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Delivering Adaptivity Through Context-awareness

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Abstract

Developing applications and deploying services for mobile users raises a number of issues and challenges that must be successfully addressed before the era of truly ubiquitous computing will dawn. In particular the desire to deploy rich multimedia applications and services is severely curtailed by the limited capabilities of the current range of mobile devices as well as the limited bandwidth of current wireless cellular networks. How best to overcome these limitations remains the focus of much research. Intelligent agents have been demonstrated as a promising solution for inherently complex and dynamic domains and their use is proposed as the basis of a solution for assembling and disseminating multimedia content to a mobile audience. Attention is particularly directed to issues concerning the adaptation of content according to the end-user physical context and their personal profile or model.

1. Introduction

Though an era of ubiquitous computing and communications has long been promised, there is still a significant gap between what is anticipated and what users currently experience. That is not to deny that significant progress has been made. Rather it is testimony to the complexities involved both in system design and implementation as an increasingly sophisticated understanding of the practicalities emerges. Thus computing systems that are truly ubiquitous are rare even in research laboratories. So the public, and to a lesser degree researchers, can only speculate as to how a world saturated with computing technology would look like and function.

One offshoot of the ubiquitous computing paradigm (Weiser, 1991), namely mobile computing (Kozuch, 2004), offers users a glimpse of what may be expected in coming years. Granted, the technology and applications are limited. However, overtime this situation may be expected to improve, although, in comparison with fixed networked workstations, mobile computing will always be the poor relation. In the case of multimedia applications, of course, this is particularly true. The limited computational resources as well as the relatively poor capacity of wireless data networks have had a detrimental affect on the deployment of rich multimedia-endowed applications and services.

In this paper, an architecture is presented for the development and deployment of intelligent multimedia-based applications and services for mobile users. In Section II, the situation of the mobile user is examined in detail. In Section III, a strategy is described for the dissemination of personalised content to mobile users. The use of Intelligent Agents as a development paradigm for intelligent mobile applications is then discussed in Section IV. To elucidate the pertinent issues, Section V presents a practical illustration of how multimedia content may be personalised and contextualised for mobile users. Finally, Section VI reviews and discusses some of the issues raised after which the paper is concluded.

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2. Multimedia for Mobile Users

Designing and developing software for mobile users provides a radical challenge for all those involved in software engineering. The difficulties encountered are not difficult to understand; however effective solutions and the identification of best practice principles remain elusive. Given the relative maturity of the desktop computing paradigm and relative short history of mobile computing, it would be naïve to expect otherwise. This is not to say that the problems are insurmountable or indeed that what has been identified as useful up until now is no longer valid. Rather, the issue facing designers and developers alike is to gain a thorough understanding of the mobile computing paradigm, identify those principles that can be usefully employed and to continue research and development to identify remedies to those areas that are identified as deficient. Given the breath and scope of mobile computing, this is a non-trivial task.

Deploying a solution that incorporates a significant multimedia component exacerbates the already numerous problems facing aspiring mobile service providers. Indeed, the computational resource differential, or gap, between static users and mobile users is significant and, in all probability, this situation is unlikely to change ever. This does not mean that multimedia rich applications for mobile users are a non-starter. Ongoing developments tentively hint of a situation arising in the not too distant future where services incorporating a substantial multimedia component will be available to mobile users. One may be cautiously optimistic that the current generation of telecommunications networks and mobile devices represent a threshold that, on being surmounted, will provide an environment for the widespread deployment of multimedia enriched services.

A number of factors need to be considered when deploying services for mobile users. Careful consideration of the end-user's context could well mean the difference between a service that addresses and meets user expectations, and one that fails to excite the market place. While not exhaustive by any means, a number of the more pertinent factors that distinguish the mobile user are summarised in Fig. 1 and discussed in some detail in the following sections.

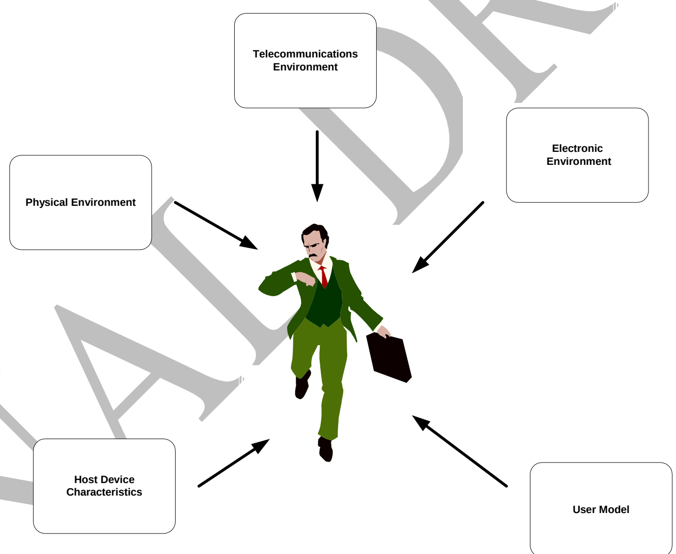

Fig. 1. Factors for consideration when deploying mobile multimedia applications.

2.1. Physical Environment

A defining characteristic of mobile computing is the unpredictability of the environment in which the user is operating. Predicting where and under what circumstances the user will access an application is practically impossible in all but the most specialist domains. Depending on the nature of the service, an initial decision must be made concerning the desirably or otherwise of ascertaining the user's location within the environment and the construction of a model of this environment. Methods of ascertaining the user's position are discussed in Section 2.3. A classic example of a service that is closely coupled with the physical environment is that of a location-aware service (Patterson, 2003). While such services may not in general require a significant multimedia input, it can be easily envisaged that services concerned with eCulture and eLearning would comprise significant multimedia usage.

Should a service require a model of the user's physical environment, a critical question arises as to how such a model may be constructed. Obviously, such a process is time consuming and may involve the development of additional tools and utilities. Note that this is in addition to the identification of the necessary content that the service requires. An alternative may be to license the necessary information from some private company or government department that has already compiled the necessary information. Many utility companies for example possess significant details of the geographic regions in which they operate. Such information is usually stored in a database or more likely, a Geographic Information System (GIS); and this data can usually be exported in some industry-standard format. Choosing such a route will, of course, have ramifications for the resultant cost of the service to the subscriber. It may be also prudent to reflect on the actual maintenance of the database or model as the provision of a service based on dated information would not be received kindly by paying users.

2.2. Network Environment

Wireless telecommunications networks have been one of the outstanding success stories over the last decade or so. As well as standard voice services, the advent of increasingly sophisticated data communications services have proved fundamental in establishing mobile computing as a paradigm in its own right. For convenience, mobile telephony networks may be categorised according to their "generation". At present, the de facto generation is 2.5G, an intermediate step between the second and third generation. However, after a somewhat protracted process, 3G networks have been deployed and are currently gaining market share. The implications of each technology for multimedia applications are now considered:

- *2.5G*. one example of a 2.5G network is the General Packet Radio Service (GPRS). Though supporting a theoretical data rate of up to 115.2kb/s, subscribers may only experience data rates of about 30 kb/s. One critical limitation of GPRS is the unpredictability of the data-rates experienced by the users. In practice, this means that service providers have to work towards the lowest common denominator scenario if they are to ensure that their subscribers are to enjoy a consistent experience. Whether this service meets expectations is of course an open question.
- *3G*. 3G networks offer a significant increase in data-rates available to customers with 300 kb/s being quoted as a realistic expectation though 2Mb/s is the theoretical maximum. Obviously, this is a significant upgrade and offers network operators and service-providers significant opportunities to launch new services and applications. In the case of multimedia, audio and video streaming become feasible as do more demanding services such as real-time video conferencing.

A discussion on networking would not be complete without reference to WiFi. Though offering excellent data-rates, the inherent difficulty concerns the scarcity of wireless hotspots. With the exception of specialist vertical applications, it cannot be guaranteed that the user will be in a hotspot zone when actually activating a service. However, it is not unreasonable to expect significant expansion of WiFi hotspots in the coming years, particularly in urban areas. In contrast, the situation in rural areas is less promising and it is not practical to expect significant and widespread deployment of WiFi in the countryside. If service providers intend that their services are truly ubiquitous, this differential must be considered. Increasingly, however, manufacturers are integrating WiFi with their products thus forming a significant WiFi-enabled customer base.

