Experiences of Developing and Deploying a Context-Aware Tourist Guide: The GUIDE Project

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ABSTRACT

The GUIDE system has been developed to provide city visitors with a hand-held context-aware tourist guide. The system has been successfully deployed in a major tourist destination and is currently at the stage where it is publicly available to visitors who wish to explore the city. Reaching this stage has been the culmination of a number of distinct research efforts. In more detail, the development of GUIDE has involved: capturing a real set of application requirements, investigating the properties of a cell-based wireless communications technology in a built-up environment and deploying a network based on this technology around the city, designing and populating an information model to represent attractions and key buildings within the city, prototyping the development of a distributed application running across portable GUIDE units and stationary cell-servers and, finally, evaluating the entire system during an extensive field-trial study. This paper reports on our results in each of these areas. We believe that through our work on the GUIDE project we have produced a blueprint for the development of interactive context-aware systems that should be of real value to those in the community who wish to develop such systems in a practical environment.

Keywords

Context-Aware, Evaluation, Interactive, Web-based, Wireless.

1. INTRODUCTION

This paper presents a comprehensive description of the work carried out as part of the on-going GUIDE project. The aim of the project has been to investigate the many issues and challenges that arise from the development and *actual deployment* of a context-aware [14] [2] electronic tourist guide in a practical real-world environment, i.e. the city of Lancaster. Since starting work on the project, we have enjoyed a great deal of collaborative support from the city's Tourist Information Centre (TIC) and also cooperation from Lancaster's City Council. This support has been crucial in enabling us to successfully build, deploy and evaluate the system.

Visitors to our city can access context-aware information and services using their hand-held GUIDE units. The information presented to visitors is tailored based on the visitor's user profile and contextual information, including the unit's physical location. In this respect, GUIDE can be considered as a sophisticated example of a Location Based Service (LBS), a class of service that, it is predicted, will have significant market impact over the coming years.

The GUIDE system utilises a high-bandwidth, cell-based, wireless infrastructure and this enables us to support interactive services and highly dynamic information (including access to the World Wide Web). In addition, this same network infrastructure provides location information to the end-systems, thus obviating the need for a separate location system, such as GPS.

The approach and focus of the GUIDE project builds upon the work of earlier context-aware tourist guides such as the Cyberguide project [12]. However, the GUIDE system has been designed to meet the real requirements of tourists as determined by a comprehensive requirements study [3]. Furthermore, the project has been concerned with addressing the many human factors issues and practical problems that have arisen from our approach.

The structure of the remainder of this paper is as follows. The related work section (section two) is followed by a detailed description of the GUIDE application (section three). In this section we discuss the application's requirements, the chosen end-system, the user interface and the functionality supported by our application. The next section (section four) details the main approaches underpinning our development of GUIDE. More specifically, we describe the design of our information model, the GUIDE software architecture that processes this information model, the use of tags for dynamically generating tailored web pages and the mechanisms employed for disseminating information. Next, section five describes the implications of disconnected operation. Our evaluation of GUIDE is described in section six while section seven points to areas of future work. Finally, in section eight, we present some concluding remarks.

2. RELATED WORK

Our work on the context-aware GUIDE system is clearly related to the work at Xerox PARC on the location-aware PARCTab [16] system. This system utilised the Olivetti Active Badge infrastructure [15] for obtaining positioning information and also for the transmission of data, such as e-mail, to the user's PARCTab. The positioning information sensed by the system was used to trigger certain events, such as notifying the user to collect a document when walking past the printer room.

The RADAR project [1] is conducting related, and more sophisticated, research into how the RF network itself can be used in order to locate and track users within a building with a view to supporting location-aware services and applications. In more detail, the system processes signal strength information at multiple base stations in order to estimate user location with a high degree of accuracy, i.e. with a location resolution in the range of 2 to 3 metres.

The Cyberguide system developed by the Future Computing Environments (FCE) group at the Georgia Institute of Technology is a classic example of a location-aware system. The initial Cyberguide system [12] used wireless transmissions to detect a tourist's position and orientation using a collection of IR beacons. These beacons transmitted unique IDs that could then be translated into a map location and orientation. The outdoor version of the system utilised Global Positioning System (GPS) data directly. The fact that mapping information (for the small area covered) was stored locally allowed the system to offer touring functionality even when disconnected from the network.

Also related to the work on GUIDE is the FCE group's Conference Assistant application [6]. This application has been designed to support conference attendees by providing them with appropriate context-aware information and collaborative tools via a PDA as they navigate conference rooms. The conference assistant was developed using a distributed architecture that relies on RF based wireless connectivity and location sensors in order to communicate changes in context between the various components of the architecture.

Closely related work in the area of intelligent electronic tourist guides is currently being conducted as part of the HIPS (Hyper-Interaction within Physical Space) project [10]. In common with GUIDE, HIPS is also investigating the use of wireless technologies and adaptive hypermedia to provide up-to-date context-aware information to tourists and the implications for human factors issues that arise from this approach.

The 'OnTheMove' project has developed a 'City Guide' application [11] designed to utilise either WaveLAN or GSM based connectivity. In common with GUIDE the position of the WaveLAN base station can be used to provide a fix on location. However, the OnTheMove system can also gain a location fix using GPS, if sufficient satellites are in view. The application uses changes in location in order to trigger the appropriate map to be downloaded and displayed.

It is worth noting that a number of other prototype network-based tourist guide systems currently exist. However, these systems are characterised by only having access to low-bandwidth wireless communications or using resource poor end-systems. Furthermore, such systems focus only on the presentation of location aware information and do not attempt to provide users with information and functionality that is tailored to the wider environmental context (e.g. the opening times of attractions and the most aesthetic routes between them) and the personal preferences of the visitor.

3. THE GUIDE APPLICATION

3.1 Application Requirements

We gathered an initial set of requirements for GUIDE from a series of semi-structured, one-to-one interviews with members of staff at our city's TIC. In addition, several days were spent at the TIC observing the information needs of visitors. During this period, the following four key requirements were identified.

