INTENTIONAL MOBILE AGENTS IN UBIQUITOUS SYSTEMS

Milene Serrano and Carlos José Pereira de Lucena
Department of Informatics, Pontifical Catholic University of Rio de Janeiro (PUC-Rio)
Rua Marquês de São Vicente 225, Ed. Padre Leonel Franca 13˚ andar, Gávea, Rio de Janeiro - RJ, Brazil

Keywords: Ubiquitous computing, Mobility, Intentional multi-agent systems, Systematic development, Service omnipresence, Device heterogeneity, User satisfaction, Adaptability, Context-awareness.

Abstract: Being everywhere, going anywhere and accessing at any time. Ubiquitous computing is the paradigm of service omnipresence, device heterogeneity, calm technology application and user satisfaction. Therefore, the success of ubiquitous systems depends on the mobile computing nature. In this paper, we introduce the application of intentional mobile agents in the systematic development of ubiquitous systems. These agents are commonly used to perform specific activities in dedicated servers, such as the content adaptability based on the ubiquitous profiles information. It demands context-awareness, which can be improved by exploring critical interactions among mobility, smart-spaces and cognitive-based autonomous entities. Finally, we show how our proposal has been appropriately applied to a ubiquitous system from the e-commerce domain.

1 INTRODUCTION

Ubiquitous computing designs a world in which the heterogeneous devices are available throughout different physical environments and the users can enjoy network services whenever and wherever they want (e.g. home, office, store and school). However, the efforts to establish the connection with these devices, the integration of different physical environments, the content adaptability and the context-awareness to better attend the users must be effectively imperceptible to them. Thus, the ubiquitous systems pose some challenges that demand an adequate technological support to improve the software engineers' work in the systematic development of this kind of system. In this context, the success of ubiquitous systems depends on the mobile computing nature. Mobile computing is involved with the mobility issue by investigating and developing computational resources to attend it, improve it and manage it. Autonomous mobile entities can be useful in dealing with this field by migrating from one smart-space to another or from one server to another to perform specific activities (e.g. content adaptability) according to the ubiquitous context.

In order to contribute to the systematic development of ubiquitous systems, we suggest the application of intentional agents by exploring critical interactions among mobility, smart-spaces and these collaboration- and cognition-based autonomous entities as an intentional multi-agent-system.

Multi-agent systems (MAS) focus on the use of many intelligent agents that interact with each other in order to achieve specific goals. The interactions can be either collaborative or selfish. The agent-based approaches have generated lots of excitement in recent years, especially in complex contexts, as they have interesting properties – e.g. autonomy, flexibility, reactivity and proactivity – and they hold out promise to be the paradigm for conceptualizing, designing and implementing the next generation of software systems. Normally, multi-agent-systems are based on behavior or intentionality. According to our experimental research (Serrano et al. 2008) (Serrano et al. 2009) (Serrano and Lucena 2010a,) the intentionality abstraction improves the cognition capacity, the "like-me" recognition (Gordon 2005) and the goal formation (Dignum and Conte 1997) by dealing with the user's wills centered on her/his beliefs, desires and intentions – the BDI model (Pokahr et al. 2005) (Georgeff et al. 1998). Furthermore, intentional agents are capable of achieving explicit ascription of human mental states and modeling human practical reasoning.

Ubiquitous computing is the paradigm of service omnipresence, device heterogeneity, calm technology application and user satisfaction. In addition, the success of the ubiquitous systems depends on the mobile computing nature. Therefore,

Serrano M. and Pereira de Lucena C..
INTENTIONAL MOBILE AGENTS IN UBIQUITOUS SYSTEMS.
DOI: 10.5220/0003111201470156
In *Proceedings of the 3rd International Conference on Agents and Artificial Intelligence* (ICAART-2011), pages 147-156
ISBN: 978-989-8425-41-6

we combine intentional multi-agent systems with the mobility issue in ever-changing environments. Furthermore, we also provide a reuse-oriented building block that supports the systematic development of ubiquitous systems – independent of their cognitive domains – by applying intentional mobile agents. The support was developed as an API driven by specific protocols in order to improve the inter-operability and the communication among the agents. Finally, we show how our intentional-mobile-agent-based proposal has been appropriately applied to a ubiquitous system from the e-commerce domain and compare this support to related work.

The remainder of this paper is organized in sections. Section 2 discusses our proposal. Section 3 presents the application of our proposal to a ubiquitous system from the e-commerce domain as well as the evaluation process performed to verify and validate our proposal. Section 4 compares our proposal to related work. Finally, Section 5 concludes and presents future research.

2 OUR PROPOSAL

We conducted our experimental research – performed in the Software Engineering laboratories at the Pontifical Catholic University of Rio de Janeiro (PUC-Rio) and the University of Toronto (UofT) over the past three and a half years – by following a process (Figure 1), which is composed of the activities presented as follows:

- **Investigate (1):** it represents the investigation of the ubiquitous computing state-of-the-art to identify and define the main ubiquitous concerns as well as the investigation of traditional and emergent technologies to deal with these concerns.
- **Develop (2):** it represents the development of intentional-MAS-driven support as reuse-oriented building blocks to guide the systematic development of ubiquitous systems. Among other contributions, we offer building blocks to deal with the content adaptability (Serrano et al. 2008); the dynamic data storage, retrieving and update (Serrano and Lucena 2010b); the non-functional requirements elicitation, modeling, and operationalization (Serrano et al. 2010); the data sharing, manipulation and access based on the user's privacy policies and preferences, the device features, the network specifications and the contract information and supported by specific capabilities and ubiquitous profiles (Serrano and Lucena 2010b); and mobility by using intentional agents contemplated with a specific capability – the ability of migrating from one agent's platform container to another. In this last building block, the containers represent different smart-spaces, which can contain different servers/providers, services, contents, resources, devices and collaborative software agents.
- **Apply (3):** it represents the application of our building blocks support to the systematic development of ubiquitous systems in different cognitive domains.
- **Evaluate (4):** it represents the evaluation of our building blocks based on the results acquired by performing tests centered on the user's satisfaction and other ubiquitous issues.
- **Evolve (5):** it represents the evolution of the applied building blocks – generating their evolved versions – according to the evaluation's results.