2.3. Electronic Resources

The ability of a mobile user to access and utilise electronic services is dictated by the quality and quantity of what might loosely be termed the electronic resources in their vicinity. While the prevailing communications infrastructure as discussed in the previous section may be viewed as the predominant electronic resource, there are others. One example of a ubiquitous electronic resource is the satellite navigation system GPS. This service covers the world and is freely available to those people equipped with the necessary receivers. Such users can anticipate position readings within a range of about 20 meters on average. The availability and reliability of satellite navigations systems will receive a further boost in 2008 when Galileo (Benedicto, 2000) is deployed. This development, in conjunction with ongoing improvements in GPS, is widely expected to usher in a new era of sophisticated navigation services affecting all the significant industrial sectors including the air, rail and maritime industries.

Recent developments in Satellite-Based Augmentation Systems (SBASs) offer prospective users further improvements in ascertaining their positions. It is anticipated that positions may be calculated to within 5 meters when SBAS techniques are utilised. One example of an SBAS is the European Ground Navigation Overlay Service (EGNOS) (Toran-Marti, 2004) which is expected to become fully operational late in 2005. While GPS receivers are generally enabled for SBAS, an alternative method of accessing an SBAS is through the Internet. Indeed, the European Space Agency (ESA) is actively facilitating this process through their SISNet initiative (Chen, 2003). It is envisaged that SISNet can be utilised when the EGNOS signal cannot be acquired. Such a scenario may arise in an urban canyon, for example. As SISNet demands the availability of an internet connection through a wireless data network, there is a cost element that must be considered.

An alternative approach to navigation support depends on the topology of wireless telecommunications networks. While a number of techniques have been proposed (Zhao, 2000), the 3G specifications for UMTS have standardised on three techniques (3GPP, 2004):

- *Cell-ID*. In this case, the geographic coordinates of the Base Station serving the subscriber are identified. The position of the subscriber must be within the radius of this cell. Though this method is easy to implement, its principal limitation concerns the variability in cell size. Thus the precision with which the subscriber's position is calculated may range from tens to hundreds of meters.
- *OTDOA*. Observed Time Difference of Arrival (OTDOA) requires the handset to measure the time taken for a signal to arrive from three separate base stations. Hyperbolic curves must be constructed and their intersection indicates the position of the subscriber. Though computationally expensive, a particular difficulty involves guaranteeing that the subscriber can see three base stations simultaneously. OTDOA is highly susceptible to fading and interference.
- *A-GPS*. Assisted GPS (A-GPS) involves the handset measuring GPS signals from satellites. Initially, the handset is informed as to where to look for the signals thus minimising delay in signal acquisition. The signal measurements are then returned to the appropriate component on the network where the position is calculated. Though increasing power consumption on the device, users can expect position reading comparable with GPS. Interestingly, it is quite straightforward to integrate A-GPS with SBAS technology thus increasing the precision of the calculated position significantly.

There is one key limitation with satellite navigation systems: they do not function indoors. The effectiveness of cellular techniques is also reduced in such circumstances. Despite the various solutions proposed, as yet, there has been no agreement on what constitutes the best approach. One possibility could well involve the deployment of so-called pseudolites (pseudo-satellites) (Kee, 2001) which, when calibrated for a building, would produce signals similar to GPS. An alternative method may involve the deployment of a network of appropriate RFID tags through the building, assuming of course that the users have access to an RFID reader.

While the previous discussion has focused on satellite navigation, future developments in wireless sensor networks may offer some intriguing possibilities for identifying salient aspects of a user's context. Contemporary advances in microprocessor fabrication have led to a dramatic reduction both in the physical size of computational devices and the power consumed by such devices. Sensing technology, batteries and radio hardware have also followed a similar miniaturization trend. These factors combined have enabled the production of match-box scale, battery powered devices capable of complex processing tasks termed Wireless Sensor Networks, thus heralding a new era for ubiquitous sensing technology. Previous deployments of these networks have been used in many diverse fields such as wildlife habitat monitoring (Mainwaring, 2002), traffic monitoring (Coleri, 2004) and lighting control (Sandhu, 2004). Thus future service providers may have a bewildering array of user contexts to choose from, increasing possibilities for service refinement albeit with the not inconsequential problem of increasing system complexity.

2.4. Host Device

Ubiquitous information access assumes the availability of an appropriate device being either in the possession of the user or accessible to them through their local environment. However, such devices, usually of the mobile phone or PDA genre, can differ substantially in their generic capability. Raw processing power, memory, screen real-estate and operating systems can all differ substantially. These issues are generally well understood and a number of solutions have been proposed in the literature (Lemlouma, 2004; Smith, 1999). The motivation for this has been driven for the most part by the desire to extend the reach of the internet to mobile users.

An understanding of the varying device characteristics and a strategy for addressing them are prerequisites for those planning on incorporating multimedia into their services. File sizes are generally large thus increasing the load on both CPU and memory resources. The nature of the screen real-estate has a fundamental effect on the end user experience. Though most devices currently support colour displays as distinct from the monochrome that was common until recently, the quality of the resultant image/video may vary substantially depending on the ability of the software to render the image or video appropriately. Screen size can also vary thus affecting the screen design and layout. In the case of sound, it may be that only simple low quality format is supported. All-in-all, ensuring a consistent and harmonious experience across multiple platforms is a non-trivial task, the minutiae of which necessitate careful consideration during the initial design stage of the service.

2.5. User Characteristics

User modelling (Kobsa, 2001;Langley, 1999; Petrelli, 1999) is concerned with the identification of salient aspects of the user and the subsequent usage of these in the customisation or personalisation of services. However, these aspects can differ substantially between applications. At their simplest, they might involve knowledge of the user's preferred configuration settings for certain software packages. At a more sophisticated level, the model might contain rules and heuristics gleaned from the continual observation of some particular aspect of the user's behaviour over a large time period. However, one popular application of user modelling techniques is the filtering or "personalisation" of content retrieved from various sources, the WWW being one particular example (Ardissono, 2005).

Prudent use of user modelling techniques offers service providers significant tools in their efforts to improve the perceived quality of their services. As mobile subscribers usually pay on a per use basis, this is important for maintaining customer satisfaction and retaining their loyalty. Likewise, when large volumes of data are concerned, as is usually the case with multimedia, an appropriate user model offers a means of minimising the amount of content being sent to the user thus maximising the use of the limited computational resources available. Simultaneously, however, this content is more likely to match users' needs and expectations thus increasing their satisfaction with service with the anticipated result of further system usage.

3. A Strategy for Multimedia Dissemination

In light of the previous discussion, a strategy for disseminating content to a potential user group as they roam about some physical environment is now presented. The first two critical tasks that must be performed concern the acquisition of content and its appropriate tagging:

1. *Environmental Model Specification*. This involves identifying those aspects of the user's environment that are necessary for the delivery of the proposed service. If a travel component is envisaged for example, the model might contain details of taxi ranks, bus stops and on on. In the case of tourists, it would contain details of tourist attractions. If a sophisticated GIS has been developed for the geographic region in question, a significant portion of what is required may be found there.

2. *Content Acquisition*. Identifying and acquiring appropriate content is an expensive and time consuming process. Depending on the nature of the service, it may be feasible to license content from third party providers. Alternatively, it may behold the provider to assemble and store the content themselves thus incurring the cost and time that this process entails.

3. *Content Tagging*. A judicious method of annotating or tagging of the content is fundamental to the eventual success or other wise of the service. If location is an important aspect then appropriate tags must be identified that facilitates the engagement of special logic or reasoning. At its simplest, this may just involve standard geographic coordinates, namely longitude and latitude. If personalisation techniques are anticipated, a suite of tags must be identified that will allow content be matched to particular users. Once the content has been assembled and tagged, and the environmental model constructed, a number of content filters may be developed. These filters will use key aspects of the user's context for identifying content that is relevant to them. It is assumed of course that a suitable mechanism is in place for harvesting the user's context.