3.1.1 Flexibility

The system was required to have sufficient flexibility to enable visitors to explore, and learn about, a city in their own way. This requirement was based on the observation that some visitors prefer to play a passive role when exploring a new city, e.g. following a guided tour; while others may choose a more active role by using guidebooks or street maps. It was deemed important that visitors would be able to control their pace of interaction with the system, e.g. being able to interrupt a tour in order to take a coffee break.

3.1.2 Context-Aware Information

The information presented to visitors by the system should be tailored to their context. We identified two broad classes of context to be used, namely: personal and environmental. Examples of personal context include: the visitor's interests, e.g. history, or architecture, the visitor's current location, attractions already visited and any refreshment preferences they might have. Examples of environmental context include: the time of day, and the opening times of attractions.

3.1.3 Support For Dynamic Information

During the requirements capture we identified a significant need to support dynamic information. Examples of dynamic information range from changes to the normal opening/closing times of attractions to the daily specials menu of the city's cafés. Such information needs to be made available to visitors when appropriate.

3.1.4 Support for Interactive Services

Studying tourist activities in our city revealed that visitors often make repeated visits back to the TIC, often during the course of a single day. In most cases this is because they need to make use of a service offered by the TIC, most commonly the booking of accommodation or travel. We therefore identified a requirement to provide visitors with remote access to interactive services in order to reduce the need for visits back to the TIC.

3.2 The GUIDE End-System

In close consultation with the TIC, we considered a wide range of devices for use as the GUIDE end-system. In particular, we considered pen-based tablet PCs, such as the Fujitsu Stylistic and TeamPad, Windows CE based machines, such as the Casio Cassiopeia, and other PDAs such as the Apple Newton. After much deliberation, we chose to use the transflective version of the Fujitsu TeamPad 7600 [8] as the GUIDE end-system (as illustrated running the GUIDE application in figure 1).

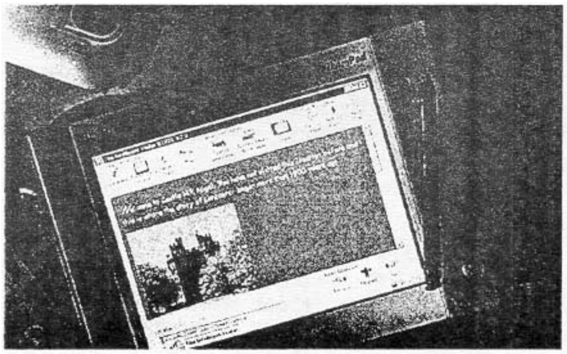

Figure 1: The GUIDE end-system.

Our main reasons for choosing the TeamPad over the models are listed below.

1. The TeamPad has a transflective screen that enables the unit's display to be readable even in direct sunlight. Furthermore, the display is of sufficient size, resolution (800 by 600) and colour depth (8 bit greyscale) to present textual and graphical information, such as maps, with the required clarity. Consequently, visitors can have a significantly richer browsing experience than that which would be afforded by smaller displays, such as those founds on PDAs.
2. Despite its relatively large screen size the unit is sufficiently light to hold with one hand for an extended period of time.
3. The TeamPad is based around a Pentium 166 MMX processor and therefore has sufficient power to run java based applications with reasonable performance. The interactive nature of the system makes the performance issue one of crucial importance. For example, unlike other network-based tourist guide systems, GUIDE utilises local processing power to provide visitors with dynamically tailored tours of the city (section 3.4.2). However, the algorithm to create a tour is computationally intensive and the longer the time taken to generate a tour the greater the likelihood of the visitor becoming frustrated. We found that the performance of the CE based machines available at the time (late 1997) was very disappointing, even for rendering simple web pages.
4. The TeamPad can run the Microsoft Windows 95 operating system and hence all of the development kits and drivers associated with this operating system were available. At the time, the Apple Newton and CE based machines did not have the required driver support, i.e. drivers for appropriate PCMCIA based wireless networking cards.

The TeamPad measures 213x153x15mm, and weighs a very reasonable 850g. We have found the unit to have a battery life of approximately two hours (when driving a wireless networking card in mainly receive mode) and to be relatively resistant to rough treatment.

3.3 The User Interface to GUIDE

The user interface to GUIDE (as illustrated in figure 2) is based around a modified browser metaphor. This decision was made for two reasons. Firstly, the metaphor matches closely the kind of information that had to be modelled, i.e. the notion of following hypertext links in order to access greater levels of detailed information about a particular attraction or event in the city.

The second reason for adopting the browser metaphor was based on the growing acceptance of the web and the increasing familiarity of the metaphor as a tool for interaction. We hoped that positive transfer from the use of common web browsers would help make the system both easy to use and easy to learn for users with previous web experience. However, we also wanted to ascertain the extent to which the basic metaphor would be appropriate for the task of supporting the additional context-aware based functionality required by GUIDE. More specifically, we wanted to investigate the extent to which differences and inconsistencies with the standard would prove confusing to users.

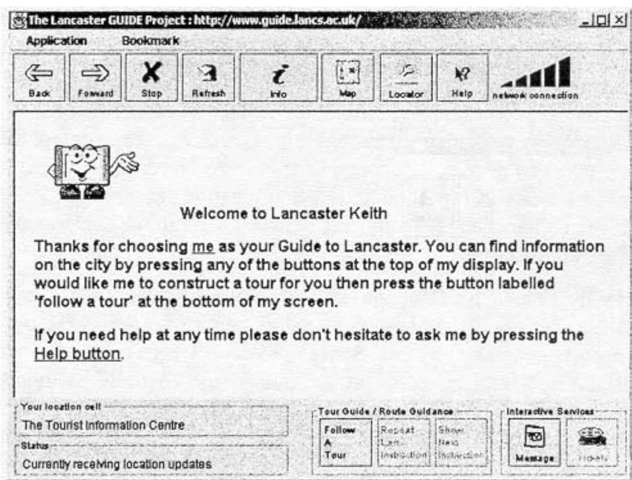

Figure 2: The user interface to GUIDE.

In order to help the system appear more approachable to visitors we have attempted to give GUIDE a friendly personality. This decision was based on the observation [13] that, in general, novice users will find a computer-based interactive system more approachable if it is perceived as having a polite and friendly personality. However, as users become more expert with using the system then this approach may become less appropriate.

