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ARTIFICIAL INTELLIGENCE AND MULTI-AGENT SOFTWARE FOR E-HEALTH KNOWLEDGE MANAGEMENT SYSTEM

Summary: In this paper, the authors describe and compare the features of examples of the multi-agent systems (MAS) in e-health. The descriptions of MAS in e-health are presented in four areas: assistive living application, diagnosis, physical telemonitoring, smart-hospital and smart-emergency application. The authors divided the e-health MAS due to the areas of supported knowledge management in e-health: (1) knowledge about the patient: K4CARE, U-R-SAFE, MyHeart, MobiHealth, (2) knowledge of the presented medical problem: OHDS, HealthAgents, IHKA, (3) contextual knowledge about the course of the conversation: CASIS, AID-N, CASCOM, Akogrimo and (4) knowledge of the health organization: ERMA, SAPHIRE.

Keywords: artificial intelligence, agent technology, e-health, knowledge management system.

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1. Introduction

Knowledge is often the basis for the effective utilization of many important resources [Sołtysik-Piorunkiewicz 2013]. In this context, multi-agent software (MAS) may play an important role in effectuating the knowledge-based view of the e-health organization by enhancing the capability to manage the knowledge it possesses. This awareness is one of the main reasons for the exponential growth of MAS for knowledge management systems (KMS). KMS are technologies that support knowledge management in organizations, specifically, knowledge generation, codification, and transfer [Davenport, Prusak 1998]. Nowadays every knowledge-based organization is trying to integrate both explicit and tacit knowledge in formal information system [Turban, Leidner, McLean, Wetherbe 2006]. KMS are implemented in an organization to cope with rapid changes of information using modern information technologies, e.g. intranets with information portals, artificial intelligence and multi-agents software, data warehouses and business intelligence.

The paper is organized as follows: first the authors present a review on knowledge management processes and systems, and then they show artificial intelligence and agent technology as a tool for managing the knowledge in e-health organization. The following section focuses on the e-health multi-agent software; the authors present a comprehensive view of characteristics of this tool and the comparative analysis of the four case studies (K4CARE, OHDS, MyHeart, CASCOM) in order to identify various areas of the e-health MAS. In the final section, the authors classify the usage of the examples of MAS to proper knowledge management processes in an e-health organization.

2. Knowledge management system

Knowledge management system is dedicated to help an organization to meet its goals and to increase its effectiveness. The literature review shows that multiple definitions of knowledge management system have been proposed in the literature, and debates about this concept have been expressed from a variety of perspectives and positions.

The knowledge management systems are based on four main phases of knowledge management cycle: knowledge generation, knowledge storage, knowledge distribution and knowledge application. Most life cycles are articulated in four phases where the first one is a knowledge creation. The second phase corresponds to the organization of knowledge. The third phase uses a different term across the models, but they all address some mechanism for making knowledge formal. Finally, the fourth phase concerns the ability to share and use knowledge in the enterprise. Therefore, in this article, the knowledge development cycle is defined as the process of knowledge generation, knowledge storage, knowledge distribution and knowledge application in an e-health organization as a knowledge-based organization. A detailed definition of these processes will be presented when linking them with the different tools of the agent functionality that support e-health knowledge management.

In this article the model of multi-agent knowledge management system is based on [Sołtysik-Piorunkiewicz 2014]:

- knowledge creation about the user,
- knowledge sharing of the presented problem,
- contextual knowledge about the course of the conversation during knowledge distribution,
- knowledge application in the organization.

3. Artificial intelligence and agent technology

Artificial intelligence, which is regarded as a scientific discipline, emerged after the introduction of the first computers. Those were ascribed to the skills characteristic of intelligent beings, including proving hypotheses, concluding, and games playmaking [*Sztuczna inteligencja i elementy…*2005]. Currently, the concept of the artificial intelligence is understood as a branch of IT, whose subject is the study of the rules governing the so-called intelligent human activities, and the creation of formal models of these behaviours, which in turn leads to the creation of computer programs that will simulate these behaviours. The above mentioned intelligent behaviours are [*Inteligentne systemy…* 2009]:

1) perception,
2) learning,
3) recognition,
4) usage of language,
5) symbol manipulation,
6) creativity,
7) solving problems.

