Theory and Practice of Multi-Agent Systems Construction

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***Abstract.* This paper generalized the theoretical bases and example of experience of construction and developing of multi-agent systems. Standards of multi-agent systems are considered. Overview of systems with mobile agents is made. Characteristic of JADE agent platform is given; its architecture is represented. A practical example of multi-agent application construction is shown.**

***Keywords:* multi-agent system, mobile agent, artificial intelligence, Java Agent developing Framework**

I. Introduction

Investigations in the sphere of intellectual agents and multi-agent systems have a long history and nowadays became one of the intensive developing directions in artificial intelligence. However, interest for these investigations increased significantly in last ten years. Multi-agent systems are able to combine different elements of artificial intelligence, distributed information systems and computer networks. Multi-agent system is as a set of intelligent agents searching for data and procedures suitable for solving user's tasks and collaborating in the process of developing these solutions. Multi-agent systems include many different components with difficult architecture, variety of mathematical methods and software used, multiple variants of interaction between agents and variety of factors of the external environment in which agents operate.

The target of this research is to consider theoretical bases of multi-agent systems developing and to show practical example of multi-agent system realization by means of JADE platform.

II. Theoretical bases of multi-agent systems

According to the work [1], the term “intellectual agent” arose primarily due to the need of simplifying of interaction between user and software. Later, the concept of “autonomous agent” appear, which means that instead of interacting with the program by calling commands and directly manipulating, the user has an ability to jointly solve the process. With this approach, the user and the computer agent jointly influence the event management and problem solving, and jointly launch it. In this approach, when the computer agent interacts with the user in one environment, the term "personal assistant" [1, 2] is used, which nowadays replaced with the term “intellectual agent”. The term “agent” has the following generalized definition: “An agent is a system that exists in a certain environment and it is part this environment. The agent influences the environment when performing its own tasks and this environment affects agent. Thus, changes made by the agent in the environment are reflected in this agent in future” [3].

Agents may have a number of properties [4]:

- autonomy – the ability to carry out the task without the need for external intervention;
- reactivity – the ability to perceive a change in the environment and take response actions;
- focus – the ability to carry out the assigned tasks;
- stability – the ability to restore its state after abnormal termination;
- sociability – the ability to interact with other elements of the environment;
- adaptability – the ability to change its behaviour according to experience and current circumstances;
- mobility – the ability to move in the environment;
- flexibility – the ability to change the own behavior.

With accordance of abovementioned, multi-agent system (MAS) can be characterized as a set of individual agents acting together and therefore characterized by a sociability property. Working MAS must include additional components, in particular, search service. For mobile agents functioning, special software components (platforms) are installed on the hosts, which support runtime environment and

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interactive interface between agents and hardware. Mobile agents transfer between network hosts in the process of their execution, and interact with the hosts' resources and other agents. That needs solving additional problems in organization of mobile agent systems. Mobile agent system is a distributed application, which supports mobile agent work.

With some degree of conditionality, research in the field of multi-agent systems can be divided into these main areas: (1) theory of agents, in which formalisms and mathematical methods are used to describing agents and their properties; (2) methods of agents' cooperation (organization of cooperative behavior) in the process of joint task solving or at any other variants of interaction; (3) architecture of agents and multi-agent systems; (4) programming languages for agents creation; (5) methods, languages and tools of agents' communication; (6) methods and software for agents mobility support (agents migration over the network). Research related to the development of multi-agent applications and tools to support their development technology is of particular importance. Problems of authentication (authorization) of agents and their security are also urgent.

III. Standards of multi-agent systems

There are dozens of systems using mobile agents. For their compatibility, specifications and standards are worked out. There are two main standards nowadays, which were created by Object Management Group и Foundation for Intelligent Physical Agents.