4. *Physical Environment Filter*. The purpose of this filter is to ensure that any content being considered for presentation to the user is consistent with their immediate environment. For a basic location-aware service, this filter may be adequate on its own. However, for more sophisticated services such as those including multimedia, it is only one component.

5. *User Model Filter*. Depending on its sophistication, and of course the nature of the proposed service(s), this filter can offer a number of criteria for filtering content. Language is one important filter, the importance of which increases as the multimedia component of the service increases. Age might also be an important criterion as some content may be inappropriate for minors. In short, if it is proposed to deliver a personalised service to users, the pertinent aspects must be identified for inclusion in the user model and, as stated earlier, the content must be tagged to facilitate the reconciling of content with individual users. If the proposed service is concerned with eLearning, the model must cater for the tracking of student progress and the identification of content that extends and enhances their pre-existing knowledge. Likewise, if the service is concerned with eCulture, the user model must comprise a cultural interest sub-model that effectively models the interests of the tourist. Naturally, the content must be tagged appropriately. Now that content that is consistent with the user's environmental context has been identified and that this has been reduced further according to the appropriate user model, the final stage in this process concerns the adaptation in light of the prevailing network and end-user device characteristics.

6. *Network & Device Adaptation*. While content may still be filtered at this stage, the primary focus is on formatting the content for display such that the end-user experience is acceptable. Note that there may be some overlap here with the user model as this may contain policies explicitly set by the user as how they wish to receive content. Some users may prefer to see content formatted in HTML format, similar to WWW pages. Others may prefer the content to be streamed to them. The current data network may not support streaming and if it does, it may be inordinately expensive for the user. All these factors

and more must be considered at this stage as this is the final chance the service provider has for optimisation and personalisation.

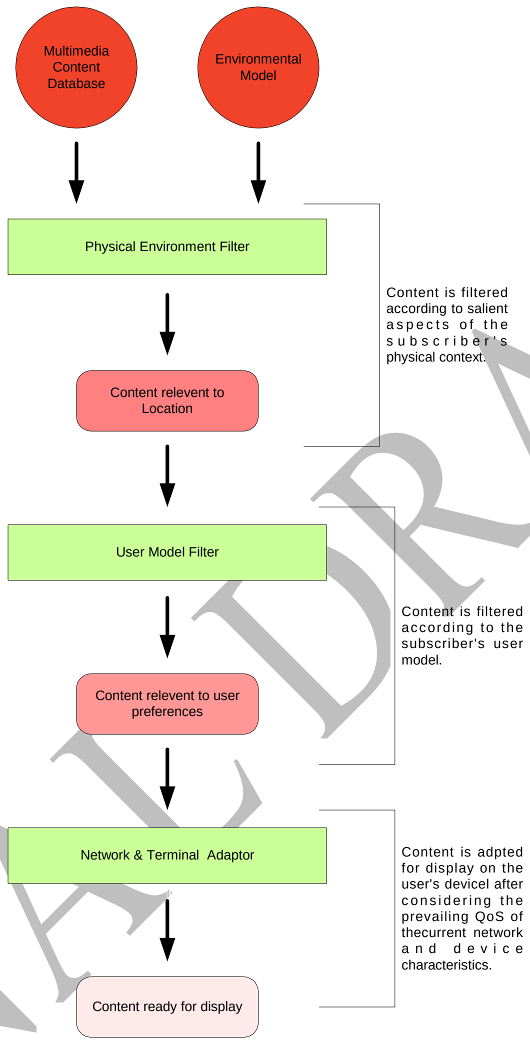

Fig.2. A strategy for adapting content for mobile users.

3.1 Intelligence Augmentation

Having outlined a strategy for filtering content, a question that naturally arises is how this process might be improved. Clearly, various aspects of it could be optimised, for example, database access and storage. Parallel processing techniques could be utilised for the filtering process. Likewise, the content selection process could be usefully augmented with techniques such as collaborative filtering (Kwak, 2001) and case-based reasoning (Sovat, 2001). Principles from autonomic computing (Kephart, 2003) could be usefully employed in making the system self-adaptive and self managing amongst others. Though all these techniques could be gainfully used, an architecture must first be defined. Ideally, this architecture would be flexible enough to handle the inherent complexity and dynamic nature of the domain in which it is deployed.

One paradigm thought particularly suitable for complex and unpredictable domains in that of intelligent agents. One of the defining characteristics of such agents is that they collaborate to deliver the required solution. This inherent collaboration facility enables the assignment of appropriate tasks to individual agents. Thus different services may require additional rules or that heuristics be incorporated into certain agents thus facilitating difference levels of intelligence throughout. In this way, the system is extendable and ultimately scalable as the number of agents can be increased, depending on system load. In the next section, an overview of intelligent agents is provided after which an illustration of the practical issues involved in designing and developing an eCulture application is described.

4. Intelligent Agents

Intelligent agents offer an alternative approach to modeling and implementing software solutions. In principle, any application that can be realized using traditional approaches may also be realized using intelligent agents. However, despite the multitude of applications described in the literature, agents have not been used in conventional software to the extent that was originally envisaged. The reasons for this vary but the key problem is that the agent research community has not demonstrated the circumstances in which an agent-based solution is demonstratably better than conventional approaches. This, and a lack of industrial strength development tools and methodologies, has confined agents to certain niche applications. These applications are generally in areas that are extremely complex and dynamic, and where traditional approaches do not succeed.

Research in mobile computing and associated areas including pervasive computing, ambient intelligence and smart environments is currently very active. However, how best to design and develop software that delivers the services envisaged in such scenarios remains an open question. Interestingly, a number of MASs have been extended so that they operate on PDAs and mobile phones. Thus, it may be cautiously suggested that intelligent agents may well offer a viable paradigm for designing and developing pervasive computing applications.

4.1 Characteristics of Intelligent Agents

Intelligent agents as a concept has been ascribed various meanings according to the domain and preferences of particular researchers. It is therefore prudent to reflect, albeit briefly, on what agents are and what we mean when we talk about intelligent agents. In general, agent characteristics coalesce around a number of elements including:

- *Autonomy*. Agents can act independently of humans.
- *Reactivity*. Agents can react to events that occur within their environment.
- *Proactivity*. Agents can exhibit goal-directed behavior and seek out opportunities that enables them fulfill their objectives or goals;
- *Social Ability*. A social ability is an essential attribute as agents are usually viewed as forming a community or a society in what is termed a Multi-Agent System (MAS).
- *Mobility*. Agents are not necessarily static entities but may be empowered to move around the network, as circumstances dictate.

Though these characteristic satisfy the criteria for agenthood in the minds of many in the research community, the AI community would augment these with a sophisticated reasoning capability. One exemplary interpretation of this are agents that incorporate a BDI-like architecture. Such agents exhibit all the characteristics of strong agenthood (Wooldridge, 2005) and incorporate a mental state comprising an aggregation of beliefs, commitments and commitment rules.

4.2 The BDI Architecture

Fundamental to the Belief-Desire-Intention (BDI) architecture (Rao, 1991) is the maintenance of a mental state that facilitates deliberation about the state of the agent's environment and the reconciliation between this state and the agent's objectives. BDI agents may follow a perceive-deliberate-act cycle. Agents perceive their environment and update their belief-set accordingly. They can then deliberate on how their objectives, that is, desires, can be best realised according to the current state of their environment. Those desires that the agent is now in a position to fulfill are formulated as intentions and those intentions are then realized. The cycle is repeated and the agent's mental state is continuously updated in light of changes to the agent's environment, ultimately determining what future actions the agent performs. In this paper, the term agent is assumed to mean one that incorporates a BDI-like reasoning mechanism.

