



# Evaluation of Agent Platforms

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Rafał Leszczyna



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European Commission  
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**Contact information**

Address: Rafal Leszczyna TP 210; Via Enrico Fermi 2749; 21027 Ispra (VA); ITALY  
E-mail: rafal.leszczyna@jrc.it  
Tel.: +39 0332 786715  
Fax: +39 0332 789576

<http://ipsc.jrc.ec.europa.eu/>  
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## 1. Introduction

Agent platform is a technological architecture providing the environment in which agents can actively exist and operate to achieve their goals. The agent platform may additionally support the development of agents and agent based applications [Leszczyna, 2006].

This report is an extended and updated version of the technical report *Evaluation of Agent Platforms* [Leszczyna, 2004], written in 2004, which summarised the results of our evaluation of agent platforms aiming at choosing the agent platform for the FP6/IST *Personalised Information Platform for Health and Life Services* project [PIPS FP6/IST eHealth Integrated Project No. 507019, ] and for the practical studies on security of agent systems.

That report has been never formally published and existed only in the 'internal' (inside of the European Commission Joint Research Centre, Cybersecurity sector, of the Institute for the Protection and Security of the Citizen) form, but despite that it has received significantly high attention among the researchers and developers interested in software agents (indicated by numerous quotations in scientific and technical publications).

Due to this interest we decided to prepare a new, updated version of that report and to publish it officially by European Commission's publication office.

The study held four years ago pointed to JADE as the most appropriate platform for our applications as it was standards compliant, open source, popular, available and maintained, supported by a community and more. The platform was chosen between nine FIPA compliant agent platforms after studying alternative platform evaluations extended with our own assessments against proposed criteria. Now, after the four years of experience with JADE, we can confirm that it was the right choice.

Currently we use JADE as the agent middleware for *MAISim - Mobile Agent Malware Simulator* - a mobile agent framework for simulating *malware* – malicious software that run on a computer and make the system behaving in a way wanted by an attacker [Skoudis and Zeltser, 2003]. The development of MAISim resulted from the lack of software and methodology for simulation of malware, while malware attacks are the most frequent in the Internet and they pose a serious threat against critical networked infrastructures.

Our Action: *Security of Critical Networked Infrastructures (SCNI)* aims at facilitating the description, assessment and governance from the security point of view of critical networked infrastructures<sup>1</sup>, including information systems, communication networks, electricity and other energy networks and water networks. The main interest is in cross-border and European-wide issues.

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<sup>1</sup> Critical Infrastructures are defined as organisations or facilities of key importance to public interest whose failure or impairment could result in detrimental supply shortages, substantial disturbance to public order or similar dramatic impact [Federal Office for Information Security (BSI), 2003]. Today most of critical infrastructures depend highly on the underlying communication networks.

The action concentrates on the cybersecurity and topological aspects of infrastructures and their interdependencies, and studies their vulnerabilities (at the technological and system levels), the potential malicious threats that might affect them, the related detrimental attacks, and the countermeasures that can be put in place for securing those systems. It also studies the conditions and potential means for making decisions on security matters, estimating the impact of these decision, and facilitating the interaction among the stakeholders.

The focus is on providing policy makers and the stakeholders of critical infrastructures with information and instruments for a better understanding of the risks, for the qualitative and quantitative evaluation of the security issues, for the determination of the security condition of systems. From the technical perspective, the action studies the security of industrial control systems (e.g. SCADA, protection and defence systems, monitoring systems), of communication infrastructures (e.g. Internet protocols and WAN), and their application in concrete industrial environments (e.g. electric power).

One of our studies concentrates on developing a systematic approach for the identification and assessment of security risk threats to information systems. The approach is based on the systematic planning, performance and description of experiments with simulations of attacks affecting control and supervision systems. We analyse the network of a critical infrastructure and on the basis of our observations we reconstruct it in our laboratory. In this configuration we implement attack scenarios. Then analyse results in order to evaluate impact of the attack, test robustness and identify countermeasures. The description, preparation, execution and results of the experiments will constitute the information source for trust cases i.e. documented bodies of evidence that provide demonstrable and valid arguments that a critical infrastructure is adequately safe and secure.

