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Gulliver's Genie: a multi-agent system for ubiquitous and intelligent content delivery

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Abstract

This paper introduces *Gulliver's Genie* a context-aware tourist guide that assists roaming tourists. The approach adopted within this system is the deployment of intelligent agents, which collectively determine the user context and retrieve and assemble multi-media presentations that are wirelessly transmitted and displayed on a Personal Digital Assistant (PDA). As a backdrop, we first consider the state of the art in terms of context sensitive tourist guides, telecommunications, positioning technology and agent technologies. Gulliver's Genie considers user context in terms of position, orientation and user profile. System agents are strong intentional agents that base deductions on a mental state comprising of Beliefs, Desires and Intentions (BDI). This paper presents the design of the system together with a glimpse of the user experience.

Keywords: Context-aware computing; Multi-agent systems; Wireless communications; Mobile computing; Tourist information systems

1. Introduction

Recent technological advances continue to bring the vision inspired by ubiquitous computing to fruition. As with any technology whose time has come, its foundations have been laid block by block, silently and unobtrusively over the preceding decades. Though the concept remains aspirational, the recent upsurge in related research demonstrates that the vision may soon become a reality. Recent advances in wireless communications and positioning technologies will form a cornerstone upon which the ubiquitous computing vision will be constructed.

Research to-date has primarily concentrated on the infrastructure required to support users in an indoor environment. As this offers greater scope for observation and control, it is quite understandable. In contrast, the outdoor environment offers a different set of challenges. In this paper, we describe how one group of outdoor users, namely tourists, might usefully benefit through the implementation of a context-aware electronic tourist guide. Section 2 outlines some related research. Recent developments in wireless communications, location aware technologies together with advances in intelligent agents are described in some detail in Section 3. In Section 4, the main components of the Gulliver's Genie electronic tourist guide are introduced. In Section 5, some conclusions are drawn and areas for further research are identified.

2. Related research

Numerous research disciplines have found the tourism sector a useful testbed for their theories and applications. Given the importance people place on their leisure activities, this is not surprising. Various sub-disciplines in the computer science arena have similarly carried out experiments and developed specialist applications with the tourist in mind. Researchers in areas as diverse as Geographical Information Systems (GIS) [1], robotics [2] and Internet related technologies [3] have found tourists a useful target group. Of particular interest are mobile or roaming tourists. A great deal of effort has been expended in observing tourist behaviour in indoor environments and

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developing electronic guides as an aid for visitors to museums [4,5] and art galleries [6]. In contrast, supporting tourists as they wander in an outdoor environment has received less attention.

Inspired by the vision offered by ubiquitous computing, Schilit et al. [7] proceeded to define the concept of *Context-aware Computing*. According to Schilit, the three key aspects of context are: where you are, who you are with and what resources are nearby. In addition to location, context could include lighting, noise level, network connectivity, communication bandwidth and social situation. As developments in mobile computing have continued unabated, other researchers including Schmidt [8] and Dey [9] have attempted to extend and redefine the concept of context and context-aware computing.

Numerous influential and pioneering context-aware research projects have been undertaken. Notable amongst these is Cyberguide [10], a context sensitive electronic tourist guide developed at Georgia Institute of Technology. The primary objective for Cyberguide was to provide a subset of those services one would expect from a real tourist guide. Likewise, researchers in the Distributed Multimedia Research group at the University of Lancaster developed GUIDE [11], a context sensitive tourist guide for the city of Lancaster.

Though location is only one aspect of context, nevertheless, it has given rise to the concept of location-aware computing and applications. Indeed so important has this idea become that telecommunications operators plan to offer such services when the Third Generation (3G) networks are finally rolled out. As part of their investigations into mobile multimedia services in a 3G network, Kreller et al. have developed City Guide [12]. Likewise, Pfeifer et al. developed Mobile Guide [13] for parts of Berlin as part of their investigation into generic platforms for supporting location-aware services. In this case particular emphasis was placed on both the middleware required to support disparate data sources and the adaptation of content for different devices.

Recently Intelligent agents have been the focus of much attention from the Artificial Intelligence community. Multiple prototype systems have been developed which demonstrate the use of agent techniques. Exemplar systems are Personal Travel Assistant, TravelMate and C-MAP.

The Personal Travel Assistant [14], utilises agents to plan travel itineraries on behalf of its users by integrating distributed, i.e. World Wide Web (WWW) based, travel services. These agents are delivered using the Zeus agent prototyping environment thus enabling the deployment of strong intentional agents. For active mobile tourists, researchers at SRI International have developed TravelMate [15], a system developed for San Francisco that utilises agents to support mobile tourists. The use of agents in supporting a multi-modal user interface was one of the primary motivations for developing TravelMate. These agents utilised the SRI Open Agent Architecture delivering a strong agent capability. Researchers in Japan have developed C-MAP [16], a context-aware mobile assistant system that provides guidance for visitors to exhibitions. Primarily concerned with interface design issues, it uses agents, represented as life-like characters on screen, for supporting communication between exhibitors and visitors.

