. & Dunlop, M.D. (2005b). 'Towards a Multidisciplinary Model of 'Context' to Support Context-Aware Computing'. To Appear in *Journal of Human-Computer Interaction*. Vol. 20. Lawrence Erlbaum Associates.

Bradley, N.A. & Dunlop, M.D. (2005c) 'An Experimental Investigation into Wayfinding Directions for Visually Impaired People'. To Appear in *Journal of Personal and Ubiquitous Computing*.

Bradyn, J.A. (1985). A review of mobility aids and means of assessment. In D.H. Warren & E.R. Strelow (Eds.), Electronic spatial sensing for the blind. Boston: Martinus Nijhoff. pp.13-27.

Brewster, S. (2002). 'Overcoming the Lack of Screen Space on Mobile Computers'. *Personal and Ubiquitous Computing*. Vol. 6. pp.188-205.

Brewster, S.A., Lumsden, J., Bell, M., Hall, M. and Tasker, S. (2003). 'Multimodal 'Eyes-Free' Interaction Techniques for Wearable Devices'. *Proceedings of ACM CHI 2003*. Fort Lauderdale, FL. ACM Press, Addison-Wesley. pp 463-480.

Brezillon, P. & Abu-Hakima, S. (1995). 'Using the knowledge in its context: Report of the IJCAI'93 Workshop'. *AI Magazine*. Vol. 16(1). pp.87-91.

Brown, P.J. (1996). 'The Stick-e Document: a Framework for Creating Context-Aware Applications'. *Proceedings of EP'96.* Palo Alto. pp.259-272.

Brown, P.J., Bovey, J.D. & Chen, X. (1997). 'Context-Aware Applications: From the Laboratory to the Marketplace'. *IEEE Personal Communications*. 4(5). p.58-64.

Bunt, H. (1997). 'Context and Dialogue Control'. *Proceedings of the First International and Interdisciplinary Conference, CONTEXT 1997.* Rio de Aliceiro, Brazil. pp.130-149.

Burrell, J. & Gay, G.K. (2002). 'E-graffiti: evaluating real-world use of a context-aware system'. *Interaction with Computers*. 14. pp. 301-312.

Carroll, J. M., Ed. (2000). Making Use: Scenario-based Design of Human-Computer Interactions. Cambridge, MA, MIT Press.

Chambers 21st Century Dictionary. (1999). Chambers. Edinburgh. pp.296.
Chen, G. & Kotz, D. (2000). 'A Survey of Context-Aware Mobile Computing Research'. Technical Report. TR2000-381. Department of Computer Science, Dartmouth College.
Cheverst, K., Davies, N., Mitchell, K., Friday, A. and Efstratiou, C. (2000). 'Developing a Context-Aware Electronic Tourist Guide: Some Issues and Experiences'. *Proceedings of CHI 2000*. 1-6 April 2000. pp. 17 – 24.
Cheverst K, Smith G, Mitchell K, Friday A, Davies, N (2001). 'The role of shared context in supporting cooperation between city visitors'. *Computers & Graphics*. 25. pp. 555–562.
Clark-Carter, D.D., Heyes, A.D. and Howarth, C.I. (1986). 'The efficiency of walking speed of visually impaired pedestrians'. *Ergonomics*. 29. pp. 779-789.
Connolly, J.H. (2001). 'Context in the Study of Human Languages and Computer Programming Languages: A Comparison'. *Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001*. Dundee, Scotland. pp.116 – 129.
Cornell, E.H. & Hay, D.H. (1984). 'Children's acquisition of a route via different media'. *Environment and Behaviour*. 16. pp. 627-641.
Coulouris, G., Naguib, H. & Mitchell, S. (2001). 'Middleware support for context-aware multimedia applications'. *Proceedings of 3rd IFIP WG 6.1 International Working Conference on Distributed Applications and Interoperable Systems*. Krakov, Poland. September 2001.
Coutaz, J. & Rey, G. (2002). 'Recovering Foundations for a theory of contextors'. *Invited presentation at the 4th International Conference on Computer-Aided Design of User Interfaces (CADUI 2002)*. Valenciennes, France. 15-17 May 2002.
Davies, G. M. & Thomson, D. M. (1988). Introduction. In G. M. Davies & D. M. Thomson (Eds.), *Memory in context; context in memory* (pp.1-10). Chichester: John Wiley & Sons.
Dervin, B. (1997). 'Given a Context by Any Other Name: Methodological Tools for Taming the Unruly Beast'. In B. Dervin & L. Foreman-Wernet (with E. Lauterbach) (Eds.). *Sense-Making Methodology reader: Selected writings of Brenda Dervin*. Cresskill, NJ: Hampton Press. pp.111-132.
Dewey, J. (1931). Context and Thought. In Richard Bernstein (ed. 1960). pp. 88-110.
DeVaul, R.W. & Pentland, A. (2000). 'The Ektara Architecture: The Right Framework for Context-Aware Wearable and Ubiquitous Computing Applications'. *MIT Technical Report*.
Dey, A.K. (1998). 'Context-Aware Computing: The CyberDesk Project'. *AAAI 1998 Spring Symposium on Intelligent Environments*. Technical Report SS-98-02. pp.51-54.
Dey, A.K. (2000). 'Providing Architectural Support for Building Context-Aware Applications'. Ph.D. thesis. College of Computing, Georgia Institute of Technology. December 2000.
Dey, A.K. (2001a). 'A den of ubiquity'. *i3 magazine: The European Network for Intelligent Information Interfaces*. Vol. 11. July 2001. p.25-27.

Dey, A.K. (2001b). ‘Supporting the Construction of Context-Aware Applications’. *Presentation at the Dagstuhl seminar on Ubiquitous Computing*. 9-14 September 2001.

Dey, A.K. & Abowd, G.D. (1999). ‘Towards a Better Understanding of Context and Context-Awareness’. Technical Report GIT-GVU-99-22. Georgia Institute of Technology.

Dey, A.K., Abowd, G.D. & Wood, A. (1999). ‘CyberDesk: A Framework for Providing Self-Integrating Context-Aware Services’. *Knowledge-based Systems*. 11. pp.3-13.