We did consider using a multimodal user interface, e.g. one in which information and navigation instructions could be delivered to the user using speech output. However, following discussions with staff at the city's TIC, we decided not to pursue the approach, at least in the development of the first prototype. Our main reservation was based on the fact that GUIDE is designed for outdoor pedestrian use and our city has its fair share of traffic noise. We were concerned that visitors might be distracted when crossing roads if the system chose that time to deliver some information. Following on from this point, in general we have reservations about the effective bandwidth of voice for information transfer and the extent to which users can control the pace of information delivery with a speech-based system.

3.4 Application Functionality

The GUIDE system provides city visitors with a wide range of functionality: a visitor can use their GUIDE unit to access context-aware information, create a tailored tour of the city, access interactive services, and send and receive textual messages.

3.4.1 Access Context-Aware Information

The visitor can use GUIDE to retrieve web-based information based on the current context, e.g. the visitor's location. In addition, the system also enables visitors to access web pages in a non context-aware manner. More specifically, by following the appropriate links visitors have general access to the World Wide Web.

In order to retrieve information the visitor can tap the 'Info' button and this will cause a set of choices to be presented in the form of hypertext links. Figure 3 shows the choices that would be available if the visitor happened to be located in the cell surrounding the tourist information centre.

It is important to note that not all the options are based on the visitor's current location. For example, the visitor is provided with the ability to search for information using a keyword search facility, irrespective of their current location.

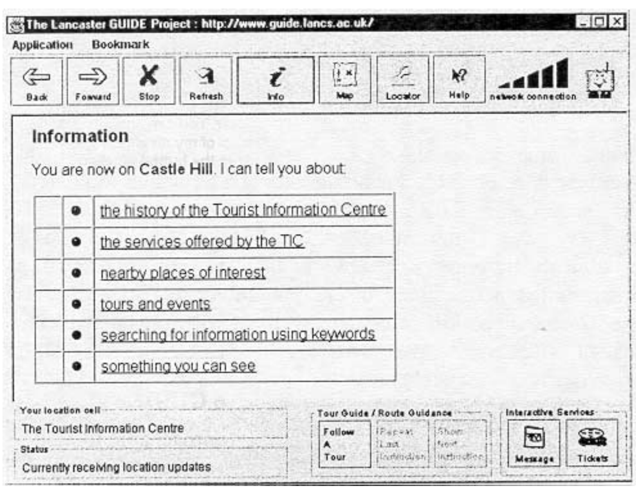

Figure 3: Accessing information using GUIDE.

An earlier version of the system did not offer the search facility and, in effect, restricted the scope of information available to a visitor to that closely related to the visitor's location. During an expert walkthrough of the system (section 6.1) it became apparent that constraining the visitor's access to information based on their location can be very frustrating for the visitor if the information they require cannot be accessed because we did not deem it to be of sufficient relevance to the area concerned.

On a more general point, our experience with this aspect of the system has taught us that designers of context-aware systems must not be over zealous when deciding to constrain the information or functionality provided by the system based on the current context.

The difficulty of pre-empting the user's goal is further highlighted when considering the situation where the visitor selects the third option in order to view a list of nearby attractions. When presented to the visitor, the list is sorted in such a way that those attractions that are open, and have not already been visited, are placed higher up the list. The assumption is made that the visitor is more likely to be interested in attractions that are open and that have not already been visited. An earlier version of the system constrained the output by removing all closed attractions from the presented list. However, this frustrated some visitors who were interested in visiting the attraction anyway, e.g. to view the architecture of a building.

3.4.2 Create a Tailored Tour of the City

The GUIDE system is designed to enable visitors to request a structured tour of Lancaster based on a set of attractions that they wish to visit. In order to ascertain this set of attractions, visitors are asked to select attractions from a set of categories such as 'Historic' and 'Recreation'. However, one of the problems with asking the visitor to choose attractions to be included in their tour is that they do not necessarily appreciate what is special in a given town. For example, everyone would like to drink stout when in Dublin even though they might not do so at home. For this reason, we also provide a 'Popular Attractions' category.

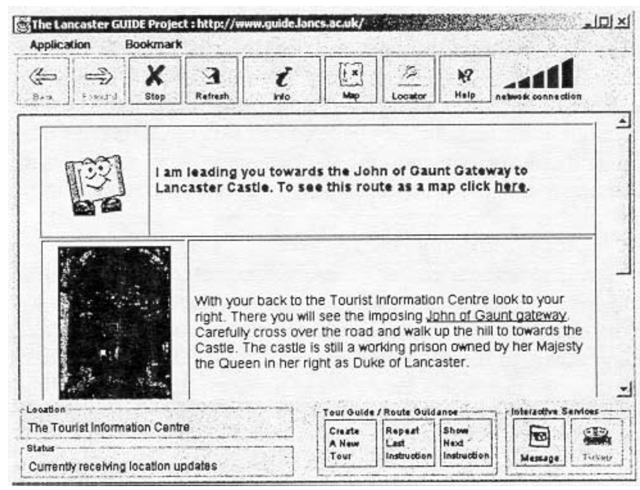

Figure 4: The presentation of navigation information.

Once a tour has been generated, the visitor is presented with a recommended sequence for visiting their chosen attractions. The visitor can then, either, agree to be taken to the next attraction in the suggested sequence, or, override this recommendation by selecting a different attraction to be their current destination. The system provides this choice in order to prevent the system behaving in an overly authoritarian manner. It does, after all, seem quite reasonable to allow a visitor to delay their current tour and get directions to the nearest café instead. However, providing this level of flexibility involved a significant increase in interface complexity and this part proved most difficult to visitors (see evaluation results).