The focus of this paper is on the description of the building block to deal with the mobility issue.

2.1 Mobility Building Block

The proposed building block approach is based on the JADEX framework (Braubach et al. 2004) and the JADE-LEAP platform (Caire 2003). The framework offers specific protocols and resources to develop BDI-model-driven mobile agents, which represent autonomous entities improved by the intentionality and the mobility properties. The platform provides two specific execution modes (split and standalone) to support the integration of heterogeneous devices (e.g. MIDP and Personal Java devices) in the agents' platform. In order to deal with MIDP devices, in which the memory and the processing capacities are limited, the split execution mode allows sharing resources with another powerful machine that is connected to the platform using the network (wire or wireless). The platform and its cognitive agents automatically control the sharing of resources, which means this is imperceptible to the users of limited hand-held devices. Moreover, in order to deal with powerful devices (e.g. Personal Java devices), which have capacity to run the platform's container, the standalone execution mode is required.

In our approach, following the JADEX resources, the migration feature, in which a platform's agent can migrate between hosts and the agent's state is persisted until there is a desire to restore it, is based on the Java's serialization mechanism. Thus, the serialization of the agents is supported at runtime, wherever and whenever it is necessary.

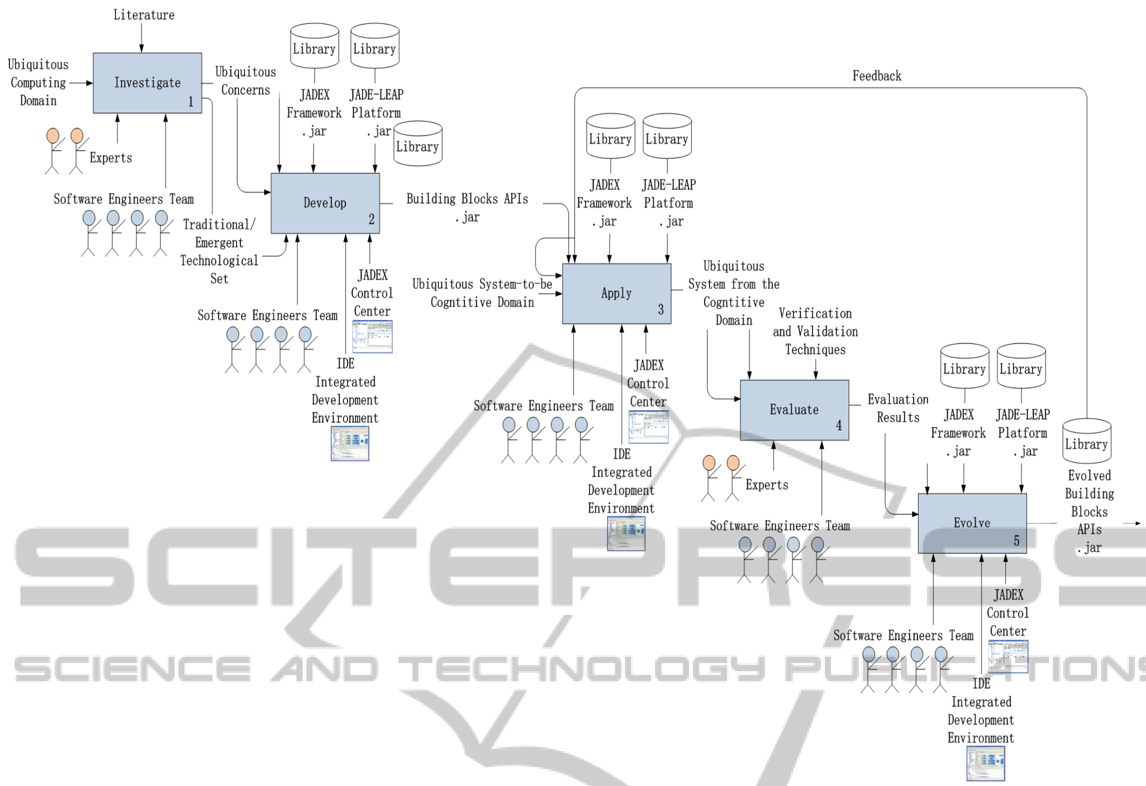

Figure 1: Research evolution process – SADT Notation (Marca and McGowan 1987).

Our main intention is to guide the software engineers in the systematic development of ubiquitous systems. Therefore, we developed a reuse-oriented support set to facilitate the implementation of intentional mobile agents. We use the concept of capability. Basically, a capability is the quality of being able to perform specific activities or services to achieve specific purposes. In this context, a mobile agent represents an agent with a special ability. It has the potential for moving from one smart-space to another and/or from one server to another, by maintaining its state. In our platform, each agent has at least one capability – called "root capability." The root capability is given by the beliefs, desires and intentions. In the JADEX, the beliefs represent the agent's notion about the real world; the desires represent the agent's goals, which are based on third parties' goals (e.g. user's goals and organization's goals); the intentions – called plans – represent sequences of tasks to achieve the goals. Beliefs, goals and plans are specified in the agent's XML file. To create additional capabilities for reuse purpose in different agents, we provide different definition files – one definition file for each created capability. The focus of this paper is on the mobility capability.

