Developing intelligent agents on the Android platform

Jorge Agüero, Miguel Rebollo, Carlos Carrascosa, Vicente Julián
Departamento de sistemas informáticos y computación
Universidad Politécnica de Valencia
Camino de Vera S/N 46022 Valencia (Spain)
{*jaguero, mrebollo, carrasco, vinglada*}*@dsic.upv.es*

Abstract

Nowadays, agents may run on different hardware platforms, which is a useful approach in Ubiquitous Computing in order to achieve intelligent agents embedded in the environment. This approach can be considered the vision of an Intelligent Ambient. In this paper, a new agent model "specially" designed for the recent *Android*[1] Google SDK is presented, where the *Android* mobile phone can be considered as a software agent. This agent model has an approach which is more practical than theoretical because it uses well-known abstractions which allow the proposed model to be implemented on different systems. The appearance of *Android* as an open system based on Linux has signalled new hope in the implementation of embedded agents. Finally, the proposed model abstractions used to design the *Android* agent have been employed to implement a simple example which shows the applicability of the proposal.

keywords: Agent architecture, agent model.

1 Introduction

Ubiquitous Computing or *Pervasive Computation* [12] is a paradigm in which the technology is virtually invisible to our environment, because it has been inserted into the ambient with the objective of improving people's quality of life, creating an *intelligent ambient* [7]. In *Pervasive Computation*, awareness is becoming common characteristic of our society with the appearance of electronic devices incorporated into all kinds of fixed or mobile objects (Embedded system), connected to each other via networks. It is a paradigm in which computing technology becomes virtually invisible as a result of computer artifacts being embedded in our everyday environment [8].

One approach to implement pervasive computing is to embed intelligent agents. An intelligent agent is a hardware or (more usually) software-based computer system which has the following properties: autonomy, social ability, reactivity and pro-activeness [13]. Embedded-computers containing these agents are normally referred to as *embedded-agents*[11]. Each embedded agent is an

---

[1] *Android* is trademark of Open Handset Alliance, of which Google is a member

autonomous entity, and it is common for such embedded-agents to have network connections allowing them to communicate and cooperate with other embedded agents, as part of a multi-embedded agent system.

The challenge, however, is how to manage and implement the intelligent mechanisms used for these embedded agents, bearing in mind the limited processing power and memory capacity of embedded computational hardware, the lack of tools for the development of embedded applications and the lack of standardisation. These challenges and other known problems [9], a remarkable difference between the conceptual agent model and the implemented, or expected, agent has been detected. For example, it is widely known that Java is a language which is frequently used in the development of agents, but the difference between Java for personal computers (J2SE) and Java embedded devices (J2ME), produces big changes in the implemented agents. This problem is often solved by adding new middleware layers, but the functionality of the agent is reduced on many platforms [7].

But now, with the arrival of the SDK *Android* made by Google as a platform for the development of embedded applications in mobile phones, a new approach for implementing embedded intelligent agents has been created. *Android* is an open source platform and the development of the applications is made with a new Java library (Java *Android* library), which is very similar to Java for personal computers (J2SE) [3]. Furthermore, the *Android* Linux Kernel could possibly be migrated to other platforms or electronic devices, allowing such agents to be executed in a wide variety of devices.

To sum up, the basic idea is to present an agent model that can be designed using components or abstractions that can be deployed on any programming platform, such as the *Android* SDK, which allows such an agent model to be implemented. This will demonstrate the feasibility of implementing embedded agents using these abstractions, reducing the gap between the design of embedded agents and their implementation. The rest of the document is structured as follows. Section 2 describes the proposed *agent model*. Section 3 briefly explains the main components of the *Android* Platform. Section 4 details agent implementation in *Android*. In section 5 a simple example demonstrating the viability of implementing the model in the *Android* SDK is shown. Finally, the conclusions of the present work are expounded in section 6.

