DESIGN OF A DECISION SUPPORT SYSTEM IN CARDIOLOGY

Lenka Lhotská

Czech Technical University in Prague/Gerstner Laboratory, Technická 2, Prague, Czech Republic

lhotska@fel.cvut.cz

Abstract: This paper discusses the possibility of utilizing a multiagent system as a platform for development of an intelligent system for medical diagnostics and monitoring. A knowledge-based model of the agents' mutual awareness (social knowledge) is presented. The tri-base acquaintance (3bA) model formalizing agent's social behaviour knowledge and agent's cooperation neighbourhood knowledge is enhanced to support attention focussing and to ensure a holistic complex perception of the problem. The paper focuses on an analysis of the content of 3bA knowledge bases for applications in medical decision support. Architecture for a multiagent system for medical decision support in diagnostics and monitoring is proposed.

Introduction

Modern health care is highly specialized. Complex examination of a single patient involves many expert consultations and laboratory tests. Medical knowledge, examinations and treatment are distributed functionally, geographically, and also temporally. There is a need for reliable and consistent information flow among all participating subjects with the aim to satisfy the global goal – improved health of a patient. Of course, the necessary information flow is not predictable in extent and structure, but it develops and changes in time due to new knowledge and reactions. To satisfy these requirements and provide adequate decision support, the use of flexible intelligent software support is becoming increasingly desirable. Distributed problem solving and agent technology offer efficient and natural solutions, because they correspond to the main properties of the medical domain, namely distribution of information, problem-solving capabilities, resources, and responsibilities, decision-making with incomplete information, iterative refinement of plans.

Recently there has been growing interest in the application of agent-based systems in health care. The most frequent medical domains in which agents have already been considered are: retrieval of medical knowledge from the Internet [1], decision support systems for monitoring and diagnostic tasks [2] or for home care, distributed patient scheduling within a hospital [3].

AADCare [4] is a system for support of diagnostics, workflow management, and treatment planning. The agent architecture comprises multiple layers of knowledge, a working memory, a communication manager and a human-computer interface. The agents exhibit both deliberative and reactive behaviour. Knowledge is divided into three layers, namely domain knowledge (knowledge base - medical facts, clinical protocols, database of patient records, database of resource availability), inference knowledge (generic, declarative inference rules for decision making under conditions of uncertainty and for managing agent cooperation), and control knowledge (which applies the inference knowledge to the domain knowledge in order to generate inferences whenever new data is added to the working memory). The working memory is similar to a global blackboard [5].

AGIL (Agent-based Information Logistics) [6] is a German research project whose objective is to develop a multiagent system for optimization of clinical information flows, i.e. for clinical information management. The concept defines three agent classes: Interface Agents, which constitute the user interface; Task Agents, which execute tasks, and Information Agents, which collect information.

Guardian [2] is a project that was completed in 1996. Its objective was to develop a prototype of intelligent agent system for monitoring intensive-care patients. The system is based on the blackboard control architecture and is composed of heterogeneous software modules that are organized in two levels. At the lower level, there are modules that perform data reduction and abstraction tasks. At the higher level, reasoning and cooperation is performed.

The literature and WWW describe other multiagent systems and their applications in number of diverse domains - see for example (www.multiagent.com, www.agentlink.org).

Tasks in Patient Treatment

In patient treatment, we can identify (at least) five separate areas that can be computer supported, namely diagnostics, prediction, monitoring, information processing, workflow management and treatment planning. All these areas can benefit from new options offered by modern information technologies. For example, in diagnostics and prediction it is possible to involve agents that can search for similar cases that have appeared elsewhere. Another possibility is to use agents for preparing and evoking an electronic medical consultation.

ISSN: 1727-1983 © 2005 IFMBE

Multiagent System as a Platform for Development of a Decision Support System in Medicine

We focused on the possibility of utilizing a multiagent system as a platform for development of an intelligent system for medical diagnostics and monitoring. A knowledge-based model of the agents' mutual awareness (social knowledge) is presented. The tri-base acquaintance (3bA) model formalizing agent's social behaviour knowledge and agent's cooperation neighbourhood knowledge is enhanced to support attention focussing and to ensure a holistic complex perception of the problem.