The intentional agent with the proposed mobility capability is used in our experimental ubiquitous environments to perform specific tasks in dedicated servers and to migrate from a smart-space to another by following the user's mobility. Figure 2 illustrates a typical intentional mobile agent way-of-working to deal with the content adaptability issue.

The adaptation necessity is determined based on the context, which involves the user's preferences and privacy policies, the features of the user's hand-held device, the network connection specifications and the contract rules established between the user and the service provider. There is an interface agent that runs inside the user's device. This agent is "light," based on behavior, to avoid problems with limited devices. The interface agent is responsible to intermediate the communication between the user and the agents' platform, in which the services and contents are offered. At the moment that the user requests a service or a content, the interface agent integrates the user's device into the platform. There are two ways to perform this integration. On one hand, if the device is limited, the integration is possible by sharing resources with a powerful machine – connected into the platform – to run the container using the split execution mode. On the other hand, if the device is powerful, the integration is possible by running the container using the standalone execution mode. When the device is integrated – it is normally instantaneous – the interface agent requests the creation of an intentional agent that represents the user in the domain, called domain personal agent. The creation depends on the AMS agent that represents an intentional agent with the capability of creating new agents into the platform. The interface agent delegates the user's goals to the domain personal agent. The latter agent tries to achieve the user's goals centered on the ubiquitous context using reasoning and learning techniques (e.g. fuzzy-logic-based techniques), ontologies and other technological resources.

Only to illustrate, we can consider that the user wants to access a video file using her/his device. Analyzing the context, the domain personal agent observes that the device has specific features (e.g. screen resolution and specific file formats for video visualization). Thus, this agent requests the adaptation of the content for the adaptation manager agent. There is one adaptation manager agent in each container. This agent requests the creation of a specific agent to execute the adaptation in a dedicated server. It avoids overloading the adaptation manager agent. Again, the creation depends on the AMS agent. As the requested agent must move from one server to another and/or from one container to another, it is created with a specific capability – the mobility capability. The created intentional mobile agent migrates to the dedicated server to perform specific tasks in collaboration with the agents that are specialized in the adaptability issue – in other words, agents that reason mainly centered on adaptability techniques. The content is adapted and the domain personal agent receives it. This agent sends the adapted content to the interface agent that performs the content visualization to the user using her/his device. Context awareness, adaptation techniques and ubiquitous profiles investigation are used to better satisfy the user's necessities. The entire process execution is imperceptible to the end user, by respecting the calm technology principle, in which Mark Weiser (Weiser and Brown 1995) argues that it is necessary to integrate the users in different smart-spaces, offer services anywhere at anytime without disturbing or even distracting her/him.

Furthermore, the infrastructure required to perform the presented process (e.g. the resources, the agents, the capabilities, the ontologies, the ubiquitous profile persistent model and the protocols) is provided by our mobility building block as an API. This API is a jar file that can be incorporated into the project of the ubiquitous system-to-be and extended to better attend its goals. The proposed reuse-oriented support is independent of the cognitive domain. The agents use the FIPA Coder and Decoder for SL Language (Bellifemine et al. 2007) based on specific ontologies (Serrano and Lucena 2010a). Thus, the offered infrastructure contemplated the systematic development of the ubiquitous system-to-be with a certain degree of commonality.

3 APPLICATION&EVALUATION

In order to evaluate our reuse-oriented building block approach, we applied it to the development of

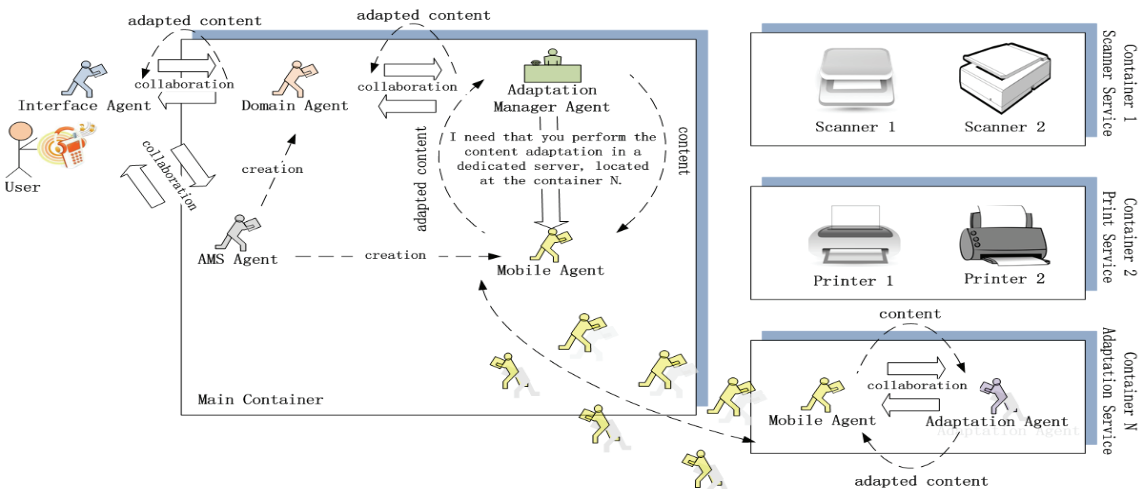

Figure 2: Intentional mobile agent way-of-working.

an intentional-MAS-driven ubiquitous system in the e-commerce domain. As follows, we describe the case study and present the reuse and the evaluation of our building block approach.