2 Agent Meta-Model

The main problem to define a platform-independent agent model is to select the appropriated concepts that will be included in the model and that will be used to build the different features and classes of agents. At the moment, there is a large amount of agent models that provide a high-level description of their components and their functionalities, but they need to be changed and manually implemented when applied to specific agent platforms. To define the agent model presented in this paper, some of the most used and complete agent model proposals have been studied. The purpose of this study was to extract their common features and adapt them to the current proposal. In this way, TROPOS[5], GAIA[14], AUML[4], INGENIAS [10] and AML[6] have been considered. So, the proposed process allows to do the analysis and design of the system according to different well-known methodologies (corresponds to the CIM). Then, the obtained design will be transformed in terms of our proposed meta-model corresponds to the PIM. The main components and basic concepts employed in the meta-model are summarized in Table ??. Moreover, the relationships between these main components are shown in Figure 1. The main components and basic concepts employed in the meta-model are summarized in Table ??. This meta-model is called *agent-π* (agent-PI: agent Platform Independent).

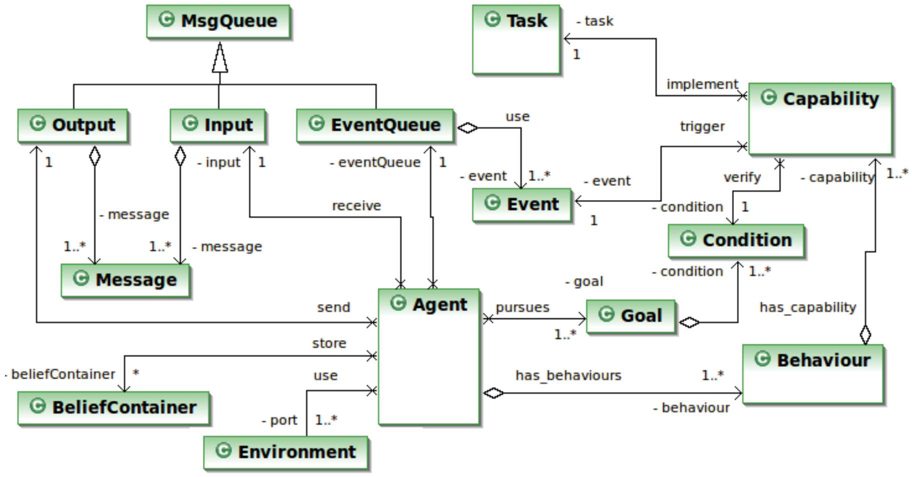


Figure 1: Summarized *agent-π* meta-model

The highest-level entity to be considered is the agent. At this level, organizations of a higher order, group rules or behaviour norms, are not taken into account in this work.

2.1 Agent

An *Agent* has an identifier and a public *name*. The *Environment* is represented by means of its relationship with the ambient or surroundings, allowing the definition of input and output ports for communicating with the outside. The agent's knowledge base is kept in its *Belief* set and its *Goal* set. The agent has two message queues, *Input* and *Output*, to communicate with the outside, and they temporally store incoming and outcoming messages respectively. Besides messages, the agent can be aware of event arrival, which is stored in *EventQueue*. Lastly, the agent has a *State*, related its life-cycle and its visibility to other agents.

With regards to the problem-solving methods, the agent has a set of core components. -The *Capabilities*- which represent the know-how of the agent and follow an event-condition-action scheme. To improve the efficiency of the agent, *Capabilities* are grouped into *Behaviours* that define the roles the agent can play. By doing so, any *Capability* related to the current situation can be kept active (ready), preventing the overloading of agent.

2.2 Behaviours

A set of *Behaviours* is defined in the agent to distinguish between different environments and attention focuses. Basically, *Behaviours* are used to reduce and delimit the knowledge the agent has to use to solve a problem. Therefore, those methods, data, events or messages that are not related to the current agent stage should not be considered. In this way, the agent's efficiency in the problem-solving process is improved. A *Behaviour* has a *Name* to identify itself. A *Goals* Set is also associated to it, which may be used either as activation or maintenance conditions (see Figure 2(a)). Lastly, a state indicating its current activation situation. More than one *Behaviour* may be active at the same time.