Evaluation of medical data is most often far from straightforward. There is no generally applicable best method or technique to be applied for particular data. Each method has its relative strengths and weaknesses. Some can only produce an approximate solution, but do so comparatively quickly; others are more accurate, but relatively slow. Furthermore, the performance of a given technique is often dependent on the nature of the data set (some work well with noisy data, others do not; some work well with data that has a high signal strength, others work comparatively well with a low signal strength; some can cope with missing data, others do not). The size of the data set may also affect the performance of the technique. When the data set is too large, the user is usually not able to evaluate the quality of data manually, he/she may not be experienced enough, he/she may skip an important part of data, etc. All this is reflected in the basic requirement on the system under consideration: the system needs to be responsive to its problem-solving context.

The best way how to overcome the problems associated with selecting a single technique, is to design a system allowing coexistence of multiple methods. However, as examples from other domains show (e.g. image processing), such systems or tools typically place a significant burden on the user. For each technique, the user is expected to know its problem solving characteristics, be able to judge when, where, and how to apply it, and to determine how best to integrate and fuse the results it produces. It would be excessively demanding to solve this problem using a single monolithic system (e.g. an expert system), because it does not allow integration of different techniques and evaluation of partial results achieved by these techniques. Therefore we decided to design and develop an open system that will provide a wide range of uncoupled base techniques (represented by separate modules) and allow the software system to determine at run-time which of them are appropriate in which circumstances. The interchange of partial and final results between individual modules will be directly supported at the software level.

Considering all the requirements and the nature of the problem domain, the most natural means for modelling and implementing the system is the multiagent approach. For our purposes, there are three basic characteristics of multiagent systems that are advantageous for application in medical diagnostics, namely cooperation, heterogeneity of individual agents, and integration of legacy systems. By an agent, we mean a software entity that exhibits the following properties [7]:

- **Autonomy**: Agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state.
- **Social ability**: Agents interact with other agents (and humans) via some kind of agent-communication language when they recognize necessity of such communication (usually with the aim to complete their own problem solving and to help others with their activities).
- **Reactivity** (responsiveness): Agents perceive their environment (physical world, a user, a collection of agents, the Internet, or combination of all mentioned entities) and respond in a timely fashion to changes that occur in it.
- **Proactiveness**: Agents do not simply act in response to their environment, they are able to exhibit goal-directed, opportunistic behaviour and take the initiative when appropriate.

The Tri-base Acquaintance Model and Its Application to Diagnostic Tasks

The basic architecture of an agent and its knowledge bases are taken over from [8]. The agent in our system consists of a functional body (usually a stand-alone program with a well-defined functionality) and a wrapper (which is responsible for involvement of the agent into the community of agents) (see Fig. 1). The tri-base acquaintance (3bA) models are encoded in agents' wrappers.

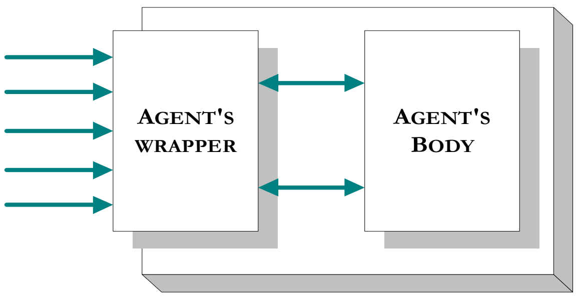


Figure 1: Structure of an individual agent

3bA models have several important purposes:

- to limit explosive communication in multiagent system;
- to ensure an immediate reply in a time-critical situation;
- to generate and maintain databases of information sources.

Within the 3bA model each agent maintains three knowledge bases where all the relevant information about the rest of the community is stored, namely the

ISSN: 1727-1983 © 2005 IFMBE

Co-operator Base, the Task Base, and the State Base (see Fig. 2).

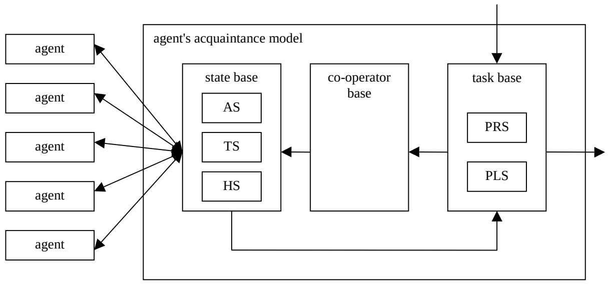


Figure 2: 3bA acquintance model

The **Co-operator Base** (CB) maintains permanent information on cooperating agents, i.e. their address, communication language, and their predefined responsibility (including information about the required form of input data for the agent's body). This data is needed to ensure preselection of a proper agent that is able to perform the required task, since in diagnostics a large volume of input data of heterogeneous nature and form is usually used. This type of knowledge is not expected to be changed very often.