3.1 e-Commerce Case Study

The case study involves two Ph.D. students, heterogeneous devices, different clients and various service/content providers. The main goal is to offer services and contents anywhere at any time, by adapting them according to the context and using calm technologies. There are various challenges posed by this case study, such as: context awareness, content adaptability, distributed environments, specific ubiquitous profiles need, device heterogeneity, different levels of user satisfaction, process complexity invisibility, like-me recognition, data storage/retrieving/update at runtime and mobility. We applied different building blocks to deal with all these concerns. Moreover, the services and contents are distributed and can be offered by different servers. These servers can be located into the main container – the same container that runs the ubiquitous systems – or into a dedicated container. The communication among these containers is supported by intentional mobile agents and the network connection (wire or wireless). The main offered contents are media contents (e.g. music, video, text and image) and file contents (e.g. executable files, docs and presentations). The security, the media/file size and the price are some quality criteria used by the agents to evaluate the contents and choose the best one to attend the user's need. Most of the tasks involved in this ubiquitous scenario – e.g. content adaptability, agents' creation, context analysis, user-environment integration, content evaluation – are performed at runtime. Thus, we use intentional agents to cooperatively combine their capabilities in order to quickly and appropriately achieve a number of goals, which are imposed in this e-commerce case study. In terms of mobility, we solve the problem by instantiating our intentional-mobile-agents-based building block.

3.2 Our Approach for Reuse

We instantiated the offered APIs to facilitate and improve the systematic development of the e-commerce ubiquitous system. Thus, our e-commerce ubiquitous system was contemplated with specific capabilities, agents, ontologies, protocols and other support in different levels – e.g. interface, domain and persistence. Concentrating our efforts in the reuse of the building block for mobility issue, Figure 3 illustrates the application of intentional mobile agents to perform tasks related to the adaptability, the service omnipresence, the context awareness and the user-environment integration issues in ever-changing smart-spaces. First, we integrate the user's device to the agents' platform, more specifically to the main container, in which the e-commerce application is running. The integration is based on the split and the standalone executions modes - see Figure 3 (Part A). Connected to the platform, the interface agent interacts with other platform agents (e.g. AMS agent and domain agent) and also can access different services (e.g. yellow pages, white pages, download service and print service). Based on the user's request (e.g. video download and file print), the interface agent requests the creation of a specific agent to represent the user in the e-commerce domain. The latter agent's goals are: "video *must be* downloaded" and "file *must be* printed." Thus, it consults the appropriate knowledge base that contains the agent's beliefs and it also analyzes the ubiquitous profiles, which are stored in a dynamic database. The beliefs represent what the domain agent knows about the real world. The ubiquitous profiles contain the user's profile, the device profile, the network profile, the contract profile, the content profile, the service profile and the smart-space profile. The agent's knowledge base and the ubiquitous profiles combined with a fuzzy logic library, which is centered on the security, price and download time quality criteria, are some mechanisms used to provide context-aware services and contents to the final users in our e-commerce case. The domain agent uses these mechanisms to make decisions, personalize the requested service and/or the content and to better attend the user's goals at runtime. It is also important to say that these mechanisms have been developing based on the users' satisfaction quality criterion, by respecting, for example, the users' preferences and privacy policies. If it is necessary to adapt the content, the domain agent requests the adaptation to the adaptation manager agent. The manager delegates this goal to a specific agent – a mobile agent – which is created at runtime by using the white pages services (AMS). The mobile agent migrates to a dedicated server – adaptation dedicated server. It collaborates with the adaptation agent to achieve the delegated goal. At that moment, specific adaptation techniques are applied. In our case study, these techniques are categorized as:

- **adaptation based on resizing**, in which the content is adapted according to the device screen resolution;

- **adaptation based on transcoding**, in which the content is modified from one format to another;
- **adaptation based on reduction**, in which the content is adapted by using data compression;
- **adaptation based on replacement**, in which a sequence with still frames composes a slide show;
- **adaptation based on integration**, in which the content is adapted by using service composition. For example, a video can be obtained by combining different image frames with the corresponding audio.

The content is adapted and the mobile agent returns to the container in which the adaptation request was performed. The domain agent receives the adapted content – in the e-commerce domain, the adapted video – and sends it to the final user in her/his hand-held device.

In the print service use, the mobile agent's creation is requested by the domain agent and the AMS agent performs the request. A mobile agent was necessary when the desired service – e.g. print service - is offered in a server that is located in another container of the platform, different from the container from which the user requested the service. The mobile agent migrates to the service's container and cooperates with other agents placed in this container to achieve its goals – "file *must be* printed." In this case, as the final user must physically access the printed file, the service's container is determined based on the physical location of both containers – the user's container and the service's container – by using a GPS. If it is not possible to perform the service because of a physical limitation, the domain agent informs the user about the problem and offers some alternatives: **(i)** the user can move herself/himself to another smart-space – offered/suggested by the agent based on the user's location – that offers the service; and **(ii)** the user can abort the goal. The latter alternative is not recommended as it negatively contributes to the user's satisfaction. However, it can be the only possible alternative in critical situations. Every decision depends on the context, whose analysis is performed at runtime and adequately supported by context-aware and location-aware technological sets.