Dey, A.K., Futakawa, M., Salber, D., Abowd, G.D. (1999). ‘The Conference Assistant: Combining Context-Awareness with Wearable Computing’. *Proceedings of the 3rd International Symposium on Wearable Computers (ISWC '99)*. October 20-21, 1999. pp. 21-28.

Dey, A.K., Salber, D. & Abowd, G.D. (2001). ‘A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications’. *Anchor article of a Special issue of Human Computer Interaction*. 16 (2-4). pp. 97-166.

Dodson, A.H.; Moore, T. & Moon, G.V. (1999). ‘A Navigation System for the Blind Pedestrian’. *Proceedings of GNSS 99, 3rd European Symposium on Global Navigation Satellite Systems*. Genoa, Italy. October 1999. pp. 513-518.

Dourish, P. (2001). ‘Seeking a Foundation for Context-Aware Computing’. *Journal of Human-Computer Interaction*. 16 (2-4).

Downs, R.M. and Stea, D. (1997). ‘Cognitive Maps and spatial behaviour: Process and Products’. In R.M. Downs and D. Stea (Eds,), *Image and Environment*. Chicago: Aldine. pp. 8-26.

Dunlop, M.D., Ptasinski, P., Morrison, A., McCallum, S., Risbey, C. & Stewart, F. (2004). ‘Design and development of Taeneb City Guide - From Paper Maps and Guidebooks to Electronic Guides’. *Enter 2004*. Cairo, Egypt. 27-29 January 2004.

ECCS. (1997). Advert for workshop on Context: *2nd European Conference on Cognitive Science*. Manchester, UK. 9-11 April 1997.

Ekbia, H. R. & Maguitman, A.G. (2001). ‘Context and Relevance: A pragmatic Approach’. *Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001*. Dundee, Scotland. 27-30 July 2001. pp.156-169.

Farmer, L. (1980). ‘Mobility devices’. In R.L. Welsh and B.B. Balssch (Eds), *Foundations of Orientation and Mobility,* New York: American Foundation for the Blind. pp. 357-412.

Fetzer, A. (1997). ‘Recontextualizing Context’. *Workshop 2: Context Organiser. European Conference on Cognitive Science (ECCS) 1997*. 9-11 April 1997.

Fink, J. & Kobsa, A. (2002). ‘User Modeling for Personalized City Tours’. *Artificial Intelligence Review*. 18(1). pp. 33-74.

Fitzpatrick, G. (1998) ‘The Locales Framework: Understanding and Designing for Cooperative Work’. PhD Thesis, Department of Computer Science and Electrical Engineering, The University of Queensland.

Floch, J, Hallsteinsen, Lie, A, & Myrhaug, H.I. (2001). ‘A Reference Model for Context-Aware Mobile Services’. *Proceedings of NIK 2001*. Tromsø, Norway.

Franklin, N. (1995). ‘Language as a means of constructing and conveying cognitive maps’. In J. Portugali (ed), *The construction of cognitive maps.* Dordrecht: Kluwer Academic Publishers. pp. 275-295.

Friedman, N. & Goldszmidt, M. (1998). ‘Learning Bayesian Network from Data’ *SRI International*.

Funk, H.B. & Miller, C.A. (1997). ‘“Context Sensitive” Interface Design’. *Proceedings of the First International and Interdisciplinary Conference, CONTEXT 1997*. Rio de Aliceiro, Brazil. pp.303-318.

Garlan, D., Siewiorek, D.P., Smailagic, A. & Steenkiste, P. (2002). Project Aura: Toward Distraction-Free Pervasive Computing. Journal of Pervasive Computing. April-June 2002, pp.22-31.

Gärling, T., Book, A., Lindberg, E. and Nilsson, T. (1981). ‘Memory for the spatial layout of the everyday physical environment: Factors affecting rate of acquisition’. *Journal of Environmnetal Psychology*. 1. pp. 263-277.

Gibson, J.J. (1979). ‘*The Ecological Approach to Visual Perception*’. Houghton-Millin. Boston.

Göker, A., Myrhaug, H.I. (2002). ‘User context and personalisation’. *Workshop proceedings of the 6th European Conference on Case Based Reasoning*. Aberdeen, UK.

Golding, A. R. & Lesh, N. (1999). ‘Indoor navigation using a diverse set of cheap, wearable sensors’. *Proceedings of the Third International Symposium on Wearable computers*. San Francisco, CA. pp. 29-36.

Golledge, R.G. (1978). ‘Representing, interpreting and using cognized environments’. *Papers and Proceedings of the Regional Science Association*. 41. pp. 169-204.

Golledge, R.G., Klatzky, R.L., Loomis, J.M., Speigle, J. and Tietz, J. (1998). ‘A geographical information system for a GPS based personal guidance system’. *International Journal of Geographical Information Science*. 12 (7). pp.727-749.

Golledge, R.G. & Stimson, R.J. (1997). *Spatial Behavior: A Geographic Perspective*. New York: Guildford Press.

Haken, H. & Portugali, J. (1996). ‘Synergetics, inter-representational networks and cognitive maps’. In Portugali, J. (ed.) *The construction of Cognitive Maps.* Dordrecht: Kluwer. pp. 45-67.

Hart, S. & Staveland, L. (1988). ‘Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research’. In Hancock, P. and Meshkati, N. (Ed.). *Human mental workload*. North Holland B.V. pp.139-183.

Helal, A.S., Moore, S.E. & Ramachandran, B. (2001). ‘Drishti: An integrated Navigation System for Visually Impaired and Disabled’. *Proceedings of the 5th International Symposium on Wearable Computers*. Zurich, Switzerland.

Hill, E., & Ponder, P. (1976). *Orientation and Mobility Techniques: A Guide for the Practitioner*. New York: American Foundation for the Blind. p.114.

Hindus, D., Mainwaring, S.D., Leduc, N., Hagstrom, A.E. & Bayley, O. (2001). ‘Casablanca: designing social communication devices for the home’. *In CHI 2001 Conference Proceedings. Conference on Human Factors in Computing Systems.* ACM. New York, NY, USA. pp. 325-554.

Höök, K (2000). ‘Steps to take before intelligent user interfaces become real’. *Interacting with Computers,* 12(4). pp. 409-426.