Computer programs are used both for experimental and practical purposes, such as [*Inteligentne systemy…* 2009]:

1) sounds recognition (speech),
2) recognition of shapes (letters, drawings, photographs),
3) theorem proving,
4) running games (chess),
5) translation from one natural language to another,
6) music composition,
7) formulation of medical diagnoses,
8) expertise formulation.

The notion "artificial intelligence" (AI) was suggested in 1956 by John McCarthy from Massachuset Institute of Technology as the subject of a conference in Dartmouth [Owoc 2006]. The aim of the conference was to summarize and intensify further research on "thinking machines". The conference was a success. After that the work on projects that concerned the field of artificial intelligence was greatly intensified.

The concept of artificial intelligence cannot be precisely defined. One can find many definitions of artificial intelligence in the literature [*Wstęp do…* 2011]. Nevertheless, it is worth mentioning the first definition of artificial intelligence, which was introduced by John McCarthy: "[...] the construction of the machines, which can be said to be similar to the human manifestations of intelligence" [*Sztuczna inteligencja…* 2005].

Definitions, which appeared later, can be divided into four categories, taking into account two main criteria. One group of the definitions refers to the process of thinking and reasoning, while others take into account the behavioural factor (called behaviour). The second distinction between the definition of artificial intelligence takes into account the category of success. The examples of the definitions used in various categories were presented in Figure 1.

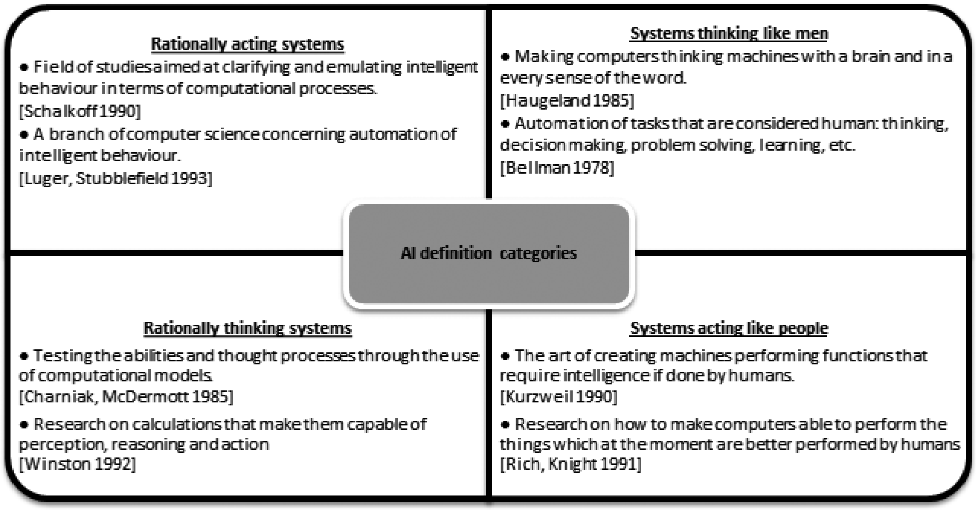

Figure 1. Organization of the artificial intelligence definitions into 4 categories

Source: own study based on [Sztuczna inteligencja… 2005].

One can distinguish two different approaches to artificial intelligence. The first one referred to as weak AI assumes that the computer allows to formulate and test specific hypotheses concerning the brain [*Inteligentne systemy*…. 2009]. The second approach, named strong artificial intelligence extends much more radical claims about AI. The followers of strong AI believe that a properly programmed computer is not only a model of brain but a brain as such [*Wstęp do*… 2011]. The origins of modern artificial intelligence can be traced to 1943, when McCulloch and Pitts proposed the neural network architecture to create intelligence. Seven years later, in 1950, A. Turing proposed the "intelligence test" [S*ztuczna inteligencja*… 2005].