2.3 Capabilities

The tasks that the agent knows how to fulfill are modeled as *Capabilities*. *Capabilities* are stored inside Behaviours and they model the agent's answer to certain events. A *Capability* is characterised by a *Name* that identifies it, its trigger *Event*, an activation Condition and the Task that has to be executed when the event arrives and the indicated condition is fulfilled (see Figure 2(b)). The State of the *Capability* is also indicated. Only *Capabilities* belonging to current active *Behaviours* are executed.

An *event* is any notification received by the agent informing it that something that may be of interest has happened in the environment or inside the agent. This may have caused the activation of a new *Capability*.

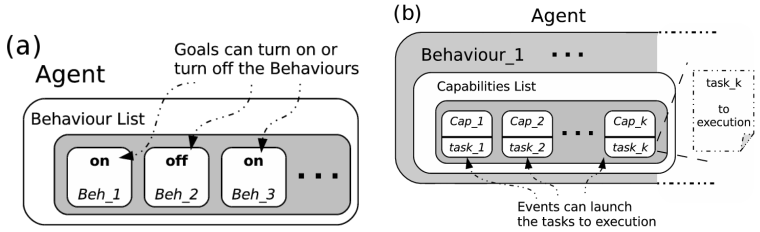


Figure 2: (a) *Behaviours* in *agent-*π, (b) *Capabilities* in *agent-*π.

All of the *Capabilities* of an active *Behaviour* will be in a state marked as Active. When an event arrives, the state of the *Capability* changes to Relevant and its activation condition is evaluated. If this condition is fulfilled, the state passes to Applyable and the associated Task begins its execution. When this Task ends, the *Capability* returns to Active again and it awaits the arrival of new events. When a *Behaviour* becomes inactive, all of its *Capabilities* stop their execution and change their state to inactive. It is assumed that all of the *Capabilities* of an active *Behaviour* can be concurrently executed, so that the system has to take the necessary steps to avoid deadlocks and inconsistencies during their execution.

2.4 Task

The last component of the agent model is the *Task*. *Tasks* are the elements containing the code associated to the agent's Capabilities. One *Task* in execution belongs to only one *Capability* and it will remain in execution until its completion or until the *Capability* is interrupted because the *Behaviour* it pertains to is deactivated. No recovery or resumption method for interrupted *Tasks* has been defined. On the other hand, the agent must have some kind of "Safe Stop" mechanism to prevent it from falling into inconsistent states.

3 *Android* Google: A new platform for mobile devices

Android is a software stack for mobile devices which includes an operating system, middleware and key applications. Developers can create applications for the platform using the *Android* SDK [3]. Applications are written using the Java programming language and run on Dalvik[2], a custom virtual machine designed for embedded use, which runs on top of a Linux kernel. The main components of the *Android* operating system are:

- **Applications:** *Android* will ship with a set of core applications including an email client, SMS program, calendar, maps, browser, contacts and more. All applications are written using the Java programming language. Every *Android* application runs on its own process, with its own instance of the Dalvik virtual machine. Dalvik has been written so that a device can run multiple VMs efficiently.

- **Application Framework:** Developers have full access to the same framework APIs used by the core applications. The application architecture is designed to simplify the reuse of components; any application can publish its capabilities and any other application may then make use of those capabilities (subject to security constraints enforced by the framework).

- **Libraries:** *Android* includes a set of libraries used by various components of the *Android* system. For example, some of the core libraries support the playback and recording of many popular audio and video formats, and also the core Web browser engine and SQLite for maintenance database.