Huang, Q. (2002). ‘Supporting Context-Aware Computing in Ad Hoc Mobile Environments’. Technical Report WUCS-02-36. Computer Science & Engineering Dep., Washington University, St. Louis, Missouri.

Jang, S, Kim, J, Ramakrishna, R.S. (2001). ‘Framework for Building Mobile Context-Aware Applications’. *LNCS 2105*. pp 139 – 150.

Jiang, X, & Landay, J. (2002). ‘Modeling Privacy Control in Context-Aware Systems’. *Pervasive Computing*. July-September. pp.59-63.

Johnson, P. (1998). ‘Usability and Mobility; Interactions on the move’. *Proceedings of the First Workshop on Human Computer Interaction with Mobile Devices*. University of Glasgow, Scotland. 21-23 May 1998.

Jones, G. J.F. & Brown, P.J. (2004). ‘The role of context in information retrieval’. *Proceedings of Workshop on Information Retrieval in Context (SIGIR 2004).* Sheffield, UK.

Jonsson, E. (2002). Inner Navigation: why we get lost and how we find our way. Scribner, New York, pp. 27-126.

Kaasinen, E. (2003) ‘User needs for location-aware services mobile’. Personal and Ubiquitous Computing. 7. pp. 70-79.

Kemmerling, M. and Schliepkorte, H. (1998). ‘An Orientation and Information System for Blind People based on RF-Speech-Beacons’. *Proceedings of TIDE*. Helsinki.

Kim, J., Yae, S. & Ramakrishna, R.S. (2001). ‘Context-Aware Application Framework based on Open Service Gateway’. *International Conference on Info- tech & Info-net 2001*. Beijing, China. pp.209-213.

Kitchin, R.M. & Blades, M. (2002). *The Cognition of Geographic Space*. I.B. Tauris: London. pp. 33-57.

Kitchen, R.M. & Jacobson, D. (1997). ‘Techniques to collect and analyze the cognitive map knowledge of people with visual impairments or blindness: Issues of validity’. *Journal of Visual Impairment and Blindness*. July-August. pp. 360-376.

Kjeldskov J. & Graham C. (2003). ‘A Review of MobileHCI Research Methods’. *Proceedings of the 5th International Mobile HCI 2003 conference*. Udine, Italy. Lecture Notes in Computer Science. Springer-Verlag, Berlin.

Kjeldskov, J. & Stage, J. (2004). ‘New Techniques for Usability Evaluation of Mobile Systems’. *International Journal of Human-Computer Studies (IJHCS)*. Elsevier. 60 (2004). pp.599-620.

Kokinov, B. & Grinberg, M. (2001). ‘Simulating Context Effects in Problem Solving with AMBR’. *Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001*. Dundee, Scotland. 27-30 July 2001. pp.221-234.

LaGrow, S. & Weessies, M. (1994). *Orientation and Mobility: Techniques for Independence*. New Zealand: Dunmore Press Limited. p. 9.

Lamming, M. & Flynn, M. (1994). ‘Forget-me-not: Intimate Computing in Support of Human Memory’. *Proceedings of FRIEND 21: International Symposium on Next Generation Human Interfaces.* Tokyo, Japan. pp.125-128.

Lines, L. & Hone, K.S. (2002). ‘Millennium Homes: A user centred approach for system functionality. *Proceedings of 1st Cambridge Workshop in Universal Access and Assistive Technology (CWUAAT)*. Cambridge, UK.

Loomis, J.M., Golledge, R.G. & Klatzky, R.L. (2001). ‘GPS-based navigation systems for the visually impaired’. In W. Barfield and T. Caudell (Eds.).

Fundamentals of Wearable Computers and Augmented Reality. Mahwah NJ: Lawrence Erlbaum Associates. pp.429-446.

Lovelace, K.L., Hegarty, M., and Montello, D. (1999). 'Elements of good route descriptions in familiar and unfamiliar environments'. In C. Freksa and D. Mark (eds), Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science, Springer Verlag. pp.65-82.

Maeda, Y., Tano, E., Makino, H., Konishi, T. and Ishii, I. (2002). 'Evaluation of a GPS-based Guidance System for Visually Impaired Pedestrians'. *Technology and Persons with Disabilities Conference 2002*. Los Angeles, California, USA. March 18-23.

Makino, H., Ishii, I. and Nakashizuka, M. (1997). 'Development of navigation system for the blind using GPS and mobile phone combination'. *Proceedings of the 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. 18. Pts 1-5.

Matsui, T. (2001). 'Experimental Pragmatics: Towards Testing Relevance-Based Predictions about Anaphoric Bridging Inferences'. *Proceedings of the Third International and Interdisciplinary Conference, CONTEXT 2001*. Dundee, Scotland. 27-30 July 2001. pp.248 - 260.

May, M. (2000). 'Accessible GPS Navigation and Digital Map Information for Blind Consumers'. ICWC 2000.

Meyer, S. & Rakotonirainy, A. (2003). 'A Survey of Research on Context-Aware Homes'. *WICAPUC: Australian Workshop on Wearable, Invisible, Context-aware, Ambient, Pervasive, and Ubiquitous Computing.* Adelaide, Australia. 4-7th February 2003.

Mitchell, S., Spiteri, M.D., Bates, J. & Coulouris, G. (2000). 'Context-Aware Multimedia Computing in the Intelligent Hospital'. *Proceedings of the 9th workshop on ACM SIGOPS European workshop: beyond the PC: new challenges for the operating system table of contents*. Kolding, Denmark. pp. 13–18.

Moran, T. & Dourish, P. (2001). Introduction to Context-Aware Computing. *Special Issue of Human-Computer Interaction*. 16.

Mynatt, E., Essa, I. & Rogers, W. (2000). 'Increasing the opportunities for Aging-in-Place'. *Proceedings of ACM Conference on Universal Usability*. Arlington, Virginia, United States. pp.65–71.

Nielsen, C. (1998). 'Testing in the Field'. In Werner, B. (Ed.). *Proceedings of the third Asia Pacific Computer Human Interaction Conference*. IEEE Computer Society.

Ochs, E. (1979). 'What a child language can contribute to pragmatics'. In: Ochs, E. & Schriffin, B.B. *Developmental Pragmatics*. New York Academic Press. pp.1-17.