The **Task Base** (TB) has two sections: the problem section and the plan section. In the *plan section* (PLS) it maintains the actual and most up-to-date plans on how to carry out those tasks, which are the most frequently delegated to the agent. The Task Base stores in its *problem section* (PRS) general problem solving knowledge on possible decision making with respect to input data type and expected output.

The **State Base** (SB) contains information about the collaborating agents, i.e. about their current state. The SB stores in its *agent section* (AS) all information on the current load of the cooperating agents. This part of the state base is updated frequently and informs the agent which of the collaborating agents are busy and which of them are available for collaboration. The *task section* (TS) stores information on the statuses of the tasks that the agent is currently solving.

This structure of the agent's knowledge bases was originally designed for process scheduling [8]. For predictive diagnoses we complemented it by an additional *hint section* (HS) to store unusual past findings as well as a "to-do list" pointing to interesting hypotheses suggested by cooperating agents (e.g. decisions about importance of alarms, distinguishing between alarms caused by life endangering state of the patient and alarms caused by failure of a device). Each hypothesis has to be verified or refuted at the earliest possible occasion, e.g. when new data concerning a specific patient arrives. This section fits best into the State Base.

The content of all three bases is dependent on the tasks the agents are supposed to solve. In the case of planning agents the dominant role is played by knowledge of task decomposition and responsibility delegation. In the case of configuration agents, the knowledge stored in the task base can be used to lead the communication scenarios. The diagnostic agents contain social knowledge about the data sources, about the process of finding appropriate data and about the current progress in required data processing by the other agents.

Instead of communicating with all the involved agents in order to find out certain information about the community, an agent equipped with the acquaintance model consults this social knowledge stored in its wrapper instead. This feature is very closely linked with the second feature. If we require an immediate reply to an input or stimulation there is usually not much time for communication with collaborating agents. The agent must react without any delay and therefore it must have the relevant information at hand, e.g. which agent should execute the task. Using negotiation in such cases is not acceptable. One of the activities where an evaluation or an integration agent can require help from the agent community is search for relevant information. The agents can browse the Internet for that purpose. If such information is later used, the source is included in the list of potential sources of information for further use.

Case Study: Medical Diagnostics and Monitoring

Each data and signal pre-processing and evaluation technique can be regarded as an autonomous software agent that cooperates, communicates and coordinates, if necessary, with other agents to try to satisfy the global goal. The concept of ADAM (Agents for Diagnostics and Monitoring) [9] defines three basic agent classes, which are necessary to ensure basic functionality and participate in direct problem solving: data collecting agents, which collect data from measuring devices, laboratory test equipment, etc.; data evaluating (interpreting) agents, which pre-process and process collected data using appropriate methods, the results are described in higher-level concepts; and integration agents, which integrate results from processing agents and evaluate them with the aim to reach appropriate conclusions. Based on the evaluation, the integration agent can directly contact data collecting agents and feed their HS with a request for a new measurement. In addition, the designed system is equipped with complementary agents ensuring system intelligence, namely learning agent, sceptical agent, database agent and info-collecting agent. The database agent collects data about all patients and as a side effect it creates a source for data mining activities. The info-collecting agent searches for complementary information on Internet or among the data collecting agents. The sceptical agent stores past findings relating observations and diagnoses as provided by info-collecting agent or resulting from experience of integrating agents. The learning agent can apply some machine learning methods to data provided by other agents in the community. In addition to these agents, we propose a meta-agent that is an independent agent observing the community. Most data collection agents have a single functionality; they are not multipurpose machines. All over it, they can take advantage from the 3bA model since the collection agent has some freedom in the choice of the best integration agent.

Knowledge is divided into four layers, namely domain knowledge (medical knowledge in agent's body), information on co-operating agents (Co-operator Base in agent's wrapper), general problem solving knowledge (Task Base in agent's wrapper), and information on current state of collaborating agents (State Base in agent's wrapper).