4.3 Agents on Computationally-restricted devices

Recent advances in PDA and smart-phone technologies have opened up a new frontier in intelligent agent research. Until recently, the computational demands that a Multi-Agent System (MAS) requires rendered their use on lightweight mobile devices impractical. As developments continue unabated in the area of mobile hardware, such considerations are becoming increasingly obsolete. A number of projects concerning the practical deployment of agents on mobile devices have been documented in the literature. Examples include the 3-APL-M (Koch, 2005), Lightweight and Extensible Agent Platform (LEAP) (Bergenti, 2001), MicoFIPA-OS (Laukkanen, 2001) and Grasshopper (Baumer, 1999).

A number of applications have been described in the literature that illustrates the potential of utilizing intelligent agents on mobile devices. AbIMA (Rahwan, 2004) is an agent-based mobile assistant that assists user prior to and during the execution of their tasks. The system is based on AgentSpeak (Rao, 1996), an architecture that incorporates BDI principles. EasiShop (Keegan, 2004) is a mobile shopping assistant. As the shopper walks along a high street, their agent proactively indicates to them shops that stock items specified on their shopping list. Further more, the agents may negotiate with shop's agents, should the shopper so desire. EasiShop has been implemented using Agent Factory (Collier, 2003; O'Hare, 1996), which again conforms to a BDI-like architecture. In the eCulture domain, CRUMPET (Poslad, 2001) focuses on the delivery of context-sensitive information to tourists. One of its defining features is its use of agents as wrappers around legacy services thus enabling agents of the tourist device utilize legacy services. CRUMPET is realized using microFIPA-OS.

5. An Agent-oriented Approach to Dynamic Content Assembly & Dissemination

In the ensuing sections, it is intended to describe in some detail how content may be dynamically assembled and disseminated using an agent infrastructure. Before doing this, it is instructive to review belief revision in BDI agents. As Agent Factory was the infrastructure used, this discussion will use Agent factory notation to illuminate the salient points.

5.1 The Belief revision Function in Agent Factory

The representation and management of beliefs lies at the core of the Agent Factory interpreter cycle. Beliefs are encoded within the Agent Factory Agent Programming Language (AF-APL). AF-APL distinguishes between two broad categories of belief, namely *current beliefs* and *temporal beliefs*. Agent Factory adopts a *linear discrete temporal model*. Beliefs therefore hold true or false at a given instance. Current beliefs represent those beliefs that hold true at a specific time point. This point may not necessarily be *now* but could be some future time point. In contrast temporal beliefs are those beliefs that persist across a range of time points (still holding true at each discrete point within this range). Beliefs are encoded within AF-APL as a first order structure enclosed within the BELIEF operator. Temporal beliefs incorporate a limited set of temporal operators in order to scope the persistence condition upon the particular belief. These operators include NEXT, UNTIL and ALWAYS. As an illustration, consider the following:

- ALWAYS(BELIEF((green(ireland))); The agent always believes that Ireland is green.
- NEXT(BELIEF(green(trafficlight)); The agent believes the traffic light will be red at the next time point.
- UNTIL(BELIEF(dating(mary,john)), !BELIEF(employed(john))); The agent believes that mary is dating john until it does not believe that john is employed.

In addition Belief Rules define inferences that can be made over the current beliefs of a given agent. Under deductive closure new beliefs will be determined. Belief rules take the form of logical implications:

- BELIEF(likes(?girl)) & BELIEF(meets(?girl)) => BELIEF(will_date(?girl));

The beliefs of an agent vary with time. At each and every clock cycle the Belief Revision Function (BRF) is activated. Beliefs drive commitment adoption and, in turn, future directed actions. At each and every clock cycle an agent perceives its environment. Such perceptions can manifest themselves in terms of event monitoring as in for example interface activities or may occur as a result of communications received from other agents. In each case these perceptions are incorporated as current beliefs and augment the existing current beliefs. In addition the interpreter utilizes these updated current beliefs in the evaluation of temporal belief conditions like the UNTIL condition. All temporal beliefs are inspected relative to the current clock cycle and those that hold true for that time point are added to the set of current beliefs. Upon this combined belief set the interpreter performs deductive closure utilising those belief rules that may exist and adopting any new inferences as beliefs. Indeed this process will continue until a steady state emerges and no new beliefs are determined. When the BRF is complete, the interpreter then undertakes the commitment management strategy - activating those commitment rules for whom the mental conditions holds true at that instance. A commitment rule defines a situation in which the agent should adopt a commitment. These commitments are adopted and will be fulfilled at this or the relevant future clock cycle. As an example, consider:

- BELIEF(has(?mp3player)) =>COMMIT(Self, Now, BELIEF(true), listen(?mp3player));

In short the commitment management strategy adopts new commitments, maintains existing commitments, refines existing commitments into plans and/or additional commitments, realises commitments as actions and handles failed commitments.

5.2 Example: Content Distribution to the Roaming Tourist

For the purposes of this discussion, the case of a tourist is considered as (s)he explore some outdoor environment. It is important to note however that the issues raised are not unique to the tourism domain and the following approach could be used in a number of other domains including mobile learning and wireless advertising. It is assumed that the tourist possesses an appropriate PDA or mobile phone. As they roam about, their position and orientation is tracked. Content that is appropriate to their position (and user model!) is continuously identified and prepared for display in anticipation of a forthcoming request. A record of any interaction that occurs is studied thus providing further material for refining the user model. Obviously, the autonomous and proactive nature of intelligent agents makes them particularly suitable for modelling and implementing such a solution. This architecture is based on a system termed Gulliver's Genie (O'Hare, 2003) that has been the subject of ongoing research over the last few years. In this section, discussion is limited to those strategies adopted by the Genie for the identification and assembly of content that is appropriate to tourists' contexts. Issues relating to the deployment of content on mobile devices and how the Genie accomplished this are described elsewhere (O'Grady, 2004).

To reflect briefly: Gulliver's Genie is similar in scope and objectives to CRUMPET, described earlier in Section 4.3. Both focus on the eCulture domain and seek to support tourists as they explore environments of cultural significance. However, there are differences between the systems in terms of those services each focuses on and how each is implemented. CRUMPET is concerned with the integration of legacy services into the tourist domain, and in this way, seeks to provide tourists with those services that they would normally expect and utilise. The Genie focuses on navigation support and, in particular, explores issues relating to the delivery of dynamic multimedia content to the tourist on an "as-needed" basis. Technically, CRUMPET is implemented using microFIPA-OS while the Genie has been realised using Agent Factory.

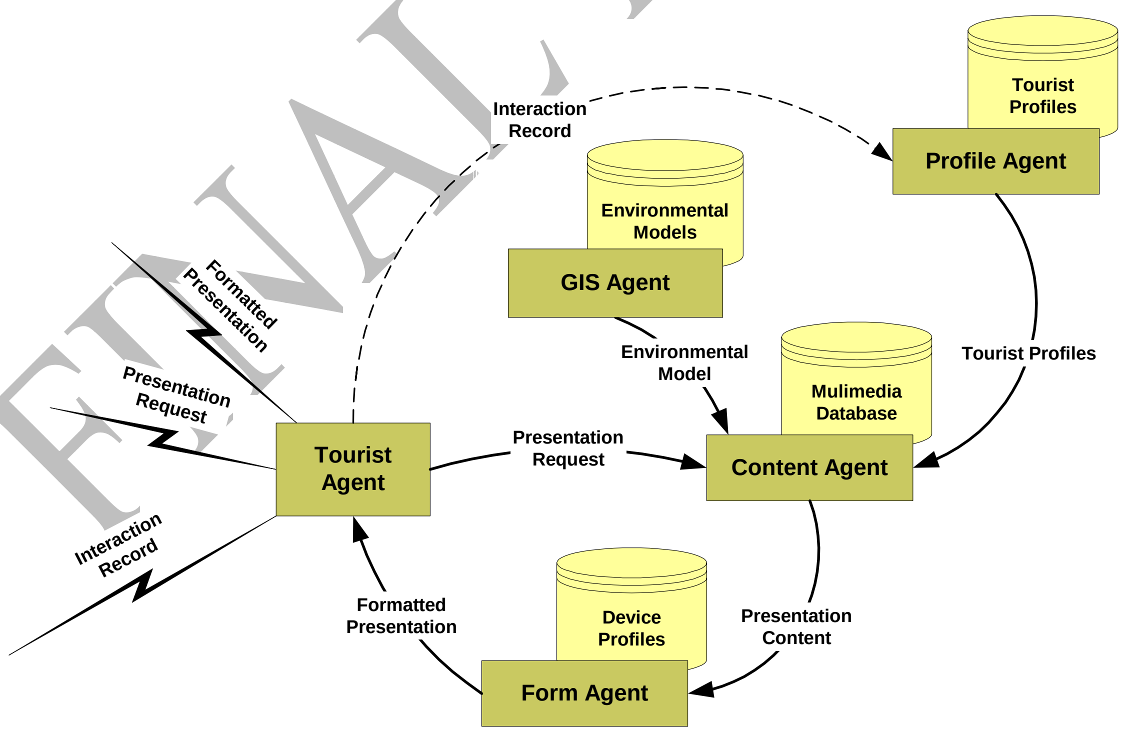

Fig 3: Architecture of the Genie Server illustrating the pertinent components and interactions.