3. Enabling technologies

3.1. Agent technologies

The use of Agent Oriented Software Engineering (AOSE) as an effective paradigm for managing complexity in the delivery of software systems has recently been recognised [17]. In particular, where such systems are comprised of many dynamically interacting components, the technology has proven particularly apt. AOSE advocates federations of autonomous, proactive, rational and social agents that can engage in opportunistic collaboration in the solution of shared or global goals. A comprehensive introduction to Multi-Agent Systems research is available elsewhere [18].

Numerous incarnations of agents can be found ranging from the reactive agent that responds in a stimulus response manner and minimises the need for a complex representational model of the agent environment (*weak agents*) through to the highly sophisticated intentional agents that maintain complex mental states which are used to support rational reasoning in a collaborative context (*strong agents*). The most common manifestation of strong agents has been through the Belief Desire Intention (BDI) [19] paradigm, an elegant and computationally tractable delivery of the fundamental *intentional* agent stance.

Within the mobile computing arena the use of agents is beginning to find favour although many of the agents utilised are of the weak variety. Often the computational real estate restrictions of Personal Digital Assistants (PDAs) (memory, processing speed, screen size) necessitates the deployment of weak rather than strong agent technology.

However recent advances both in the emergence of agent prototyping environments for developing Java agents (*Aglets, JATlite, JACK, Agent Factory Lite*) and the availability of a micro edition of Java that can be hosted on all PDAs namely J2ME (Java 2 Micro Edition) have meant that stronger notions of agenthood can now be delivered in the mobile and ubiquitous sector.

3.2. Cellular telecommunications

Cellular telecommunications is one of the technological success stories of the late 20th century. It is widely deployed, indeed ubiquitous one might say, affordable and reliable. Though the boundaries between traditional telecommunications and computing are disappearing, it is hoped that those characteristics that have enabled the wireless communications success story, for example, adherence to standards, emphasis on Quality of Service (QoS) and robust user hardware, will be embraced in the delivery of mobile and context-aware services.

Modern cellular networks were first deployed on a large scale during the 1980s. These legacy systems, commonly referred to as First Generation (1G), were restricted to voice applications. By the end of the decade, the cellular landscape was characterised by a multitude of incompatible systems. However, technological developments and capacity constraints have meant that such systems would soon be obsolete. In particular, advances in digital communication techniques promised more efficient use of the available radio spectrum as well as the provision of a wider range of services including data services. Cellular networks, which embraced digital technologies were first deployed in the early 1990s and are commonly referred to as Second Generation (2G) networks. Almost all networks deployed throughout the world at present belong to this generation (Table 1).

Of all the 2G networks deployed, the Global System for Mobile Communications (GSM) was by far the most successful. GSM was an original European initiative designed to replace the multiple incompatible 1G systems with one single standard. Operators in each European country would then deploy networks that conformed to this standard. By adhering to this standard, manufacturers had access to a larger market and could achieve significant cost benefits through economies of scale. Indeed, the development of GSM in Europe was influenced as much by political considerations, as by the available technologies [20]. Among the design criteria laid down for GSM were good speech quality, low terminal cost, an ability to support handheld terminals and, most importantly, support for international roaming [21].

Poor support for data rates have proved one of the key limitations for 2G technology. This situation has been aggravated by high demand for services based on wireless data, for example, wireless Internet access. GSM supports a standard data rate of 9.6 kb/s which can be increased to 14.4 kb/s using compression techniques. Clearly this is not adequate. In response to this situation, the telecommunications industry, under the auspices of the International Telecommunications Union (ITU), developed specifications for the 3G of cellular networks. Among the requirements for 3G systems are [22]:

Table 1
The prevalent 2G networks currently deployed throughout the world

Network	Deployed	Launched
GSM (Global System for Mobile Communication)	Europe, Worldwide	1992
D-AMPS (Digital Advanced Mobile Phone Service) (IS-54/IS-136)	USA	1991
IS-95 (Interim Standard-95 or cdmaOne)	USA	1993
PDC (Personal Digital Cellular)	Japan	1991

- Support for roaming between different 3G network operators;
- A data rate of 144 kb/s for users moving quickly, i.e. vehicles;
- A data rate of 384 kb/s for pedestrians;
- A data rate of 2 Mb/s in a low mobility or office environment;
- Support for voice quality comparable with fixed line networks.

Deploying 3G networks has proved difficult and expensive. Only operators in Japan are planning an immediate rollout of 3G compliant networks. Operators in most other countries are planning a migration strategy based on the incremental deployment of technologies that will ultimately make their networks 3G compliant. Such technologies have been termed 2.5G and, in the case of GSM, include High Speed Circuit Switched Data (HSCSD) [23], General Packet Radio Services (GPRS) [24] and Enhanced Data-rates for GSM Evolution (EDGE) [25]. HSCSD is of particular interest as, unlike GPRS and EDGE, it has been successfully deployed for some time. It uses the existing GSM infrastructure and air interface so its integration is straightforward. Data rates of up to 57.6 kb/s (4 channels @ 14.4 kb/s) are achievable. However, HSCSD is inefficient for certain applications, e.g. browsing the WWW where data comes in bursts and there may be long periods of inactivity. Nevertheless, it has given people a glimpse of what 3G technologies will provide.

