



Title	Exploiting multi-agent systems in realizing adaptivity in the mobile tourist domain
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Publication date	2009-04
Publication information	O'Hare, G. M. P. (Greg M. P.), Michael J. O'Grady, Stefan Poslad, and Leonid Titkov. "Exploiting Multi-Agent Systems in Realizing Adaptivity in the Mobile Tourist Domain" 22, no. 2 (April, 2009).
Publisher	IOS Press
Item record/more information	http://hdl.handle.net/10197/1810
Publisher's version (DOI)	10.3233/AIC-2009-0447

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Exploiting Multi-Agent Systems in Realizing Adaptivity in the Mobile Tourist Domain

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Ongoing developments in an array of mobile computing technologies have rendered the deployment of intelligent agents feasible on lightweight computational devices such as mobile phones. This development extends the Multi-Agent System (MAS) paradigm to a new frontier, opening up significant avenues of research in intelligent mobile computing, amongst others. To demonstrate the potential of this approach, the practical realization of adaptivity in two classic agent-based mobile computing applications is considered. Though focusing on the tourist domain, it is contended that the approach adopted is generalisable to a broad category of mobile computing applications.

Keywords: Adaptivity, Mobile Computing, Intelligent Agents, Embedded Agents, Ambient Intelligence

1. Introduction

Mobile computing has, and continues to, manifest itself in diverse application domains. However, the practical deployment of agents on mobile lightweight devices represents a new frontier for intelligent agent deployments, as well as offering

significant potential for innovative mobile service provision. One area where the potential of agents could be fruitfully harvested in the mobile computing domain is that of adaptivity. Frequently, realizing an adaptive solution demands input from a variety of sources. The inherent collaboration essential to Multi-Agent Systems (MASs) make agents a particularly apt solution in this case. For the purposes of this discussion, the mobile tourist domain is considered as it may be perceived as an exemplar of those opportunities and challenges particular to the mobile computing domain. However, it must be observed that the application domain itself is frequently characterised by the nature of the content provided. Thus, the issues discussed here are in many respects generic, and the demonstrated adaptivity may easily be harnessed in other mobile computing domains - pervasive learning and mobile commerce to name but two.

This paper explores the contribution that agency can make to realising system adaptivity in mobile computing scenarios. Its novelty is manifested in a variety of forms. It demonstrates a practical and mature deployment of intentional agents in the mobile computing domain - the two systems that form the basis of this discussion, CRUMPET and Gulliver's Genie, are the first mature deployments in this area. More specifically, the paper considers the importance of adaptivity in this domain, reviews how adaptivity is achieved in both systems and compares the approach employed by each.

2. Background

A number of frameworks have been developed for deploying agents on computationally lightweight devices. One example of such an agent platform is the Lightweight and Extensible Agent Platform (LEAP) [6], which supports the deployment of agents on a heterogeneous network of fixed and mobile devices. MicroFIPA-OS [7], an exten-

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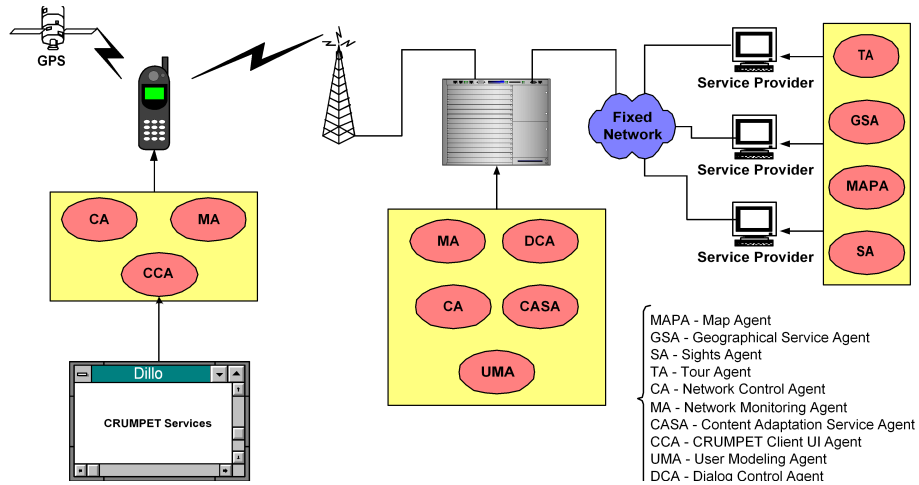


Fig. 1. CRUMPET service architecture - each service component is wrapped and appears as agent.

sion of the open source platform FIPA-OS [8], is especially optimized for mobile devices. Likewise 3APL-M [19] is a recent extension of 3APL [20]. Tacoma [9] and Grasshopper [10] typify examples of other frameworks that have been extended so as to operate on mobile devices.