Recently agent technology has become one of the most important areas of Artificial Intelligence (AI) research. An agent is an entity capable of performing some tasks and helping a human user in that way. Agents can be biologic (for example people), computational (software agents) or robotic. Software agents could be defined as a computer program that aim is carrying out some task on behalf of a user. The most important properties of agents are: intelligence, autonomy, cooperation and ability to learn [Coppin 2004].

Agent software which is combined into one system is named multi-agent system (MAS). It can be a very powerful tool. The following statements are characteristic in multi-agent systems [Coppin 2004]:

1) each agent disposes not complete information that is why an agent is not capable to solve the entire problem on its own,
2) only combined agents can solve a problem,
3) system does not use any centralized mechanism for solving a problem.

The main aim of agents is observing knowledge base in the current situation context and supporting the process of making a decision concerning an action by experts in their domain. The last step is executing that action on the environment [Cortés, Annicchiarico, Urdiales 2008].

Agents are often confused with expert systems. This results from the fact that those two entities have a knowledge base. A basic difference between them is how they use a knowledge base. Experts systems use logic in every situation, whereas agents act more like people: more important is to find result and accept some level of its probability than to find a perfect result [Henderson 2007].

4. Multi-agent software in e-health

There is a diversity of areas in medical industry and health care systems that could benefit from systems based on agent technology (especially MAS) [Cortés, Annicchiarico, Urdiales 2008]:

1) systems diagnosing diseases,
2) systems that recommend treatment,
3) patient history examination systems,
4) the support of palliative care units.

The descriptions of multi-agent systems in e-health are presented in table 1 [Bergenti, Poggi 2009], [Cortés, Annicchiarico, Urdiales 2008], [Furmankiewicz, Sołtysik-Piorunkiewicz, Ziuziański 2014], [K4CARE], [Peleg, Broens, González-Ferrer, Shalom 2013], [U-R-SAFE], [Ziuziański, Furmankiewicz, Sołtysik-Piorunkiewicz 2014] in four areas:

1) assistive living application: CASIS, K4CARE,
2) diagnosis: IHKA, OHDS, HealthAgents,
3) physical telemonitoring: MobiHealth, U-R-SAFE, AID-N, MyHearth, SAPHIRE,
4) smart-hospital, and smart-emergency application: ERMA, Akogrimo, CASCOM.

Table 1. Examples of multi-agent systems

Area	Name	Description
1	2	3
Assistive Living Applications	**CASIS** Context-Aware Service Integration System	Supplying context-aware healthcare services to the elderly resident in the intelligent space.
	K4CARE (2006)	Project combining healthcare and ICT experiences to develop, apply, and validate a knowledge-based healthcare model for assistance to patients living at home (elderly, the disabled persons, and the patients with chronic diseases).

Table 1, cont.

1	2	3
Diagnosis	**IHKA** Intelligent Healthcare Knowledge Assistant	Healthcare knowledge procurement system based on six agent types for dynamic knowledge gathering, filtering, adaptation and acquisition from a healthcare enterprise memory.
	OHDS Ontology based Holonic Diagnostic System	System supporting doctors in the diagnostic and treatment, and overseeing processes of the evolution of new epidemics. System is based on the exploration of all data pertinent to each case and on the scientific data contained in various professional databases
	HealthAgents	Research project with the goal of improving the classification of brain tumours distributed network of local databases.
Physical Tele-monitoring	MobiHealth	The main goal of it is telemonitoring of patients at home by monitoring, storage and transmission of vital signs data coming from the patient body area network (BAN).
	U-R-SAFE Universal Remote Signal Acquisition For hEalth	Research project with the goal of realizing a telemonitoring environment for elderly people and patients with chronic diseases.
	AID-N Advanced Health and Disaster Aid Network	Light-weight wireless medical system for efficiently gathered and distributed information on the vital signs and locations of patients.
	MyHeart	Research project whose focus was on preventing cardiovascular diseases using sensors integrated in clothing to monitor heart activity.
	SAPHIRE	Research project whose goal was monitoring chronic diseases both at hospital and at home using a semantic infrastructure.
Smart-Hospital, Smart-Emergency Applications	**ERMA** Emergency Medical Assistant	The main aim of ERMA was providing meaningful diagnoses and intervention suggestions to the healthcare team acting on behalf of the patient in the cases of emergency trauma with particular emphasis on types of shock and stabilization of arterial blood gases.
	Akogrimo	Research project whose main goal is the integration of the next generation grids with the next generation networks.
	CASCOM Context-Aware Health-Care Service Co-ordination in Mobile Computing Environments	The main aim of the project is to implement, validate, and try a value-added supportive infrastructure for Semantic Web based business application services across mobile and fixed networks.