A. *MASIF standard*

Object Management Group Association elaborated Mobile Agent System Interoperability Facilities (MASIF) [4]. The main attention paid to the standatization of the following problems of mobile agent technology:

- agent management (programmer has a role of system administrator and manages the different mobile agents by means of standard operations and methods – to create, to pause, to resume and to finish agent);
- agent identification (standardized syntax and semantics of agent names and agent systems allow agent systems and agents to identify each other, and allow clients to identify agents and agent systems);
- typification and targeting of agent platform (an agent cannot be transferred to another platform if the agent system type cannot support the agent; location syntax is standardized so agent systems can find each other).

According to MASIF standard [5], mobile agent system is divided on the regions (Fig. 1). The region joins platforms with common permissions. It also includes a registry containing information about platforms and agents located in this region. To be compatible with the MASIF standard, it must implement the MAFFinder interface. It defines how agents, locations, and platforms are created, deleted, and transferred.

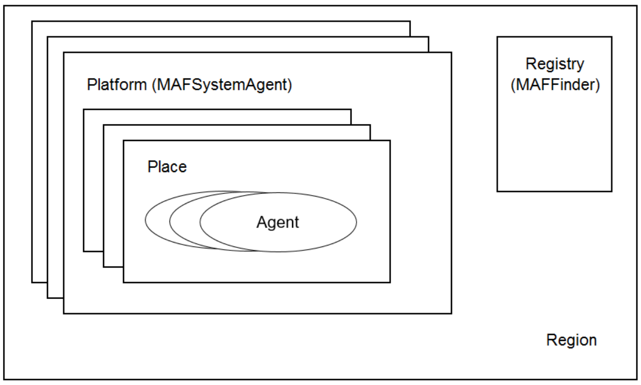

Fig. 1. Multi-agent system organization in according with MASIF standard

Platform (agent system) can create, interpret, start, transfer and delete mobile agents. To be compatible with the MASIF standard, it must implement MAFAgentSystem interface. It defines operations of receiving/transmitting, creating/deleting, interrupting/ resuming agents. The platform is identified by the name and address. The platform includes at least one location and a connection interface. The location provides the agent runtime environment on the computer. It can contain multiple agents at the same time. The connection interface implements a communication service, a name service, and a security service.

B. *FIPA standard*

Foundation for Intelligent Physical Agents (FIPA) – a non-profit organization established in 1996. Its main task is to develop specifications that determine the interaction of agents [6] and consider the following main topics:

- agent management (the architecture of agent platforms is unified, which include message routing and agent lifecycle management services);
- agent communication language (the syntax of a language, intended to interact between agents of different systems, is described);
- interaction with non-agent software (methods of interaction between agent and user as well as between agent and non-agent software are unified by means of shells including specified

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ontology and dynamic mechanism of registrations);

- agent security management (key security threats in agent management are defined and possible facilities of protection are described);
- mobile agent management (transmission and start operations of agent platform are unified which are need for mobile agent management);
- ontology service (service of support of correct understanding of requests, messages, terms in the subject area context is described);
- application areas (applications using agent technology are considered, for example – network assistant, audio- and videoconferences; by means of them developed specifications are tested).

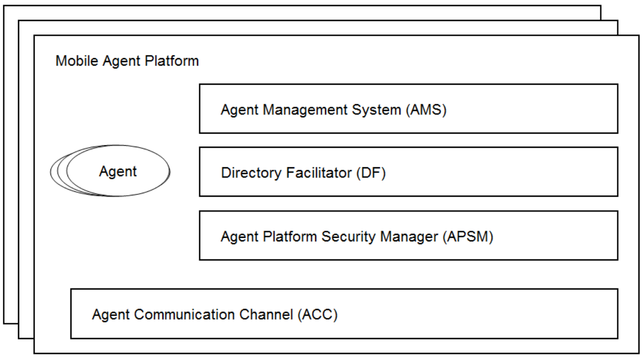
Mobile Agent Platform
Agent Management System (AMS)
Agent
Directory Facilitator (DF)
Agent Platform Security Manager (APSM)
Agent Communication Channel (ACC)

Fig. 2. Multi-agent system organization in according with FIPA standard

According to FIPA specifications, mobile agent systems consist of platforms with following components (Fig. 2):

- Agent Management System (AMS) manages the creation, removal, deactivation, restart, authentication, and migration of agents on the platform; it supports “white pages” service that stores the current location of mobile agents;
- Directory Facilitator (DF) realizes “yellow pages” service which stores agents description;
- Agent Platform Security Manager (APSM) is responsible for implementing the security policy at the transport level and verifying the execution of agent management operations;
- Agent Communication Channel (ACC) uses information from agent management system for routing messages between agents.