In the case of BDI agents, an extension of Agent Factory [11], Agent Factory Micro Edition (AFME) [12], has been developed for J2ME-enabled phones and sensors.

The emergence of shrink wrapped Multi-Agent System (MAS) software bundles has resulted in the recognition that such an approach is now viable within the delivery of mobile tourist systems [13]. Recent research has provided early examples of these and include Tourist Guide-USAL [14] which partly harnesses a BDI approach, and the Multi Agent Tourist System [15] which was constructed using LEAP. However this paper focuses upon two particularly mature systems, those of CRUMPET and Gulliver's Genie, and explores commonalities in their approach to delivering adaptivity. These systems are described extensively elsewhere [1] [2] [3] [4] and their design, realisation and form are not the purpose of this paper. Nevertheless, a brief description of each is necessary to seed the ensuing discussion.

3. CRUMPET

CRUMPET (Creation of User-friendly Mobile Services Personalised for Tourism) [1] [2] seeks to

deliver novel mobile tourism information services and to leverage the properties of intelligent agents in their delivery. CRUMPET adapts information delivery to differing contexts such as the location, the person, the destination device and the network characteristics. CRUMPET uses shared explicit XML descriptions in order to integrate information from different stake-holders such as heterogeneous service providers, mediators and users. It is implemented using microFIPA-OS and hosted on an IPAQ.

CRUMPET has developed two categories of services - tourism domain specific services, and middleware services to support adaptivity such as location-awareness and personalization. Each service category is wrapped and represented by an agent. Typically domain specific services could include hotel information, restaurant guides and sight-seer guides. Middleware provision included a basic Geographical Information System (GIS) service and higher-level GIS services such as maps which highlight features and tours that include current location, destination and the recommended route to the destination. Middleware also includes network link adaptation agents, a subscription service to notify users when their registered interests are triggered, and a content adaptation agent utilized in tailoring information for a given mobile terminal. Additionally, three agent types collectively serve to represent the interests of the user: a client agent which handles the interaction by the user; a user model agent that represents the user preferences; and a broker to reduce

the complexity of the service interaction on behalf of the user.

3.1. Architecture

CRUMPET makes use of agents' autonomy and agents' semantic social interaction protocols. Each stake-holder such as the user, mediator and provider can control the service from its own perspective yet interoperate in a highly sophisticated manner when needed. For example, agents can decide how much information they will reveal to providers, they can negotiate in order to get the best service level agreement, or refuse if their minimum constraints are not met. CRUMPET agents utilize a set of standard FIPA-ACL social interaction protocols to share information and tasks. Inherent in the FIPA-ACL model commissioned, is the notion of an ontological-based semantic model. CRUMPET can combine and integrate multiple XML-based domain specific ontologies for tourism, personalization and system management using ontology mediation, and by employing a logic-based semantic language FIPA Semantic Language (FIPA-SL) to make inferences about the ontology and the interactions. Furthermore, inherent in the standard FIPA-ACL protocol model that CRUMPET uses is a belief-based mentalistic model. Agents can for example share information when they believe that the other party does not already know the information; agents can also share tasks when they believe that another party has the capabilities and intention to help them. CRUMPET agents are deliberative, they build models of the environment in which they are situated and can subsequently adapt their behaviour to the state of the environment such as network QoS, person, location and terminal.