3.3. Determining positioning through electronic means

Using technologies that can determine one's geographical position have become popular in recent times. Indeed the possibilities offered by such technologies have increased commercial awareness of location-aware computing though the development of so-called proximity services, the market for which is expected to grow dramatically in the coming years. Needless to say, position forms a key component in most context-aware and ubiquitous computing systems. Currently, techniques utilising satellites are predominant but it is expected that techniques, that utilise the cellular network infrastructure will be available in the coming years.

Satellite Techniques. The possibility of using signals from space as a method of determining position arose as a result of the Russian space program in the 1950s. By 1990 both the US and Russian military were actively deploying satellites and testing the technology and, by the mid 1990s, both had working satellite constellations. As the cold war had ended, the Russian effort GLONASS was not maintained due primarily to a lack of financial resources. In contrast, the US effort, the Global Positioning System (GPS) has remained fully operational. A landmark was reached in 2000 when the practice of intentionally degrading the GPS signal through a process known as Selective Availability (SA) was discontinued. Instead of position readings being accurate to within 100 m, readings are now accurate on average to less than 20 m, depending on the receiver capability. However, an accuracy of 20 m is not adequate for some applications, for example surveying. A more accurate technique, Differential GPS (DGPS) was developed for such scenarios though more expensive equipment is required.

While GPS is free, accurate and available throughout the world, it still remains under the control of the US military. Realising the strategic importance of an independent satellite navigation system, the European Transport Council decided in June 1999 to proceed with its own initiative-GALILEO. Though specified as a stand-alone global system, GALILEO is designed to be interoperable with both GPS and GLONASS. Its primary objective is to provide state-of-the-art positioning and timing services with adequate guarantees concerning accuracy and availability.

Cellular Network Techniques. A number of techniques have been developed that utilise the inherent structure and features of cellular telecommunications networks to estimate position. Research in this area has increased as a result of the E-911 directive from the Federal Communications Commission (FCC) in the USA, which obliges network operators to include functionality for determining the location of emergency E-911 calls. The most important of these techniques are now described:

Cell Identification (Cell-ID). is an easy and quick method to locate a user. If the geographic location of the Base Station to which the user is currently attached is known, then the position of the user is restricted to being within the radius of the cell served by the Base Station. A major disadvantage is that the size of cells can vary substantially between rural and urban areas leading to variations in position accuracy.

Timing Advance (TA). is based on the existing GSM TA parameter, which is used for synchronising between the handset and the Base Station. It can be used to calculate the amount of time the signal needs to reach the handset. Calculating the distance is then a simple exercise. Distances can be calculated to a precision of 550 m.

Time of Arrival (TOA). Requires measuring the propagation time between a handset and three Base Stations. From these measurements, three circles can be drawn and the intersection will give the position of the user. However, signal propagation delays can introduce errors into the final calculation. In addition, there may not always be three Base Stations available, particularly in rural areas.

Enhanced Observed Time Difference (E-OTD). Requires the measurement of the time difference between three signals from different Base Stations. Using this, hyperbolic curves can be constructed and, as in TOA, the intersection of the curves will indicate the position of the user. E-ODT is sometimes referred to as Observed Time Difference of Arrival (O-TDOA).

Angle of Arrival (AOA). Determines the position of a subscriber using triangulation techniques. By utilising a complex array of antenna elements, the angle of signals originating from a handset can be measured. After measuring the angles at a number of base stations - a minimum of two is required, the position can be estimated based on the point of intersection of lines projected outwards from the cell at the corresponding angles.

Assisted GPS (A-GPS). is an innovative technique that has received widespread attention. GPS units are dispersed throughout the network coverage area, e.g. one at each Base Station. These can then indicate to the handset what satellites it should use. Once the handset has read the appropriate signals, it can then transfer this data back to a server for processing, i.e. calculating position. Integrating DGPS into such a system is relatively trivial.

Enhancing cellular networks with positioning techniques has proved difficult. Even though the E-911 directive was originally scheduled to come into force in October 2001, this deadline passed without any network operator being capable of offering location information as part of the standard E-911 service. Nevertheless, services based on location are likely to be offered when 3G networks are finally rolled out. TA, E-OTD and GPS are the agreed technologies for networks utilising both GPRS and EDGE [26] while the planned 3G successor to GSM, namely the Universal Mobile Telephone System (UMTS) will support Cell-ID, O-TDOA and A-GPS [27].