Source: own study based on [Bergenti, Poggi 2009], [Cortés, Annicchiarico, Urdiales 2008], [Furmankiewicz, Sołtysik-Piorunkiewicz, Ziuziański 2014], [K4CARE], [Peleg, Broens, González-Ferrer, Shalom 2013], [U-R-SAFE], [Ziuziański, Furmankiewicz, Sołtysik-Piorunkiewicz 2014].

One of the examples of agent using in e-health is K4CARE, which is used in the assistive living area. K4CARE is a specific targeted research project, which was realized by thirteen academic and industrial institutions from seven countries over three years [K4CARE]. Table 2 presents institutions involved in the project.

Table 2. Institutions involved K4CARE

Number	Country	Institution
1.	Czech Republic	Ceske Vysoke Uceni Technicke v Praze
2.		Vseobecna Fakultni Nemocnice v Praze
3.	Germany	European Research and Project Office GmbH
4.	Hungary	Computer and Automation Research Institute of the Hungarian Academy of Sciences
5.		Szent Janos Hospital
6.	Italy	Azienda Unita Sanitaria Locale Roma B
7.		Universita degli Studi di Perugia
8.		Telecom Italia Spa
9.		Comune di Pollenza
10.		Santa Lucia Institute
11.	Romania	Fundatia Ana Aslan International
12.	Spain	Universidad Rovira I Virgili
13.	United Kingdom	The Research Institute for the Care of the Elderly

Source: own study based on [K4CARE].

K4CARE is an answer for human health needs in modern societies. The main receivers of agent are [Bergenti, Poggi 2009]:

1) older people,
2) people with disabilities,
3) people with chronic diseases.

Many of those people need professional care for 24 hours for their whole life. K4CARE connects healthcare and information and communications technology (ICT) experiences of several western and eastern European Union countries to create, implement, and validate a knowledge-based healthcare model for the professional assistance to patients at home. The main objectives of K4CARE agent are presented in Figure 2.

As an example of multi-agent system in diagnosis area OHDS has been chosen. OHDS (Ontology based Holonic Diagnostic System) combines the advantages of the holonic paradigm with multi-agent system technology and ontology design, in order to realize a highly reliable, flexible, scalable, adaptive, and robust diagnostic system for diseases [Hadzic, Ulieru, Chang 2014]. The main task of OHDS is to support

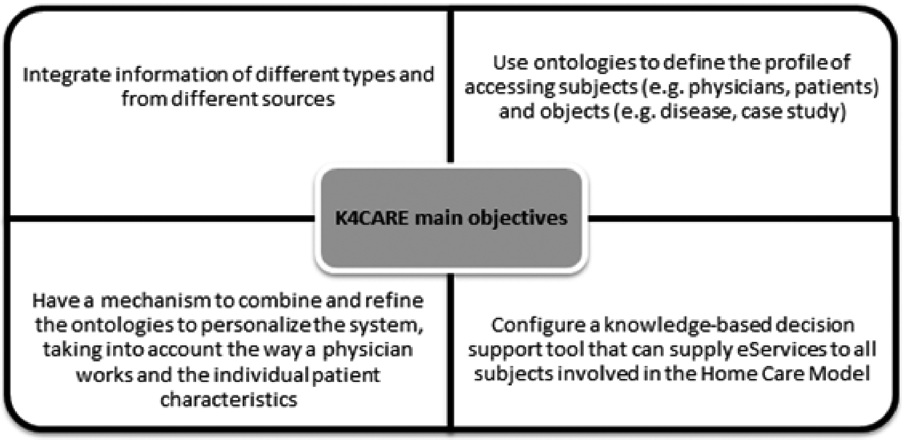

Figure 2. The main objective of K4CARE agent

Source: own study based on [K4CARE].

the doctors in the diagnostic, treatment and supervision processes of the evolution of new epidemics. This is possible based on the exploration of all data important to each case and on the scientific data contained in different professional databases [Bergenti, Poggi 2009].