- ***Android* Runtime:** *Android* includes a set of core libraries which provides most of the functionality for the Java programming language. *Android* Runtime provides abstract components for creating applications.

- **Linux Kernel:** *Android* relies on Linux version 2.6 for core system services such as security, memory management, process management, network stack and driver model. The kernel also acts as an abstraction layer between the hardware and the rest of the software stack.

There are four building blocks in an *Android* application: ***Activity***, ***Intent Receiver***, ***Service*** and ***Content Provider***. An application does not need to use all of them, but they can be combined in any order to create an application. Each application has a manifest file, called `AndroidManifest.xml`, which lists all of the components used in the application. This is an XML file where you declare the components of your application:

---

[2] *Android* Virtual Machine

- **Activity:** The most common of the four *Android* building blocks. An activity is usually a single process with an interface in an application. Each Activity is implemented as a single class that extends the Activity base class. The Activity displays a user interface, composed of Views, which responds to events.

- **Intent Receiver:** An event handler. It allows the reaction of the application to events (called Intents) to be defined. Examples of these are when the phone rings, when the data network is available or when it's midnight. Intent Receivers do not display a UI (User Interface), although they may use notifications to alert the user if something interesting has happened. The application does not have to be running for its Intent Receivers to be called; the system will start the application, if necessary, when an Intent Receiver is triggered.

- **Service:** A Service is a long-life code that runs without a UI. It is a process running in the background without interaction with the user for an indeterminate period of time. A good example of this is a media player application, whereby the music playback itself should not be handled by an activity because the user will expect the music to keep playing even after navigating to a new screen. In this case, a Service will remain running in the background to keep the music going.

- **Content Provider:** Applications can store their data in files, a database or any other mechanism. The Content Provider, however, is useful for sharing data with other *Android* applications. The Content Provider is a class that implements a standard set of methods in order to let other applications store and retrieve the type of data that is handled by that Content Provider.

4 The Andromeda Platform

Andromeda (ANDROid eMbeddED Agent platform)[1, 2] is an agent platform specifically oriented to embedded agents over the *Android*[3] operating system. The agents developed inside this platform are based on the *agent-*π meta-model. *Android* can be seen as a software system specifically designed for mobile devices which includes an operating system, a middleware and key applications. Developers can create applications for the platform using the Android SDK. Applications are written using the Java programming language and they run on Dalvik (the *Android* Virtual Machine), a custom virtual machine designed for embedded use, which runs on top of a Linux kernel.

The proposed Andromeda platform includes all the abstract concepts of the *agent-*π meta-model. The implementation was done using the main API components of *Android* (SDK 1.0). The correspondence between the *Android* components and the main *agent-*π abstract concepts are explained a below.

---

[3] Android System, http://code.google.com/android/

4.1 Agent

The *Agent class* is designed to handle the arrival of events. Therefore an agent has to consider the changes to its environment (this may be of interest to the agent) to determine its future actions activating and deactivating the appropriate *Behaviours* in response to any internal or external situation. In this way, Agent class is implemented as one *Android Service*.

To implement the agent-π model, some methods of Service class have to be overloaded. The `onCreate()` method allows agent variables to be initialised. Then the `onStart()` method is executed, enabling the agent components. The agent is executed until the user decides to stop its execution. At that moment, the user employs the `selfstop()` or `stopService()` method, allowing the effective termination of the agent execution. Every agent component is stopped and destroyed (Tasks, Capabilities and Behaviours).

The agent interface designed has several methods that allow the agent-π to be implemented, but there are two methods that it is important to mention: the `init()` method, where the user may write the code necessary to initialise the agent, and the `run()` method, which activates roles that the agent has to play (activate the *Behaviours*). The `init()` is executed within the Service's `onStart()`, which is called when the agent starts for first time. The Agent class can also launch a UI (User Interface), one Activity, to interact with users and to show its internal state and progress. The programming interface is shown in Figure 3.

```
public class Agent extends Service {
    private AID myAID;
    private Goals mygoals;
    private List<Behaviour> myListBehaviours;
    . . .
    public void init()
    private void run()
    public boolean changestate(Behaviour behaviour, boolean cond)
    public void addbehav(Behaviour myBehaviour)
    public void destroy()
    protected void agentDestroy()
    . . .
}
```

Figure 3: Agent interface of *agent-π*.