This report is organised as follows. In the next section we provide a short overview of agent related concepts and the terminology, and in particular the definition of an agent platform. In Section 3 we begin to describe the evaluation, stating the first criterion (a precondition) to be satisfied by the platform. The subsequent criteria were defined based on the outcome of the study of the alternative literature. The study and the results are presented in Section 4. Then, in Section 5, we present the tables in which we compile the results of the evaluation against the defined criteria. Finally, in Section 6 we draw our conclusions.

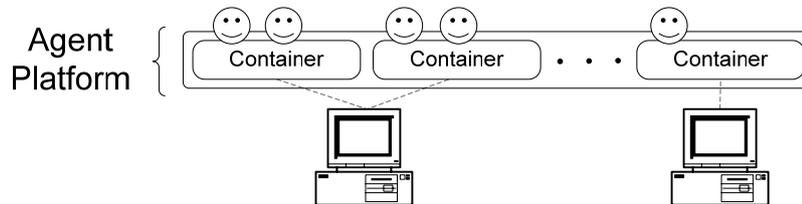
## **2. Mobile Agents and Agent Platforms – an Overview**

*Mobile agents* are the *software agents* able to roam network freely, to spontaneously relocate themselves from one device to another.

Software agents are software components that are [Bellifemine et al., 2003]:

- *Autonomous* – able to exercise control over their own actions.

- *Proactive* (or *goal-oriented* or *purposeful*) – goal oriented and able to accomplish goals without prompting from a user, and reacting to changes in an environment.
- *Social* (or *socially able* or *communicative*) – able to communicate both with humans and other agents.



**Figure 1 Software agents operate on agent platforms. Agent platforms are deployed horizontally over various hardware devices (PCs, PDAs etc) through containers.**

Software agents operate on *agent platforms*. *Agent platform* is an execution environment for agents. It supplies the agents with various functionalities such as agent intercommunication, agent autonomy, yellow pages, mobility etc.

Agent platforms are deployed horizontally over multiple hardware devices (such as PCs, PDAs, cellular phones etc) through *containers*. Each container is an instance of a virtual machine and it forms a virtual agent network node. On each device *at least* one container may be set up (but there may be much more, like hundreds of them). Containers make agent platform independent from the underlying operating systems. Mobile agents are able to migrate from one container to another. Consequently, when containers are deployed on different devices, mobile agents can migrate between different devices.

Agent platforms can be imagined as agent communities where agents are managed and are given the means to interact (communicate and exchange services). Many agent communities may coexist at the same time. Depending on the implementation of the platform, agents may be able to leave one community (platform) and join another<sup>2</sup>.

### 3. Standards Compliancy

We wanted the platform to be standards compliant.

Standards, as *established documents that provide rules and guidelines for activities or their results, aimed at the achievement of the optimum degree of order in a given context* [ISO/IEC, 2008] bring the premise that the

<sup>2</sup> Further information on software agents an interested reader can find in [Chess et al., 1994, Chess et al., 1995, Franklin and Graesser, 1996, Carzaniga et al., 1997, Fuggetta et al., 1998, Milojevic, 1999, Yee, 1997, Gray et al., 2000, Jansen and Karygiannis, 2000].

conforming solutions will possess desirable characteristics such as quality, reliability, efficiency and interchangeability - and at an economical cost [ISO, 2008]. That they will implement the specified functions and that it will be done in a proper, expected way.

When relating a standardised solution to one which is implemented in an arbitrary manner there is higher probability that the former will receive wider acceptance among the users and that it will be used more widely. This characteristic is essential especially in the case of a new technology, when one must decide which product to use, while there is still a strong uncertainty and lack of recognition of mature and proven tools. *This is just the case of software agents and agent platforms.*

Thus the primary criterion for selecting the most adequate agent platform was the compliancy to agent standards.