A structured tour is broken down into a number of distinct steps or stages. Once a visitor has completed one stage, they can request the system to describe the next stage of the tour by touching the 'show next instruction' button. Stages in the tour are described using a navigation instruction. These instructions provide the visitor with a piece of text explaining, in some detail, how to get from their current location to the next attraction in the tour (see figure 4). In addition, the visitor is also presented with

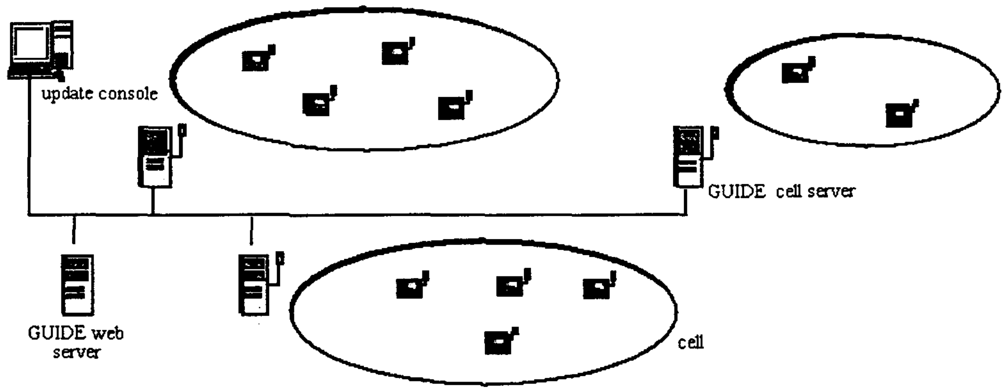

Figure 5: The cell-based wireless communications infrastructure used by GUIDE.

information on their current location and this may include one or more hypertext links should the visitor wish to find out further information.

It is important to note that, given the same set of attractions, the ordering of the tour recommended by the system can actually change dynamically. This can occur when, for example, a visitor stays at a location longer than anticipated or if one of the attractions announces that it will close early. The system regularly calculates whether or not the current order for visiting the remaining attractions is appropriate given current time constraints.

3.4.3 Access Interactive Services

By providing remote access to interactive services, such as the booking of hotel accommodation, visitors can save time by making bookings via their GUIDE unit. In addition to providing remote access to those services provided by the TIC, the GUIDE system also enables access to other services, such as enabling visitors to query those films on show at the city's cinema and enabling visitors to book seats at the cinema remotely.

3.4.4 Send and Receive Messages

This messaging service enables groups of visitors, who may have separated in order to visit different attractions in the city, to keep in touch and also enables visitors to request information from staff at the TIC.

4. ARCHITECTURAL APPROACH

When engineering the GUIDE system we wanted to explore how the use of a high-bandwidth cell-based wireless networking infrastructure could be used to disseminate dynamic information to handheld GUIDE units. In particular, we required an infrastructure capable of enabling GUIDE units to achieve high-speed access to general web resources, including graphically intensive web pages. We also wanted to explore how the cell-based nature of the network could be used to provide GUIDE units with positioning information. Details of this wireless network, the caching strategies used and our overall model for representing context-sensitive information are described in detail in the following sections.

4.1 The Cell-based Communications Infrastructure

The network infrastructure that is used by the GUIDE system comprises a number of interconnected cells as illustrated in figure 5.

The wireless network is based on Lucent Technolgies' 802.11 compliant WaveLAN system. The version used by GUIDE operates in the 2.4GHz band and offers a maximum bandwidth of 2 Mbps per cell. Currently, six communication cells have been deployed within a region of the city that is popular with tourists.

A single Linux-based *cell-server* is associated with each cell and this server is responsible for broadcasting information to GUIDE units as they enter the cell-server's zone of coverage. Each cell-server has two network interfaces. The first interface is used as a link back to the university network. In some cases, cell-servers were installed at locations where the university already holds leased lines. In buildings owned by the City Council we have installed BT Keyline links, these are based on Symmetric DSL technology and effectively provide a two-way 2 Mbit leased line.

In the near future, we plan to extend the communications infrastructure (currently comprising 6 cells) with additional cells. However, some of these cells will require the placement of cell-servers in buildings where the installation of leased-lines is inappropriate. Within these buildings, we intend to obtain a link back to the university is provided by the EDNET wireless network [7] which has been installed to provide internet access to local schools.

Although, the range of WaveLAN is approximately 200m in free space, WaveLAN signals have very poor propagation characteristics through buildings and, therefore, by the strategic positioning of cell-servers, we have been able to create relatively small and asymmetric cells. Within the context of GUIDE this is a positive feature because by creating smaller, non-overlapping cells more accurate positioning information can be provided. For example, in Lancaster we have been able to create a communications cell for the TIC, which covers the immediate area surrounding the TIC but does not (by a small number of metres) crossover into the cell associated with the nearby city castle. Indeed, the TIC cell has a coverage area that resembles the shape of a squashed rectangle rather than that of a circle and at its

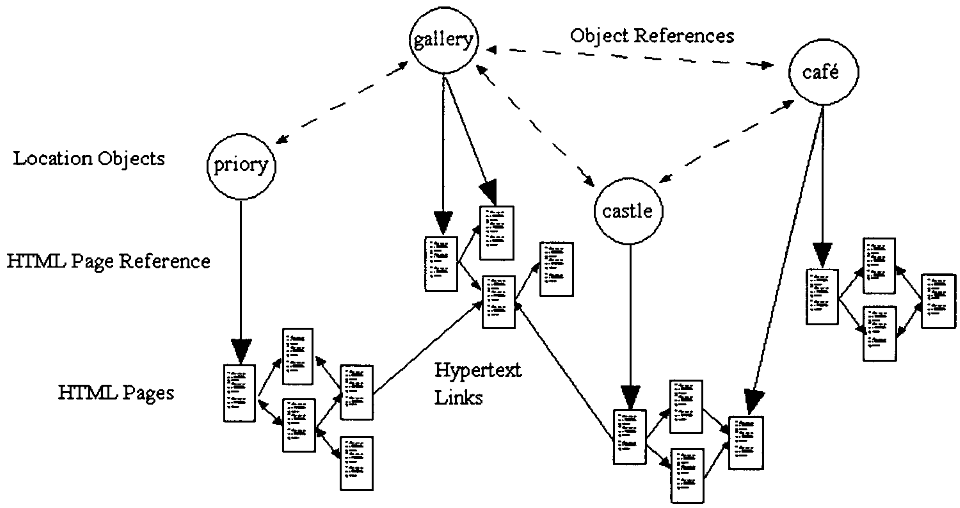

Figure 6: The GUIDE information model.

narrowest point, measures only 15m across. In order to manage the strategic positioning of cells, it was necessary to repeatedly place the WaveLAN antenna at different heights and positions and then use the test software supplied by Lucent technologies to determine how the range of the cell had been affected.

