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A novel robust metric for comparing the intelligence of two cooperative multiagent systems

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Abstract

Cooperative multiagent systems are used for solving many computational hard problems. In the scientific literature, the intelligence of cooperative multiagent systems is considered at the systems' level and is based on the "intelligent problem solving" consideration (highly efficient and flexible problems solving; difficult problem solving, with missing or erroneous data; efficient solving of NP – hard problems). In this paper, we propose a novel accurate metric called *MetrIntComp* (Metric for Cooperative Multiagent Systems Intelligence Comparison) for a robust comparison of two cooperative multiagent system's intelligence, effective even in the case of small differences in intelligence between the considered systems. For proving the effectiveness of the metric we considered an illustrative case study for two cooperative multiagent systems composed of simple agents, in that the intelligence emerge at the systems' level, each of them specialized on solving the same type of computational difficult, NP-hard problem. The conclusion of the case study was that the metric is able to make a differentiation between the two multiagent systems even the numerical difference between the measured intelligence is small. Based on this fact, the two multiagent systems could not be considered that belong to the same class of intelligence.

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1. Introduction

Most of the developed intelligent systems are agent-based systems [2, 3, 10, 16]. We call agent-based system generally agents and multiagent systems. Most of the developed multiagent systems are cooperative. In a cooperative multiagent system, the agents cooperatively solve the undertaken problems. Not all the agent-based systems are intelligent. It is not a mandatory property for an agent or a multiagent system to be intelligent.

In our approach, we will refer to agent-based systems, cooperative multiagent systems composed of two or more agents that cooperatively solve problems. The members of such a system are not necessarily intelligent but at the system's level emerge an increased intelligence. The study of those aspects related to computing systems intelligence is important in order to develop computing systems that are able to solve hard problems with different types of difficulties. Many times the most feasible solution

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of difficult problems solving consists in the intelligent agent-based systems approaches. Cooperative multiagent systems are used for many problems solving [2, 3].

Many times, in the scientific literature a cooperative multiagent system is considered intelligent based on the simple consideration that the efficient and flexible cooperation between the agents emerge in intelligence at the systems' level. Intelligent multiagent systems could be composed even of simple agents, who very efficiently solve problems. The existence of some properties that could be associated with intelligence does not allow a quantitative evaluation, just proves its existence. We consider that the evaluation of a system's intelligence should be made by some metrics that measure the "quantity of intelligence".

In this paper, we propose an accurate metric called *MetrIntComp* (Metric for Cooperative Multiagent Systems Intelligence Comparison) for the robust comparison of two cooperative multiagent systems' intelligence. For demonstrating the effectiveness of the metric we designed an illustrative case study of two cooperative multiagent systems, specialized in solving the TSP (Traveling Salesman Problem) that is an NP-hard problem. The metric is able to treat the variability in the intelligence of the multiagent systems. Depending on different situations, a cooperative multiagent system sometimes behaves with lower intelligence, other times behaves with higher intelligence.

The upcoming part of the paper is organized as follows: Section 2 presents different considerations related to intelligent agent-based systems and metrics for measuring the intelligence; in Section 3 is presented our proposal, in Section 3.1. is presented the proposed metric, Section 3.2 shows a case study, Section 3.3 includes a discussion on the proposed metric and the results of the case study; In Section 4 the conclusions of the research are presented.

2. Intelligent Agent-based Systems. Measuring Agent-Based System's Intelligence

In this section, we present some considerations related to intelligent agent-based systems, application of agent -based systems and some elaborated metrics for measuring the intelligence.

There are numerous researches presented in the scientific literature, that are focused on the development of agent-based systems able to intelligently solve different computational hard problems [2, 3, 16]. There are many interesting applications of intelligent agent-based systems, like regulation of the buyers' distribution in management systems based on simultaneous auctions [17], methods for the management of distributed electricity networks using market mechanisms [18], multiple energy carrier optimizations [19], users expect intelligent virtual agents to recall and forget personal conversational content [20], discovering Semantic Web services using SPARQL and intelligent agents [21], Intelligent Transportation Systems modeling with combinatorial auctions [22], web services and intelligent agents-based negotiation system for B2B eCommerce [23], tasks scheduling and communications management in a critical care telemonitoring system [24], and so on.

There is no unanimous definition of the agents' intelligence [2]. The intelligence estimation of the agent-based systems is realized based on different considerations. Many times the intelligence of an agent-based system is considered based on capabilities, like [3]: learning, self-adaptation, and evolution.

To illustrate the impossibility to define the agents' intelligence, let us consider the differences in intelligence between static software agents vs. of mobile software agents. Generally, mobile agents are more limited in intelligence than the static agents. There are very few developed mobile agents that could be considered intelligent. Limitations in the mobile agents' endowment with intelligence are based on some practical reasons, like: network overloading (the transmission of a large number of intelligent mobile agents - many times knowledge-based, with increased size, may overload the network with data transmission), hosts overloading (a large number of intelligent mobile agents, that execute complex computations, at a host may overload that host), limited communication possibility (the mobile agents migrate during their operation in the network, based on this fact it is difficult to estimate where a mobile agent is at a moment of time).

The chapter [16] argues that intelligent agents must know more than just the task they are performing during collaboration with humans. Intelligent agents should be able of managing engagement with the humans. The implementation of the affect is important in pertaining an efficient collaboration. The agents should develop a collaboration relation with the humans.

There are some researches [4, 9] focused on the study of decision making in the frame of cooperative coalitions. Decisions taken in the frame of coalitions, often outperform the decisions of individuals that operate in isolation.

In many cooperative multiagent systems, the intelligence could be considered at the level of the whole system [2, 3]. The intelligence in these systems is higher than the individual agents' intelligence [2, 3]. Yang, Galis, Guo and Liu [8] present an intelligent mobile multiagent system composed of simple reactive agents. The mobile agents are specialized in a computer network administration. They are endowed with knowledge retained as a set of rules. The multiagent system could be considered intelligent based on the fact that it simulates the behavior of a network administrator.

There are different metrics developed for making different measurements in intelligent systems. Such metrics not always are developed for measuring the whole system's intelligence, but only for measuring some aspects that represent interest. The paper [44] analyses the fault tolerant systems. A fault tolerant system is able to diagnose and recover from faults. Sometimes this property of the systems is associated with the intelligence. The authors propose a useful metric for evaluation that is the effectiveness measure of fault- tolerance.

The paper [45] presents a study realized by the US National Institute of Standards and Technology (NIST) related to the creating standard measures for intelligent systems. The researchers outline the question related with how precisely intelligent