As the reuse-based process involves different

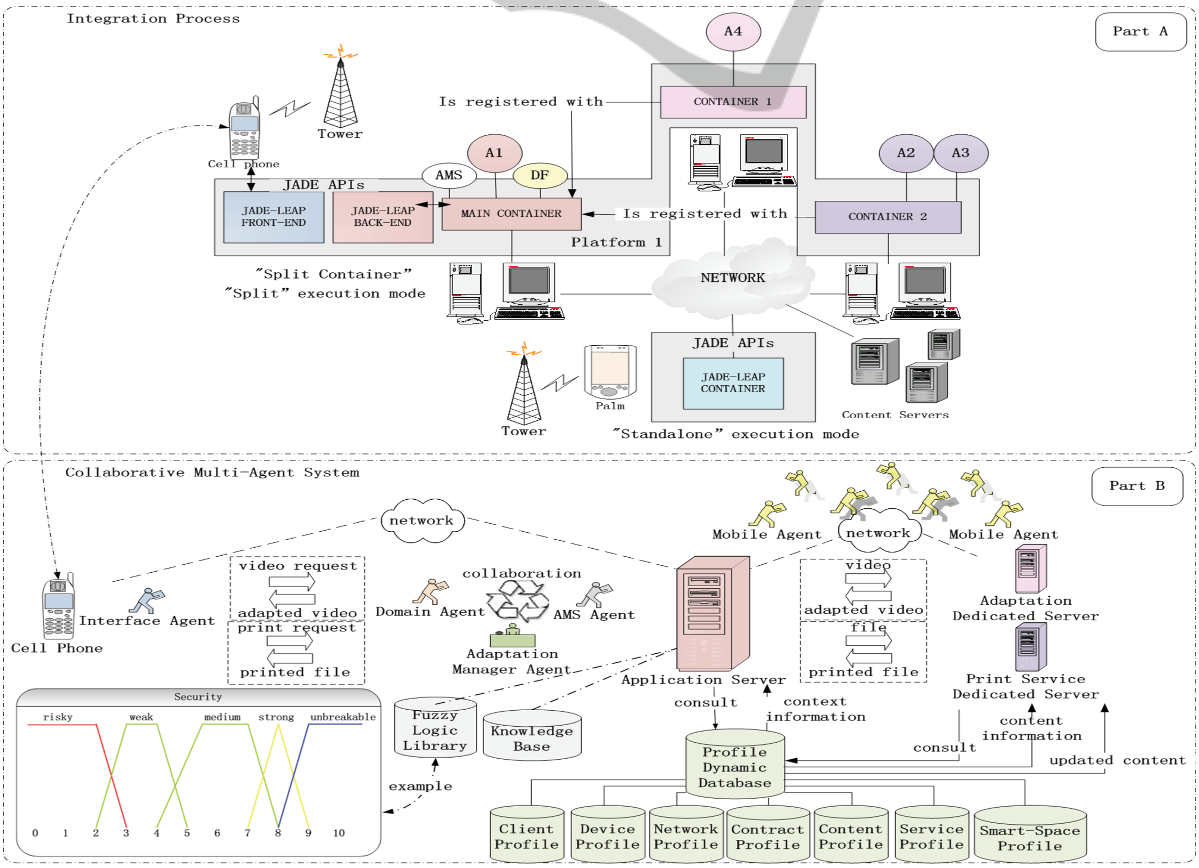

Figure 3: Intentional mobile agent – integration, adaptation and service omnipresence.

support sets to deal with specific ubiquitous concerns, Figure 3 (Part B) just shows part of this process. Other important details are presented as observations: **(i)** the agents' communication is based on specific protocols (e.g. FIPA Request Protocol (FIPA 2002a)), languages (e.g. FIPA-ACL (FIPA 2002b) and FIPA SL Content Language (FIPA 2002c)) and ontologies (Serrano and Lucena 2010a). The protocols, the languages and the ontologies define a set of allowed speech acts and their associated semantics, by improving the agents' inter-operability and facilitating the support's reuse; **(ii)** the data storage, retrieving and update are supported by our dynamic database infrastructure (Serrano and Lucena 2010b); **(iii)** the content adaptability is guided by our intentional-MAS-driven framework for content adaptation (Serrano et al. 2008); **(iv)** the agent deals with the human-mental states centered on the BDI model, reasoning techniques and learning techniques. In this context, we use a fuzzy logic library (Bigus and Bigus 2001,) which is instantiated to incorporate different quality criteria according to the cognitive domain of the ubiquitous-system-to-be; and **(v)** we use a unique identifier to represent each agent at the platform. Moreover, to avoid problems with the agent's identification and the desired service's analysis, all the agents and the services are registered into the yellow pages of the platform (or Directory Facilitator DF (Pokahr et al. 2005) (Braubach et al. 2004)) when they are created and they are deregistered at the end of their "life." The agent's identifier as well as its registration can be accessed – considering the determined privacy policies – by all containers connected to the platform. Thus, all the servers, providers, services, contents and devices mentioned in the e-commerce domain are connected to the platform and have a virtual location based on their container. It is important to emphasize that if it is necessary to obtain the real physical location, we also use different location-aware technological support, such as the GPS.

3.3 Evaluating our Approach

In order to evaluate the adequacy of the proposed support, we performed different tests, such as: agents' spent time to achieve the adaptability-related goals from the user's request to the solution; the AMS response time to create a new mobile agent at runtime; and the user's satisfaction in relation of the received services and contents, which were respectively performed and adapted by intentional agents (both mobile and not mobile). In order to facilitate the reader's evaluation, the tests were basically performed using heterogeneous devices – memory and processing capacities; three notebooks – each of them as the main machine of the container in which they were virtually located; several content servers and service providers – distributed in the network; and the network wireless connection. More details are presented in Table 1.