4. Developing a context sensitive tourist guide

4.1. Objectives for a context-aware tourist guide

In the remainder of this paper, we will introduce Gulliver's Genie - a handheld travel assistant developed at University College Dublin (UCD). The *raison d'être* for Gulliver's Genie[2] is the dissemination of context sensitive information to tourists with particular emphases on meeting the needs and expectations of cultural tourists. Once equipped with the Genie, a tourist, while visiting a city, would have access to a wide variety of personalised information concerning the various attractions as well as to other standard location-aware services. The ability to provide personalised, multi-media enhanced presentations about such attractions in a timely manner is fundamental to the Genie. As this information is stored in a central repository, updating it in response

[2] In the remainder of this paper Gulliver's Genie may well be abbreviated to the Genie.

to unanticipated events is straightforward. While the Genie was designed with the need of outdoor users in mind, it could also be applied indoors provided a suitable location-sensing mechanism, e.g. InfraRed (IR) were available.

Gulliver's Genie builds upon work undertaken as part of the Hyper-Interaction in Physical Spaces (HIPS) project [28–30] which sought to achieve the simultaneous navigation of a physical space and its associated information space. When designing the architecture for the Genie, three criteria were strictly adhered to:

Ease-of-Deployment. Maximum use had to be made of the pre-existing technological infrastructure. In practice, this was easy to achieve as both the GPS and wireless data communications services are practically ubiquitous. The option of constructing specialised environments endowed with a rich technological infrastructure, as is the case in smart environments, was not feasible.

Portability. Populating an information space for use by the Genie ought to be straightforward. Being equipped with a GPS receiver, laptop and sound recorder is adequate and sufficient in order to develop initial prototypes for demonstrating the possibilities of the Genie. To ensure maximum system diffusion, a great deal of effort has been expended in order to ensure that the Genie runs on as wide a variety of devices as possible (laptops and PDAs). For this reason the Java programming language was employed as it works on a multitude of devices and its networking capabilities are excellent.

Ease-of-Use. System interaction should be simple and intuitive. With this in mind, two methods of interaction were planned for:

- Implicit. Tourists interact with their environment by moving within it. Obviously, inferences can be made from their movement and the Genie should plan accordingly.
- Explicit. Explicit user interaction must be supported, whereby users can prompt the system. For example, if a multimedia presentation is being played, the user may want to listen to all the available options or perhaps none at all. Alternatively, the tourist may be hungry and would like a list of suitable restaurants within his/her immediate vicinity.

4.2. Overview of Gulliver's Genie

The architecture of the system is based on the classic client-server model:

Genie Client. The client is essentially a handheld computer or PDA that supports those technologies required by the Genie. The client must be capable of displaying multimedia presentations. Therefore support for sound and colour is essential. It must also be expandable so that extra components may be added. In the case of the Genie, support for GPS is essential, as is support for wireless communications.

Genie Server. This is a sophisticated system, which supports roaming tourists. Among its components are a multimedia database augmented with simple GIS functionality, and software for assembling personalised presentations. The core component on the server is a Multi-Agent System (MAS) which instantiates and manages all the agents required by the Genie.

4.3. Use of agents within Gulliver's Genie

Users are supported by a suite of agents, two of which reside on the handheld device and the remainder on the server side. All agents are implemented using the Agent Factory (AF) system [31], an environment, developed in part by one of the authors, which supports the rapid fabrication of agent-based applications. Agent Factory provides an integrated environment for the development of such applications through the provision of a suite of tools which support the design, implementation, visualisation and debugging of agents. Agent Factory was developed using Smalltalk-80 and is implemented as two distinct environments, namely, the run-time environment and a development environment.

Agent Factory was designed for the development of agents that paid little credence to computational constraints. When deploying agents for handheld devices, it soon became apparent that AF would, in its current form, prove inappropriate. There exists a scarcity of Smalltalk environments for PDAs and their computational demands, in terms of software footprint, proved prohibitive. An alternate approach was adopted delivering a second implementation of the agent runtime environment or *Agent Virtual Machine (AVM)* using Java. This system is known as *Agent Factory Lite* [32,33]. In this way, agents would continue to be developed in a PC environment but could be deployed on any environment that complied with the PersonalJava specification. Thus server hosted agents within the Genie are Agent Factory (Smalltalk) agents, whilst client hosted agents are Agent Factory Lite (Java) entities. Both however are interoperable and are governed by exactly the same virtual machine which delivers the agent deductive machinery.

4.4. The Gulliver's Genie runtime environment

The Genie is currently hosted on a custom built PDA simulator on a Toshiba Libretto running Windows 98. It is developed entirely in Java with a view to porting it to other platforms, in particular PDAs. For position reading, a Garmin GPS receiver is generally used although the system has also been tested successfully using a Crux PCMCIA GPS receiver. For orientation purposes, a custom built electronic compass (EC) is used. However, the GPS bearing parameter can also be used to estimate orientation, as not everybody will have access to an EC. The compass is most useful in confined areas where there may be a number of tourist attractions clustered together. For example, one test site was the Piazza del Campo in Siena, which has a number of attractions surrounding it. A tourist may merely stand in the middle and turn while viewing them, rather than approaching each individually. Wireless communications is supported by a PCMCIA wireless modem (Nokia Card Phone). As well as supporting standard GSM data rates, it also supports HSCSD, assuming of course, that the local network operator offers this service.

