Jadwiga Sobieska-Karpińska
Marcin Hernes

Wrocław University of Economics

LEARNING METHODS OF COGNITIVE AGENTS RELATED TO DECISION AREAS IN DSS

Introduction

In the present socioeconomic conditions, making a quick and correct economic decision is becoming the basis for enterprise competitiveness. The economy forces the enterprise management staff to make complex operational, tactical and, first of all, strategic decisions related to the future of the organisation [Kisi08]. The enterprise decision-makers usually act in the conditions of risk and uncertainty because they are unable to foresee the effects of the decision made or can foresee them with a very low probability [Kubi09]. Hence, the entire decision-making process is extremely complicated.

The decision-making process can be supported by the use of various tools, particularly IT systems. The IT tools (systems) applied today support decisions made mainly at the operational and tactical levels, while being insufficient at the strategic level. This is because they enable only an analysis of the form of information, relationships between economic values, yet do not support the process of analysing its meaning. Hence, the tools serve mainly the purpose of transforming the collected data (which are normally disordered and unstructured) into information, which is useful, clear and easy to interpret, thus more helpful to the decision-maker. The IT systems also enable support for knowledge management but without the possibility to analyse its meaning. However, the need to make decisions on the basis of not only information and knowledge but also experience, which has been treated as the human domain to date, arises increasingly more frequently. Therefore, it is becoming reasonable to employ tools which fulfil cognitive and decision functions, such as the ones occurring in the human brain, and owing to that they permit the understanding of the actual meaning of the observed economic phenomena and processes occurring in the business environment. Such tools include among others cognitive agents, which often cooperate with each other as part of a multi-agent system in order to achieve the set goal [SoHe13].

The most important properties of all cognitive agent architectures are the manner of organising their memory and learning methods. Memory is a repository of knowledge about the world and oneself, goals and current actions. Memory organisation depends on the method of representing knowledge [HaBl04, Hech07]. Learning is a process that transforms the memorised knowledge and the manner of using it. Hence, the learning ability determines having cognitive abilities by computer programs, including cognitive agents. A program that lacks the learning ability cannot understand the meaning of the phenomena occurring in the environment.

Learning methods are unsystematised in the relevant literature. On the one hand, authors of the studies regarding various cognitive agent architectures describe learning procedures of the agent in a given architecture in detail, but on the other hand they do not classify this procedure. This hampers comparison of learning procedures of individual agents. On the other hand, authors of the studies related to learning systems, e.g. [Cich09], carry out a multifaceted classification of learning methods, which is, however, overgeneralised, i.e. the classifications refer to the broadly defined class of learning systems, which makes it difficult to identify the methods that can be used in the learning process of cognitive agents in decision support systems.

Therefore, this paper aims at analyzing and systematizing learning methods, which are or can be used in architectures of the cognitive agents that operate in decision support systems.

In the first part of article, the research methods have been described. The cognitive agents' functioning in DSS is then presented. In the final part of article the classification of the cognitive agents learning methods is presented.

1. Research methodology

The research have been realized through the following stages:

1. Analysing of the decision areas in DSS by using such research methods like the literature studies, the observation of phenomena in the enterprises, the case studies of different practical application of DSS.
2. Studying the learning methods and architectures of the multi-agent DSS and cognitive agents. The literature studies, a study of documents and the case studies have been used in this stage.

3. Analysing the relation between the areas of DSS and the agents' learning methods by using the observation of phenomena and case studies of several prototypes of cognitive agent's architectures (mentioned in section 2). Also computer simulation have been used – selected frameworks of cognitive agents have been installed and the learning of the particular agent have been simulated.

2. Cognitive agents in DSS

Conducting an analysis and systematising learning methods requires a prior presentation of the properties of the decision support system that uses cognitive agents along with determination of the types of the decisions which are supported by the system and characterisation of cognitive agents.