Table 1: Performed tests' conditions.

Main Devices	***Basic Specification***
Notebook 1	2.53GHz Intel® Core 2 Duo P9500 Processor 3GB of RAM 320GB Serial ATA Hard Drive Windows Vista Business
Notebook 2	1.83GHz Intel® Centrino™ Duo T2400 Processor 2GB of RAM 120GB Hard Drive Windows XP
Notebook 3	1.6GHz Intel® Centrino™ M Processor 730 1GB of RAM 100GB 4200 Hard Drive Windows XP
Network	***Basic Specification***
Skyline 1 Skyline 2 Skyline 3	Wireless Connectivity 54mbps of Speed
Heterogeneous Device	***Some Examples***
Mobile and Fixed Limited and Powerful Devices	Simple Cell-phone Smartphone Palm Notebook Desktop

Figure 4 illustrates the agents' spent time to adapt images from the user's request to the solution. For each test we considered one image adaptation. The original resolution of the images varies from 1024 x 768 to 266 x 335 pixels. Moreover, the most common adaptation techniques can be categorized as the combination of resizing to adapt the resolution with transcoding to change the media format. We performed various tests in this field by using a log agent to precisely determine the time. However, we are only considering the worst 12 results in order to facilitate the visualization. The spent time varies from 0.219 seconds to 0.297 seconds.

Figure 5 shows the AMS response time to create a new mobile agent at runtime. Again, we illustrated the 12 worst results to facilitate the visualization. The response time varies from 0.196 seconds to 0.232 seconds. It means that it is almost instantaneous with the creation process.

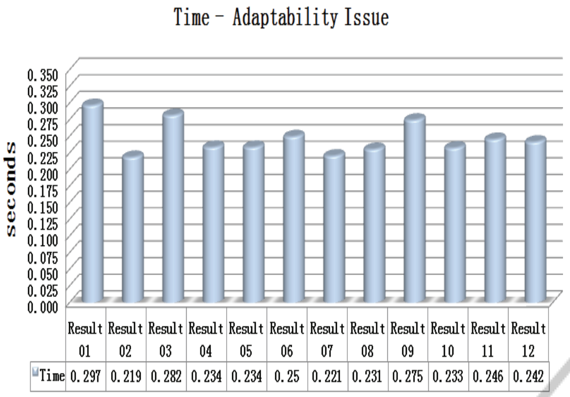

Figure 4: Adaptability issue evaluation.

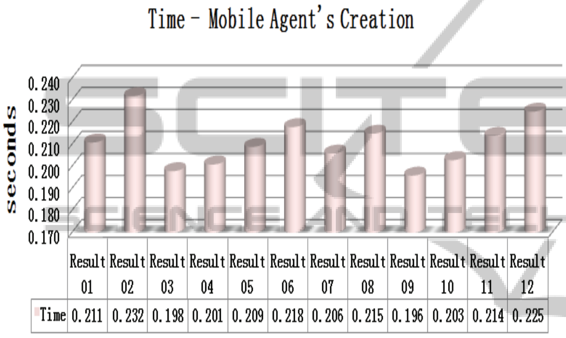

Figure 5: Mobile agent's creation evaluation.

Figure 6 presents the users' satisfaction. We used a scale that varies from excellent (minimum of 90% of satisfaction) to unacceptable (no satisfaction), in which we have five intermediary alternatives: very good (minimum of 80% of satisfaction), good (minimum of 70% of satisfaction), regular (minimum of 60% of satisfaction), poor (minimum of 40% of satisfaction) and very poor (minimum of 30% of satisfaction).

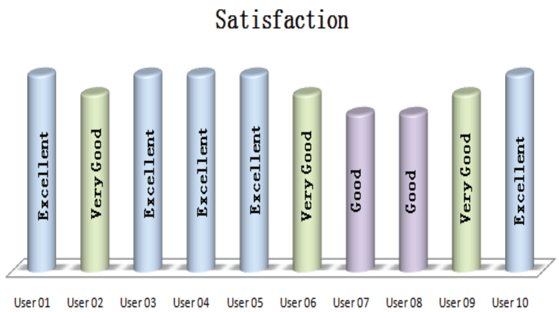

Figure 6: User's satisfaction issue evaluation.

We illustrated the 10 worst results to facilitate the visualization. The satisfaction varies from good to excellent. It helped us to conclude that we are on the right direction and that the proposed building blocks set represented a suitable support in the development of the e-commerce ubiquitous system mainly centered on the user's satisfaction issue.

4 RELATED WORK

There is interesting work that proposes support for the mobility issue in ubiquitous and pervasive contexts. Some of them are:

In (Senart et al.2006,) Senart et al. describe the application of context-based reasoning to support mobility in ubiquitous systems. They use sentient objects as mobile intelligent entities to extract, interpret and manipulate context information in order to drive their behavior in ad-hoc mobile networks. The sentient objects communication is supported by a middleware centered on the event abstraction. The authors applied their proposal to an application from the Intelligent Transportation System.

In (Satoh 2002,) Satoh presents a framework based on location-tracking systems to navigate mobile agents to stationary or mobile computers. Each mobile agent is a collection of Java objects and equipped with an identifier - called *TaggedAgents*. The author presents some practical applications (e.g. follow-me applications and a user-navigation system.) Moreover, he describes some important design principles, which are used to develop the proposed framework, such as: autonomy, scalability, extensibility and personalization.