An additional benefit of producing small non-overlapping cells is that it enables us to disable WaveLAN roaming. Had roaming been enabled then additional and unwanted network traffic would have resulted to support handover as units moved between WaveLAN cells. By disabling the roaming facility, GUIDE units are effectively silent on the network unless they request information that is not on the current broadcast cycle [12].

However, in many cases, we have not found it possible to create very accurate cell boundaries due to the reflection of signals, interference and changes in propagation patterns resulting from fluctuations in the density and placement of objects within the cell. For example, where we have placed a cell for one of Lancaster's public squares, the degree of propagation down the square's access roads varies with the prevailing conditions.

4.2 Design of an Information Model

The information model adopted by GUIDE was required to represent or store the following four distinct types of information:

1. information which can be tailored to reflect the current context. More specifically, this is often modelled as information that can react to events such as 'it is raining' and 'the user is outside the castle and has an interest in history'.
2. geographic information, which can be either expressed in geographic terms (e.g. 'location *a* is at co-ordinates *x,y*') or symbolic terms (e.g. 'the cottage museum is in the castle hill area').
3. hypertext information, which can be either global (i.e. internet based) such as the world-wide-web or stored locally.
4. active components, which are capable of storing state (such as a visitor's preferences) and of performing specific actions or satisfying certain requests.

Although each particular information type has been successfully modelled, no models could be found that were capable of handling the full complement of information types described above [5]. In more detail, data models for supporting context-sensitive information such as stick-e-notes [2], are not well suited for managing geographic information such as proximity relationships. Similarly, the data models supported by the current range of object oriented Geographic Information Systems are ill-suited for representing context-sensitive information [4] because they lack the necessary triggering mechanisms required for handling the events raised by changes of context.

The lack of availability of an appropriate model provided the motivation for developing our own information model (figure 6). This model is based on the integration of an active object model with a hypertext information model.

The information model contains two distinct object types: navigation point objects and location objects. Navigation point objects represent waypoints between location objects are used to support the construction of tour guides. Alternatively, location objects actually represent attractions in the city and are the fundamental building block of our model. One example of a location object is the castle. This object would have state representing its physical location within the city, opening times, and links to other nearby locations. Location objects also support methods to enable state information to be accessed and modified. For example, two of the methods supported by the object representing the castle would be:

GetImmediateNeighbours()

This method returns a list of object references for those objects that are immediate neighbours of the current object and is therefore useful when performing navigation tasks.

ProvideDescription()

This method is used to return a handle to information about the location object based on the visitor's profile. For example, if the visitor required information in German then this method would return a handle to information on the castle presented in German. This provides coarse-grained tailoring of the information according to user profiles. The fine-grained tailoring of information is achieved using tags as described later in this section.

The information model allows geographical information to be represented by creating relationships (modelled as objects) between navigation point and location objects. These relationships can have attributes (weights) assigned to them to denote, for example, the distance between two objects by a variety of means of transport. Using this representation, other objects can traverse the object graph in order to determine, for example, neighbouring locations or optimal routes between points.

The information model was populated to represent those attractions and shops that are in approximately the same region as that covered by the cell-based communications infrastructure and this involved the creation of 400 object instances. This set of objects comprises 120 location/navigation point objects and 280 relationship objects. The current approach adopted by GUIDE is to store all such objects belonging to the information model on the local client and this requires approximately 300 Kbytes of storage. This technique enables GUIDE units to perform route guidance calculations, irrespective of whether or not network connectivity is available.

Although GUIDE units are able to cache parts of the information model locally, due to the dynamic nature of the information and the potential storage requirements associated with storing the model in its entirety, simply caching the model at the local client is not an appropriate solution. In the GUIDE system, the communications infrastructure is used to disseminate the latest version of the information model to GUIDE units [5]. This is achieved using a broadcast based approach [8]. In more detail, units listen on a well-known multicast IP address for those parts of the information model currently being transmitted in the broadcast cycle. In this way, units entering a cell receive (and locally cache) pages related to the cell.

It is important to note that the information model and the communications infrastructure are independent. Indeed, in the near future we plan to install a new communications cell to cover the Lancaster Priory but this will not require any amendment to the information model.

In order to allow hypertext pages to reference the object model we enable the authors of hypertext pages to augment their pages with tags that control the display of the information (see examples below). These tags take the form of special instructions that are able to query the GUIDE object model. For example a tag might be used customise a page to include a tourists name or their location.

A selection of the tags currently supported and in use by GUIDE are described below:

```
<GUIDETAG INSERT POSITION>
```

This tag can be used to insert a tourist's location dynamically into the page being displayed. So, if a tourist followed a link and asked 'tell me about the area that I am in' the resulting page could include this tag to inform the visitor of their location.

```
<GUIDETAG INTEREST ((HISTORY > 50) AND
(ARCHITECTURE > 50))
```

This tag allows a user's profile to be queried and thus enables the application to tailor pages based on the preferences of the visitor.

```
<GUIDETAG INSERT NEIGBOURS>
```

This tag can be used to generate information relating to nearby attractions dynamically as illustrated in the following example. An example of a page containing this tag (removing the unnecessary HTML META information) is illustrated in figure 7.

```
<HTML>
<P><B><FONT SIZE="5" FACE="Comic Sans
MS">The following attractions are near to you
now.</FONT></B></P>
<P><FONT FACE="Comic Sans MS">Note: The
list below is ordered according to closeness and
whether or not they are open or
closed.</FONT></P>
<P><FONT FACE="Comic Sans MS"><BR>
<GUIDETAG INSERT NEIGHBOURS>
</FONT></P>
</HTML>
```

Figure 7: Example of page containing GUIDE tags.