It is assumed in this paper that the decision support system belongs to the class of multi-agent systems since it is built of many cooperating cognitive agents. The system supports decisions regarding the following areas (the listed areas are characterised in detail in the relevant literature; due to the raised issues and the volume of this paper, they will not be characterised in detail) [Plik08, ByHe13]:

- production management,
- environmental scanning,
- customer and supplier relationship management,
- logistics,
- human resource management,
- finance and accounting,
- investment,
- analyses and forecasting,
- supply chain management.

The discussed system operates as follows (Figure 1):

- cognitive agents operate with the use of various decision-making methods in groups related to individual decision areas (for example, a group can be constituted by agents that make investment decisions regarding supply chain management),

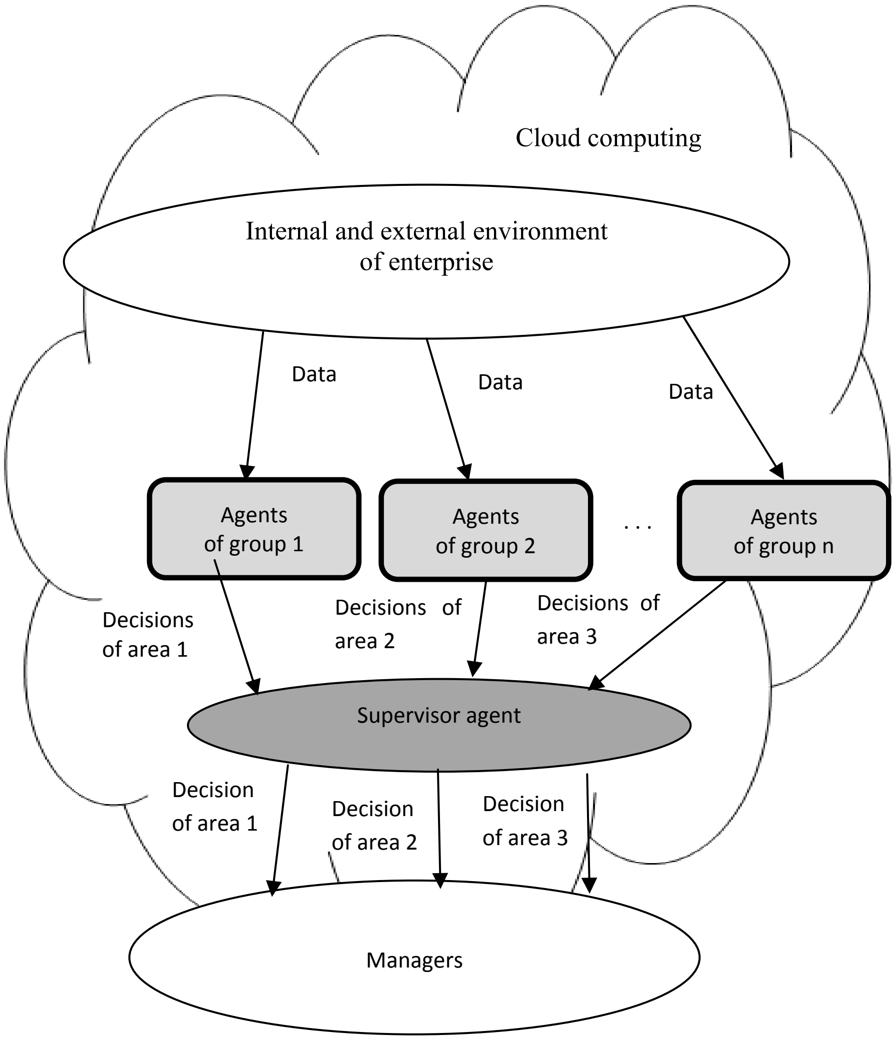

Fig. 1. Functional schema of multi-agent decision support system

Source: Own work.

- environmental scanning – a few or ten-odd agents can operate in each group),
- each agent receives stimuli from the external and internal enterprise environment,
- agents make decisions in response to the events occurring in the environment (for instance, the lack of a raw material that is necessary for production, competitors changing a product price),
- the Supervisor agent analyses decisions of individual groups and then presents only one decision from each decision area (made, for examples, as a result of using the consensus method) to the user [SoHe12]).

Since the system is built of multiple cognitive agents, this technology will be briefly characterised in the further part of this paper.