While the Libretto has proved an excellent testbed for developing and refining the Genie concept, it is not reasonable to expect tourists to wander cities armed with mini-laptops. After evaluating a number of pre-eminent PDAs, it was decided to use the Compaq IPAQ 3660 model as an initial host. This model is equipped with 64 MB of RAM and comes with a dual slot PCMCIA expansion pack. The default operating system supplied with the IPAQ is Windows CE. Though running a PersonalJava environment is feasible, it was decided to remove Windows CE and install the SavaJe XE operating system. As this supports Java 2 compliant applications, the porting process proved relatively straightforward. However, problems were encountered with the Nokia Card phone. Like all new operating systems, SavaJe has a paucity of device drivers. While it supports standard Universal Asynchronous Receiver Transmitter (UART) compatible devices, unfortunately, the Card Phone is not fully compatible. Thus, while the Genie is running on the IPAQ in the laboratory, we are currently developing a device driver to ensure support for a HSCSD enabled wireless modem.

The Genie server is currently hosted on an NT workstation. It hosts the Jakarta Tomcat Servlet engine for routing requests to the server. For database purposes, DB2 is used. Agent Factory is hosted on its own Workstation and standard TCP/IP is used for communicating between it and the server.

4.5. Architecture of Gulliver's Genie

The architecture of the Genie is shown in Fig. 1. Each of its functional components will be described in turn.

4.6. Client components

PDA Controller. This is the core component on the Genie client. It is responsible for the initial configuration of the client. Following initialisation, the PDA Controller continues to monitor the various inputs to the system and respond accordingly.

Input Module. It monitors any explicit user interaction with the Genie and routes requests to the appropriate component usually the PDA controller or the Display Module.

Display Module. Normally the Display Module displays a map with the user's position and orientation highlighted. Traditionally, tourists are accustomed to map imagery. The map is thus used by the Genie as the default display metaphor. As the user moves, the map is scrolled automatically. It also responds to explicit user scroll requests. When a presentation is available and the Cache Agent recommends that it should be shown, the Display Module displays it on screen and initiates the presentation. Depending upon user selections, it may play other links in the presentation. If there is no user activity for a prescribed time period, the presentation is removed and the default state is restored.

GPS Agent. The GPS Agent is responsible both for managing and interpreting the sensor data. It monitors both the GPS receiver and the EC and performs a QoS audit on the data before it is distributed to the various components. For example, it monitors the quality of the signal, i.e. whether the GPS receiver is functioning normally (3D navigation) or otherwise (2D navigation or no satellites available). If the signal is inadequate or even unavailable, the position reading will be affected and will not be introduced into the system. If the GPS Agent is satisfied that the position reading is valid, it then informs the display module which proceeds to update the user's position on the screen. Subsequently it compares this position with previous positions and decides if the user's activity has changed from, for example, walking to standing. If this is the case, it immediately informs the tourist's own agent (*Tourist Agent*) on the server. If the user's activity has not changed, the GPS Agent deliberates on whether the user has made what it considers to be a *meaningful movement*, i.e. moved more that 20 m from the last known position which was registered with the tourist's agent on the server. If this should prove to be the case, then a message is dispatched to the tourist's agent requesting that it updates its last known position for the tourist.

Cache Agent. Data transfer rates on wireless networks are notoriously slow. To improve performance, a pre-caching mechanism was implemented via an agent. The concept is relatively straightforward. Once the server has been updated with a new position reading, it generates a list of nearby attractions and passes it on to the Cache Agent. This then monitors GPS positions from the GPS Agent and adjusts its list accordingly. Once it has identified an attraction that it anticipates the tourist will visit, it asks the Tourist Agent on the server for a presentation about that particular exhibit. The anticipation process involves consultation with the User Profile Agent, which uses an individual's profile as a predictor of future interests and activities. Under normal circumstances, the Tourist Agent, having already anticipated this request, will have a number of presentations assembled and waiting. The appropriate presentation is immediately downloaded and stored until the tourist