A very important question is how the agents should recognize which is to start the pre-processing or direct processing (without a pre-processing step) of the accepted input data. We can imagine two modes: preliminary screening and careful examination. The mode is usually linked with applied methods. During preliminary screening (or monitoring) we require real-time processing so that the system can immediately react to an unusual situation. Therefore the agents must work quickly. However, during successive diagnostic tasks we require as precise an evaluation as possible. Such methods are usually more time consuming. As it has been mentioned above, it is advantageous to use different methods for different data types, depending on the nature of the data, the presence of noise, etc. In some cases, e.g. processing of patient history data or numerical values from laboratory tests, it is usually not necessary to apply any pre-processing, and the processing step can be initiated.

Whenever data (measurements) enter the multiagent system, a rough evaluation has to be performed first, in an attempt to distinguish life-critical situations: a multiagent system has to work in a completely different mode in such a case [10].

Application of ADAM to the Domain of Cardiology

The analysis and design mentioned in the previous section was made quite general so that it could be applied to different medical domains. However, it would not be possible to develop a large system covering broad spectrum of medical problems from scratch. Therefore we led discussions about more focused topic with medical doctors at the University Hospital and the First Faculty of Medicine of the Charles University. We came to the conclusion that the first application we would try to implement would be in cardiology. There were four main reasons for that decision:

- We have a long-term and intensive cooperation with cardiologists and physiologists.
- The problem domain has reasonable size. The doctors have a number of patients, most of them under long-term follow-up, thus having a rich data source.
- We have already implemented several stand-alone systems that are aimed at pre-processing and processing cardiological data and can be integrated into the ADAM system.
- It would be very difficult and time consuming to design, implement and verify full application, e.g. for monitoring at ICU.

We tried to identify partial but comprehensive problem that could be subsequently integrated into the ICU monitoring system. So the task was formulated as design and implementation of a knowledge-based decision support of diagnostics in cardiology utilizing a multi-agent platform. The first step in the process was thorough analysis of medical data available and necessary for the cardiological domain. We focused on those cardiovascular problems that are frequent in the population and are linked with civilization and lifestyle (hypertension, obesity, smoking, alcohol, stress, high cholesterol level, etc.). The data available can be divided into several groups:

- ECG signals (12-electrode standard ECG, vectorcardiograph, body surface potential mapping (BSPM) – 64 – 128 electrodes, 3- or 12-electrode Holter signal);
- patient history (mostly textual information, not structured);
- therapy, medication (mostly textual information, partially structured);
- biochemical tests (numerical data).

At chronic patients, there are available data from regular examinations (usually one in 6 or 12 months). In that case it is possible to follow development of the patient state in time in dependence on treatment. In addition, there are patient data stored in the hospital information system that may serve as additional data source. However cooperation with this central database represents a difficult problem because most of the information stored is not structured.

Since the data sources and data formats are very heterogeneous we have to develop separate agents for collecting and subsequently processing data from these sources. The most complex part of the system is the part for ECG processing. We have to differentiate concrete types of ECG measurement according to number of electrodes used and length of recording. Different methods are used for processing of short-term recordings – conventional ECG or BSPM for patients at rest (usually 20 seconds up to 1 minute); or long-term recordings – Holter signal (usually 24 hours when the patient is performing his/her usual activities). The conventional ECG cannot record short-term changes, mostly paroxysmal (e.g. all types of paroxysmal tachycardia, or fibrillations if they last for a short period, cardiac causes of unconsciousness, heart failure – short-term asystole, short-term ventricular tachycardia). During 24-hour (or even 36-48-hour) Holter monitoring, it is possible to record not only permanent changes as with conventional ECG but also short-term, paroxysmal changes. There are different requirements on processing speed and precision. ECG data collecting agents are single-purpose agents, each responsible for collecting data from pre-defined type of

ISSN: 1727-1983 © 2005 IFMBE

ECG device. One reason is that each ECG device generates its own data format and works with different sampling frequency; both are dependent on the producer. The data collecting agents transform data into unified format for further processing; send the data to pre-processing agents and to the patient database.