The cognitive agent is defined in the relevant literature in a variety of ways, yet the most common definition is the one explaining that such an agent is a computer program which [SaVe08]:

- is capable of taking actions in the environment in which it is present,
- can communicate directly with other agents,
- is directed by a set of habits, inclinations which are specific goals or an optimised benefit function,
- has its own resources,
- is capable of receiving stimuli from its environment, however to a limited extent,
- can have partial knowledge about the environment,
- has skills and can offer services,
- can reproduce, clone,
- committed (using behaviour) to the achievement of the goals using the available knowledge, resources and skills as well as the ability to receive stimuli from the environment and communicate taken into account,
- can recognize the environment and learn by gaining experience.

In other words, the cognitive agent is an intelligent program, which not only draws conclusions on the basis of the received data and takes specific actions to achieve the goals, but also, unlike the reactive agent, learns and gains experience at the same time.

The literature presents many solution of cognitive agent's architecture. In the study [Duch 2010] considering the taxonomy of cognitive agent architectures with respect to memory organization and learning methods, three main groups of the architectures were distinguished:

1. Symbolic architectures of cognitive agents which use declarative knowledge included in relations recorded at the symbolic level, focusing on the use of this knowledge to solve problems. This group of architectures includes, among others: State, Operator And Result (SOAR) [Lair08], CopyCat [HoMi95].
2. Emergent architectures of cognitive agents using signal flows through the network of numerous, mutually interacting elements, in which emergent conditions occur, possible to be interpreted in a symbolic way. This group of architectures includes, among others: Cortronics [Hech07], Brain-Emulating Cognition and Control Architecture (BECCA) [Rohr14].
3. Hybrid architectures of cognitive agents which are the combinations of the symbolic and emergent approach, combined in various ways. This group of architectures includes, among others: The Novamente AI Engine [GoWa12], The Learning Intelligent Distribution Agent (LIDA) [FrPa06].

As was emphasised in the introduction to this paper, the most significant properties of cognitive agents include the manner of organising their memory and learning methods.

Memory organisation concerns the manner of locating various types of memory in the agent architecture, including [GoWa12]:

- recognition (perceptual), permitting identification of familiar objects or perception of deviations from expectations,
- associative, automatically leading to simple conclusions, implementation of classical conditioning processes,
- procedural, that is memory of manual skills and action sequences,
- semantic, permitting interpretation of sense and access to complex knowledge structures,
- workspace, permitting combination of various fragments of information in larger wholes.

Learning methods, that is the second property of cognitive agent architectures, will be analysed and systematised further in this paper from the perspective of application with reference to individual decision areas.

3. Classification of cognitive agents learning methods

Learning is defined as a process that transforms the stored knowledge and the manner of its application [Duch 10] but also as any autonomous change occurring as a result of experiences in the system and leading to improvement in the operation of the system [Cich09].

Learning methods are divided by various criteria (Table 1). The most important of them include the external information type and the used mechanism type.

Table 1

Classification of the learning methods

<table>
<tr><th>Criterion</th><th>Learning method's name</th><th>Features</th></tr>
<tr><td rowspan="3">External information type</td><td>supervised</td><td>independent of the type of decision areas, independent of the agent's architecture group</td></tr>
<tr><td>reinforced</td><td rowspan="2">depends on the type of decision areas, independent of the agent's architecture group</td></tr>
<tr><td>unsupervised</td></tr>
<tr><td rowspan="8">The used mechanism type</td><td>analytical</td><td rowspan="2">depends on the type of decision areas, depends on the agent's architecture group (used in symbolic group)</td></tr>
<tr><td>deductive</td></tr>
<tr><td>associative</td><td rowspan="2">depends on the type of decision areas, depends on the agent's architecture group (used in emergent group)</td></tr>
<tr><td>competitive</td></tr>
<tr><td>perceptual</td><td rowspan="4">independent of the type of decision areas, depends on the agent's architecture group (used in hybrid group)</td></tr>
<tr><td>episodic</td></tr>
<tr><td>procedural</td></tr>
<tr><td>conscious</td></tr>
</table>

Source: Own work.