The two organizations provide standards for agent technology: Foundation for Intelligent Physical Agents (FIPA) [Foundation for Intelligent Physical Agents (FIPA), ] and Object Management Group (OMG) [Object Management Group (OMG), ]. Other agents related standardization processes exist [DARPA, 2006, University of Maryland Baltimore County, 2000] but they focus on separate methodologies and solutions (such as communication languages and development of semantic web) which can be applied into various domains, and of which the software agents can take advantage.

FIPA, with James Odell, a person very active in the field of software agents since the birth of the agents paradigm, author of numerous books and papers (see <http://www.jamesodell.com/publications.html>), as the acting chair, is now a part of IEEE Computer Society standards committees. FIPA aims at promoting agent-based technology and the interoperability of its standards with other technologies. Since its foundation in 1996 has promoted a number of initiatives and events that contributed to the development and uptake of agent technology. In 2002, FIPA completed a process of standardising a sub-set of all its specifications. The sub-set is composed of 25 specifications that made it to standardisation stage. FIPA specifications represent a collection of standards which are intended to promote the interoperation of heterogeneous agents and the services that they can represent. The specifications describe different aspects of agent technology:

- Agent communication.
- Agent management.
- Agent message transport.
- Agent abstract architecture.
- Agent applications.

OMG in the document titled "Multi Agent Facility" (MAF) [Object Management Group (OMG), 2000] also specifies agent management and the elements which in FIPA approach constitute abstract architecture: agent and agent system names, agent system types, location syntax. In these overlaying

areas the OMG approach is slightly less abstract and suggests use of Common Object Request Broker Architecture (CORBA) [Object Management Group (OMG), 2004]. The OMG effort is also more a bottom-up activity while FIPA is more top-down. Until release of the FIPA 2000 specification, the main difference between specifications was that MAF addressed the mobility aspect of agent while FIPA didn't. This situation changed with already mentioned FIPA 2000 specification which dealt with agents' mobility and tried to integrate FIPA and MAF. The specification was later assigned the state of deprecated but it doesn't change the fact that both specifications cover the agent mobility to quite the same level since work on MAF finished with the latest release in 2000 and has never been continued<sup>3</sup>.

Taking all these facts into consideration we decided to choose between platforms conforming to FIPA specifications. A supplementary MAF compliancy we perceive as added value.

At <http://www.fipa.org/resources/livesystems.html>, FIPA enlists the platforms compliant with FIPA specifications:

- Agent Development Kit [Tryllian, ]
- April Agent Platform [Network Agents Research Group, ]
- Comtec Agent Platform, FIPA-OS [Emorphia, ]
- Grasshopper [IKV++ GmbH, ]
- JACK Intelligent Agents [Agent Oriented Software Group, ]
- JADE [Telecom Italia Lab, ]
- Java Agent Services API [JCP, ]
- LEAP (now subcomponent of JADE)
- ZEUS [ISR Agent Research, ]

The platforms are shortly described and links to host internet sites are given.

#### **4. Towards the Definition of Further Criteria: Relative Work**

The next step was to define the additional criteria which would allow us to elect one of the ten FIPA compliant platforms. For this purpose we studied other agent platform evaluations, performed by alternative groups of researchers and developers.

The evaluation approaches presented there differ in complexity and comprehensiveness. For example [Chatzipapadopoulos (Editor) and Perdikeas (Editor), 1998] proposes very comprehensive criteria consisting of

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<sup>3</sup> For the day of 7<sup>th</sup> August, 2008, the division of OMG - OMG Agent Platform Special Interest Group performs the standardisation tasks in the field of software agents (see <http://agent.omg.org>).

numerous standalone requirements, interworking requirements and special requirements. Unfortunately the study was performed in 1998, still before the agent technology reached some stability. Also from our perspective, the study was of lesser usefulness, as among the evaluated platforms only one (Grasshopper) was FIPA compliant.