Architecturally, the Genie may be regarded as comprising a fixed component – the server, which supports a number of mobile tourists or clients. The architecture of the Genie Server is outlined in Fig. 3 and the constituent agents are now briefly described:

- *Tourist Agent*. In the Multi-Agent system (MAS), each user or tourist is represented by their own individual agent. This agent monitors the tourist's activity, captures salient aspects of their context and situation and forwards this as necessary to other interested agents. In this case, the Tourist Agent provides a tuple consisting of the user's spatial context and the profile model. Based on these, the other agents with the MAS collaborate to produce content that is appropriate to the user's context, or, possible future context.
- *Content Agent*. The primary task of the content agent is the pre-emptive identification and assembly of content such that the Tourist Agent can make it available to users in an as-needed basis. This is fundamentally a collaborative activity. The GIS Agent provides an environmental model of the tourist's current vicinity. A model of the tourist is provided by the Profile Agent. Based on these, the content is filtered accordingly and the Form Agent formats the content such that it can be displayed on the tourist's device.
- *GIS Agent*. A geographic model of the physical environment is maintained by the GIS Agent. Given the current position of the user, it can construct what may be termed a local model of the tourist's current vicinity. The contents of this model will vary according to the sophistication of the primary environmental model. However, as it is assumed that the user is a stereotypical tourist, the model will consist of a list of objects of cultural significance.
- *Profile Agent*. Maintaining and updating user models or profiles is the primary service provided by the Profile Agent. All content presented to the user must conform to their model. These issues are discussed in more detail in Section 5.3.
- *Form Agent*. Adapting the content to a format appropriate to the user's host device marks the final stage of the assembly process. As well as a device profile, it is necessary to consider both the network technology as well as further user preferences. At present, two presentation formats are supported. The first assumes that availability of a Synchronized Multimedia Integration Language (SMIL) (W3C, 2001) player and constructs the presentation accordingly. The second, informally termed the Genie format, is a format particularly customised for PDAs such as the HP IPAQ. Most of the recent work on the Genie has involved the incorporation of SMIL based functionality. SMIL has been chosen for a number of reasons:
  - It is an international standard ratified by the WWW consortium;
  - It can form the basis of an interface similar to that users are familiar with on the WWW without the need to write a customised tool for rendering HTML;
  - It has been formally approved by the 3GPP as the core technology around which MMS messages are rendered on mobile phones. In this way, it is hoped that porting the Genie onto such phones will become less strenuous.

Fundamental to all this of course is the successful capture and interpretation of the tourist's spatial context, namely their physical position and orientation. This process takes place on the tourist's device where an agent interrogates a GPS sensor from it determines the user's spatial context and makes some deductions regarding the tourist's movement. By reconciling this with a local model of the immediate physical environment, a decision can be made on the client regarding the desirability of requesting a cultural presentation or otherwise. Should a presentation be requested, a sequence of events similar to those outlined in Fig. 4 takes place. In the next section, the process for identifying suitable content and updating individual models is described.

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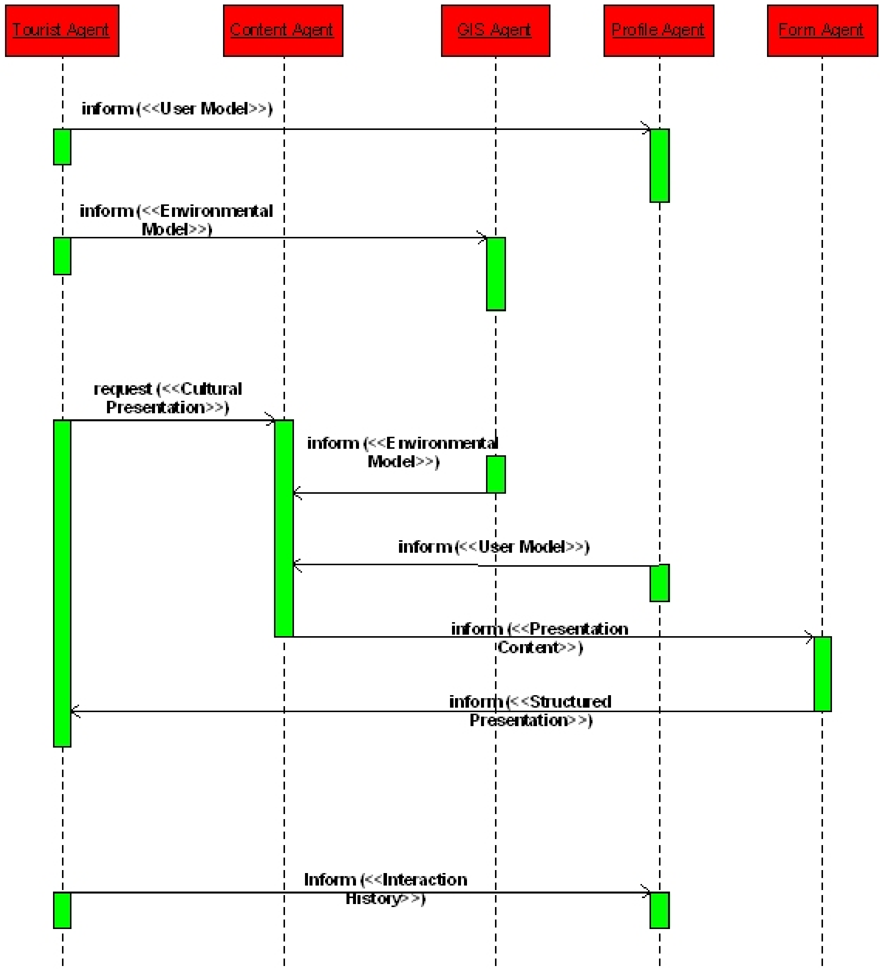

Fig 4: UML Sequence diagram illustrating the essential interactions between the agents. For clarity, some of the more obvious interactions have been omitted.

5.3. Some User Modelling Issues

Initially, a user must explicitly specify the contents of their user model. However, due to the inherent dynamic nature of user models, a facility is provided for their ongoing refinement. A user model may be regarded as consisting of two components:

- *Static*. A static component may be regarded as comprising those aspects of the user that, for the most part remain relatively static over time and are common to all users. For example, age and sex are two obvious examples. Languages spoken might be another aspect, as is occupation. Though like age, the actual values of these latter two may change over time.
- *Dynamic*. Dynamic aspects of a user's model are those that may change relatively quickly over time. Examples include current location and activity. However, evolutionary aspects of a user's model are also considered for inclusion in this component. In particular, a user's cultural interests may be regarded as a component that evolves over time.

Static components covered by the user model in the Genie include amongst others age, sex, nationality, spoken language and occupation. When initially registering, these aspects must be specified and will not change unless explicitly requested. The dynamic component of the Genie user model is, as expected, concerned with tourists' interests. For this version, six

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cultural interests have been specified. These include: art, architecture, folklore, history, literature and religion. Again, users must initially specify what their interests are and the Genie will present content according to these.