Given the criterion of external information type, the following learning methods are distinguished:

1. Supervised (with a teacher) – the so-called set of training pairs composed of the input vector and desired (output) response vector. System parameters are modified as long as it responds correctly to the entire learning set.
2. Reinforced – it is a variant of supervised learning where information about values desired on the system output is absent, and only the information or action taken by the system (change in weight values) gives positive or negative results in the sense of the desired system behaviour. If the actions taken by the learning system give positive results, the trend for appropriate system behaviour in similar situations in the future is reinforced. Where the result is negative, the trend of such a system operation is weakened.
3. Unsupervised (without a teacher) – in unsupervised learning the desired response is unknown. Due to the lack of information about the correctness of the response, the system has to learn by analysing the response to the stimuli the nature of which is poorly known or unknown to it. During the analysis, system parameters are subject to changes, which is called self-organisation.

When analysing the learning methods distinguished by the external information type, it can be noticed that supervised learning can be used with reference to all decision areas. However, since it is usually implemented by the human, it is characterised by a high level of time-consumption and subjectivism. Time-consumption results from the fact that the human needs a specified time to teach the agent to take appropriate actions in response to the events occurring in the environment (the human needs to analyse such events first). In the initial phase of the system operation, which requires an intensive learning process of the agent, time-consumption exerts an adverse impact on the decision-making process since, due to the turbulence of the business environment, decisions should be made in near real time. Subjectivism, in turn, occurs because the human can transfer only the knowledge he or she has to the agent. However, in many cases, the human role in the learning process of agent is necessary for instance for environmental scanning since it is the human that should teach the agent to respond to competitors' activities.

The reinforced learning method can be used with reference to decision areas such as customer and supplier relationship management, logistics, analyses and forecasting, supply chain management. In these areas, the human can be a critic with reference to the decisions made by the agent (evaluate the effects of a decision as positive or negative). This method is characterised by a lower level of subjectivity (the agent learns by using its knowledge rather than the knowledge transferred by the human).

The unsupervised learning method, in turn, can be used with reference to areas related to analyses and forecasting as well as investment. For example, where it is necessary to support decisions regarding investing on the capital market, it is enough the cognitive agent employs the unsupervised learning method (it can learn based on historic data). This method is characterised by the highest level of objectivism – the human has no impact on learning of the agent. In this method, in turn, the problem of learning convergence gains in significance – with an incorrectly functioning procedure of this process learning of the agent can prove ineffective.

Taking into consideration criterion of the used mechanism type, the learning methods depend on the discussed group of cognitive agent architectures, and so:

1. The following learning mechanisms have been introduced to symbolic architectures:
   - analytical (deductive) learning, which uses knowledge to create new facts on its basis [Mitch97],
   - inductive learning, which discovers new general rules on the basis of observation by making attempts to approximate the structure of a given domain [PrFe06].
2. In emergent architectures (ones processing numerically represented knowledge) two learning types are used:
   - associative learning consisting in creating relationships between stimuli, between stimuli's properties, between the stimuli and the response in the neural network (for example the trial and error method) [YuGr10],
   - competitive learning, where neurons compete with each other to become active (stimulated); only one neuron can be active, while the rest are inactive [Hayk09].
3. In hybrid architectures, in turn, the following learning types are distinguished:
   - perceptual, which regards the recognition of new objects, categories, relationships, and is based on changing the strength of synaptic connections between nodes or on creating new nodes and connections in the perceptual memory,
   - episodic, which means memorising specific events: what, where, when, which occur in the workspace, and hence are available in consciousness,
   - procedural, that is learning new actions and action sequences necessary to solve the presented problems, is carried out in two ways: one is selecting actions from a familiar repertoire, and the other is constructing new representations for action sequences by means of reinforced learning,

- conscious reference to learning new conscious behaviours or reinforcing the existing conscious behaviours which occur when a given component of the situational model is often in the semantic memory [ByHe13].