Oxford Pocket Dictionary of Current English. (1992). Clarendon Press. Oxford. p.181.

Pascoe, J. (1998). 'Adding Generic Contextual Capabilities to Wearable Computers'. *Proceedings of 2nd International Symposium on Wearable Computers*. pp. 92-99.

Pascoe, J., Ryan, N., Morse, D. (2000). 'Using While Moving: HCI Issues in Fieldwork Environments'. *Transactions on Computer-Human Interaction*. 7(3). pp.417-437.

Petrie, H. (1995). ‘User requirements for a GPS-based travel aid for blind people’. In J.M. Gill and H. Petrie (Eds.), *Proceedings of the Conference on Orientation and Navigation Systems for Blind Persons*. Hatfield, UK. 1-2 February. London: Royal National Institute for the Blind.

Pignotti, E., Edwards, P. & Grimnes, G.A. (2004). 'Context-Aware Personalised Service Delivery'. Proceedings of the Sixteenth European Conference on Artificial Intelligence - ECAI-2004, (Ramon Lopez de Mantaras & Lorenza Saitta, eds.), Valencia, Spain.

Pitt, I.J. & Edwards, A.D.N. (1996). ‘Improving the usability of speech-based interfaces for blind users’. *2nd annual ACM conference on Assistive technologies*. Vancouver, Canada. April 1996. pp.124 – 130.

Preece, J.; Rogers, Y.; Sharp, H.; Benyon, D.; Holland, S. & Carey, T. (1994). ‘Task Analysis’. Chapter 20. In *Human-Computer Interaction.* Addison-Wesley. Harlow, England. pp. 409-429.

Rabiner, L. R. (1989). 'A tutorial on hidden Markov models and selected applications in speech recognition'. *Proceedings of IEEE*. 77 (2). pp.257-286.

Ross, D.A. and Blasch, B.B. (2000). ‘Evaluation of Orientation Interfaces for Wearable Computers’. *Proceedings of Fourth International Symposium on Wearable Computers (ISWC’00)*. Atlanta, Georgia. October 18-21, 2000. pp.51-61.

Ryan, N., Pascoe, J. & Morse, D. (1997). ‘Enhanced Reality Fieldwork: the Context-Aware Archaeological Assistant’. In: V. Gaffney, M. Van Leusen & S. Exxon (eds.), *Computer Applications in Archaeology*. pp.34-45.

Sabelman, E.E., Burgar, C.G., Curtis, G.E., Goodrich, G., Jaffe, D.L., Mckinley, J.L., Van Der Loos, M. and Apple, L.G. (1994). ‘Personal navigation and wayfinding for individuals with a range of disabilities’. Project *report: Device development and evaluation*.

Sadeh, N., Chan, E., Van, L. (2002). ‘MyCampus: An Agent-Based Environment for Context-Aware Mobile Services’. *Proceedings of Workshop on Ubiquitous Agents on embedded, wearable, and mobile devices: Conference on Autonomous Agents & Multiagent Systems*. University of Bologna. 16 July 2002.

Salber, D., Dey, A.K. & Abowd, G.D. (1999). ‘The Context Toolkit: Aiding the Development of Context-Enabled Applications’. *Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems.* Pittsburgh, Pennsylvania, USA. 15-20 May 1999.

Salovaara, A. & Oulasvirta, A. (2004). ‘Six modes of Proactive Resource Management: A User-Centric Typology for Proactive Behaviors’. *Proceedings of NordiCHI’04*. ACM Press. pp. 57-60.

Samulowitz, M. (2000). ‘Designing a Hierarchy of User Models for Context-Aware Applications’. *Workshop on ‘Situated Interaction in Ubiquitous Computing’ at CHI 2000*. 3 April 2000.

Sato, K. (2003). ‘Context-Sensitive Interactive Systems Design: A Framework for Representation of Contexts’. *Proceedings of the 10th International Conference on Human-Computer Interaction*. 3. pp.1323-1327.

Schilit, B., Adams, N. & Want, R. (1994). ‘Context-Aware Computing Applications’. *First International Workshop on Mobile Computing Systems and Applications*. pp.85-90.

Schilit, B. & Theimer, M. (1994). ‘Disseminating Active Map Information to Mobile Hosts’. *IEEE Network*. 8(5). pp.22-32.

Schilit, B., Theimer, M., & Welch, B.B. (1993). ‘Customizing mobile applications’. *In proceedings of USENIX Mobile & Location-Independent Computing Symposium*. Cambridge, Massachusetts. August 1993. pp.129-138.

Schmidt, A. (2001). ‘Context-Awareness, Disappearing and Distributed User Interfaces: Experience, Open Issues and Research Questions’. *Presentation at the Dagstuhl seminar on Ubiquitous Computing*. 9-14 September 2001.

Schmidt, A., Aidoo, K.A., Takaluoma, A., Tuomela, U., Laerhoven, K.V. & Van De Velde, W. (1999). ‘Advanced Interaction in Context’. Proceedings of First International Symposium on Handheld and Ubiquitous Computing, HUC’99. Karlsruhe, Germany. September 1999. pp.89-101.

Selker, T. & Burleson, W. (2000). ‘Context-Aware Design and Interaction in Computer Systems’. SEWPC: Workshop on Software Engineering for Wearable and Pervasive Computing. *At ICSE 2000: The 22nd International Conference on Software Engineering*. Limerick, Ireland. 4-11th June 2000.

Shoval, S.; Ulrich, I. & Borenstein, J. (2000). ‘Computerized Obstacle Avoidance Systems for the Blind and Visually Impaired’. In: *Intelligent Systems and Technologies in Rehabilitation Engineering*. Editors: Teodprescu, H.N.L. & Jain, L.C. CRC Press. pp. 414-448.

Siewiorek, D., Smailagic, A., Furukawa, J., Moraveji, N., Reiger, K. & Shaffer, J. (2002). ‘SenSay: A Context-Aware Mobile Phone’. School of Computer Science, Carnegie Mellon University.

Smith, S. (1988). ‘Environmental Context – Dependent Memory’. Chapter 2. In: Davies, G.M. & Thomson, D.M. *Memory in context; context in memory*. John Wiley & Sons. Chichester. pp.13-34.