Pierre-Michel Ricordel and Yves Demazeau [Ricordel and Demazeau, 2000] on the other hand propose different approach which relates to four stages of software engineering: analysis, design, development and deployment and generally relies on assessing how an agent platform supports each of the stages. Finally authors discuss the strengths and weaknesses of four compared platforms: AgentBuilder, JACK, MadKit and ZEUS.

Publications [Bross et al., 2000] and [Burbeck et al., 2004] share multiple common criteria: standards' compatibility, security protection, communication and agent mobility (*strong* – ability of system to migrate code and execution state of executing unit – or *weak* - migration of code only). Moreover [Bross et al., 2000] takes under consideration agent life cycle and product-related criteria while [Burbeck et al., 2004] assesses availability, usability and documentations and development issues (practical applications/development projects) of agent platforms. The latter evaluation is especially handful, as it focuses mostly on FIPA compliant platforms and assesses all of platforms being in the interest of this paper. After the study the authors recommended subsequently: Grasshopper, JADE and Aglets (the last is not FIPA compatible). Another interesting study is presented in [Nguyen et al., 2002] where authors evaluate three agent platforms JADE, Tryllian and SAP (the first two are on FIPA's list) against diverse performance criteria.

A study which comprises the qualitative part followed by experimental evaluations, was performed by Raquel Trillo et al. [Trillo et al., 2007]. According to the criteria (focused on performance of agent mobility and distributed communication) stated by the authors SPRINGS (<http://sid.cps.unizar.es/SPRINGS/>) agent platform seems to be the best option. However again the result is of lesser usefulness, as the platform is not FIPA compliant and it is weakly recognised among agent developers and researchers.

The situation in the domain of agent technology changes very quickly in the sense that it is quite possible that platforms described one year ago can already be no longer maintained or even unavailable. This is because the technology is relatively novel and mostly in research phase. The greater number of platforms was released by academic environments or companies' laboratories for research purposes.

Being aware of this fact we formulated the following questions to be answered for each evaluated platform:

- Is the platform still maintained?
- Is the platform's authors' research group still active?
- Is the platform being developed?
- Is the platform popular? Is it in broad use?

- Is the platform easy accessible?
- What is the date of the latest release of platform?
- Does a light-weighted release of the platform exist?
- How is the platform available?

These questions finally helped us in choosing *the one* platform.

The tables presented in the next section illustrate the results of evaluation.

## 5. Platform Currentness and Popularity

**Table 1.** Is the platform still maintained?

Agent Development Kit	Yes
April Agent Platform	No, since October 2002
Comtec Agent Platform	No longer accessible
FIPA-OS	No, since October 2001
Grasshopper	No, since November 2003; No longer accessible via URL given on FIPA homepage
JACK Intelligent Agents	Yes
JADE	Yes
JAS (Java Agent Services API)	No, since May 2002
ZEUS	No, since January 2006

**Table 2.** Is the platform's authors' research group still active?

Agent Development Kit	Yes. Tryllian is commercial company which creates adaptive enterprises through the Distributed Business Process Integration Suite. By using Java technology & services Tryllian facilitates complex organizations and business communities to increase their enterprise agility.
April Agent Platform	No evidence, since last platform release in October 2002
Comtec Agent Platform	Rather not – nor platform or any information accessible

FIPA-OS		No current evidence. In 2003 Emorphia focused on assistance for administrative tasks that involve people-to-people collaboration, specifically the negotiation and coordination of meetings.
Grasshopper		No current evidence. The latest accounted activity is dated on October 2003. IKV++ is a company providing business customers with consultancy, information technologies and customized solutions for the provision of communication and information services.
JACK Agents	Intelligent	Yes. The (AOS) is the developer and supplier of software products for building and deploying agent-oriented applications.
JADE		Yes. The JADE-Board is a not-for-profit organization with the mission of promoting the evolution and the adoption of JADE by the mobile telecommunications industry as a java-based de-facto standard middleware for agent-based applications in the mobile personal communication sector. Currently the JADE Board lists 5 members: Telecom Italia, Motorola, Whitestein Technologies AG, Profactor GmbH, and France Telecom R&D.
JAS		Probably. On Java Community Process homepage it is written that work on JAS is in progress however the latest document was issued 20 Mar 2002.
ZEUS		No evidence, since last platform release in January 2006

**Table 3.** Is the platform being developed?

Agent Development Kit		Yes
April Agent Platform		No recent information evidencing any development activities since last version of platform was released in October 2002
Comtec Platform	Agent	Rather not – nor platform or any information accessible
FIPA-OS		No recent information evidencing any development activities since last version of platform was released is available.
Grasshopper		No recent information evidencing any development activities since last version of platform was released is available.