In (Sousa and Garlan 2002,) Sousa and Garlan describe an architectural framework - AURA - that supports two important concerns in ubiquitous systems development: mobility and adaptation. First, it allows a user to preserve her/his work when moving among different environments. Second, it allows performing adaptations in a particular environment at runtime. Various elements compose the proposed framework, such as: task manager, service suppliers, context observer and environment manager.

The previous work and others found in the literature related to mobility and adaptation issues in ubiquitous computing do not use the intentionality abstraction to design and implement the autonomous entities that support the development of ubiquitous systems.

There are some advantages to developing intentional-agents (Gordon 2005) (Dignum and Conte 1997) (Bigus and Bigus 2001) (Yu 1997,) such as the BDI-based agents presented on our reuse-oriented building blocks for mobility and adaptability issue. Considering that the new goals' formation is a fundamental feature of autonomous entities, "*existing formal theories of agents are found essentially inadequate to account for the formation of new goals and intentions of the agent*" (Dignum and Conte 1997). In addition, the agent's cognition capacity and the rationale significantly increase using the distributed intentionality (Yu 1997) as a goal-orientation-centered approach. The agents based their decisions on reasoning and learning techniques (e.g. the BDI model and the JADEX agents' engine – Figure 7) and the user's satisfaction, being aware in relation to the ubiquitous context. In this scenario, the context awareness is centered on the agents' beliefs, desires and intentions as interpretation of the human-mental states. Moreover, some common problems are avoided by using BDI-based agents, for example: it is really simple to deal with the agents' adaptability according to different ever-changing environments, by dynamically updating the agents' knowledge bases, their beliefs, their goals' formation and their sequence of tasks to achieve the desired goals. In the proposed support set a fuzzy logic library improves the agents' reasoning engine (Figure 7). Furthermore, the intentionality abstraction is closer to the human-reasoning representation than the object and/or the behavior abstractions. Strengthening our argumentation, we can define the world "intention" as the state of one's mind at the time one carries out an action.

5 FINAL CONSIDERATIONS

Multiple devices with multiple features, from multiple vendors with heterogeneous technological capabilities, equipped with various communication technologies and distributed in different smart-spaces. This is the typical scenario in ubiquitous contexts, in which the mobility, the adaptability, the context-awareness, the integration need and other issues are essential. Moreover, not disturbing the users or even distracting them is desirable. Therefore, the use of calm technologies is appropriate. Contributing to this field, we propose different reuse-oriented building blocks to support the systematic development of ubiquitous systems. In this paper, we concentrate our efforts on the presentation of the building block to support the mobility issue in ubiquitous systems. We evaluate our approach by applying it to the development of an e-commerce ubiquitous system, by focusing on adaptability, mobility, context-awareness, integration, device heterogeneity and user satisfaction issues. Finally, we compare our intentional-agent-based proposal to existing approaches, centered on sentient objects and behavioral agents, by describing some advantages through working with intentionality: **(i)** agents with powerful cognition capacity to appropriately deal with the human-mental states; **(ii)** easy agents' adaptability according to the ever-changing context; and **(iii)** adequate reasoning engine based on the agents' beliefs, desires and intentions and a fuzzy logic library, in which the fuzzy sets and the fuzzy variables represent quality criteria (e.g. security, price and download time) used to better achieve the user's goals.

As future work, we intend to improve our reuse-oriented building blocks set by following the technological evolution. Recently, we have been in-

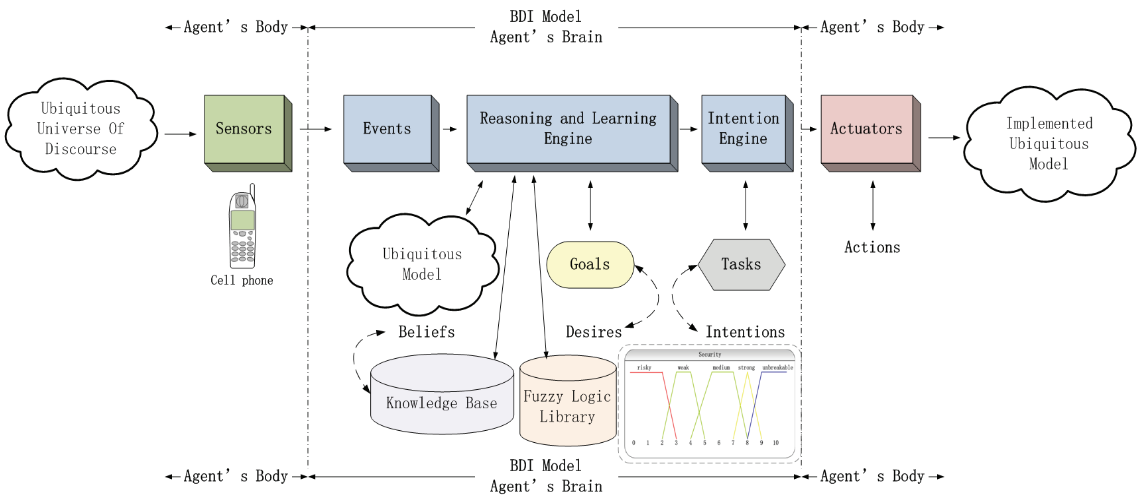

Figure 7: JADEX agents' engine improved by our approach.

vestigating other alternative solutions related to the agents' reasoning and learning support (Letier 2002) (Riedmiller and Merke 2002) (Wiewiora et al.2003). Our main goal in this field is a comparative study that shows the advantages and disadvantages of each alternative according to specific issues: human-practical reasoning, agent cognition capacity, goals formation support and human-mental states interpretation/representation.