When analysing the learning methods distinguished based on the above criterion, it needs to be noticed that analytical and inductive learning used in symbolic cognitive agent architectures can be used with reference to the decision areas where knowledge can be represented symbolically, that is environmental scanning, customer and supplier relationship management, finance and accounting, investment, analyses and forecasting. Business processed in these areas can be pursued with the use of the symbolic knowledge, for example a report on competitors' activities, customer profile characteristics.

Associative and competitive learning, which is used in emergent architectures, can be used with reference to areas such as production management, logistics, or supply chain management. Business processes in these areas are pursued mainly with the use of numerical knowledge (controlling machines and equipment, calculating the best transport routes).

However, it needs to be clearly emphasised that decision problems in enterprises usually require processing knowledge recorded symbolically and numerically at the same time. For instance, in spite of the fact that in the production management area knowledge is represented mainly numerically, creating a bill of materials requires processing symbolically recorded knowledge. Therefore, in multi-agent decision support systems, it is advisable to apply perceptive, episodic, procedural and conscious learning methods used in emergent architectures.

The presented criteria for dividing learning methods complement each other. For example, when applying conscious learning, both supervised, reinforced and unsupervised learning methods can be used depending on the decision area.

The presented classification of learning methods enables determination of the methods that can be used in a given cognitive agent architecture and with reference to a specific decision area. Through that, not only comparing individual cognitive architectures but also selecting architectures appropriate for solving problems from a given decision area is facilitated.

Conclusions

Learning, apart from memory organisation manner, is the most important property of cognitive agent architectures that has a direct impact on the possibility to use a specific architecture for solving problems in a given field. So far the literature describes the areas of decision in DSS and the learning methods, however it don't describes the relation between them. Thus, the analysis and systematisation of learning methods of cognitive agents conducted in this paper permits the developers of multi-agent decision support systems to compare them and choose the agent architectures that can be used with reference to decisions from a given area. Owing to that, the system can give suggestions to the user or make independent decisions in a near real time, which ultimately exerts a positive impact on the operation of the entire enterprise.

Further research works should concern, among others, developing a prototype of DSS using cognitive agents architecture, implementing different learning methods and verification of their practical usability and performance.

References

[ByHe13] Bytniewski A., Hernes M.: Wykorzystanie agentów kognitywnych w budowie zintegrowanego systemu informatycznego zarządzania. In: T. Porębska-Miąc, H. Sroka (eds.): Systemy Wspomagania Organizacji. Wydawnictwo Uniwersytetu Ekonomicznego, Katowice 2013.

[Cich09] Cichosz P.: Systemy uczące się. Wydanie 2. WNT, Warszawa 2009.

[Duch10] Duch W.: Architektury kognitywne, czyli jak zbudować sztuczny umysł. In: R. Tadeusiewicz (ed.): Neurocybernetyka teoretyczna. Wydawnictwa Uniwersytetu Warszawskiego, Warszawa 2010.

[FrPa06] Franklin S., Patterson F.G.: The LIDA Architecture: Adding New Modes of Learning to an Intelligent, Autonomous, Software Agent. Proc. of the Int. Conf. on Integrated Design and Process Technology. Society for Design and Process Science, San Diego, CA 2006.

[GoWa12] Goertzel B. Wang P.: Introduction: What Is the Matter Here? In: B. Goertzel, P. Wang (eds.): Foundations of Artificial General Intelligence. Atlantis Press 2012.

[HaBl04] Hawkins J., Blakeslee S.: On Intelligence: How a New Understanding of the Brain Will Lead to the Creation of Truly Intelligent Machines. Times Books, 2004.

[Hayk09] Haykin S.O.: Neural Networks and Learning Machines. Prentice Hall, 2009.

[Hech07] Hecht-Nielsen R.: Confabulation Theory: The Mechanism of Thought. Springer, 2007.

[HoMi95] Hofstadter D.R., Mitchell M.: The Copycat Project: A Model of Mental Fluidity and Analogy-making. In: D. Hofstadter, Fluid Analogies Research group (eds.): Fluid Concepts and Creative Analogies. Basic Books, 1995, Chapter 5.