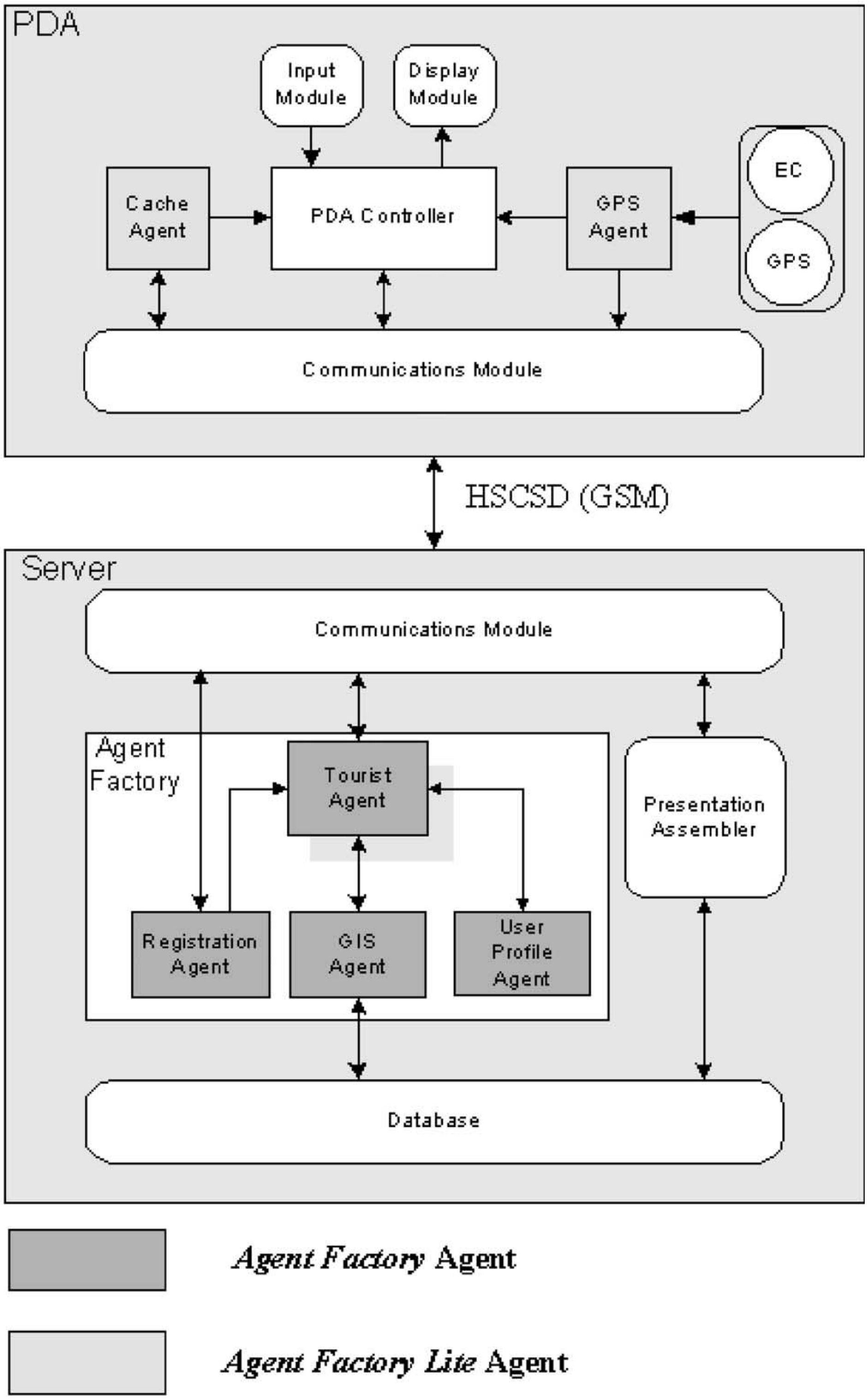

Fig. 1. Architecture of Gulliver's Genie.

approaches the attraction. The Cache Agent then notifies the PDA Controller that a presentation is available and the controller proceeds to arrange for the presentation to be displayed.

Communications Modules. Both the client and the server have communications modules that essentially perform similar functions. All requests and responses are routed to the appropriate module. For development purposes, TCP/IP running on a standard Ethernet connection was utilised. However, for live testing, HTTP over a dialup connection to a local mobile ISP was used.

4.7. Server components

Agent Factory. On the server side the Agent Factory system provides the scaffolding for the operation of the four server side agents. The BDI deductive machinery is delivered enabling agents to reason based on a *belief set* and the application of *commitment rules* resulting in an adoption of commitments that will be honoured at some future time point. Agents interact by way of an Agent Communication Language (ACL) called Teanga. This Multi-Agent System forms the core component on the server side and consists of the following agents:

Registration Agent. After verifying and authenticating that a tourist is eligible to use the Genie, the Registration Agent proceeds to instantiate an agent from the Tourist Agent template creating a personal tourist agent for each individual. This agent is then allocated a socket address and the Communications Module is instructed to route all messages from the tourist to the specified socket. The Registration Agent additionally performs some house keeping tasks, for example, when a tourist is finished using the Genie, the Registration Agent proceeds to terminate her/his particular tourist agent and redeploy its associated resources.

Tourist Agent. Once tourists connect to the Genie server, an individual agent from the Tourist Agent template is instantiated for them. This agent maintains a snapshot of the tourist's activity at any particular time. For example, the last position of the tourist is known, as is the status of the GPS signal. In consultation with the GIS Agent, it maintains a list of exhibits that the tourist is currently near and is responsible for ensuring that the Cache Agent is always furnished with an up-to-date list of exhibits, which it can subsequently monitor. The Tourist Agent frequently appraises the User Profile Agent of salient and observed user behaviour, which it subsequently uses to dynamically update the user profile.