Smailagic, A., Siewiorek, D.P., Anhalt, J., Gemperle, F. (2001) ‘Towards Context Aware Computing: Experiences and Lessons Learned’. *IEEE Journal on Intelligent Systems*. 16(3). June 2001. pp 38-46.

Sørensen, C., Wu, M., Sivaharan, T., Blair, G.S., Okanda, P., Friday, A. & Duran-Limon, H. (2004). ‘Context-aware middleware for applications in mobile ad hoc environments’. In ACM/IFIP/USENIX International Middleware conference 2nd Workshop on Middleware for Pervasive and Ad-Hoc Computing. Toronto, Canada. October 2004.

Stewart, J. (2001). ‘A trail Prediction Using A Global Positioning System’. MSc Thesis. Department of Computer and Information Sciences. Strathclyde University, Glasgow, UK.

Strothotte, T., Fritz, S., Michel, R., Raab, A., Petrie, H., Johnson, V., Reichert, L. and Schalt, A., (1996). ‘Development of Dialogue Systems for the Mobility Aid for Blind People: Initial Design and Usability Testing’. *Proceedings of ASSETS ’96*. Vancouver, British Columbia, Canada. pp. 139-144.

Suchman, L. (1987). Plans and Situated Actions: The Problem of Human-Machine Communication. Cambridge: Cambridge University Press.

Want, R., Hopper, A., Falcão, V. and Gibbons, J. (1992). ‘The Active Badge Location System’. *ACM Transactions on Information Systems*. 1. pp. 91-102.

Ward, A., Jones, A. & Hopper, A. (1997). ‘A New Location Technique for the Active Office’. *IEEE Personal Communications*. 4(5). pp.42-47.

Wilson, D & Sperber, D. (2004). 'Relevance Theory'. In G. Ward & L. Horn (eds) *Handbook of Pragmatics*. Oxford. Blackwell. pp. 607-632.

Wittgenstein L. (1958). *Philosophical Investigations*. Blackwell. Oxford.

Weiser, M. (1991). 'The computer for the 21st century'. *Scientific American*. 265 (September). pp. 94-104.

Yan, H. & Selker, T. (2000). 'Context-Aware Office Assistant'. *Proceedings of the 5th international conference on Intelligent user interfaces*. New Orleans, Louisiana, United States. pp.276 – 279.

Zetie, C. (2002a). 'Market Overview - The Emerging Context-Aware Software Market'. Unwired Express website. http://www.unwiredexpress.com

Zetie, C. (2002b). 'Context: Delivering the True Value of Enterprise Mobile Computing'. Unwired Express web site. http://www.unwiredexpress.com

Ziemke, T. (1997). 'Embodiment of Context'. *Workshop 2: Context Organiser. 2nd European Conference on Cognitive Science (ECCS).* Manchester, UK. 9-11 April 1997.

APPENDICES

A-1 Route descriptions study with sighted people

Consent Form

Background to study

My research involves investigating the design of a mobile computer to help people navigate. This study involves investigating what kind of route information would be of use, and what type of mobile needs/requirements would need to be supported.

The interview will take around 30 minutes. In the first part you will be asked for some general details. In the second part you will be asked to describe four routes within Glasgow. In the third and final part, you will be asked some questions about route information and the design of a mobile navigation device.

Declaration

Your feedback will be kept confidential and anonymous. You are permitted to leave at any time. Please do not hesitate to ask any questions. Please sign below if you are happy to continue with the study.

Signature:______________________________ Date: _________________

Part 1: Pre-study Questionnaire

Your views and comments will remain confidential and anonymous.

Please do not hesitate to ask any questions.

SECTION 1: Personal Details

1.1 What sex are you? *Please tick.*

Male ☐ Female ☐

1.2 Which age category do you fall into?

Under 18 ☐ 19-25 ☐
26-35 ☐ 36-45 ☐
46-65 ☐ 66+ ☐

1.3 What is your nationality? ....

1.4 What type of work do you do?

SECTION 2: Your familiarity with Glasgow

2.1 Do you live in Glasgow?

Yes ☐ No ☐

If NO, go to 2.3.

2.2 How long have you lived in Glasgow?

Less than 1 year ☐ 1-3 years ☐
4-7 years ☐ 8-11 years ☐
12-15 years ☐ 16+ ☐

2.3 Please provide your opinion of the following statement.

	Strongly Disagree	Disagree	No opinion	Agree	Strongly Agree
I know the Glasgow city centre well.	☐	☐	☐	☐	☐

SECTION 3: Your experiences

3.1 Have you used a route navigation system before (e.g. in-car navigation system, handheld GPS device)?

Yes ☐ No ☐

If YES, could you please specify?

....

Part 2: Study of route descriptions

Starting from Glasgow Central Train Station, please verbally describe how to walk to Buchanan Bus Station (shown in the picture above).

Starting from Glasgow Central Train Station, please write down how to walk to the Glasgow School of Art (shown in the picture above). ***Please note that diagrams are not permitted.***

Part 3: Post-study Questionnaire

Your views and comments will remain confidential and anonymous.

Please do not hesitate to ask any questions.

SECTION 1: Rating the Importance of information

1.1 Please provide your opinion of each statement below.

If guided to a destination….	*Strongly Disagree*	*Disagree*	*No opinion*	*Agree*	*Strongly Agree*
a) **Structural** information would be important for navigation (e.g. buildings, monuments, bridges, etc)	☐	☐	☐	☐	☐
b) **Textual** information would be important for navigation (e.g. names of streets, areas, buildings, etc)	☐	☐	☐	☐	☐
c) **Directional** information would be important for navigation (e.g. left, right)	☐	☐	☐	☐	☐
d) **Environmental** information would be important for navigation (e.g. sun position, close by mountains, rivers, etc)	☐	☐	☐	☐	☐
e) **Numerical** information would be important for navigation (e.g. coordinates in space, speed of travel, distance, etc)	☐	☐	☐	☐	☐
f) **Diagrammatical** information would be important for navigation (e.g. symbols on signs, such as of a train station)	☐	☐	☐	☐	☐
g) **Sensory** information would be important for navigation (e.g. smelling, hearing, or touching features of the environment to help you navigate)	☐	☐	☐	☐	☐
h) **Descriptive** information would be important for navigation (e.g. *red* building, *tall* tree, etc)	☐	☐	☐	☐	☐
i) Other: …. would be important for navigation	☐	☐	☐	☐	☐
j) Other: …. would be important for navigation	☐	☐	☐	☐	☐

1.2 **Using the letters of each type of information in the last question (a-j), what type of information would you want when guided to unknown destinations?**

....