While this is adequate for bootstrapping the initial personalisation mechanism, it is necessary to move beyond this and try to establish the level of the user's interest in each cultural interest. This is particularly important in a mobile multimedia scenario as both device characteristics and the latent network require a compromise be reached between what the content the user might like to see, what is feasible on the device and under the latent network operating conditions, as well as other parameters that may need consideration, for example, cost. Therefore, it is necessary to reflect on what the user has explicitly selected and, conversely, explicitly ignored. It is essential therefore that an accurate record of the user's interaction is returned for further processing by the Profile Agent. The cultural interest tag associated with each piece of selected content is identified and the weight associated with this tag is incremented in the user model. Given the relatively few interest items that are being tracked, it was not thought necessary to implement a negative scoring scheme. In this way, content that the Genie considers to be of more interest to the tourist is given a higher priority and a more prominent role in the dynamically assembled presentation.

Content is classified by the Genie as follows:

- Anchored: Such content includes images and sound scripts that introduce the tourist to the attraction. All Genie presentations must comprise one and only one piece of anchor content.
- Required: Content labelled "required" must be included in the presentation. An example might be the opening times of the attraction, something all visitors would be interested in.
- Model Specific: Content can be specified for both static and dynamic aspects of the user model. Recall that the static component consists of language, age, sex, nationality and occupation. The dynamic component, or interest sub-model, supports six core cultural interests: art, architecture, folklore, history, literature and religion. Almost any combination of these attributes can be associated with content.

5.4. How the Profile Agent's Mental State Evolves

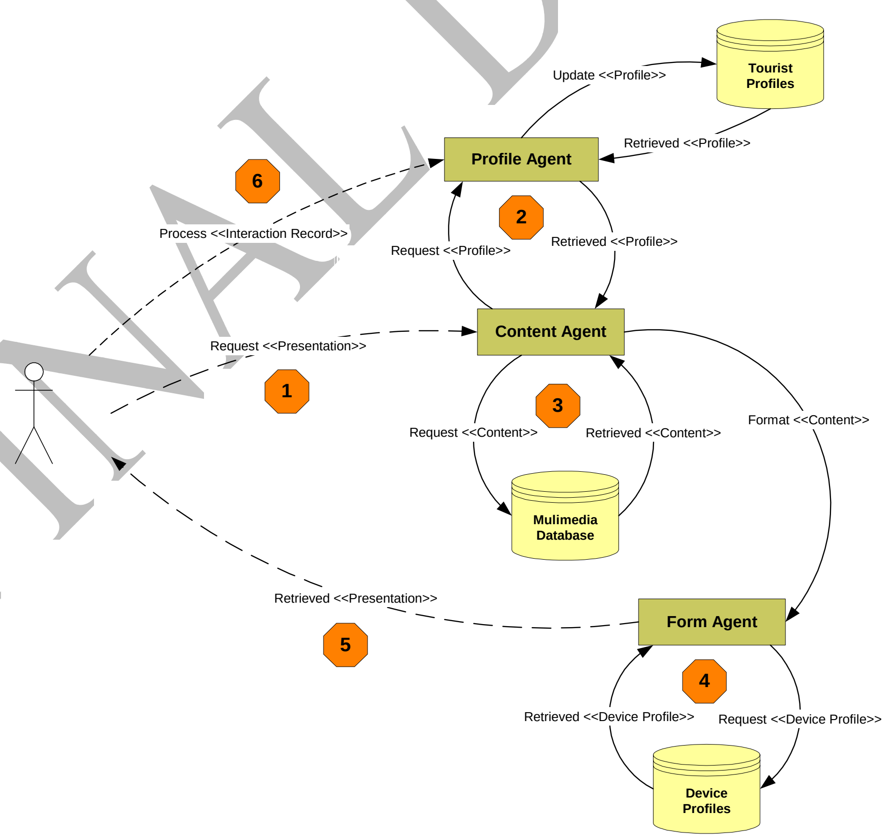

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Fig 5: key steps in the presentation construction process.

As an illustration of how the tourist's profile evolves, and in parallel, how the Profile Agent's mental state evolves, the key steps in the process, numbered in fig. 5, are now described in sequence.

1. An incoming request for a multimedia presentation is received. Note that agents on the client have a model of the user's environment thus they know exactly what presentation they require. All these requests are handled by the Tourist Agent, which is in effect the tourist's proxy on the network.

2. The Content Agent requests the particular tourist's profile from the Profile Agent. Using the appropriate entries in the profile tables in the database, the tourist's profile is assembled. For the purposes of this discussion, let's assume the profile as understood by the Profile Agent and reflected in its mental state is as follows:

   ALWAYS (BELIEF (**Name** (Sophie)))
   BELIEF (**Age** (41)
   ALWAYS (BELIEF (**Sex** (Female)))
   ALWAYS (BELIEF (**Language** (English)))
   UNTIL (BELIEF **(Interest** (Art, 18)), Belief (HyperLink_activated (Art))
   UNTIL (BELIEF (**Interest** (Architecture, 20)),
   BELIEF (HyperLink_activated (Architecture))
   UNTIL (BELIEF (**Interest** (Folklore, 12)), BELIEF (HyperLink_activated (Folklore))
   UNTIL (BELIEF (**Interest_Preference**(Architecture, Art, Folklore)),
   BELIEF (Significant_Event(True)))

   As can be seen, Sophie is interested in art, architecture and folklore; and the Profile Agents believes, from past experience, that her explicit preference are Architecture, Art and folklore, in that order. All of this information is encapsulated in the tourist's profile and the relevant aspects dispatched to the Content Agent.

3. Having received the profile (or parts thereof), the Content Agent is now in a position to extract media content that conforms to this profile from the multimedia database. The relevant profile attributes are used as search criteria as is the tourist's spatial context, which is included in the initial request for media content. However, the Content Agent must also factor into its deliberations any policies that the tourist may have specified initially, or indeed, any heuristics that may have emerge over time. So for example, tourists may set a limit on the amount that they are prepared to pay for each presentation. In this case, the mental state may include the following beliefs:

   UNTIL (BELIEF (Network (3G)), BELIEF (Network_Connection (Unavailable)))
   UNTIL (BELIEF (**KB_Charge** (0.001), !BELIEF **(Network** (3G)))
   ALWAYS (BELIEF (**Max_Cost** (2.00)))

   In the case of a 3G network or a WiFi connection, presentation size is only affected by the cost the tourist specifies. However, should the connection be GPRS, the issues of size is of critical importance as this would adversely affect the download time. Thus it would be advisable to limit the presentation size, in addition to any restraints arising from the tourist's stated policy on costs. Thus the Content Agent might adopt the following belief:

   BELIEF (**Network** (GPRS)) =>
   ADOPTBELIEF (UNTIL (BELIEF (Max_Size_KB (500), !BELIEF (Network (GPRS)))

4. Having identified a combination of multimedia items that satisfy size and cost constraints, as well as conforming to the cultural interests explicitly represented in the profile, the next task is to adapt or format the content such that it can be displayed on the tourist's device. Two format variations are currently supported. The first is oriented towards PDA-like interfaces and is a propriety Genie format. The second is for SMIL-enabled devices. The choice depends on the device and user preferences. For example, if it is known that the tourist has a 3G capable device, can play SMIL files and might prefer a WWW style interface, a commitment rule similar to the following might be activated:

   BELIEF (**Network** (3G)) &
   BELIEF (**Device** (SMIL_enabled)) &

BELIEF (**Preferred_interface** (WWW_style)
=> COMMIT (SELF, NOW, Prepare_SMIL_Presentation (Sophie, ?content))

In this case, a SMIL presentation would be created around the selected content. In contrast, should the tourist be equipped with a more basic device, for example, a relatively old PDA, another commitment rule might be activated:

BELIEF (**Network** (GPRS)) &
BELIEF (**Device** (SMIL_disabled))
=> COMMIT (SELF, NOW, Prepare_GENIE_Presentation (Sophie, ?content))

In this case, a presentation using the standard propriety Genie format would be created. During construction of the multimedia presentation, all anchor and required content is first incorporated into the presentation template. After this, content relating to their cultural interest is included. In this case, all content of an art, architectural and folklore nature is included, assuming of course that such content exists for the attraction in question. Thus content coherence is ensured. In this case, content will be prioritised in the following order: Architecture, Art, and Folklore, in accordance with the tourist's deduced preferences.