4.2 Behaviour

The Behaviour class works as a container of the Agent Capabilities and it can group as many Capabilities as the user desires. All of them can be activated and deactivated when events arrive. Behaviours are implemented by means of an IntentReceiver class from the *Android* APIs. This base class receives intents sent by events from the *Android* platform. An IntentReceiver has to be dynamically registered to treat intents, using the `registerReceiver()` method. The *IntentReceiver* will be running on the main agent thread. The Receiver will be called when an intent arrives which matches the intents filters, i.e. bind an intent to an object that is the receiver of the intent.

As the agent may play one or more roles at any moment, the *Behaviour class* can activate new roles to register the respective handler (of intents). For example, a role may be activated as a special Agent *Behaviour* when the phone battery is low. This can be done by an *IntentReceiver* that receives the intent LOW_BATTERY.

The *Behaviour* interface designed has several methods, but two main methods are provided to *add* and *remove* the *Capabilities*: `add(capability)` and `remove(capability)`. When the user has to create a new *Behaviour*, the constructor method must be called, which supplies the *Behaviour name* and its trigger *Event* as `Behaviour(Name, Event)`. To illustrate this, Figure 4 shows part of the programming interface implemented.

```
public class Behaviour extends IntentReceiver{
    private List<Capability> myListCapability;
     . . .
    public void add(Capability mCapability)
    public boolean remove(Capability mCapability)
    public void activate()
    public void deactivate()
     . . .
}
```

Figure 4: *Behaviour* interface of *agent-π*.

4.3 Capabilities

Capabilities are characterised by their trigger *Event*, an activation *Condition* and the *Task* that must be executed when an event arrives, and the indicated condition that is fulfilled. The *Capability* is implemented by means of an *IntentReceiver* class from the *Android* APIs. This base class receives intents sent from events in the *Android* platform, so that it is similar to *Behaviours*.

A *Capability* is always running an *IntentReceiver*. When an intent arrives and the condition is fulfilled, the code in `onReceiveIntent()` method is considered to be a foreground process and will be kept running by the system to manipulate the intent. It is at this moment that the *Task* is launched.

The *Capability* interface designed has one important method for matching a *Task* to its corresponding *Capability*: this is the `addTaskRun(task)` method. When the user has to create a new *Capability* the constructor method must be called, supplying the *Capability name* and its trigger *Event* as `Capability(Name, Event)`. In Figure 5 part of the programming interface is shown.

```
public class Capability extends IntentReceiver{
     private Condition condition;
     private Boolean state;
     . . .
     public void activate()
     public void deactivate()
     public void setCondition(Condition condition)
     public boolean addTaskRun(Task nametask)
     . . .
}
```

Figure 5: *Capability* interface of *agent-π*.

4.4 Tasks

Now, *Task* class is one special process to run as an *Android* Service. To implement the *Task*, some methods of *Service* class have to be overloaded. The `onCreate()` method allows *Task* variables to be initialised when it is launched. The `onStart()` method allows the user code to be executed, throughout a call to a `doing()` method that has to be overloaded by the programmer. Now, the main method of *Task* interface is `doing()`, where the user writes the Java program to be executed (see the interface in Figure 6).

```
public class Task extends Service implements Runnable {
    public MsgQueue outputQ
    . . .
    public void doing()
    public synchronized void pause()
    public synchronized void resume()
    public void taskDestroy()
    public final void send(Message msg)
    public final Message receive(MessageTemplate pattern)
    public final Message blkReceive(MessageTemplate pattern, long time)
    . . .
}
```

Figure 6: *Task* interface of *agent-π*.