GIS Agent. It provides GIS related services to the Tourist Agents and interfaces with the GIS component in the database. In particular, the GIS Agent handles cache update requests and recommends a list of exhibits for the Cache Agent to monitor. Ultimately, it is the Tourist Agent that decides whether the Cache Agent should have its list updated or otherwise.

User Profile Agent. This agent dynamically updates the individual user profile reflecting user activities and inferred preferences. For example, once a tourist has listened to a given presentation, a record of what has been actively selected (and implicitly ignored) by the tourist is returned to the corresponding Tourist Agent. This then asks the User Profile Agent to update the relevant user model accordingly.

Presentation Assembler. As the name suggests, this component builds presentations for users. On receiving a request to build a presentation, it liases with the User Profile Agent for information concerning the individual user and the attraction in question. This information acts as a *filter of admissibility* and it proceeds to dynamically build a presentation that matches the user's interests. As part of the pre-caching strategy employed by the Genie, the Presentation Assembler actually pre-caches presentations on the advice of the Tourist Agent. When a request comes in from the Cache Agent, this cache is then searched for the appropriate presentation. It then arranges for the presentation (including images, sound files and text) to be dispatched to the client.

Database. Underpinning the entire Gulliver's Genie system is a sophisticated database. The data stored within it may be classified as follows:

Multimedia. Genie presentations consist of a rich combination of sound, images, text and video clips. These media elements and the meta-data associated with them are stored in the multimedia section of the database.

Geo-spatial. Managing electronic geocoded maps is of fundamental importance. In addition, geo-spatial data allows the association of a set of GPS readings with a particular tourist attraction.

User Model. All users of the Genie must first register. User profiles (language, nationality, age, gender) and Interest profiles (art, literature, and so on) are developed and dynamically maintained for each user.

4.8. What the tourist experiences

As tourists make their way towards some tourist attraction, the Genie displays an electronic map with their position and orientation highlighted upon it. This can be seen in the first two screen shots contained within Fig. 2. As they approach a particular tourist attraction, the Genie will start precaching a presentation. Upon completion of precaching, and, provided the tourist is within a critical distance of the attraction, a presentation will be displayed. The presentation structure is simple and consistent. Feedback derived from early prototypes and user evaluations indicate that users demand a simple, consistent and sufficient interface. A small image is displayed showing the attraction in question. This acts as an initial positive reinforcement for the tourist. Beneath this a title appears, followed by a list of available topics (*follow up links*), which the tourist can choose from (Fig. 2). Each link has an associated sound file. Normally the first topic is played by default. This sound script and the initial image provide a brief introduction to the attraction. After this has been played, the tourist may, using the *gameboy* controls, select

