COMPUTER SCEINECE DEPATMENT
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AIN-SHAMS UNIVERSITY

Machine Learning Algorithms for Multi-Agent Systems

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By

Khaled Mohamed Khalil Mohamed Mohamed

Under Supervision of

Prof. Dr. Abdel Badeeh Mohamed Salem
Professor of Computer Science
Faculty of Computer and Information Sciences
Ain Shams University

Prof. Dr. Taymour Mohamed Nazmy
Professor of Computer Science
Faculty of Computer and Information Sciences
Ain Shams University

Dr. Mohamed Hassan Abdel-Aziz
Basic Sciences Department
Faculty of Computer and Information Sciences
Ain Shams University

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List of Publications

1. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "Intelligent Techniques for Resolving Conflicts of Knowledge in Multi-Agent Decision Support Systems," in Proceedings of ICICIS'13: The Sixth International Conference on Intelligent Computing and Information Systems, ISSN: 1687-1103, 2013.

2. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "MLIMAS: A Framework for Machine Learning in Interactive Multi-Agent Systems," in *Journal of Procedia Computer Science*, Elsevier, ISSN: 1877-0509, vol. 65, pp. 827–835, 2015.

3. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "Machine Learning Algorithms for Multi-agent Systems," in Proceedings of IPAC 2015 the International Conference on Intelligent Information Processing, Security and Advanced Communication, ISBN: 978-1-4503-3458-7, article no. 59, 2015.

4. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "Multi-Agent Model for Job Scheduling in Cloud Computing," in *NAUN International Journal of Computers*, ISSN: 1998-4308, vol. 11, pp. 11-17, 2017.

5. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "Cloud Simulators – An Evaluation Study," in *International Journal Information Models and Analyses (IJ IMA)*, ISSN: 1314-6416 (Print), ISSN: 1314-6432 (Online), vol. 6, no. 1, pp. 3-25, 2017.

6. Khaled M. Khalil, M. Abdel-Aziz, Taymour T. Nazmy, Abdel-Badeeh M. Salem, "Multiply-Sectioned Bayesian Network for Multi-Agent Learning Based Meta Resources Scheduling in CloudSim," in Proceedings of the ICICIS 2017 The 8th International Conference on Intelligent Computing and Information Systems, IEEE, ISSN: 1687-1103-2017, ISBN: 977-237-172-3, vol. 2, pp. 185-190, 2017.

Abstract

Multi-Agent Systems are used in a wide range of applications such as e-commerce, simulation, robotics, traffic control, manufacturing, health care, and Cloud Computing. The complexity of many tasks arising in these domains makes them difficult to solve with preprogrammed agent behaviors. Agents instead need to discover a solution on their own, using learning. The heart of the problem is how agents will learn the environment independently and then how they will cooperate to achieve the system goals. Furthermore, how the agents could coordinate and decide in order to achieve these goals. The objective of this study is to answer these commonly asked questions from the machine learning perspectives.

Multi-Agent Learning is not merely a matter of "straight" learning, but a matter involving complex patterns of social interaction and cognitive processes, which leads to complex collective functions. Many of the techniques developed in machine learning can be transferred to settings where there are multiple, interdependent, interacting learning agents, although they may require modification to account for the other agents in the environment. Furthermore, Multi-Agent Systems present a set of unique learning opportunities over and above single-learner machine learning. In a Multi-Agent System, an agent is always acting in the context of other agents, and so it must adapt its plans according to its expectations of the others.

Considering these interlinked issues of uncertainty and coordination, this thesis attempts to build upon existing algorithms for learning and decision making under uncertainty, including explicit models of other agents. A framework for interactive Multi-Agent Learning is proposed. Then, two modified machine learning algorithms are provided for collaborative agents learning, namely: Q-Learning and Multiply Sectioned Bayesian Network. The main case study applied in experiments is the Job Scheduling problem in Cloud Computing Systems. A model for multi-agent based Job Scheduling in Cloud Computing is proposed. Then, several jobs scheduling scenarios are experimented with the proposed framework and the two proposed machine learning algorithms showing the feasibility and improvements to the case-study performance.