Two main architectural variations are used to deliver CRUMPET services: a thick-client (see Fig. 1) and a thin-client version. The thick-client executes some agents on the mobile terminal; this enables agents to monitor the mobile terminal wireless link at both ends to thereby supporting content delivery adapted to the quality of the wireless link. The thin-client in comparison does not support network link content adaptation - it simply runs a mini Web browser and a client to transmit information from the positional determination device such as a GPS (Global Positioning System) receiver attached to the mobile terminal. There-

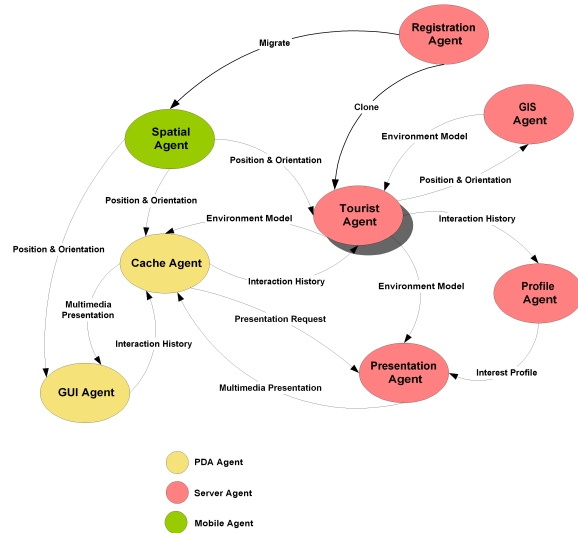


Fig. 2. Architecture of Gulliver's Genie.

fore dependant upon the need for adaptation and the type of mobile terminal available, a thick or thin-client configuration may be used.

4. Gulliver's Genie

Gulliver's Genie [3] [4] evolved out of an earlier mobile tourist information system HIPS [5], and is concerned with facilitating the delivery of services with a substantial and dynamic multimedia component on devices of limited computational capacity. From a tourist perspective, two services are provided: navigation support and the provision of cultural content.

At present, the Genie is deployed on an IPAQ. GPS is used for position determination and 3G/GPRS for data communications. All agents on the PDA are implemented using AFME while those on the server use the standard Agent Factory Framework.

4.1. Architecture

The architecture of the Genie is illustrated in Fig. 2. In essence, the Genie is a Multi-Agent System (MAS) that comprises a suite of agents on the tourist's device or client, supported by another suite of agents hosted on a fixed networked server. All agents communicate using Agent Factory ACL.

Three agents are hosted on the mobile device. A Spatial Agent monitors GPS and determines the

tourists spatial context. The Cache Agent maintains a temporary cache on the device containing a model of the local environment and a multimedia presentation pertaining to the nearest attraction in their vicinity. The GUI Agent manages all aspects of the user interface including map and presentation rendering.

Each tourist is represented by a proxy agent, the Tourist Agent, on the Genie Server. This agent coordinates all communications between the fixed MAS component and the mobile component of the device. The GIS Agent maintains a model of the environment and prepares sub-models according to tourists' contexts. The Profile Agent maintains user models of tourists registered with the Genie. Finally, the Presentation Agent assembles multimedia presentations for those exhibits registered in the environmental model.

5. Adaptivity

Within the context-sensitive service delivery arena, adaptivity [21] [22] is essential to the effective and efficient delivery of services, thus both CRUMPET and Gulliver's Genie embrace system adaptivity within their respective designs. System adaptivity manifests itself in four key areas, location, device & network, personalization and future situation prediction.

5.1. Location-awareness

An awareness of a tourist's spatial context is fundamental to the adaptivity employed by both the CRUMPET and the Genie. In both cases the interface is adaptive in a simple and intuitive fashion. It is continuously updated so as to represent the tourist's current location. Though straightforward, some collaboration between the agents is still necessary to realise this. For CRUMPET, the UI Agent must communicate with the Map Agent on the server in order to source a map customised to the tourist's preferences. For the Genie, the Spatial Agent provides the current spatial context to the GUI Agent. However, it will only do this if the movement is meaningful - for the Genie, meaningful movement is where the user has moved a distance greater than 20 meters from when their position was last notified to the GUI Agent. The rule adopted, expressed in Agent Factory Agent programming Language (AFAPL) is as follows:

```
Belief(meaningfulMovment(?currentPosition,
?lastPosition)
=> COMMIT(Self, Now, BELIEF(true),
inform(GUI Agent, ?currentPosition)
```

20 meters is assumed to be the average error associated with a GPS position. However, the scale of the map will also influence whether an update is reflected on the interface. There is no advantage in updating the position on screen unless it will be obvious to the tourist that the position has indeed changed. Location is actually a key driver for other elements of the adaptivity exhibited by both systems including the results of spatial queries in CRUMPET as well as the preparation of multimedia presentations by the Genie.