5. Finally, the presentation is returned to the agents on the tourist's device. Two outcomes are possible. The first is that the agents do not show the presentation and discard it. This would happen, for instance, if the tourist changed their mind and adopted a different trajectory or route from that originally envisaged. Such an event would be perceived by the agents on the tourist's device and the appropriate beliefs, driving a commitment to discard the presentation, would be adopted. However, if they proceed to visit the attraction in question, the agents will collaborate to render the presentation on the device and, of course, monitor any interaction that occurs.

6. When a presentation has been completed, a record of the interaction that the tourist engaged in with the presentation is returned to the Profile Agent. These activities may act as a catalyst for profile revision. To facilitate profile updating, it is necessary to tag the appropriate media elements with some metadata that indicate their cultural interest relevance. When the hyper- links in the presentations are activated by the tourist, the corresponding interest element can be ascertained and interpreted. On completion of the presentation, this record is returned to the Profile Agent for analysis and the subsequent updating of the tourist's profile. Assume that the tourist has, in this instance, listened to an element of the presentation dedicated to art. In this case, their profile, as represented by the Profile Agent's mental state would be as follows:

ALWAYS (Belief (**Name** (Sophie)))
BELIEF (**Age** (41), Now)
ALWAYS (BELIEF (**Sex** (Female)))
ALWAYS (BELIEF (**Language** (English)))
UNTIL (BELIEF **(Interest** (Art, *19*)), BELIEF (HyperLink_activated (Art))
UNTIL (BELIEF (**Interest** (Architecture, 20)), BELIEF (HyperLink_activated (Architecture))
UNTIL (BELIEF (**Interest** (Folklore, 12)), BELIEF (HyperLink_activated (Folklore))
UNTIL (BELIEF (**Interest_Preference** (Architecture, Art, Folklore)),
BELIEF (Significant_Event(?interest)))

As can be seen, the weight associated with art has been incremented accordingly. However, the order of the cultural interests remains the same. Indeed, the selection of a media object with a specific interest tag attached is a significant event in itself. If it so happened that Sophie had actively selected a number of items relating to art, the weight would be increased accordingly. If this should result in the order of her interest preferences changing, then the Profile Agent would also interpret this as being a significant event. In short, Sophie's preferences would no longer be valid and would require revision. The following commitment rules would be adopted:

BELIEF (Link_Activated (?interest))
=> ADOPTBELIEF(BELIEF(Significant_Event (?interest)))

BELIEF **(Significant_Event** (?interest))
=> COMMIT (SELF, NOW, Update_Interest_Profile (Sophie, ?interest))

In this case, the Profile Agent would review the interest scores and adopt a new list of Sophie's preferences. Furthermore the corresponding entry in the profile database would also be updated. All future presentations dispatched will reflect this new ordering of preferences until such time as another significant event occurred.

To elucidate further: When the Profile Agent updates the tourist's profile, a recalibration of the interest weights is typically involved. Factors which are regarded as synonymous with heightened interest are non-interrupted presentation listening, repeated presentation listening, explicit activation of follow-up content, duration of content interrogation to mention but a few. Having determined if recalibration is necessary, or indeed if additional attributes need to be added, the Profile Agent updates the relevant aspects of the user profile. The dynamics of the individual user profile (together with the device profile and network profile) are the key drivers to system content adaptivity. At present, the user device and network profiles are explicitly encoded in the mental state of the Profile Agent. Consequently, the dynamics of such profiles need to be reflected through a belief revision function. This process necessarily places a computational demand on the system performance. Intuitively, we merely want mental state revisions pertaining to user device and network profiles to occur when a *significant* change occurs. It is the responsibility of the Profile Agent to determine such significant changes. System adaptivity is permitted through the Profile Agent autonomously determining the *significance threshold*. In situations where system responsiveness is paramount, content relevance may be compromised through less frequent mental state updates reflecting user profile changes.

5.5. Some Implementation Details

The Genie has been delivered on the original and current range of IPAQ PDAs. All software is implemented in Java, in particular PersonalJava. Originally, the Jeode JVM was used but more recently, the J9 JVM from IBM has been experimented with. For wireless communications, the Option GlobeTrotter, a GPRS PCMCIA cardphone was acquired. A standard GPS CompactFlash (CF) unit has been used for position identification. For multimedia rendering, the Java Media Framework (JMF) is used on basic PDA models. SMIL presentations are rendered using the open source Ambulant Player on current IPAQ models. Intelligent agents have been realised both on the server and on the PDA using the Agent Factory (AF) (Collier, 2003; O'Hare 1996) runtime environment. The AF IDE was used for agent design and implementation. Agent UML (AUML) (Baur, 2001) was used for the initial design and modelling of all the agents comprising the Genie.

6. The Tourist Experience

As an example of how the Genie operates, consider the case of a tourist exploring central Dublin and encountering one of the most significant building there – the General Post Office (GPO). Initially, a brief description and overview of the building is presented such as that illustrated in Fig. 6. This introduces the building and provides some brief information concerning its origins and place in Irish history. Such information would be of interest to all tourists that come within its vicinity. However, as the building is both architecturally and historically important, a significant amount of information could be presented to the tourist. In this case, the tourist model indicates that they are not particularly interested in history but welcome information of an architectural or historical nature. Such tourists would be presented with additional information such as that illustrated in Fig. 7.

Trials that focused on the broad area of usability have been conducted on the Genie. These are described elsewhere (O'Grady, 2005). Though feedback was generally positive and a number of relevant issues came to light, an attempt to measure the effectiveness of the scoring mechanism used in the tourist model proved inconclusive. Reasons for this may well include the rather restricted number of attractions that could be provided on a campus and visited within the space of an hour. However, the potential of the Genie for delivering information that was appropriate to their own individual context was generally recognised.

It is prudent to reflect at this point on the issues raised in Section III concerning content acquisition and tagging. Developing an information space for the tourist domain is a non-trivial task; a situation that is likely to be the case in other domains also. In particular, the necessity for identifying appropriate content and associating it with users of a particular genre is more an art than a science. Fundamental to this process is a thorough understanding of the subject matter and the target user group. Given the diversity both of the average environment, at least from a tourist perspective, as well as the diverse interests of the end-user group, constructing the environmental model and specifying the necessary multimedia components may require a dedicated team and take significant time. The care, effort and time expended in this endeavour will be one of the critical factors that determine the success (commercial viability) of the service or otherwise.

Fig. 6. An initial overview of the GPO

Fig. 7. What a tourist interested in architecture might experience.

7. Conclusion

This paper has presented an architecture for the development and deployment of intelligent multimedia applications for the ubiquitous and mobile computing community. This architecture entitled Gulliver's Genie supports content adaptivity through context awareness. Gulliver's Genie adopts a Multi-Agent Systems approach in the intelligent delivery of personalised content. Context is viewed as an aggregation of user profile, user device, network state and physical environment. We illustrate how multimedia content is delivered to a mobile tourist in a personalised and contextualised manner. Content is personalised to the user's perceived needs, where these needs are captured within the user profile. Content is contextualised based upon such factors as network category and device capabilities. We demonstrate such system adaptivity by way of presentation assembly in either the propriety Genie format or that of SMIL.

Ongoing work involves the porting of the architecture to a 3G enabled mobile phone, a prototype of which is already running in the laboratory. Future work will involve the augmentation of the user modelling component with more sophisticated techniques including collaborative filtering. From a multimedia perspective, the SMIL player will be integrated into Genie rather than run as a separate application as is the case at present. It is also planned to investigate the use of MPEG streaming and the dynamic construction of MPEG video based on user, network and device profiles.

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References

Ardissono, L., Goy, A., Petrone, G., and Segnan, M. 2005. A multi-agent infrastructure for developing personalized web-based systems. ACM Trans. Inter. Tech. 5, 1 (Feb. 2005), 47-69.

Bauer, B., Müller, J.P., Odell, J. Agent UML: A Formalism for Specifying Multiagent Interaction, Agent-Oriented Software Engineering, 2001.