Finally, the *intents* are used to model the **Goals** that activate the *Behaviours* and **Events** that allow the *Tasks* of a *Capability* to be executed. To manipulate and store the agent *Beliefs*, the *ContentProvider* is used as a database. The *Communication* between agents is implemented creating FIPA ACL messages.

Table 1 shows the *Android* blocks used for building components of the *agent-π* model and other necessary components. Thereby this model inserts a new layer in the *Android* system architecture[3]. This new layer, called *Agent interface*, modifies the architecture, as seen in Figure 7.

Table 1: The *Android* components used in the *agent-π* model.

agent-π Components	*Android* Components	Overloaded methods
Agent	Service	onCreate(), onStart(), onDestroy()
Behaviour	IntentReceiver	registerReceiver(), onReceiveIntent()
Capability	IntentReceiver	registerReceiver(), onReceiveIntent()
Task	Service	onStart(), onDestroy()
Events	Intents	IntentFilter()
Believes	Contentprovider	–
ACL Communications	http	–

5 Example

An example of two agents talking by means of a chat session is used to show the applicability of this proposal. So, a simplified Chat Session between two agents that send and receive ACL messages is proposed. This simple example is presented with academic goals, to explain and show how to use an agent interface designed in *Android* platform only. This example does not attempt to illustrate the interaction of a complex agent.

The implementation of the agent was done in an *Android* emulator, because currently there are no real phones where applications can run. The first step

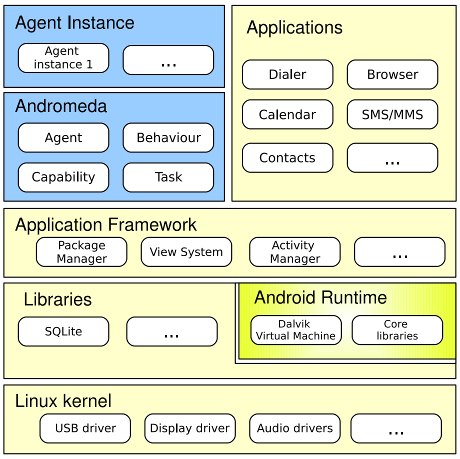
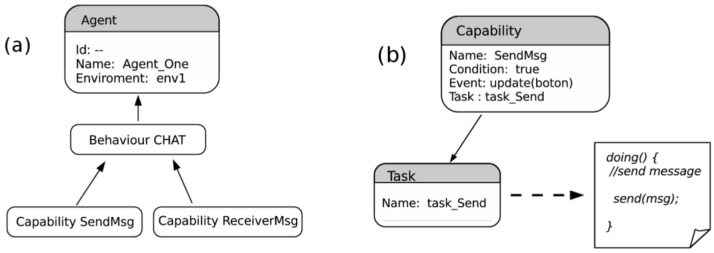


Figure 7: Agent interface in *Android* System Architecture.

of the design process is to identify the roles of the agents. As agents simply send and receive information from each other, we model the agent with only one *Behaviour*, which is called *CHAT*. A simple chat session has one *Capability* where users send information whenever they want and another *Capability* which awaits the arrival of a message. Therefore, two *Capabilities* are created: one to transmit a message and the other to receive it (see Figure 8(a)).

Each agent *Capability* has the mission of sending or receiving messages. It is necessary to remember that a *Capability* receives intents. When the intent arrives and the condition is fulfilled, the *Task* is launched. The *Capability* that sends messages is called *SendMsg*, and its *Task*, *task_Send*, transmits the information when users press the send button (see Figure 8(b)).



```
doing() {
 //send message

  send(msg);

}
```

Figure 8: (a) Agent Model for chat session, (b) *Capability* SendMsg.