Once this page has been retrieved from the cache (locally from the client) or from the remote proxy it can be processed by the appropriate software filter causing the GUIDE tag to be replaced with the appropriate HTML code. Considering the example of figure 7 (and given the visitor's location being near the city's TIC) the processed page would be displayed as shown in figure 8.

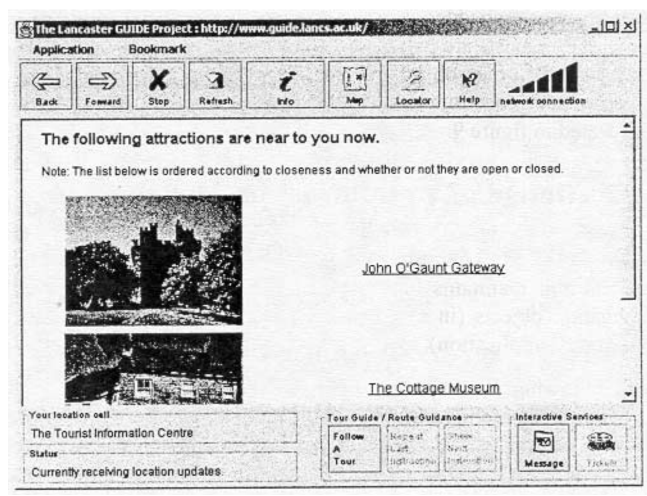

Figure 8: The dynamically created 'nearby places' page.

The effort required for populating the information model with information for a given city should not be underestimated. Indeed, nearly eight person months of time was invested in populating the information model with the 400 objects and approximately 400 HTML pages required to represent just part of the city. Without this investment in time, the field trial of the system by visitors to

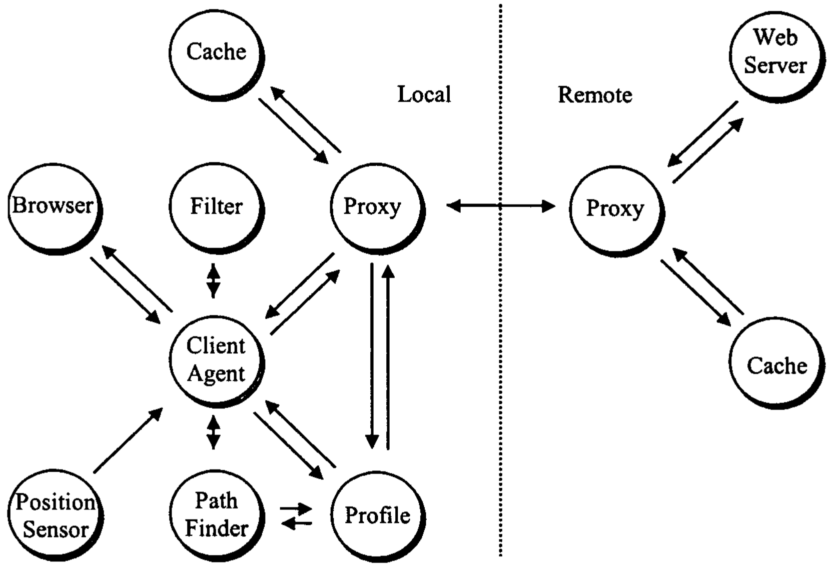

Figure 9: The GUIDE software architecture.

the city (described in section 6.2) would have lacked much of its validity. To help simplify the process of creating location and navigation objects we developed a 'city editor' application. This application provides designers with a very useful graphical tool for automatically creating and customising location and navigation objects for a given city. In addition, by associating arcs between objects represented as nodes, designers can stipulate the geographic relationships between location and navigation objects. In this respect, the GUIDE information model has a high level of portability for mapping onto different cities.

4.3 The GUIDE Software Architecture

Visitors interact with their GUIDE units through their own local web browser embedded within the GUIDE application. In effect, all HTTP requests are processed by a local web proxy, which may interact with other objects in order to service the request. The objects that constitute the GUIDE software architecture are illustrated in figure 9.

The key component in our architecture is the client agent object. This object services user requests for information and dispatches events, e.g. position updates, to the appropriate components in the system. The client agent also creates location and navigation objects and maintains handles to currently active location and navigation objects (in a similar fashion to a CORBA ORB in a distributed application).

The following six steps illustrate the interaction of the various objects when reacting to a change in the visitor's current location.

Step 1) The position sensor object listens for beacons from cell servers.

Step 2) On hearing a beacon the position sensor object notifies the client agent of the visitor's new location e.g. the city's castle.

Step 3) The client agent searches through the objects currently in memory to determine whether or not an instance of the appropriate location object already exists. If it does, then a handle to that object is returned, otherwise a new instance of the object is instantiated.

Step 4) On receiving a handle to the landmark object, the client agent can invoke methods on the landmark. Initially, the client agent invokes a method to return the nearby attractions. For reasons of performance, these objects (which are the most likely objects to be used) are loaded in main memory.

Step 5) The visitor can then use their web browser to request information such as, 'What attractions are nearby ?'.

Step 6) The local proxy object processes such requests by fetching an appropriate page of information from either: the local cache, the remote cache or the central web server. The filter object would process or tailor this page by interrogating other components such as the visitor's profile.

In the current GUIDE system, the application loads all objects when the application is initialised. The objects are then passed to the PathFinder object (see figure 9) that is responsible for generating a model of the city from the objects.

5. THE IMPLICATIONS OF DISCONNECTED OPERATION

One can argue that, in the future, fully connected environments will be commonplace in outdoor as well as indoor environments. However, it seems unlikely that the problem of excessive power consumption, caused by fully connected operation, will disappear in the near future. For this reason, it is dangerous to simply assume that one can ignore the problems of connectivity when considering the future role of mobile context-aware systems.

The GUIDE end-system can become disconnected for significant periods of time. During these periods, GUIDE units are unable to receive static information that is not in the local cache, dynamic information or location beacons. Consequently, during periods of disconnection, the system must rely on those parts of the information model that are cached locally. In addition, certain aspects of GUIDE's functionality are no longer available, e.g. the messaging service and access to interactive services, such as ticket booking.