JACK Agents	Intelligent	Yes
JADE		Yes, very actively
JAS		No JAS implementation of the FIPA abstract platform available
ZEUS		No recent information evidencing any development activities since last version of platform was released is available.

**Table 4.** Is the platform popular? Is it in broad use?

Agent Development Kit		Tryllian doesn't provide any estimates of the numbers of users, but the platform gained wider popularity after it had become open source
April Agent Platform		No information provided
Comtec Agent Platform	Agent	Rather not – nor platform or any information accessible
FIPA-OS		About 50 000 downloads
Grasshopper		No information provided
JACK Agents	Intelligent	AOS Group inform about their partners rather than users. JACK has established a worldwide customer base, with sales handled from AOS in the US, UK and Australia. JACK product support is available worldwide
JADE		The platform is very popular (40 000 downloads already in 2002)
JAS		No JAS implementation of the FIPA abstract platform available
ZEUS		No information provided

**Table 5.** Is the platform easy accessible?

Agent Development Kit	Yes, from ADK homepage. For more information about purchasing the ADK 3.0 for commercial use or educational purposes it is necessary to complete and send the Information & Evaluation Request Form and our ADK. <a href="http://www.tryllian.com/technology/product1.html">http://www.tryllian.com/technology/product1.html</a>
April Agent Platform	Yes, from SourceForge <a href="http://sourceforge.net/projects/networkagent/">http://sourceforge.net/projects/networkagent/</a>
Comtec Agent Platform	No, it is not accessible

FIPA-OS	Yes, from SourceForge <a href="http://sourceforge.net/projects/fipa-os/">http://sourceforge.net/projects/fipa-os/</a>
Grasshopper	No, it is not accessible
JACK Intelligent Agents	Yes, from JACK homepage.
JADE	Yes, from JADE homepage. It is compulsory to fill in the registration form and become a user. <a href="http://jade.tilab.com/">http://jade.tilab.com/</a>
JAS	No.
ZEUS	Yes, from ZEUS homepage <a href="http://sourceforge.net/projects/zeusagent/">http://sourceforge.net/projects/zeusagent/</a>

**Table 6.** What is the version and the date of release of the latest release of platform?

Agent Development Kit	3.2.0; date not available
April Agent Platform	4.4.3; October 17, 2002
Comtec Agent Platform	Platform not accessible
FIPA-OS	2.2.0; March 18, 2003
Grasshopper	2.2.4, date not available
JACK Intelligent Agents	4.1, date not available
JADE	3.6; May 5, 2008
JAS	Platform not released
ZEUS	2.0 patch 2; January 10, 2006

**Table 7.** Does a light-weighted release of the platform exist?

Agent Development Kit	No
April Agent Platform	No
Comtec Agent Platform	No
FIPA-OS	MicroFIPA-OS
Grasshopper	No
JACK Intelligent Agents	iPAQ JACK Runtime
JADE	LEAP
JAS	No
ZEUS	No

**Table 8.** How is the platform available?

Agent Development Kit		Dual-licensed under the LGPL and under a proprietary license
April Agent Platform		Open Source; GNU General Public License
Comtec Platform	Agent	Not available
FIPA-OS		Open Source; Public Domain
Grasshopper		Free of charge for non commercial use
JACK Agents	Intelligent	It is necessary to complete registration form; Evaluation version of JACK is for free; Commercial version is for fee. Academic version is discounted
JADE		Open Source; GNU General Public License; It is compulsory to fill in the registration form and become a user
JAS		This API is not available.
ZEUS		Open Source; Mozilla Public License