1.3 **Would the importance of each type of information (as rated in 1.1) alter depending on the <u>route</u> you are taking?** Yes ☐ No ☐

Please explain.

....

....

....

....

1.4 **Would the importance of each type of information (as rated in 1.1) alter depending on your <u>task or activity</u> (e.g. being guided to the train station to catch a train, or being guided to an Art Gallery)?** Yes ☐ No ☐

Please explain.

....

....

....

....

1.5 **When being guided to destinations, would you like to be able to change the type of information given to you depending on your task and route?** Yes ☐ No ☐

Please explain.

....

....

....

....

SECTION 2: Design issues relating to usability

2.1 **When new information regarding your route is available, would you prefer the mobile device to prompt you with this information or would you prefer to access this information in your own time?**

Note: You can select both options, but explain your reason for this.

Mobile device alerts you ☐ You access information when you want ☐

Could you explain your answer?

....

....

....

2.2 What would be your preferred method of receiving route information? Note: you can select both, but explain your reason for doing this.

Speech output ☐ Visual Display ☐

Could you explain your answer?

....

....

....

SECTION 3: Other Issues

3.1 Do you have any further views or opinions that you would like to mention?

....

....

....

SECTION 4: Contact details (optional)

Name: ______________________

Telephone: ______________________

E-mail: ______________________

Thank you for completing this questionnaire

B-1 Route descriptions study with visually impaired people

Background to study

My research involves investigating the design of a mobile computer to help visually impaired people to navigate and orientate. This study involves investigating what kind of route information would be of use, and what type of mobile needs/requirements would need to be supported.

The interview will take around 30 minutes and will be recorded in full using a microphone connected to a Minidisk player. In the first part you will be asked for some general details. In the second part you will be asked to describe two familiar routes of your choice. In the third and final part, you will be asked some questions about your mobile needs and also some questions about the design of a mobile navigation device.

Declaration

Your feedback will be kept confidential and anonymous. You are permitted to leave at any time. Please do not hesitate to ask any questions. Are you happy to continue with the interview?

Part 1: Pre-Interview Questionnaire

1 What sex are you? *Please tick.*

Male ☐ Female ☐

2 Which age category do you fall into?

Under 18 ☐ 19-25 ☐
26-35 ☐ 36-45 ☐
46-65 ☐ 66+ ☐

3 Do you live in Glasgow?

Yes ☐ No ☐

If NO, go to 2.3.

4 How long have you lived in Glasgow?

5 Please provide your opinion of the following statement.

	Strongly Disagree	*Disagree*	*No opinion*	*Agree*	*Strongly Agree*
I know the Glasgow city centre well.	☐	☐	☐	☐	☐

6 Could you describe the level of vision that you have?

7 How long has your level of vision been like this?

8 Have you ever used a mobile computer to help you navigate?

Yes ☐ No ☐

If YES, how did you find them to use?

Part 2: Study of route descriptions

Route 1: ______________________________

Could you describe this route as if you were giving directions to someone experiencing a similar visual impairment as yourself?

Route 2: ______________________________

Could you describe this route as if you were giving directions to someone experiencing a similar visual impairment as yourself?

Part 3: Post-Interview Questionnaire

SECTION 1: Mobility issues

1.1 **Do you currently use a mobility aid?**

1.2 **What are the limitations of mobility aids (if any)?**

1.3 **What information would be useful to you when navigating?**

1.4 **What are the main problems you experience when out and about?**

SECTION 2: Usability Issues of a mobile navigation device

2.1 **When new information regarding your route is available, would you prefer the mobile device to prompt you with this information or would you prefer to access this information in your own time?**

Note: You can choose both options, but explain your reason for this.

Could you explain your answer?

2.2 **Various methods can be used to give you information, such as Braille displays, speech output, non-speech output, and vibration alerts. Which method would you prefer and why?**

2.3 **Do you have any concerns about using a mobile navigation aid or the methods used in giving you information?**

SECTION 3: Other Issues

3.1 **Do you have any further views or opinions that you would like to mention?**

3.2 **If further information was needed, would you mind if I contacted you again?**

SECTION 4: Contact details

Name:	
Telephone:	

C-1 Experimental documentation for main study

Study description

In a short time, I will ask you to walk to 2 landmarks inside and 2 landmarks outside. In order to reach each landmark, my laptop computer will give you verbal directions via a set of headphones - for hygiene purposes, the pads that cover the earphones are changed for each participant. Also, at certain points along the route, I will give you information about the environment in which you are walking.

Once you arrive at each landmark, I will ask you some questions about the information that was given to you. I'd also like to measure your pulse rate – this is a fairly simple procedure that involves places two fingers on sensors on a wristwatch.

Just to say that I will be with you at all times, and if at any time you wish to stop or feel uncomfortable please let me know.

So are you happy with the conditions of the study?

Do you have any questions before we begin?

Starting pulse rate__________

Indoor landmarks

Landmark 1

Pulse Rate__________ No of errors___________ Time Taken____________

Number of questions asked___________

Q1. In this first question, I'm going to ask you to rate your perceived level of workload when navigating to this first landmark.

MENTAL DEMAND	1 **Low**	2	3	4	5 **High**
PHYSICAL DEMAND	1 **Low**	2	3	4	5 **High**
TEMPORAL DEMAND	1 **Low**	2	3	4	5 **High**
OWN PERFORMANCE	1 **Excellent**	2	3	4	5 **Poor**
EFFORT	1 **Low**	2	3	4	5 **High**
FRUSTRATION LEVEL	1 **Low**	2	3	4	5 **High**

Q2. How useful was the information given to you through the earphones?

1 **Very unhelpful**	2	3	4	5 **Very helpful**

Q3. How useful was the information that I gave you?