IV. Systems of mobile agents

There are several dozens of mobile agent systems. Some of them (Gypsy, JADE, Ajanta, JATLite, etc.) were elaborated in the universities with the purpose of research of this technology. Other systems (such as ASDK, JAFMAS, etc.) exist on the library level, providing the programmer with only basic classes for implementing the main components: agents, platforms, interaction mechanisms and security. Independent systems are developed on the base of them, for examples MagNet and E-Commercia. Recently commercial systems appear, such as Gossip by Tryllian company, Bee-gent and Plangent by Toshiba company. Unfortunately, the technical documentation is not available for them. Some of the projects on mobile agent technology investigation (ARA by Kaiserslautern University, Mole by Stuttgart University, Odyssey by General Magic company, etc.) are closed nowadays. There are number of mobile agent systems for solving narrowly specialized tasks (for example, Voyager System by ObjectSpace company).

V. Agent platform Java Agent Development Framework

Java Agent DEvelopment Framework (JADE) is one of the most popular agent platform. JADE project is developing by Telecom Italia Lab from 2000 year. JADE agent platform is typical middleware – software with a set of tools for creation and management of the multi-agent systems. JADE includes dynamic environment where JADE agents can live, class library which programmers can use for their own agent creation, and a set of graphical tools allowing to manage started agent activity.

JADE platform is distributed and includes a set of containers. Container is a dynamic runtime environment for multi-agent applications in which agents exists. Each container can contain multiply agents. A set of active containers is called a platform. One of the containers is always the main one, all other containers are connected to it and registered at the time of start-up. Therefore, the first container at the launch of the platform should be the main one, and all other containers should be non-main containers and should know in advance how to find the main container on which they will be registered, that is, they should have data about the host and port. Another main container running anywhere in the network is another platform on which new regular containers can register. Fig. 1 illustrates this concept based on an example showing two JADE platforms consisting of three and one container, respectively.

JADE agents are defined with unique names. Provided that they know the names of other agents, they can communicate, regardless of their actual location: in a common container (agents A2 and A3), in different containers on the same platform (agents A1 and A2), or in general on different platforms (A4 and A5). The user

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does not have to know how the dynamic JADE environment works, but he needs to run it before starting to execute his agents.

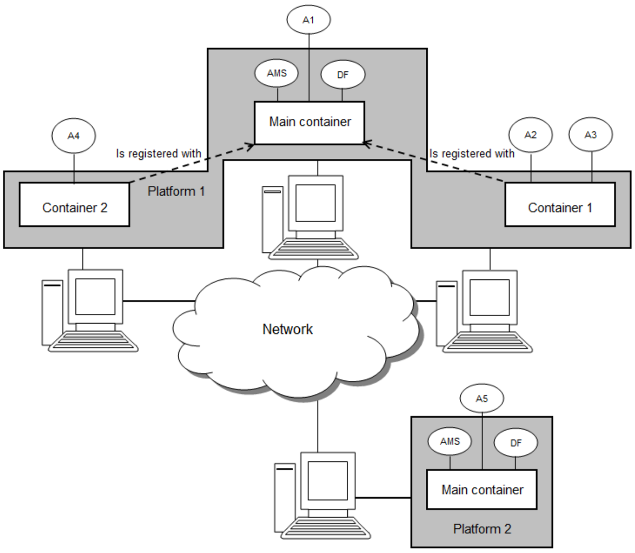


Fig. 3. JADE agent platform

In addition to the possibility of receiving registrations from other containers, the main container differs from the usual container in that it contains two special agents, which are launched automatically simultaneously with the container: AMS and DF.