Baumer, C., Breugst, M., Choy, S., Magedanz, T., "Grasshopper - A Universal Agent Platform based on OMG MASIF and FIPA Standard", First International Workshop on Mobile Agents for Telecommunication Applications (MATA'99), Ottawa, Canada, 1999.

Benedicto, J.,Dinwiddy, S.E., Gatti, G., Lucas, R., Lugert, M. GALILEO : Satellite System Design and Technology Developments, European Space Agency, 2000.

Bergenti, F., Poggi, A., LEAP: A FIPA Platform for Handheld and Mobile Devices, Proc. 8th International Workshop on Agent Theories, Architectures and Languages (ATAL-2001), Seattle, WA, USA, 2001.

Chen, R., Toran-Marti F., Ventura-Traveset, J. "Access to the EGNOS signal in space over mobile-IP", GPS Solutions, vol. 7, no. 1, pp. 16-22, May 2003.

Coleri, S., Cheung, S.Y., Varaiya, P.: Sensor Networks for Monitoring Traffic. In: Allerton Conference on Communication, Control and Computing. (2004)

Collier, R., O'Hare, G. M. P. Lowen, T. D., and Rooney, C. F. B., Beyond Prototyping in the Factory of Agents, In Proc. 3rd Int. Central and Eastern European Conference on Multi-Agent Systems (CEEMAS), Prague, Czech Republic, 2003.

Kee , C., Yun , D., Jun, H., Parkinson , B., Pullen, S., Lagenstein, T., Centimeter-Accuracy Indoor Navigation Using GPS-Like Pseudolites, GPS World, November, 2001.

Keegan, S. & O'Hare, G.M.P, Easishop: Delivering Cross Merchant Product Comparison Shopping for the Mobile User, Proceedings of the15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'04), 5th-8th September Barcalona, Spain, IEEE Press, 2004.

Kephart, J.O. Chess, D.M. The Vision of Autonomic Computing, IEEE Computer, vol. 36, no. 1, pp. 41-50, January 2003.

Kobsa, A. 2001. Generic User Modeling Systems. *User Modeling and User-Adapted Interaction* 11, 1-2 (Mar. 2001), 49-63.

F. Koch, J-J. Meyer, F. Dignum, and I. Rahwan. Programming Deliberative Agents for Mobile Services: the 3APL-M Platform. AAMAS'05 Workshop on Programming Multi-Agent Systems (ProMAS'2005). pp. 179-192. Utrecth, NL. Jul/2005.

Kozuch, M. Mahadev Satyanarayanan Bressoud, T. Helfrich, C. Sinnamohideen, S. , Seamless mobile computing on fixed infrastructure, Computer, vol. 37, no. 7, pp. 65-72, 2004.

Kwak, M. Cho, D-S. Collaborative filtering with automatic rating for recommendation, IEEE International Symposium on Industrial Electronics (ISIE 2001), vol 1, pp. 625 – 628, 2001.

Langley, P., 1999. User Modeling in Adaptive Interfaces. In: Proceedings of the Seventh International Conference on User Modeling, June. Springer, Banff, Canada, pp. 357–370.

Laukkanen, M., Tarkoma, S., Leinonen, J., FIPA-OS Agent Platform for Small-footprint Devices, Proceedings of the ATAL Conference, Seattle, USA, 2001.

Lemlouma, T., Layaida, N. Context-aware Adaptation for Mobile Devices, in Proc. of the International Conference on Mobile Data Management, Berkeley, California, USA, 2004, IEEE.

Mainwaring, A., Polastre, J., Szewczyk, R., Culler, D., Anderson, J.: Wireless Sensor Networks for Habitat Monitoring. In: InternationalWorkshop on Wireless Sensor Networks and Applications. (2002)

O'Grady, M.J.. O'Hare, G.M.P., Sas, C. Mobile agents for mobile tourists: a user evaluation of Gulliver's Genie, Interacting with Computers, In Press, 2005.

O'Grady, M. J., O'Hare, G. M. P.: Just-in-Time Multimedia Distribution in a Mobile Computing Environment, IEEE Multimedia, vol. 11, no. 4, pp. 62-74, 2004.

O'Hare, G. M. P., O'Grady, M. J.: Gulliver's Genie: A Multi-Agent System for Ubiquitous and Intelligent Content Delivery, Computer Communications, 26 (11), 2003, 1177-1187.

O'Hare G.M.P. Agent Factory: An Environment for the Fabrication of Multi-Agent Systems, in Foundations of Distributed Artificial Intelligence (G.M.P. O'Hare and N. Jennings eds) pp449-484, John Wiley and Sons, Inc., 1996

Patterson, C.A., Muntz, R.R., Pancake, C.M. Challenges in Location-Aware Computing, IEEE Pervasive Computing, vol. 2, no. 2, April-June 2003.

Petrelli, D., De Angeli, A., and Convertino, G. A user-centered approach to user modeling. In Proceedings of the Seventh international Conference on User Modeling (Banff, Canada). J. Kay, Ed. Springer-Verlag New York, Secaucus, NJ, 255-264.

Poslad, S., Laamanen H., Malaka R., Nick A., Zipf, A., 2001. Crumpet: Creation of user-friendly mobile services personalised for tourism, Proceeding of the Second IEE International Conference on 3G Mobile Communication Technologies, London, UK

T. Rahwan, T. Rahwan, I. Rahwan and R. Ashri Agent-based Support for Mobile Users using AgentSpeak(L), In M. Winikoff, P. Giorgini and B. Henderson-Sellers (eds.). Lecture Notes in Artificial Intelligence, vol. 3030, 2004. Springer.

M.J. O'Grady, G.M.P. O'Hare and C. Donaghey. Delivering Adaptivity through Context-awareness, Journal of Network and Computer Applications, Volume 30, Issue 3, 2007, pp. 1007-1033.

Rao, A.S., Georgeff, M.P.: Modelling Rational Agents within a BDI Architecture. In: Principles of Knowledge Representation. & Reasoning, San Mateo, CA. 1991.

A. S. Rao (1996) "AgentSpeak(L): BDI agents speak out in a logical computable language" In W. Van de Velde and J. W. Perram, editors, Agents Breaking Away: Proceedings of the 7 th 24 European Workshop on Modelling Autonomous Agents in a Multi-Agent World, (LNAI Volume 1038), 42-55. Springer-Verlag.

Sandhu, J., Agogino, A., Agogino, A.: Wireless Sensor Networks for Commercial Lighting Control: Decision Making with Multi-agent Systems. In: AAAI Workshop on Sensor Networks. (2004)

Smith, J.R., Mohan, R., Li, C. Scalable Multimedia Delivery for Pervasive Computing, ACM Multimedia '99, Vol. 10, pp. 131-140, Orlando, FL, USA, 1999.

Sovat, R.B.; Aluisio, S.M.; de Carvalho, A.C.P.L.F., RaBeCa: a hybrid case-based reasoning development environment, Proceedings of the 13th International Conference on Tools with Artificial Intelligence, pp. 61-68,2001.

Toran-Marti, F., Ventura-Traveset, J. The ESA EGNOS Project: The First Step of the European Contribution to the Global Navigation Satellite System (GNSS), Navigare Conference, 2004.

W3C, RecommendationSynchronised Multimedia Integration Language (SMIL 2.0), 2001.

Weiser, M.The Computer of the 21st Century, Scientific American, vol. 265, no. 3, September, 1991.

Wooldridge, M., Jennings, N. Intelligent Agents: Theory and Practice, Knowledge Engineering Review, vol. 10, no. 2, 1995, pp. 115-152.

Zhao, Y. Mobile Phone Location Determination and Its Impact on Intelligent Transportation Systems, IEEE Transactions on Intelligent Transportation Systems, 1 (1), 2000.

3GPP TS 25.305, Universal Mobile Telecommunications System (UMTS); User Equipment (UE) positioning in Universal Terrestrial Radio Access Network (UTRAN); Stage 2(3GPP TS 25.305 version 6.1.0 Release 6), 2004.