## 6. Conclusions

As you can see in Tables 1-8, restricting the criteria only to the platforms which were continuously maintained limited our choice to ADK, JACK and JADE. Then, further on, when we wanted the platform to be also well supported (documentation, mailing list, platform updates) and free, only one framework remained on the field: *JADE*. *JADE* is licensed under Lesser General Public License (LGPL), meaning that users can use both binaries and code of the platform without any restrictions. It is widely used (the fact evidenced by a high number of downloads, the activeness of the mailing lists, the number of references in publications and documented case studies). A light-weighted release of *JADE* is available – the *JADE* Lightweight Extensible Agent Platform (LEAP). *JADE* is continuously developed, improved and maintained by the developers from the Telecom Italia Lab (Tilab), where it was originated, and by contributing *JADE* community members. *JADE* is also conveniently accessible. The developers and users can download the current version of *JADE* and additionally the recent snapshots with the latest improvements of the environment [Telecom Italia Lab, ]. Moreover, *JADE* supports the development of ontologies used to represent agents' knowledge. The ontologies can be designed using Protégé [Stanford Medical Informatics, ] and then converted into *JADE* compatible Java classes using JadeJessProtege (plugin for Protégé [Caire, 2002]). In February, 2007 a comprehensive book on *JADE* was published: *Developing Multi-Agent Systems with JADE* [Bellifemine et al., 2007], which guides the *JADE* users through the arcane of programming with *JADE*.

Since the time we had chosen *JADE* for the first time we had many occasions to test the platform at work.

JADE was the technical platform which served us during our studies on anonymity of software agents [Leszczyna and Górski, 2005, Leszczyna and Górski, 2006a, Leszczyna and Górski, 2006b, Leszczyna, 2006, Leszczyna, 2007], after which we proposed two untraceability protocols and other solutions to support anonymity [Leszczyna, 2006] and could offer a new add-on for JADE to JADE community of users and developers [Leszczyna, 2005b]. These solutions we applied to the E-Health domain where users' privacy plays a very important role [Leszczyna, 2005a].

For the last two years we have been applying JADE for the experiments with simulations of computer attacks against critical infrastructures. The experiments are performed with *MAISim - Mobile Agent Malware Simulator*, deployed over JADE. MAISim allows simulation of diverse malicious software and (thanks to the platform-independency characteristic to the agent technology, and strongly supported by JADE) can be deployed over the network of an arbitrary information system [Leszczyna et al., 2008a, Leszczyna et al., 2008b, Leszczyna et al., 2008c, Leszczyna et al., 2008d].

All these experiences proved that JADE was the right choice for the agent platform.

As already mentioned earlier, the information in the IT domain tends to become obsolete very soon. It can be seen just by the example of this report, as it is a second, updated version of a document written four years ago. For this reason we would like to encourage the gentle readers to leave us their feedback<sup>4</sup> whenever they see that the information provided in this report doesn't anymore respond to the actual state. Based on the feedback we would like to release subsequent versions of the report.

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<sup>4</sup> Please contact – Rafal Leszczyna – [rafal.leszczyna@jrc.it](mailto:rafal.leszczyna@jrc.it) or [rafal.leszczyna@eti.pg.gda.pl](mailto:rafal.leszczyna@eti.pg.gda.pl)

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**Abstract**

This report is an extended and updated version of the technical report Evaluation of Agent Platforms, which summarised the results of our evaluation of agent platforms aiming at choosing the agent platform for the FP6/IST Personalised Information Platform for Health and Life Services project. Agent platform is a technological architecture providing the environment in which agents can actively exist and operate to achieve their goals. The evaluation indicates JADE as the most appropriate platform for our applications as it is standards compliant, open source, popular, available and maintained, supported by a community and more. The platform was chosen between nine FIPA compliant agent platforms after studying alternative platform evaluations extended with our own assessments against proposed criteria.

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