First, an evaluation study is provided for Cloud Simulators. The scope of the study is to find the weak points of the existing Cloud Simulators for improvements. This thesis focused on the Job Scheduling concepts. Second, a Multi-Agent based model is proposed for the problem of Job Scheduling in Cloud Computing Systems. The proposed model improved the end-to-end utilization by 30% and the delay performance by 10%. The cause behind that is the shared blackboard pattern where agents store their information about the available resources. Third, a framework for Machine Learning in Interactive Multi-Agent Systems is proposed for a novel metaphor of interactions between agents. The proposed framework works on sharing information within the learning process among agents in the team. Proposed modifications to Q-Learning algorithm are provided following the proposed interactive framework and results are showing great improvement in the performance of the whole system. The mathematical basics are presented following the proposed behavior. Improvements provided include 2 times improvement in average reward received and 80% improvement in the number of trails to reach the goal. This is because agents were being able to get recommendations from other agents about their next actions that maximize their overall performance. At the end, another proposed and modified Multiply-Sectioned Bayesian Network algorithm is used for meta-scheduling problem in Job Scheduling in Cloud Computing. The proposed algorithm is saving computation power and storage for the meta-scheduling problems by 60%. Also, it improves the search time for a best fit machine by 40%. The proposed modifications to the algorithms works like a router that routes the request to the group of machines that has the highest belief to get the request assigned successfully taking in consideration the available resources and utilization.

The results of this work is believed to be one step towards enhancing existing machine learning algorithms for Multi-Agent Systems in dynamic environments. Moreover, there is a possibility of employing the proposed framework and algorithms to other applications areas of e-Health and data analysis with some modifications.

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List of Abbreviations

Acronym	Definition
MAL	Multi-Agent Learning
MASs	Multi-Agent Systems
MSBN	Multiply-Sectioned Bayesian Network
QoS	Quality of Service
SLA	Service Level Agreement

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Chapter 1

Introduction

Chapter 1: Introduction

In a Multi-Agent System (MAS), an agent is always acting in the context of other agents, so it must adapt its plans according to its expectations of the others. This needs to take other agents, coordination and decision making into account. In uncertain and open systems, the protocols for coordination must function against a background where agents are not fully aware of the situation, the resources available to them, or the presence or goals of the other agents. In addition, agents decisions' must function under constrains of uncertainty and preference of other agents.

Considering these interlinked issues of uncertainty and coordination, thesis work attempted to build upon existing techniques for learning and decision making under uncertainty, including explicit models of other agents, thus tackling the problem of providing coordinated behavior in uncertain MASs. Moreover, acknowledging the growth of MASs in real and increasingly large applications, factor issues associated with scalability into proposed solutions will be endeavored. Thesis started by formalizing study aims and objectives, then brief of contributions is provided. After that, the thesis highlighted the main activities and overall structure and layout of the thesis chapters.

1.1 Thesis Motivation

This thesis is motivated by the increasing application scenarios of MASs. By definition, MASs consist of a number of agents that have limited communication and computation capabilities. One common and basic requirement in these MASs is that agents need to cooperate and make decisions in uncertain and dynamic environments. Agents can learn to handle such problems. In addition, agents have many inherent advantages of learning capabilities such as robustness and flexibility.

To solve the aforementioned limitations, this dissertation turns its attention to machine learning algorithms. The first part of the thesis is focused on the modeling of the domain problem in the metaphor of MASs. Then, the second part is working on modifying two machine learning algorithms to follow the proposed model mechanism. To bridge the

gap between the two parts, this thesis proposes an interactive framework which provides both agent-level and system-level implementations. In summary, agent performance can be improved by cooperation with other agents and learning from the surrounding environment. This is exactly the motivation of this research.

1.2 Thesis Objectives

The focus of this research is to better explore and understand the effects of learning capability of agents in their interactions, information feedback, and decision making. This thesis developed a multi-agent based model for Job Scheduling in Cloud Computing Systems. Then, a framework is proposed for interactive learning metaphor in MASs. After that, two machine learning algorithms are adapted and they are presented in the form of the proposed framework.

1.3 Thesis Contributions

The main contributions of this thesis are summarized below:

- A multi-agent based model has been developed for Job Scheduling in Cloud Computing. This model maps the functions of the Job Scheduling domain into MAS that benefits from the capabilities of the MAS into the field of Cloud Computing resource management.
- A multi-agent based interactive framework has been developed. The proposed framework is based on sharing the information within the learning process to gain other agents knowledge about the domain.
- The Q-Learning algorithm has been extended following the proposed interactive multi-agent based framework to show the improvement of scheduling results.
- The Multiply-Sectioned Bayesian Network (MSBN) has been extended to handle another point in the Job Scheduling field, which is the meta-scheduling. Meta-scheduling is interested into routing the tasks to the groups of resources that can fit the task requirements.