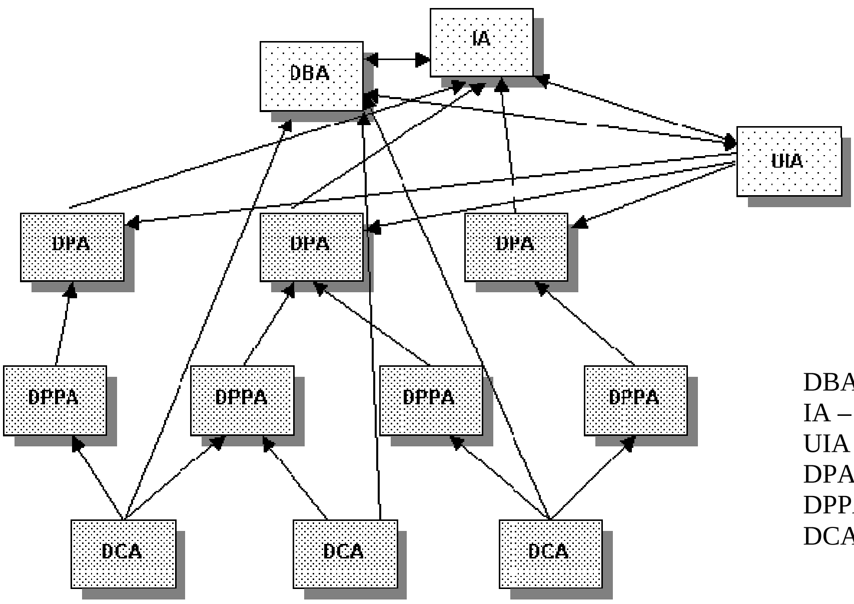
We have slightly modified the general ADAM architecture [9] and left out several types of agents in the first phase. The basic architecture for our application is shown in figure 3. We have divided the data evaluating/interpreting agents into two levels, namely data pre-processing and data processing agents. On the level of data pre-processing, there are several agents that serve for pre-processing of data coming from different data collecting agents and their visualization. They have to perform all necessary steps, starting from noise filtering that must be done carefully so that minimum information is lost. Pre-processing of signals is performed both in time and frequency domains and results in extraction and computation of the most descriptive features (e.g. amplitude and length of individual waves, frequency spectrum, temporal trends, heart-rate variability). The basic methods used in pre-processing agents are wavelet and Fourier transforms. The agents can work in automatic mode when they extract relevant features and send them for further processing or in interactive mode when the user can make visual inspection using visualization modules of the agents.

Data processing agents utilize machine learning methods (decision tree, neural networks, k-NN classifier). First they are trained on corresponding data sets. There have been developed several models for specified diagnoses (e.g. arrhythmias, fibrillations). Their outputs serve as inputs for the integration agent. The *integration agent* is a knowledge-based system that has several different inputs, namely results from processing agents, data of patient history from the database (or manual input from the doctor), evaluation of biochemical tests. The rule-based diagnostic expert system FEL-EXPERT [11] is used in the agent body. The result of the system's computation is a proposed diagnosis and treatment of the given patient. The *database agent* controls operations with a local database. This database is structured and contains data about examined patients. The measured signals are stored in separate files and in the patient record there are links to these files. The patient record contains features extracted and computed from the signals, patient history, results of biochemical tests, suggested diagnosis, confirmed diagnosis, proposed treatment, and medication. The *user interface agent* serves for the communication with the user. At present the results from the biochemical test must be inserted manually as well as additional information from the hospital central database.

At present we do not utilize all the properties that multi-agent technology offers. The most important properties at the moment are the integration of legacy systems into multi-agent system and standard communication among agents. As a cooperation model we have chosen the organizational structure, more or less fixed. The reason is that the sequences of data collecting, preprocessing and processing operations are given. We work with heterogeneous agents where each agent has its role predefined.

Implementation

We were looking for such an environment that would maintain basic multi-agent necessities, which are communication standards, agent administration etc.



DBA – database agent
IA – integration agent
UIA – user interface agent
DPA – data processing agent
DPPA – data pre-processing agent
DCA – data collecting agent

Figure 3: ADAM Architecture for Diagnostics

FIPA (Foundation for Intelligent Physical Agents) [12] provides a set of such standards and reference implementation that have emerged from industrial needs and achievements of the research community. The ADAM system is being built using JADE software framework [13], which is fully implemented in JAVA language. The agent platform can be distributed across machines (which not even need to share the same OS) and the configuration can be controlled via a remote GUI. The configuration can be even changed at run-time by moving agents from one machine to another one, as and when required. The platform independency is important advantage of JAVA solutions. JADE has several interesting features that at least make process of implementation easier. The one of these features is the agent Sniffer that enables user to observe message flow among agents.