5.2. Device & Network Characteristics

A distinguishing feature of CRUMPET is its strong support for adaptivity from a device and network perspective. In the case of the host device, deploying an application on a suite of devices of differing capabilities is a formidable technical challenge, and may have a detrimental effect on perceived usability if not completed in a satisfactory fashion. Device awareness is supported by linking a terminal profile to each type of device. When a new user session is initiated, those agents residing upon the mobile terminal register themselves on the network and transmit the terminal profile to the access node middleware agent services. These then collaborate with a Content Adaptation Agent (CASA) to tailor information for a given mobile terminal. Two agents are dedicated to managing the network link, a Monitor Agent (MA) and Control Agent (CA). Monitoring the QoS of the data transmission link is the task of the Monitor Agent, and this parameter is made available to other interested agents, allowing further adaptation of the content. The Control Agent controls data transmission and the management of connections between the mobile terminal and the fixed node.

5.3. Personalization

Personalisation is a shared characteristic of both CRUMPET and the Genie, and in each case, content displayed to tourists has been filtered using pertinent personal characteristics. In both systems, an agent has been assigned this task and

provides the requisite service to other agents. In the case of CRUMPET, the User Modelling Agent (UMA) represents user preferences while the Profile Agent provides a similar function in the Genie. In both cases, explicit feedback is used to seed the user models but implicit feedback is used for refinement. For example, in the case of the Genie, the GUI Agent records all interactions and forwards these records to the Profile Agent for further processing.

5.4. Future Situation Prediction

Both CRUMPET and the Genie are concerned with possible future tourist behaviour but in very different practical instances. CRUMPET can use a predictive approach to QoS by modelling user class route habits to anticipate user routes together with network links available to those routes. The Genie in contrast is interested in those tourist attractions that the tourist is likely to encounter in the immediate future. Anticipated these and planning to have personalised presentations ready when the tourist finally encounters an attraction is indeed a collaborative process. In the first instance, the Spatial Agent ensures that GIS agent is notified of significant movement by the tourist. This enables the GIS Agent to construct Environmental Models for the tourists, which are provided to the Presentation Agent and the Cache Agent. The Presentation Agent proceeds to build, in conjunction with the Profile Agent, personalised presentations. Once the Cache Agent has decided that a tourist is likely to encounter an attraction, it will request the required presentation from the Presentation Agent, and store it in the cache on the mobile device. Finally, should the Cache Agent determine that the tourist has encountered the attraction, it will collaborate with the GUI agent to render the presentation.

6. Agent-enabled Adaptivity

Delivering applications within the constraints of mobile devices and wireless networks that conform to user expectations that emerge from fixed workstation environments is fraught with difficulty. Realizing an adaptive solution represents an additional veneer of complexity and further complicates the issue, though there may be a signifi-

cant improvement in the end-user experience. Both CRUMPET and Gulliver's Genie have adopted an approach based upon intelligent agents in an effort to address such complexity. Agents offer a very attractive approach for modelling system components. However, it is the ease with which the interactions between them can be modelled which has proved most useful. As can be seen in the corresponding architecture diagrams (Fig. 1 and Fig. 2), the tasks assigned to individual agents are intuitive but rarely self-contained. Collaboration is a fundamental feature of multi-agents systems, and both CRUMPET and the Genie are no different in this regard. In order to deliver adaptivity, the agents must depend upon information from their colleagues. At the base level are agents that interface with GPS and monitor the prevailing conditions on the network. Based on information from these, the other agents comprising the MASs can tailor their services accordingly. When, where and how the tourist uses these services can complete the feedback loop thus enabling the ongoing refinement of individual user models. How the various characteristics of agenthood are harnessed to deliver adaptivity can now be considered.