The *Capability* that receives messages is called *ReceiveMsg* and its *Task*, *task_Receive*, waits for the arrival of other agent messages. So, agents are ready to begin the process of communication and the exchange of information in the Chat. Messages will be displayed on the phone screen. Now, to program the agent interface (for this preliminary implementation), proceed as explained below:

- Create one *Behaviour* with *name*= `CHAT`.

- Create one *Capability* for sending messages, with *name= SendMsg*, and the *condition* (intent), which wakes it up.
- Then add the *Task* (`task_Send`) that permits the ACL message to be sent.
- Create another *Capability* for receiving messages, with *name= ReceiveMsg*, and the *condition* (intent), which wakes it up.
- Then add the *Task* (`task_Receive`) that permits the ACL message to be received.
- Add these two *Capabilities* to the *Behaviour*.
- Add the *Behaviour*, using the `addbehav()` method. The agent is executed and the messages will be displayed on the emulator screen (see Figure 9).

Agent_One: Hello, I am Agent1
Agent_One: I am Android Agent?
Agent_Two: hi, I am Agent2
Agent_Two: me too, I am Android Agent :-)
Agent_One: Ok!
Agent_One: bye Agent2
Agent_Two: bye...

Figure 9: Chat in the emulator screen.

The program for implementing the agent which has been designed is shown in Figure 11 and to illustrate the Java code that the user writes in the Task, Figure 10 shows the program for sending Chat messages, the task: `task_Send`.

```
public class task_Send extends Task {
    public void doing() {
      . . .
        //create or get the id agent
        AID agentReceiver = new AID();
        agentReceiver.setName("AGENT TWO");
        agentReceiver.addAddresses("192.168.1.105");

        //Compose the ACL message to send another agent
        Message  msg = new Message(Message.INFORM);
        msg.setContent(content);
        msg.addReceiver(agentReceiver);
        send(msg);
}
```

Figure 10: *Task* for send Chat messages.

6 Conclusions

A general agent model for building intelligent agents on the *Android* platform has been presented. This model can be easily adapted to almost any platform

```
public class MyAgent extends Agent {
  public void init(){
    . . .
       //Create one Behaviour
       Behaviour myBehaviour= new Behaviour("CHAT");

       //Create two capabilities and its condition trigger
        Capability myCapabilityTX =  new Capability("SendMsg");
        Capability myCapabilityRX = new Capability("ReceiveMsg");

       //Condition and intent trigger of send
       Condition mycondSend = new Condition() {
          @Override
          public boolean expression(Intent intent) {
             if (intent.getAction() == "Android.intent.action.MY_SENDMSG") {
                return true;
              }else { return false; }
     . . .
        //Set the conditions different of null
        myCapabilityTX.setCondition(mycondSend);
        myCapabilityRX.setCondition(mycondReceive);

       //Create and add tasks that send and receive the chat messages
       Task myTaskTX =new task_send;
       myCapabilityTX.addTaskRun(myTaskTX);
       Task myTaskRX =new task_Receive;
       myCapabilityRX.addTaskRun(myTaskRX);

       //Add the Capabilities to the Behaviour
       myBehaviour.add(myCapabilityTX);
       myBehaviour.add(myCapabilityRX);

       //Add Behaviour the agent and execute it
       addbehav(myBehaviour);
}
```

Figure 11: *agent-π* Agents Chat.

or architecture hardware/software. Moreover, the agent model has been implemented and tested on the *Android* platform. The agent interface designed allows embedded agents to be implemented according the requirements of the user.

The use of the *Android* platform demonstrated the utility and probed the feasibility of designing a platform-independent agent. The use of the proposed model abstractions for *agent-π* agent reduces the gap between the theoretical model and its implementation.

The embedded agent design achieves the functionality required of it. Furthermore, the *Android* platform promises to be a new platform for implementing novel agent models. This is because Java API is very similar to the Personal Computer version, allowing an embedded agent-based approach to be implemented with even more advanced mechanisms. This is a useful feature in Pervasive Computing. Additionally, as *Android* platform is a Linux system, there is a high probability that the platform can be migrated to a range of different devices.