MyHeart has been chosen to represent a multi-agent system in physical telemonitoring area. MyHeart is biomedical and healthcare research within the European Union. It started in 2003 and was run until 2010. Philips Research was the main contributor of MyHeart. As the name suggests the project was related to heart or rather to heart disease (Cardiovascular disease, CVD). This project was very important because this kind of diseases are the prominent reason of death in the western world [Sinadinakis 2011]. MyHeart project identified key product ideas that could help to prevent and to manage CVD, which is presented in Figure 3 [MyHeart 2014].

Technology used in mentioned areas is named intelligent biomedical clothes (IBC). It is connected with wireless-based telemetry and user interaction systems and it uses embedded textile sensors. One of the most important developed technologies in MyHeart relates to the signal processing algorithms. It is necessary to extract electrocardiography (ECG) data from the electrodes located in vest and bed sensors [Sinadinakis 2011] [MyHeart 2014]. MyHeart is solution delivering of following opportunities [Sinadinakis 2011]:

1) monitoring vital signs of inhabitants,
2) diagnosis making,
3) trend detecting,
4) reacting on all above.

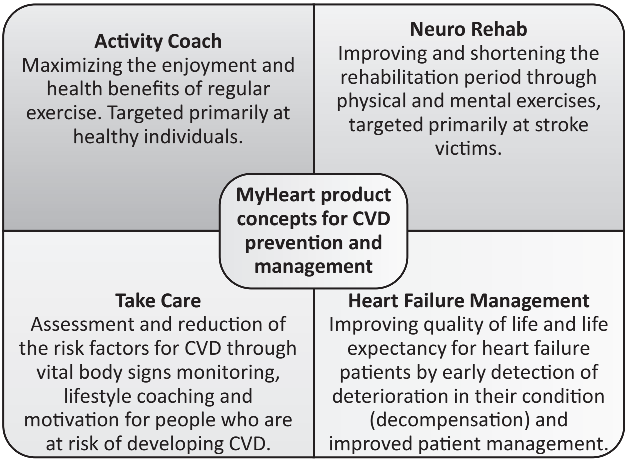

Figure 3. Key product ideas helping to prevent and manage CVD identified by MyHeart project

Source: own study based on [MyHeart].

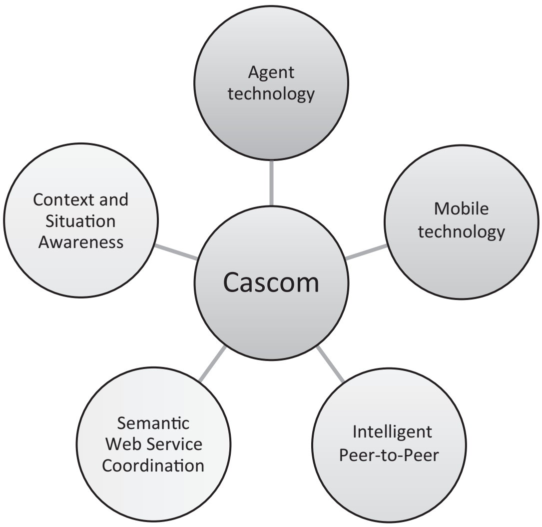

Fig. 4. Used technologies in CASCOM

Source: own study based on [Bergenti, Poggi 2008].

As an example of smart-hospital, smart-emergency applications CASCOM have been chosen. It is mainly a compilation of three growing up technologies: multi-agent systems, semantic Web and services and Peer-to-Peer (P2P) [Bergenti, Poggi 2008]. More accurate list of the technology used is presented in Figure 4 [Schumacher, Helin 2008].

The main aim of CASCOM is to develop, validate, and trial supportive infrastructure for business application services for mobile workers and users across the networks (fixed and mobile) [Cascom 2014]. The authors of the project have presented an e-health scenario showing possibilities of this solution touching one of the biggest challenges in emergency healthcare: making a decision on the treatment of patients without their medical history [Bergenti, Poggi 2008].