1 **Very unhelpful**	2	3	4	5 **Very helpful**

Q4. I'm now going to list pairs of workload dimensions, and what I want you to do is to tell me which member of each pair provided the most significant source of workload variation in these two indoor routes.

Physical Demand vs. Mental Demand; Temporal Demand vs. Mental Demand; Own Performance vs. Mental Demand; Frustration vs. Mental Demand; Effort vs. Mental Demand; Temporal Demand vs. Physical Demand; Own Performance vs. Physical Demand; Frustration vs. Physical Demand; Effort vs. Physical Demand; Temporal Demand vs. Own Performance; Temporal Demand vs. Frustration; Temporal Demand vs. Effort; Own Performance vs. Frustration; Own Performance vs. Effort; Effort vs. Frustration

Outdoor landmarks

Landmark 1

Pulse Rate__________ No of errors___________ Time Taken____________

Number of questions asked___________

Q1. The same as last time, I'm going to ask you to rate your perceived level of workload when navigating to this first landmark.

	1	2	3	4	5
MENTAL DEMAND	1 Low	2	3	4	5 High
PHYSICAL DEMAND	1 Low	2	3	4	5 High
TEMPORAL DEMAND	1 Low	2	3	4	5 High
OWN PERFORMANCE	1 Excellent	2	3	4	5 Poor
EFFORT	1 Low	2	3	4	5 High
FRUSTRATION LEVEL	1 Low	2	3	4	5 High

Q2. How useful was the information given to you through the earphones?

1	2	3	4	5
Very unhelpful				Very helpful

Q3. How useful was the information that I gave you?

1	2	3	4	5
Very unhelpful				Very helpful

Q4. I'm now going to list pairs of workload dimensions, and what I want you to do is to tell me which member of each pair provided the most significant source of workload variation in these two indoor routes.

Physical Demand vs. Mental Demand; Temporal Demand vs. Mental Demand; Own Performance vs. Mental Demand; Frustration vs. Mental Demand; Effort vs. Mental Demand; Temporal Demand vs. Physical Demand; Own Performance vs. Physical Demand; Frustration vs. Physical Demand; Effort vs. Physical Demand; Temporal Demand vs. Own Performance; Temporal Demand vs. Frustration; Temporal Demand vs. Effort; Own Performance vs. Frustration; Own Performance vs. Effort; Effort vs. Frustration

D-1 Design Framework exercise given to students

The task

Your task is to design *two* different context-aware systems. Each system is to support a different user scenario, both of which will be given to you. You will also be given a different 'design framework' in order to design each system. Your designs may include:

- the primary goal of the user,
- the scenarios within which user activities are carried out,
- the requirements of the user,
- the flow of contextual information between the user, application and environment,
- the types of contextual services executed by the application, and the organisation and management of sensed contextual data,
- the usability issues that arise from knowing about context.

Feel free to structure your designs in any way you wish, though ensure that you carefully consider each step or point made within the design framework. *You do not need to apply every step/issue, though ensure that you make a mental justification for not doing so.*

During the exercise, you should assume that the context-aware system you are designing will possess various types of technology at its disposal, and operates within a ubiquitous environment. For instance, the device will be able to derive information from/about, communicate with, and provide information for (i) computers embedded within everyday objects, (ii) people using similar wireless technology, and (iii) complex networks, servers, and other contextual resources.

Conditions

Please work in pairs.
You will be given 30 minutes for each design scenario.
If you have any questions about the task procedure, please feel free to ask.
You will not be marked, though you may be expected to demonstrate what you have learnt in the exam.

Design Framework 1:

1. ***Acquisition of user context data***
    1.1. Specify the user's primary goal.
    1.2. Investigate scenarios that are likely to be encountered or *meaningful* activities that would need to be carried out. Investigate what users would use or would be influenced by in those scenarios or when carrying out those activities. Consider the following:
    - *Physical context*: The environmental location consisting of surrounding/nearby physical objects (e.g. buildings, cars, trees, etc). This also includes the presence, state and purpose of those objects, and the types of information they transmit through audio, visual, odour, texture, temperature, and movement (and in different weather conditions).
    - *Social context*: The relationship with, and the density, flow, type, and behaviour of, surrounding people (e.g. sitting on a crowded train).
    - *Task context*: The functional relationship of the user with other people and objects, and the benefits (e.g. resources available) or constraints (e.g. time pressure) this relationship places on the user achieving his/her goal.
    - *Temporal context*: The temporal context is embedded within everything, and is what gives a *current* situation meaning, based upon *past* situations/occurrences, expected *future* events, and the higher-level temporal context relating to the time of day, week, month, or season.
    - *Application context*: The application's context concerns any information that has been or is being displayed on the user-interface.
    - *Cognitive context*: A user's cognitive processing abilities; short- and long-term memory abilities; dislikes/preferences; opinions/beliefs; cultural interpretations; perceptual sensing abilities; perception of levels of privacy and security; cognitive mapping strategies, etc.

    1.3. Investigate scenarios where *incidental* or unpredictable events occur in the environment or where incidental activities are carried out by the user. Similar to 1.2, investigate what users would use or would be influenced by in the environment in those scenarios or when carrying out incidental activities.

2. ***Acquisition of application context data***
    2.1. In relation to 1.2, list types of *meaningful* services the application could provide.
    2.1.1. For each service, indicate the types of contextual information needed to infer or identify the user's context (e.g. GPS location). Consider the dimensions of context described in 1.2, as well as:
    - *User's context*: Information regarding (i) the user's personal diary, including planned activities, notes and reminders, as well as user-defined application settings and preferences (e.g. possibly setting levels of privacy), (ii) physiological sensing such as heart rate to measure levels of anxiety, and (iii) monitored behavioral patterns of the user.
    - *Application's context:* The capabilities and limitations of both the application (such as battery usage life, processor speed, memory capacity, sensors, input/output technologies, etc.) and the sources from which data is derived (such as the processing speed of a web-based server).

    2.1.2. Explore different types of sensors, technologies, capabilities, services, and networks from which contextual information could be derived. Also consider the high level structure within which the context-aware device will function – e.g. constraints placed on the availability of contextual information.