5.1 Providing Awareness Information

One approach for dealing with the potential for disconnected operation would have been to hide the issue of connectivity from the user completely. Given this approach, only when the visitor performed some action that explicitly required connectivity, such as booking a cinema ticket, would the visitor be informed that the service was currently unavailable. The problem with this approach is that the behaviour of the system would seem unpredictable and inconsistent as the unit switched between connected and disconnected modes of operation. To help alleviate this problem, the user interface to GUIDE has been designed to encourage the user to form a suitable mental model of the system, i.e. one in which the functionality of the system is not static but dependent on whether or not wireless connectivity is currently available. The following subsections describe the various user interface design choices we have made in order to enable the user to realise which mode they are currently in.

5.1.1 Use of a Metaphor to Provide Connectivity Feedback

A familiar metaphor was required for providing visitors with feedback regarding the state of connectivity and encouraging them to associate this with available functionality. To arrive at a suitable metaphor, we considered how connectivity feedback is provided on mobile phones. The user of a mobile phone is given feedback of their connectivity in the form of 'bars of connectivity' and when a user receives no bars of connectivity they expect limited functionality, i.e. the inability to send or receive calls. The 'bars of connectivity' metaphor has thus been incorporated into the user interface as shown in figures 2,3,4,8 and 10.

In the current GUIDE system, although the metaphor is based on the familiar five bars of connectivity, the system only uses the metaphor to display one of two states, i.e. either all bars or no bars. The system determines which of the two states should be displayed based upon whether or not it is receiving location beacons at the expected frequency. During end-user trials (section 6) it was found that the slight liberties taken with the metaphor did not invalidate its desired function, i.e. as a simple means for communicating the availability of network connectivity to a non-technical member of the general public.

5.1.2 Showing the Status of Location Updates

Up-to-date positioning information is not available when GUIDE units are disconnected from the network. For this reason, we have incorporated a location status window into the user interface (as shown in figures 2,3,4,8 and 10) in order to keep the user informed of the ongoing reception of location information by the system. When location information has not been received for a while, the visitor is shown the time (in whole minutes) that has elapsed since the last location update was received. It is important to note that even if the GUIDE system utilised a GPS system for obtaining positioning information, there would still exist periods when location information would not be available. This is often the case when using GPS in a city environment because the position of tall buildings can prevent the GPS system from 'seeing' a sufficient number of satellites to obtain a fix on location.

5.2 Using the Visitor's Assistance to Solve Location Problems

When visitors do leave cell coverage and up-to-date positioning information becomes unavailable, the GUIDE system tries to locate the visitor by establishing a form of partnership between itself and the visitor. In more detail, the visitor is shown a series of thumbnail pictures showing attractions in the vicinity of the visitor's last known location (see figure 10). Providing the visitor is then able to recognise and select one of the pictures, the GUIDE system to once again ascertain the visitor's location within the city.

During our initial evaluation of the system we have found the response of users to selecting their position based on a picture thumbnail to be positive.

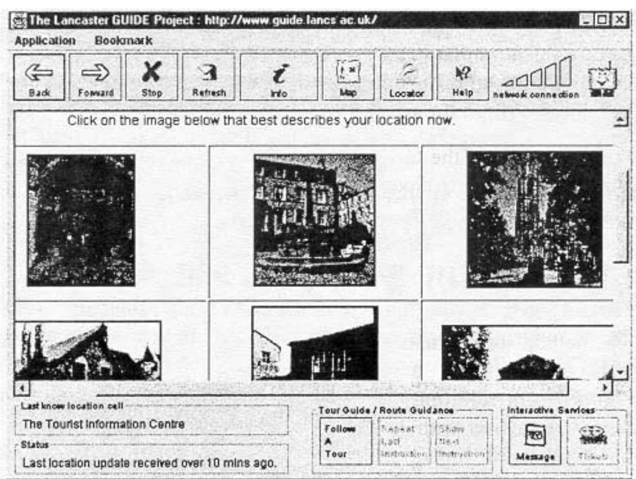

Figure 10: Using the visitor's assistance to ascertain their location.

6. THE EVALUATION OF GUIDE

Our evaluation of the GUIDE system involved two distinct phases: an expert walkthrough of the system and a field trial. This section summarises the results of these evaluation phases. A more detailed discussion of the evaluation and its results can be found in [3].

6.1 Expert Walkthrough

An expert walkthrough of the GUIDE system was performed in order to provide a crude first pass evaluation of the system's usability. The walkthroughs involved four experts, with backgrounds spanning user-centered design and computer supported learning. Experts were asked to use a talk-aloud protocol while using the system and were then interviewed and asked to criticize the system. Examples of problems that were identified and fixed for the field trial included the need for button

Table 1: Profiles of visitors involved in the evaluation.

Age Profile	Number	Gender		Previous Web Experience
		Male	Female	
10-20	6	4	2	6
21-35	15	7	8	7
36-55	26	12	14	8
56-70	13	6	7	1

layout to be consistent with that of other browsers and the need to provide animated feedback to signify when a page is downloading.

6.2 Field Trial

The main objective of our evaluation at this stage of the project was to validate and refine our initial set of requirements against a set of end-users. In addition, we wanted to know whether or not people were prepared to accept the use of a computer-based context-aware tourist guide. Consequently, we wanted to measure the quality of the visitors experience [10] as opposed to absolute performance times for accessing specific pieces of information.

The evaluation of the GUIDE prototype by field trial was subject to a number of constraints. In particular, we felt acutely aware that we would be impinging on the leisure time of tourists. For this reason, we asked visitors to use the system as they wished and for only as long as they felt happy, rather than performing some predefined series of tasks.

Our method for evaluation was based on direct observation, with visitors encouraged to use a talk-aloud protocol for audio recording. In addition, we maintained a time-stamped log of user's interaction with the system in order to gather a record of the number of links followed. Following each test, a semi-structured interview was performed in order to obtain the visitor's subjective opinion of the system. We felt that this approach was suitable given the main objective of the evaluation. More specifically, by shadowing users we could observe those parts of the interface that caused problems while the semi-structured interviews enabled us to follow up on any problems encountered during the trial.