Another example of HealthAgents system is based on multi-agent technology and designed for diagnosing and forecasting brain tumors. Other example is SAPHIRE that is a multi-agent system for monitoring remote healthcare through electronic clinical guidelines [Cortés, Annicchiarico, Urdiales 2008].

5. The study of multi-agent software in e-health knowledge management systems

The model of e-health knowledge management systems is based on some criteria the agent software could support:
1) knowledge about the user,
2) knowledge of the presented problem,
3) contextual knowledge about the course of the conversation,
4) knowledge of the organization [Sołtysik-Piorunkiewicz 2014].

The study of MAS is based on four agent functionalities in e-health knowledge management systems:
1) knowledge about the patient,
2) knowledge of the presented medical problem,
3) contextual knowledge about the course of the conversation in e-health,
4) knowledge of the e-health organization.

The authors studied 13 different MAS dedicated for e-health: 2 examples of assistive living applications of MAS, 3 examples of diagnosis of MAS, 5 examples of physical telemonitoring of MAS, and 3 examples of Smart-Hospital, Smart-Emergency Applications of MAS. After the comparative study of different examples of MAS the authors classified them based on agent functionality in e-health knowledge management system.

The summary of the study is shown in table 3.

6. Conclusions

The features of the agent functionality in knowledge management e-health systems are divided into four areas. The results of the study show the following groups of e-health MAS: (1) knowledge about the patient: K4CARE, U-R-SAFE, MyHeart, MobiHealth, (2) knowledge of the presented medical problem: OHDS, HealthAgents, IHKA, (3) contextual knowledge about the course of the conversation: CASIS,

Table 3. Agent functionality in e-health knowledge management system

Multi-agents systems		Agent functionality in e-health knowledge management systems			
Area	Name	knowledge about the patient	knowledge of the presented medical problem	contextual knowledge about the course of the conversation	knowledge of the health organization
Assistive Living Applications	K4CARE	X			
Physical Telemonitoring	U-R-SAFE	X			
Physical Telemonitoring	MyHeart	X			
Physical Telemonitoring	MobiHealth	X			
Diagnosis	OHDS		X		
Diagnosis	HealthAgents		X		
Diagnosis	IHKA		X		
Assistive Living Applications	CASIS			X	
Physical Telemonitoring	AID-N			X	
Smart-Hospital, Smart-Emergency Applications	CASCOM			X	
	Akogrimo			X	
	ERMA				X
Physical Telemonitoring	SAPHIRE				X

Source: own study.

AID-N, CASCOM, Akogrimo and (4) knowledge of the health organization: ERMA, SAPHIRE. The future research will find the features of usability aspect of MAS for knowledge management system in e-health organization.

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SZTUCZNA INTELIGENCJA I MULTIAGENCI OPROGRAMOWANIA W SYSTEMIE ZARZĄDZANIA WIEDZĄ W E-ZDROWIU

Streszczenie: W niniejszym artykule autorzy opisują i porównują cechy przykładowych systemów wieloagentowych w e-zdrowiu. Systemy wieloagentowe w e-zdrowiu zostały przedstawione w czterech obszarach: aplikacje wspomagające życie pacjenta, diagnostyka medyczna, telemonitoring oraz inteligentne szpitale. Autorzy podzielili systemy wieloagentowe e-zdrowia ze względu na obszary zarządzania wiedzą wspierane w e-zdrowiu: (1) wiedza o pacjencie: K4CARE, UR-SAFE, MyHeart, MobiHealth, (2) znajomość prezentowanego problemu medycznego: OHDS, HealthAgents, IHKA, (3) wiedza kontekstowa z przebiegu rozmowy z pacjentem: CASIS, AID-N, CASCOM, Akogrimo i (4) znajomość organizacji ochrony zdrowia: ERMA, SAPHIRE.

Słowa kluczowe: sztuczna inteligencja, technologie agentowe, e-zdrowie, system zarządzania wiedzą.