2.1.3. Evaluate how this information might be sensed, managed, interpreted, and presented to the user.

2.2. In relation to 1.3, list types of *incidental* services, either to support incidental scenarios or incidental activities of the user. Also include events and activities that may be unknown to the user, such as informing the user of a friend in a nearby pub.

2.2.1. Repeat 2.1.1 – 2.1.3.

2.2.2. Prioritise incidental services with respect to meaningful services.

3. Usability design considerations

3.1. Investigate how meaningful and incidental application services might be presented to the user. Consider the importance of (or priority attached to) the service with respect to the user's *focal* activity and contextual environment.

3.1.1. Evaluate the timing of meaningful and incidental information (e.g. blind users may not wish incidental information when crossing a busy street).

3.1.2. Based upon 2.1.2 & 2.1.3, evaluate which output technologies should be used to provide meaningful and incidental services. Speech output, for instance, may be more appropriate when the user's task is visually demanding.

3.1.3. Investigate whether incidental and meaningful services should be pushed to the user (e.g. if his/her actions result in a dangerous situation), or pulled by the user (e.g. the user may not want his/her current activity to be interrupted).

3.2. Investigate privacy and security issues surrounding personal user information (e.g. user's location) being communicated to external sources. Which focal activities and situations would the user agree or disagree to having their location tracked by service providers, friends, family or other people?

3.3. Investigate the extent to which information should be temporally filtered once a user acquires knowledge and experience of particular contexts, activities, and situations.

3.4. If the application supports contextual augmentation, explore the human and social implications of allowing users to disseminate incidental and meaningful messages for others Consider 3.1.3 when exploring the retrieval of messages by others, e.g. should the user leaving the message be forced to prioritise information?

3.5. Investigate how the application should respond to situations where information or services are wrongfully inferred, inaccurate, or unknown. During conflicts of interest, control should be deferred to the user.

Scenario for Design Framework 1

Alice is blind and on holiday in Glasgow. She wants to learn about and experience its culture, history, entertainment, and art. She wishes to use her context-aware device to plan for, and facilitate, her mobile activities.

Design Framework 2

The principles listed below are not hard and fast rules. There will always be situations where they might not apply. However, designers must explicitly rule them out as unnecessary, or requiring too great a trade-off against some other design factor such as response time, as opposed to not considering them at all.

1. *Inform* the user of current contextual system *capabilities and understandings*
2. Provide *feedback* including:
    a. Feedforward – What will happen if I do this?
    b. Confirmation – What am I doing and what have I done?
3. Enforce *identity and action disclosure* particularly with sharing non-public (restricted) information – Who is that, what are they doing and what have they done?
4. Provide *control* (and defer) to the user, over system and other users' actions that impact him/her, especially in cases of conflict of interest.

Realizing these principles depends upon the context-aware system infrastructure being able to model relevant human details of the context, based on technically sensed events. These are listed below:

- *Identity* of others and oneself within, and enabled by capabilities of, the context. This might include some definition of role or interpersonal relationship that implies certain capabilities within some situation or with respect to others in that situation. This also includes control over your own self-representation—what information you give out about your identity.
- *Arrival* of others or of oneself in a context, or *commencement* of a context.
- *Presence* of others and oneself within a context. This might include information about location and capabilities.
- *Departure* of others or oneself from a context, or *termination* of a context.
- *Status and availability* of one's own and others' actions or data to the context. This might usefully include an indication of *activity* and might also include representation of some *abstractions of status* such as 'participating,' busy,' 'out,' 'in transit' or 'waiting' and *abstractions of availability* such as 'public,' 'shared,' 'restricted' or 'private' that imply intentions or potentials within the context. However, requiring the user to constantly update this information is unacceptable.
- *Capture* of information by the context, e.g., video, identity, location, action, etc.
- *Construction* of information by the context; i.e., how data might be interpreted, aggregated and stored.
- *Access* of information (by systems or people) from the context.
- *Purpose* – what use is made of information from the context (by systems or people), e.g., viewing, copying, modification, and, in particular, persistence or *storage*.
- *Type of situation* – information about the governing *social rules* of the context and the *technical implementations* of those rules that follow from the situation. Familiar constructs such as 'lecture,' 'meeting,' 'library,' ''exhibition,' 'interview,' may be useful as metaphors for encapsulating a set of rules.

Scenario for Design Framework 2

Bob is blind and has just arrived at Glasgow Airport. He is travelling to London for a school reunion dinner. He needs to fly to Stanstead and then catch a train to King's Cross Train Station. This should allow him time to walk to his hotel and check in before meeting his friends in the restaurant. Bob wishes to use his context-aware device to plan for, and facilitate, his mobile activities.

E-1 Example application of framework by a group of students

Context-aware computing 11 March 2004

Chee Cheng

Scenario

Bob is blind and has just arrived at Glasgow Airport. He is travelling to London for a school reunion dinner. He needs to fly to Stanstead and then catch a train to King's Cross Train Station. This should allow him time to walk to his hotel and check in before meeting his friends in the restaurant. Bob wishes to use his context-aware device to plan for, and facilitate, his mobile activities.

Your high-level design:

Primary goal: To travel from Glasgow to London in order to attend a school reunion dinner.

Meaningful user scenarios:
- Travel to Glasgow airport.
- Check-In at correct desk.
- Find correct departure gate.
- Once at Stansted, find the rail link to King's Cross.
- Once at King's Cross, navigate to his hotel.
- Navigate to restaurant to meet friends

Incidental user scenarios:
- ~~Delay~~ Flight and train delays, possibly resulting in changes to travel connections
- Bob gets lost in the airport.
- Bob's luggage gets lost.

Meaningful application services:
- Sensing Bob's location in order to transmit appropriate audio ~~instructions~~ directions to airport, Check-in Desk, Departure Gate, etc.
- Using web-based servers to acquire the time of Bob's train from online timetables.

Incidental application services:
- Adjusting journey details due to travel delays.
- Giving advice regarding the location of information desks if his luggage does not appear.

Usability issues:
- Determining how best to transmit information (eg Braille, speech output, other tactile feedback etc.).
- The timing of messages transmitted to Bob (eg insuring that Bob doesn't receive messages at inappropriate times).