Over a period of approximately four weeks we had 60 people volunteer to use the system. Roughly half of these volunteers were canvassed near the city's castle while the other half answered to adverts to come and trial the system. These adverts were places on posters around the city and also on local radio. The makeup of the volunteers in terms of age, gender, web-experience etc. is shown in table 1.

The results of the evaluation that we found most interesting are listed below:

1. All visitors expressed the opinion that the location-aware navigation and information retrieval mechanisms provided by the system were both useful and reassuring, and stated that they enjoyed using GUIDE to explore the city.
2. The vast majority of visitors said that they were prepared to trust the information presented by the system, including the navigation instructions. A number of visitors suggested that their level of trust was not constant but varied with the apparent accuracy of the information presented.
3. Surprisingly, all visitors seemed quite prepared to use a 'computer' as a tool to explore the city. Specifically regarding the teampad, the majority of visitors were basically happy with the dimensions and weight of the unit.
4. The vast majority of visitors without previous web experience felt comfortable using the system to follow a tour and retrieving information by navigating hypertext links after a brief (usually about five-minute) training session. However, a number of visitors found the flexibility provided by the tour guide facility a little bewildering and we intend to make a future version of this facility substantially simpler to use.
5. A significant majority of visitors said that they were aware that their GUIDE unit utilized wireless communications in a similar way to a mobile phone and appreciated the relationship between the degree of connectivity and the level of functionality available at a given point in time.
6. Analysis of the access logs revealed that visitors in the 10 to 20 age profile seemed to revel in the technology and visited approximately twice as many links (per minute of usage) as those from other age profiles (this does not mean they read and assimilated this information of course).
7. The majority of visitors appreciated that the system knew of their location to within a certain area and that this relied upon the reception of location updates.

7. CURRENT STATUS AND FUTURE WORK

Today, visitors to Lancaster can come into the TIC and ask a member of staff for a GUIDE unit. The visitor will be given a short training session on how to use the system before being asked to sign a disclaimer form. Once they have supplied their credit-card details (as means of a deposit) they are allowed to leave the TIC with their GUIDE unit to help them explore the city.

The TIC are currently in the process of securing funding to employ a full-time member of staff whose main responsibility will be to update information for the GUIDE system. This task will include duties such as entering the daily specials menu from participating cafés and keeping track of any changes to the normal opening times of the city's attractions.

One of our current directions for developing the GUIDE system is to extend the role of connectivity in GUIDE by supplementing the existing GUIDE infrastructure with the latest low-power, micro-cellular, wireless technologies, such as Bluetooth. This will enable GUIDE to support communications within buildings. In addition, the use of micro-cellular wireless communications systems will enable us to determine users' locations with greater accuracy, without requiring bulky differential GPS equipment, and thus enhance the navigational capabilities of the system in particular areas of the city.

In the near future, we plan to increase the diversity of context-sensitive interactive services and to harness the enthusiasm of the younger generation of visitor by developing games and educational tools, such as treasure hunts, that can be played using GUIDE. In addition we would like to explore the potential for making parts of the information model 'public', thus providing visitors with the capability to share their experiences and recommendations with other visitors or family members.

Another area in which we hope to conduct future research concerns the suitability of existing techniques and methodologies for designing and evaluating context-aware interactive systems such as GUIDE. In particular, such systems are highly adaptive by their nature but this clearly conflicts with the design principle of ensuring predictability within the system.

8. CONCLUSIONS

This paper has described our experiences of developing, deploying and evaluating GUIDE, an electronic context-aware tourist guide. The development of the system can be considered from engineering, information and human factors viewpoints.

Considering the system from an engineering perspective, we note that the system is built upon a high-bandwidth, cell-based, wireless communications infrastructure. This infrastructure has a dual role, firstly, it is responsible for broadcasting location beacons in order to provide positioning information, and, secondly, the infrastructure is used to disseminate both static and dynamic information to mobile GUIDE units. We found that the cell-based granularity of positioning information provided by the communications infrastructure was sufficient for the requirements of the system. The relatively high-bandwidth provided by the infrastructure is very useful for maintaining reasonable download speeds when visitors require access to information held on the web. We found the ability to support interactive services was beneficial to tourists and, furthermore, that the location resolution provided by such an approach was adequate for the application domain. The distributed object-based GUIDE software architecture is responsible for servicing requests for web-based information and handling contextual events, such as changes in the visitor's location or the opening times of attractions.

Looking at the system from an information viewpoint, we found it necessary to design our own information model. This model combines the event-based aspects of context-aware models with the geographic functions commonly associated with geographic information systems (GIS). Crucially, this model is independent of the communications infrastructure and enables us to create objects that can respond to events and tailor their behaviour to reflect the current context. The information model also provides access points into a collection of web pages whose presentation can be tailored dynamically through the use of special GUIDE tags. These tags enable page authors to interrogate the information model at run-time. GUIDE units are able to cache portions of the information model locally and this enables visitors to access information even when outside of communications coverage. In addition, the system can request the visitor's assistance in order to overcome the lack of location information available when in a communications cell. The population of the information model with appropriate content was a time consuming task but was absolutely necessary to enable the validation of the system's design and an evaluation of the systems usability.

Considering the system from a human factors perspective, the GUIDE system has been designed to meet a set of real end-user requirements. The project has also been concerned with many of the human factors issues that arise from the need to develop a user interface that can successfully cope with the units network connectivity, i.e. switching between connected and disconnected modes of operation. Through our field trial evaluation, we found a high level of acceptability for the system across a range of different types of end-user. During the development of GUIDE, we discovered an interesting trade-off, i.e. the need to produce a system that uses context to simplify the user's understanding of, and interaction with, an inherently complex system versus the need not to overly constrain the functionality or information presented by the system, based on the current context. This is, of course, an interesting instance of the fundamental tradeoff between prescription and freedom.

Although the GUIDE system is publicly available today, we have maintained our links with the TIC and are in the convenient position of having the control to make changes to the GUIDE system and monitor the results of these changes as part of our on-going research. We believe that through our work on the GUIDE project we have successfully produced a blueprint for the development of interactive context-aware systems that should be of real value to those in the community who wish to develop such systems in a real environment.

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