JADE provides the programmer with following main facilities: (1) FIPA-compliant agent platform, including AMS and DF components which automatically activate when platform start; (2) distributed agent platform where agents are executed as Java-flows, live in containers, and only one Java-application and Java Virtual Machine can be run on each host; (3) multi-threaded execution environment with two-level scheduling; (4) object-oriented programming environment; (5) library of ready-to-use interaction protocols; (6) graphical user interface for management of several agents and containers from remote host; etc.

VI. PRACTICAL EXAMPLE OF MULTI-AGENT APPLICATION

Let us consider the example of trading multi-agent system which realized in JADE environment. The application include 4 agents:

- TraderAgent will search EmployerAgent with the best proposal in the yellow pages list and try to negotiate a deal with him;
- EmployerAgent tries to negotiate a deal with TraderAgents which interested in him and then conducts negotiations with MajorBuyerAgent, which give it the best proposal;
- MajorBuyerAgent firstly searches the best proposal from EmployerAgent, then searches interested BuyerAgent for the better deal with EmployerAgent, and at the end give it final proposal;
- BuyerAgent looks for the most profitable proposal among MajorBuyerAgents, then waits for negotiations between the MajorBuyerAgent to which it signed up and TraderAgent.

Fig. 4 illustrates an example of JADE agent platform running.

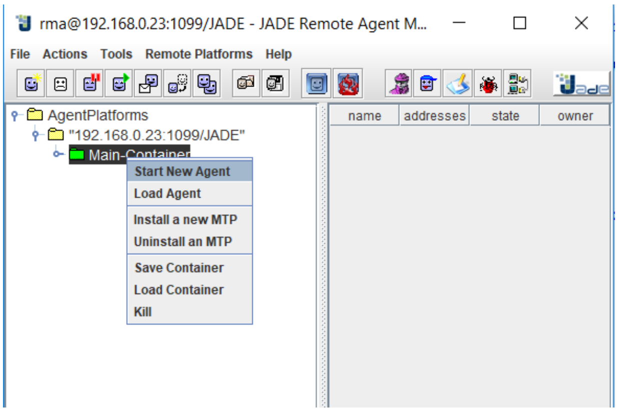
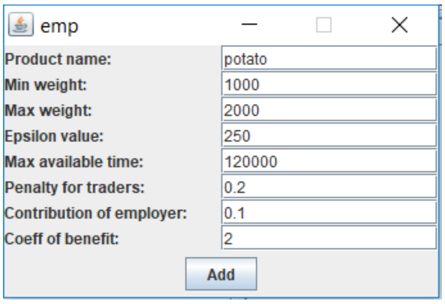


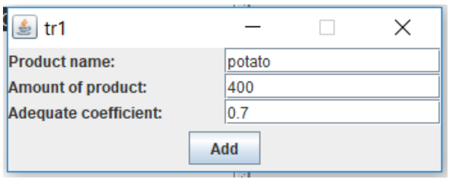
Fig. 4. JADE agent platform running

Fig. 5-9 illustrates the processes of creation of all actors of the trading platform.



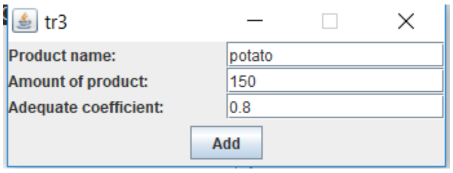
Product name:	potato
Min weight:	1000
Max weight:	2000
Epsilon value:	250
Max available time:	120000
Penalty for traders:	0.2
Contribution of employer:	0.1
Coeff of benefit:	2