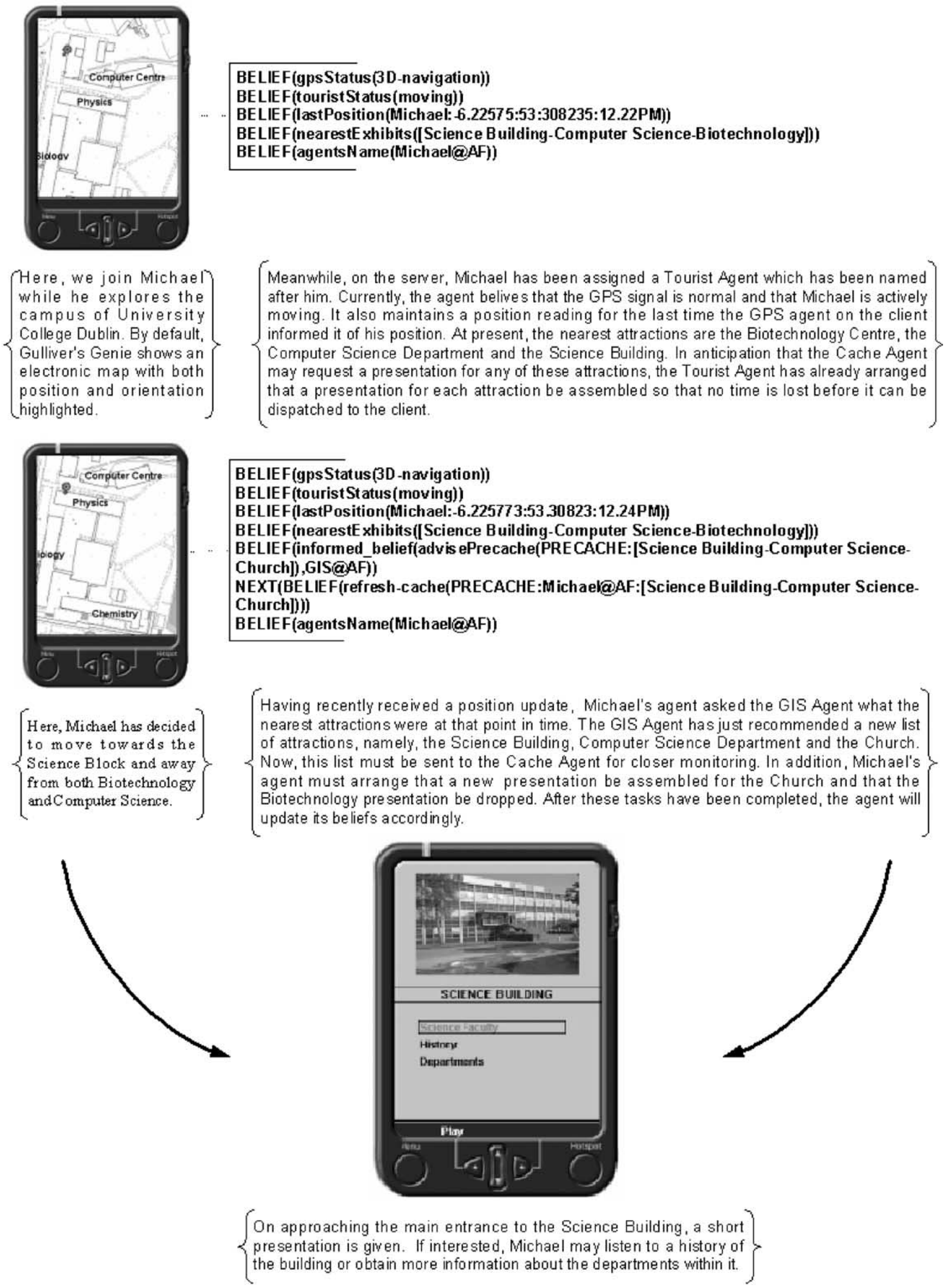

Fig. 2. Sequence depicting a typical tourist experience and associated agent behaviour.

other topics of interest. Each topic consists of an image and sound script or a short video clip. As the tourist moves away, the Genie returns to its default state and restores the map and position indicator. Fig. 2 also depicts the evolving mental state of the BDI agents.

Adaptive presentations are provided reflecting the individual's interests. Thus the follow up links will vary as will their associated content. Furthermore individuals can annotate the information space by depositing and attaching individual insights by way of *hotspot* creation. This process enables authors to create mixed media content, associate this with proscribed activation points and to designate an audience. Subsequently, this content acts as an experiential overlay available to designated groups or constituencies.

5. Conclusion

Though the development and deployment of context-aware tourist guides is feasible, there are still a number of technological and ethical issues that need to be resolved. Bandwidth issues persist. HSCSD was used in testing the Genie. This guaranteed a bit rate of over 42 kb/s. Though a significant improvement over the standard 9.6 kb/s supported by standard GSM, it is not adequate. While some success has been achieved through the Genie's intelligent precaching approach, some further improvement is called for. A logical solution is to utilise GPRS for data communication. However, even here there could be problems. GPRS supports a maximum theoretical data rate of 171 kb/s. However, there may not be QoS guarantees with this, at least not initially. In contrast to HSCSD, which guarantees 42 kb/s, GPRS may well only deliver 9.6 kb/s as a minimum and then, if there are any spare channels available, these may be allocated for data traffic thus increasing the data throughput. As HSCSD is viewed as an interim technology, Gulliver's Genie will eventually be enhanced to support GPRS. However, we must wait until GPRS is actually deployed and see what policies local operators put in place before we can refine our agent's behaviour accordingly.

While the granularity of cellular based position techniques and GPS is not adequate to meet users' needs at present, we are optimistic that the situation will improve as the market for location-aware services increases. Ultimately, we feel that A-GPS may well be deployed widely. As it is a standardised technology for the 3G successor to GSM, namely UMTS, we think this is quite probable. However, as changes will be required to handsets, this is unlikely to occur in the short term.

Top end PDAs are just about capable of hosting Gulliver's Genie. True diffusion and dissemination of the Genie, like most other location and context-aware products, is however stifled by a myriad of problems. Alas, most of these are familiar. Incompatible systems, inaccurate statements about hardware and software capabilities, lack of device drivers and so on. Indeed, while such issues have plagued software developers, they are also likely to retard the implementation of the ubiquitous computing concept.

On-going development work is recasting some of the non-agent components into the agent framework. The presentation assembler in particular is undergoing an agent makeover. Further to this the Agent Factory Lite system supports truly mobile agents that can migrate through the wireless network. We are currently investigating the delivery of *premium services* and system *housekeeping services* like load monitoring and balancing mobile agents that report to the user PDA when appropriate.

Our discussion would not be complete without some reference to the ethical and legal issues that affect the deployment of systems like the Genie. The idea of a third party knowing one's position and knowing about one's preferences, albeit only in specific genres, makes many uneasy about potential technological abuse. Clearly, there is an onus on the computing industry and the research community to address these security and privacy issues in a meaningful way. A failure to do so may well hinder the popular use of location-aware technologies and lead people to miss out on services that could make a substantial contribution to the improvement of their quality of life. Ultimately users must *opt in* to the monitoring which is an inextricable part of these systems.

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