REFERENCES

Bellifemine, F.; Caire, G.; Grenwood, D., 2007. *"Developing Multi-Agent Systems with JADE. Wiley Series in Agent Technology,"* John Wiley & Sons Ltd, ISBN-13: 978-0-470-05747-6, 286 pages.

Bigus, J. P.; Bigus, J., 2001. *"Constructing Intelligent Agents Using Java: Professional Developer's Guide,"* 2nd Edition. ISBN 10:047139601X, ISBN 13:9780471396017, John Wiley & Sons.

Braubach, L.; Pokahr, A.; Lamersdorf, W., 2004. *"Jadex: A Short Overview,"* In Net. ObjectDays'04: AgentExpo, pp. 195-207, September.

Caire, G., 2003. *"LEAP User Guide,"* TILAB, December.

Dignum, F.; Conte, R., 1997. *"Intentional Agents and Goal Formation,"* Proceedings of the 4th International Workshop on Intelligent Agents IV, ISBN:3-540-64162-9, Vol. 1365, pp. 231-243.

FIPA ORG. 2002a. *FIPA Request Interaction Protocol Specification*. Document no. SC00026H.

FIPA ORG. 2002b. *FIPA ACL Message Structure Specification*. Document no. SC00061G.

FIPA ORG. 2002c. *FIPA SL Content Language Specification*. Document no. SC00008I.

Georgeff, M.; Pell, B.; Pollack, M.; Tambe, M.; Wooldridge, M., 1998. *"The Belief-Desire-Intention Model of Agency,"* 5th International Workshop on Intelligent Agents: Agent Theories, Architectures, and Languages (ATAL98), ISBN:3-540-65713-4, Vol. 1555, pp. 1-10.

Gordon, R. M., 2005. *"Intentional Agents Like Myself. Perspectives on Imitation: From Mirror Neurons to Memes,"* Hurley & Chater, N., MIT Press, Chapter 15.

Letier, E., 2002. *"Reasoning about Agents in Goal-Oriented Requirements Engineering,"* Thesis Dissertation, UCL-FSA/INGI - Département d'ingénierie informatique.

Marca, D. A.; McGowan, C. L., 1987. *"SADT: structured analysis and design technique,"* McGraw-Hill, ISBN:0-07-040235-3, 392 pages, USA.

Pokahr, A.; Braubach, L.; Lamersdorf, W., 2005. *"Jadex: A BDI Reasoning Engine,"* Multiagent Systems, Artificial Societies, and Simulated Organizations, Vol. 15, pp. 149-174.

Riedmiller, M.; Merke, A., 2002. *"Using Machine Learning Techniques in Complex Multi-Agent Domains,"* Adaptivity and Learning, Springer.

Satoh, I., 2002. *"Physical mobility and logical mobility in ubiquitous computing environments,"* Lecture notes in computer science, International conference on mobile agents No. 6, Vol. 2535, pp. 186–201, Spain.

Senart, A.; Bouroche, M.; O'Connor, N.; Hughes, B.; Singh, K.; Cahill, V., 2006. *"Supporting Mobility using Context-Based Reasoning,"* System Support for Ubiquitous Computing Workshop, 7 pages, September.

Serrano, M.; Lucena, C. J. P. de, 2010a. *"Applying FIPA Standards Ontological Support Intentional-MAS-Oriented Ubiquitous System,"* 12th International Conference on Enterprise Information Systems (ICEIS'10), Vol. SAIC, pp. 114-121, Funchal, Madeira, Portugal, June.

Serrano, M.; Lucena, C. J. P. de, 2010b. *"Agent-Oriented Dynamic Database for Intentional Development of Ubiquitous Systems,"* PUC-Rio, Monograph on Computer Science, No. 07/10, ISSN 0103-9741, 24 pages, May.

Serrano, M.; Lucena, C. J. P. de; Mylopoulos, J.; Yu, E., 2010. *"Experiences with Model Reuse: Non-Functional Requirements Catalogues for Ubiquitous Systems,"* PUC-Rio, Monograph on Computer Science, No. 08/10, ISSN 0103-9741, 20 pages, May.

Serrano, Milene; Serrano, Maurício; Lucena, C. J. P. de, 2008. *"Framework for Content Adaptation in Ubiquitous Computing Centered on Agents Intentionality and Collaborative MAS,"* Fourth Workshop on Software Engineering for Agent-oriented Systems (SEAS'08/SBES'08), pp. 1-12.

Serrano, Milene; Serrano, Maurício; Lucena, C. J. P. de, 2009. *"Ubiquitous Software Development Driven by Agents' Intentionality,"* 11th International Conference on Enterprise Information Systems (ICEIS'09), Vol. SAIC, pp. 25-34, Milan, Italy, May.

Sousa, J. P.; Garlan, D., 2002. *"Aura: an Architectural Framework for User Mobility in Ubiquitous Computing Environments,"* 3rd Working IEEE Conference on Software Architecture, pp. 29-43, Montreal.

Weiser, M.; Brown, J. S., 1995. *"Designing Calm Technology,"* Xerox Parc, 6 pages, December.

Wiewiora, E.; Cottrell, G.; Elkan, C., 2003. *"Principled Methods for Advising Reinforcement Learning Agents,"* Twentieth International Conference on Machine Learning (ICML-2003), Washington, DC.

Yu, E., 1997. *"Towards Modelling and Reasoning Support for Early-Phase Requirements Engineering,"* 3rd International Symposium on RE, pp. 226-235, January.