As future work, the services that this first version of the agent can deliver will be enriched and enhanced. The prototype has been developed using an emulator for *Android*. The evaluation of the performance of the agent architecture presented will be carried out when the first mobile phone using the *Android* system is launched.

While this article was being written a Jade[4] version for *Android* system was developed. Though the authors have not carried out an in-depth evaluation of Jade in the *Android* architecture, it must be stated that the agent model described in this paper presents a conceptually different to JADE model, because this model is wholly integrated with *Android's* building block and JADE is not.

7 Acknowledgment

This work was partially supported by CONSOLIDER-INGENIO 2010 under grant CSD2007-00022 and by the Spanish government and FEDER funds under TIN2006-14630-C0301 project.

References

[1] J. Agüero, M. Rebollo, C. Carrascosa, and V. Julián. Does Android Dream with Intelligent Agents? In *International Symposium on Distributed Computing and Artificial Intelligence 2008 (DCAI 2008)*, volume 50, ISBN: 978-3-540-85862-1, pages 194–204, Salamanca, Spain, 2008.

[2] J. Agüero, M. Rebollo, C. Carrascosa, and V. Julián. Towards on embedded agent model for Android mobiles. In *The Fifth Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (Mobiquitous 2008)*, volume CD Press, ISBN: 978-963-9799-21-9, pages 1–4, Dublin, Ireland, 2008.

[3] Android. The Android Software Development Kit (SDK), July 2009.

[4] B. Bauer. UML Class Diagrams Revisited in the Context of Agent-Based Systems. *Proceedings Agent-Oriented Software Engineering*, pages 101 – 118, 2002.

[5] J. Castro, M. Kolp, and J. Mylopoulos. A Requirements-Driven Development Methodology. *Conference on Advanced Information Systems Engineering*, pages 108 – 123, 2001.

[6] R. Cervenka and I. Trencansky. *The Agent Modeling Language – AML*, volume ISBN: 978-3-7643-8395-4. Whitestein Series in Software Agent Technologies and Autonomic Computing, 2007.

[7] D. J. Cook and S. K. Das. How smart are our environments? An updated look at the state of the art. *Pervasive Mob. Comput.*, 3(2):53–73, 2007.

[8] P. Davidsson and M. Boman. Distributed monitoring and control of office buildings by embedded agents. *Inf. Sci. Inf. Comput. Sci.*, 171(4):293–307, 2005.

[9] F. Doctor, H. Hagras, and V. Callaghan. A type-2 fuzzy embedded agent to realise ambient intelligence in ubiquitous computing environments. *Inf. Sci. Inf. Comput. Sci.*, 171(4):309–334, 2005.

---

[4] http://jade.tilab.com/

[10] J. Gomez Sanz. *Modelado de Sistemas Multi-Agente*. Phd thesis, Universidad Complutense de Madrid, Spain., 2002.

[11] H. Hagras, V. Callaghan, and M. Colley. Intelligent Embedded Agents. *Information Sciences*, 171(4):289 – 292, 05 2005.

[12] E. Schoitsch and A. Skavhaug. Special: Embedded Intelligence. In *ERCIM NEWS. European Research Consortium for Informatic and Mathematics*, number 67, October 2006.

[13] M. Wooldridge and N. R. Jennings. Agent theories, architectures, and languages: a survey. In *ECAI-94: Proceedings of the workshop on agent theories, architectures, and languages on Intelligent agents*, pages 1–39, New York, NY, USA, 1995. Springer-Verlag New York, Inc.

[14] F. Zambonelli, N. R. Jennings, and M. Wooldridge. Developing multiagent systems: The GAIA methodology. *ACM Trans. Softw. Eng. Methodol.*, 12(3):317–370, 2003.