[Kisi08] Kisielnicki J.: Management Information Systems. Placet Press, Warsaw 2008.

[Kubi08] Kubiak B.F.: Knowledge and Intellectual Capital – Management Strategy in Polish Organizations. In: B.F. Kubiak, A. Korowicki (eds.): Information Management. Gdansk University Press, Gdansk 2009, pp. 16-24.

[Lair08] Laird J.E.: Extending the SOAR Cognitive Architecture. In: P. Wang, P. Goertzel, S. Franklin (eds.): Frontiers in Artificial Intelligence and Applications, Vol. 171. IOS Press, 2008, pp. 224-235.

[Mitch97] Mitchell T.: Machine Learning. McGraw-Hill Companies, Inc., 1997.

[Plik08] Plikynas D.: Multiagent Based Global Enterprise Resource Planning: Conceptual View. „WSEAS Transactions on Business and Economics" 2008, Vol. 5, Iss. 6.

[PrFe06] Prince M.J., Felder R.M.: Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. „Journal of Engineering Education" 2006, Vol. 95, Iss. 2, pp. 123-138.

[Rohr14] Rohrer B.: An Implemented Architecture for Feature Creation and General Reinforcement Learning. Workshop on Self-Programming in AGI Systems, Fourth International Conference on Artificial General Intelligence, Mountain View, CA, http://www.sandia.gov/rohrer/doc/Rohrer11ImplementedArchitecture Feature.pdf [11.04. 2014].

[SaVe08] Sathish Babu B., Venkataram P: Cognitive Agents Based Authentication & Privacy Scheme for Mobile Transactions (CABAPS). „Computer Communications" 2008, 31(17), pp. 4060-4071.

[SoHe12] Sobieska-Karpińska J., Hernes M.: Consensus Determining Algorithm in Multiagent Decision Support System with Taking into Consideration Improving Agent's Knowledge. Proceedings of Federated Conference on Computer Science and Information Systems (FedCSIS), 2012.

[SoHe13] Sobieska-Karpińska J., Hernes M.: The Postulates of Consensus Determining in Financial Decision Support Systems. Proceedings of Federated Conference on Computer Science and Information Systems (FedCSIS), Kraków 2013.

[YuGr10] Yusoff N., Grüning A.: Supervised Associative Learning in Spiking Neural Network. „Lecture Notes in Computer Science" 2010, Vol. 6352, pp. 224-229.

METODY UCZENIA SIĘ AGENTÓW KOGNITYWNYCH A OBSZARY DECYZYJNE W SWD

Streszczenie

Stosowane obecnie systemy informatyczne wspomagają podejmowanie decyzji głównie na szczeblach operacyjnym i taktycznym, natomiast stają się niewystarczające na szczeblu strategicznym. Umożliwiają one bowiem jedynie analizę formy informacji, powiązań pomiędzy wartościami ekonomicznymi, natomiast nie wspomagają procesu

analizy ich znaczenia. Zasadne staje się zatem wykorzystanie narzędzi, które realizują funkcje poznawcze i decyzyjne, jakie zachodzą w ludzkim mózgu, dzięki czemu potrafią zrozumieć rzeczywiste znaczenie obserwowanych zjawisk i procesów gospodarczych zachodzących w otoczeniu organizacji. Do narzędzi tych należą między innymi agenty kognitywne, które często współpracują ze sobą w ramach systemu wieloagentowego, aby skutecznie osiągnąć wyznaczony cel. Jedną z najważniejszych cech agentów kognitywnych jest umiejętność uczenia się.

W niniejszym artykule dokonano analizy i usystematyzowania metod uczenia się agentów kognitywnych, które mogą być wykorzystane w konkretnych obszarach decyzyjnych wspomaganych przez system informatyczny. W pierwszej części przedstawiono charakterystykę i strukturę wieloagentowego systemu wspomagania decyzji. Następnie omówiono aspekty związane z problematyką architektur agentów kognitywnych. W końcowej części artykułu przedstawiono metody uczenia się agentów wyróżniane ze względu na różne kryteria, które mogą być wykorzystane w odniesieniu do danych obszarów decyzyjnych.