Fig. 5. Creation of EmployerAgent



Product name:	potato
Amount of product:	400
Adequate coefficient:	0.7

Fig. 6. Creation of TraderAgent1-2



Product name:	potato
Amount of product:	150
Adequate coefficient:	0.8

Fig. 7. Creation of TraderAgent3

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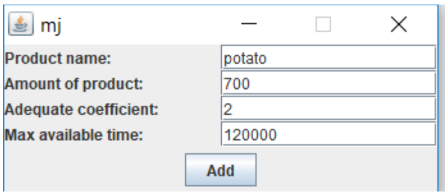
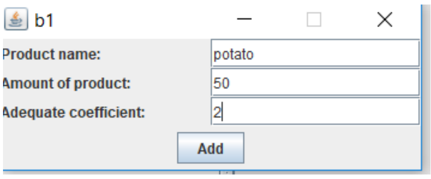


Product name: potato
Amount of product: 700
Adequate coefficient: 2
Max available time: 120000

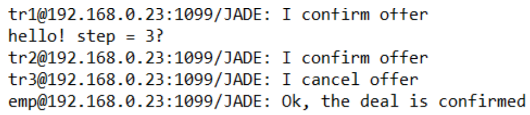
Fig. 8. Creation of MajorBuyerAgent



Product name: potato
Amount of product: 50
Adequate coefficient: 2

Fig. 9. Creation of BuyerAgent

Protocol of EmployerAgent and TraderAgent communication at the first stage of the deal is following (Fig. 10).

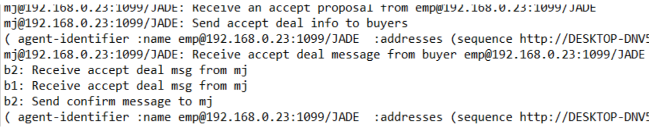


```
tr1@192.168.0.23:1099/JADE: I confirm offer
hello! step = 3?
tr2@192.168.0.23:1099/JADE: I confirm offer
tr3@192.168.0.23:1099/JADE: I cancel offer
emp@192.168.0.23:1099/JADE: Ok, the deal is confirmed
```

Fig. 10. Protocol of MAS working at the first stage of the deal

TraderAgents 1-3 have less product amount in sum than minimum established by EmployerAgent. In this case EmployerAgent raises additionally a penalty for a shortage from TraderAgents. As can be seen from the protocol, that satisfied two agents, but didn't satisfy third agent, since in this case third agent lost an unacceptable amount of profit for itself.

Fig. 11 contains listing of the MAS work protocol at the 2nd stage (communication between MajorBuyerAgent, BuyerAgent and EmployerAgent).



```
mj@192.168.0.23:1099/JADE: Receive an accept proposal from emp@192.168.0.23:1099/JADE
mj@192.168.0.23:1099/JADE: Send accept deal info to buyers
( agent-identifier :name emp@192.168.0.23:1099/JADE  :addresses (sequence http://DESKTOP-DNV5
mj@192.168.0.23:1099/JADE: Receive accept deal message from buyer emp@192.168.0.23:1099/JADE
b2: Receive accept deal msg from mj
b1: Receive accept deal msg from mj
b2: Send confirm message to mj
( agent-identifier :name emp@192.168.0.23:1099/JADE  :addresses (sequence http://DESKTOP-DNV5
```

Fig. 11. Protocol of MAS working at the second stage of the deal

MajorBuyerAgent and BuyerAgent1-2 were able to gain the product amount in the order exactly as much as EmployerAgent had. Therefore, the transaction was successfully completed.

VII. CONCLUSION

Analysis of the existing software and own experience of multi-agent system developing [7–9] shows, that using of intellectual agents allows simplifying such procedures as information search and processing in Internet, using of media-services, different business tasks of big data processing and other tasks related with information search, recognition and processing. The process of MAS design and developing is well standardized. The main standards in this area is MASIF and FIPA. The most popular agent platform for MAS developing and functioning is JADE. As a practical result of the research conducted the trading multi-agent system has been elaborated, taking into account the preferences of all actors in the process, flexibility, sustainability and consistency of their interactions.

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