GPS is harnessed in both cases and, likewise, an agent is assigned the task of monitoring the device. The autonomous nature of the agent is a prerequisite for this function as the tourist is continuously mobile. Furthermore, their reactive nature enables them to react to defined events and circumstances as they arise. As the agent has access to the raw GPS sensor data, it can analyse this for trends in behaviour such as moving quickly or remaining stationary. It can also identify meaningful movement that identifies when it is necessary to inform the other agents of the tourist's position. For example, the navigation screen might need to be updated on a regular basis, possibly every 10 seconds while it may be sufficient to inform the agents on the fixed networked node every 30 seconds or so. However, this process itself can be adaptive in that the tourist's position may be updated more regularly according to the preferred scale of the map or as they converge on a cultural attraction. From a software engineering perspective, the agent can encapsulate the required functionality for position determination. Furthermore it can be augmented such that it can manage networked-based solutions or Satellite-based Augmentation System (SBAS) technology. Indeed, accuracy of positioning tech-

nology, if a number are available, can be a significant determinant for user satisfaction [23].

Tourists may possess a number of devices and may access CRUMPET or the Genie from any one of them. Thus, it is essential that the capabilities of the device be recognised on the commencement of a session. CRUMPET uses an agent hosted on the device to automatically identify it and to communicate this to other agents in the MAS so that its profile may be identified and content adapted accordingly. Monitoring the QoS is more challenging. This demands a continuous process as the QoS parameter may change dynamically even during a single communication session. Thus the agent must autonomously monitor it, make intelligent decisions about the implications of any changes, and communicate these such that the service can adapt in an appropriate manner.

To deliver a multimedia service in a *just-in-time* basis as the Genie seeks to do demands that the tourist's situation at any moment in time be determinable. This obligates the agents to utilise their social ability to ensure that the Cache Agent always has a relevant environmental model such that the spatial context can be used to construct the immediate prevailing situation. This is a prerequisite to a key decision this agent must make: is it probable that the tourist will encounter an arbitrary cultural attraction and when should downloading an appropriate presentation commence? Again, the agents' autonomous nature is harnessed here, but the Cache Agent must act in a proactive manner to commence this process.

Both CRUMPET and the Genie assign user modelling to an individual agent, and this represents a service these agents can provide to the other agents in their respective MASs. However, user models are dynamic and must be maintained. Thus it beholds the agents controlling the user interface to monitor interactions and to return records of these to the user model agents for analysis and model refinement.

7. Reflection

Both CRUMPET and the Genie successfully demonstrated the viability of the agent paradigm on mobile devices and how adaptivity might be realised on such devices. The agent platforms harnessed by both required significant modification

to the original frameworks. In the case of CRUMPET, it was necessary to optimize FIPA-OS for small devices. This involved avoiding the use of threads, minimizing garbage collection through the maximum reuse of existing objects, lazy instantiation, and use of scalar types instead of objects where possible and avoiding string concatenation. In the case of Agent Factory, the decision making infrastructure was optimised and syntactic modifications to the agent programming language were made. Not surprisingly, the embedded complexity had a negative effect on the responsiveness of both systems, a fact identified in subsequent user evaluations. However, the current generation of mobile devices are an order of magnitude more powerful and encompass optimised compilers and interpreters. These are key developments and enable the deployment of mobile applications that can incorporate intelligent agent functionality. These developments ensure mobile computing is now a viable platform for proper agent-based adaptive applications thus opening a new frontier for agent research. Indeed, the recent release of the Android platform, amongst others, is particularly timely in that it seamlessly encapsulates those features, for example GPS, that required significant integration effort to realise the original CRUMPET and Genie platforms.

Intriguingly, a further frontier is emerging, namely that of ubiquitous sensor networks. Wireless Sensor Networks (WSNs) represent platforms that are at least one order of magnitude less in term of computational resources. However, some of these platforms will support agent frameworks, for example Agilla [18]. One emerging example is Squawk [16] a VM for WSNs together with the Sun SPOT (Small Programmable Object Technology) mote [17]. How such WSN platforms will ultimately harness agent technologies remains to be seen.

8. Conclusion

The dynamic and rich context within which mobile and ubiquitous systems function demands system adaptivity. This paper advocates the use of Multi-Agent Systems as a key instrument in the delivery of such. Two exemplar systems, those of CRUMPET and Gulliver's Genie, have been harnessed to illustrate the use of such techniques and how collaborative intelligence can empower deci-

sions pertaining to adaptivity. Though the systems described focus on the tourism domain, the applicability of the approach may be easily adapted for other domains.

Acknowledgements

Gregory O'Hare and Michael O'Grady gratefully acknowledge the support of Science Foundation Ireland under Grant No. 07/CE/I1147.

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