Conclusions

This paper has described the possibility of using agent architecture for developing a decision support system for medical domain. This has been illustrated by a case study: the design of a multiagent system for supporting medical diagnostics. Cooperating agents provide a very natural means of automating the pre-processing and (at least partially) the evaluation of a vast amount of medical data utilizing all available medical knowledge. The current phase of the project is targeted at implementing the system and putting it into full use.

There are a number of issues that require further investigation. First, a more comprehensive set of pre-processing and processing techniques is required. Second, the agents should be able to adapt and learn from the social interactions they experience. Agents should learn which acquaintances give reliable results in which circumstances. Based on this knowledge they should be able to adapt their selection appropriately. The 3bA model represents a general acquaintance model that allows the construction of various global community functional architectures. As practical applications in different fields show [8], the 3bA architecture can also be used by meta-agents accomplishing meta-level reasoning. A meta-agent can collect all detailed observations obtained by individual agents and can apply various data mining techniques to identify interesting relations, which might be used later to improve the predictive diagnostic processes. Corresponding changes in the agent's hint section have to be suggested.

Acknowledgments

This work has been supported by the research program "Information Society" under Grant No. 1ET201210527 "Knowledge-based support of diagnostics and prediction in cardiology".

References

[1] BAUJARD O., BAUJARD V., AUREL S., BOYER C., and APPEL, R.D. (1998): 'MARVIN, a multiagent softbot to retrieve multilingual medical information on the Web', *Medical Information* **23**, pp.187-191

[2] LARSSON J. E. and HAYES-ROTH B. (1998): 'Guardian: An Intelligent Autonomous Agent for Medical Monitoring and Diagnosis', *IEEE Intelligent Systems and their Applications*, **13**(1), pp.58-64

[3] DECKER K. and LI J.(1998): 'Coordinated hospital patient scheduling', Proceedings of the Fourth International Conference on Multi-agent systems, ICMAS-98, Paris

[4] HUANG J., JENNINGS N.R. and FOX J. (1995): 'An agent-based approach to health care management', *Applied Artificial Intelligence* **9**, pp.401-420

[5] HAYES-ROTH B. (1985): 'A blackboard architecture for control', *Artificial Intelligence* **26**, pp.251-320

[6] KNUBLAUCH H., ROSE T. and SEDLMAYR M.(2000): 'Towards a multi-agent system for proactive information management in anesthesia', Proc. of the Agents-2000 Workshop on autonomous agents in health care, Barcelona

[7] WOOLDRIDGE M. and JENNINGS N.R.(1995): 'Agent theories, architectures, and languages: a survey', in WOOLDRIDGE M., JENNINGS N.R., (eds): 'Intelligent agents', (Heidelberg: Springer-Verlag)

[8] MARIK V., PECHOUCEK M. and STEPANKOVA O. (2002): 'Organization of social knowledge in multi-agent systems', *Integrated Computer-Aided Engineering* **9**, pp.1-12

[9] LHOTSKA L., and STEPANKOVA O. (2004): 'Agent architecture for smart adaptive systems', Trans. of the Inst.of Meas. and Control, 26 (3), pp. 245-260

[10] HERNANDO M.E., GOMEZ E.J., ALVAREZ P. and DEL POZO F. (2002): 'Intelligent alarms integrated in a multi-agent architecture for diabetes management', Intelligent e-health applications in medicine and other medical applications of adaptive/hybrid intelligent systems. University of the Aegean, Chios, Greece, Vol. 1, pp. 64-68

[11] LHOTSKA L., MARIK V. and VLCEK, T. (2001): 'Medical applications of enhanced rule-based expert systems', *Int.Jour. of Med. Inf.* **63**, pp.61-75

[12] FIPA: Agent Management. Internet site address: http://www.fipa.org

[13] BELLIFEMINE F., POGGI A., and RIMASSA G.(2000): 'Developing multi-agent systems with JADE', *Seventh International Workshop on Agent Theories, Architectures, and Languages* (ATAL-2000), Boston, MA

ISSN: 1727-1983 © 2005 IFMBE