Applications of Collaborative Multi-Agent Technology to Business: A Comprehensive Survey

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Intelligent, multi-agent technology offers a host of new opportunities to businesses across industry and business segments

The collaborative, intelligent, multi-agent technology has witnessed a considerable attention in recent years. This technology promises to offer a host of new opportunities to business communities in almost all the vertical industry and horizontal business segments. Applications built using these technologies enable dynamic data and information acquisition, aiding planning and decision making. In this paper, an attempt has been made to present a landscape of plausible applications, which could be very useful to the current CxOs of enterprises in planning future business strategies.

MULTI AGENT SYSTEMS (MAS) : BACKGROUND

An intelligent agent is a distinct kind of software program concept that has a goal, has knowledge of one or more domains of relevance, is autonomous (pro-active) in achieving its goal, is reactive to the changes to the environment in which it pursues its goal and is capable of communicating with humans and other agents [1, 2]. These agents possess basic characteristics like (i) role to play, (ii) one or more goals to achieve, (iii) capability to take actions autonomously, (iv) capability to monitor the environment periodically and pro-actively and effect changes, if required, (v) capability to sense and react to the changes to environment, and (vi) capability to communicate with humans, and extended characteristics like (i) specific knowledge in one or more subjects, (ii) capability to communicate and collaborate/ compete with other agents, (iii) ability to be mobile and move around in the environment, if needed, to achieve the goals [3].

Henceforth in this paper, the term agent refers to a software agent with the above mentioned basic and/or extended characteristics.

Simple problems can be solved by agents with basic characteristics whereas complex problems require multiple intelligent agents that collaborate and/or compete among themselves. Systems built using the extended characteristics are known as multi-agent systems (MAS) [4].

Some popular applications of MAS are:

- Multiple agents with different roles collaborate among themselves to continuously monitor road traffic and effect changes to signal durations at road intersections in order to improve traffic flow [5]

- A personal assistant agent (residing on a mobile wireless connected device of its owner) detects and interacts with other similar agents of a local social-network in a geography and offers a variety of services of interest to its owner [6]

- A set of agents with different roles collaborate among themselves in a supply-chain management environment leading to enhanced productivity and quality [7, 8].

PRIOR SURVEYS

A survey on applications of agents in telecommunications describes how (i) agents in 'Integrated in Service Provision' help in mediating all personal communication from different media sources with specific user needs, (ii) agents help in automating some of the network management and supervision tasks, and (iii) agents help distributed problem solving [9].

Abbott and Siskovic discuss the various ways in which agents can be used in managing the network resources, in configuring software programs, in the maintenance and repair of software programs, in e-mail filtering, network monitoring and protection, etc [2].

A survey on applications of agents in medical science presents agents-based Intelligent Decision Support Systems (IDSS) in areas of clinical management and clinical research [10]. The study also analyzes the applications of agents-based IDSS in Neonatal Intensive Care Unit (NICU).

Mladenic shares a survey on the applications of agents in text analytics and learning where machine learning approaches viz., content-based approach and collaborative approach, with various user interface agents have been discussed [11].

A survey carried on 'Distributed Artificial Intelligence (DAI)' illustrates how multi-agents coordinate with each other in accomplishing complex tasks and handling conflicting situations. It also discusses game theory involving inter-agent cooperation [12]. Yet another survey by Kowalczyk et al., narrates various short overviews on intelligent and mobile agents in e-commerce [13].

Tveit describes an overview of agent oriented software engineering [14]. Hoekstra offers a survey on the usage of intelligent agents in dynamic scripting, genetic algorithms and neural networks for video games business [15].

However, given the possibility that future ITES is likely to heavily depend on and utilize the collaborative MAS technology, the details offered by the above surveys are found to be inadequate. CXOs require a comprehensive and latest view on the landscape of applications of MAS technology to various vertical and horizontal business segments. Our survey addresses this need.

APPLICATIONS OF MULTI-AGENT TECHNOLOGY

There is evidence of fairly exhaustive surveys on the applications of MAS technology to various vertical industrial segments such as banking and capital markets [16, 17, 18], travel and tourism [19, 20, 21], telecommunications [6], transportation and services [22] and bioinformatics [23, 24, 25] and horizontal business domains such as knowledge management [26], supply chain management [7] and software project management [27, 28, 29, 30]. The subsequent sub-sections present a landscape view of these applications.

Application of MAS Technology in Vertical Industry Segments

Banking and Capital Markets

The rapid growth of e-commerce in recent years has given rise to concerns in the area of tax evasion and mitigation. Wei et al., [16] explore and exploit the power and features of mobile, multi-agent technology to offer a new solution to this taxation problem, even while preserving the privacy of the purchaser. The authors propose the use of five types of mobile agents, viz. purchaser agents, seller agents, bank agents, tax agents and certification agents, that interact with each other in the creation and tracking of Electronic Invoice (EI) and Electronic Tax Voucher (ETV) leading to efficient and simplified e-commerce taxation mechanism. The authors simulated the proposed solution using IBM's Aglet workbench.

The phenomenal growth in the area of mobile wireless network users has led to a great opportunity for the banking industry to offer mobile banking services such as the capability for the users to perform various banking transactions viz., seek account balance, get alerts on changes to bank accounts, perform money transfers, pay utility bills, etc., through their mobile devices. Adagunodo et al., present an 'Interactive SMS Banking Agent' based innovative, incrementally scalable, mobile banking solution [17]. In this solution, the real time (24 hours a day and 7 days a week) SMS banking agents run on a server (thus avoiding the need for distribution and deployment) and offer a range of banking transactions through SMS facility on mobile devices.

There are many areas of social operations such as visiting a restaurant, a hospital, an entertainment park or a theater, where users would like to know dynamically and easily about the availability of resources. Muguda et al., in their paper describe a very interesting application of mobile agents [18]. They discuss their experiments to characterize and model the benefits of planning in such environments, where resources can be reserved and such reservations can be traded in a market place.

Travel and Tourism

If people can dynamically get details on their mobile wireless network enabled handheld devices about a historical place, monument or a piece of art work that they are currently looking at, it can be of immense value to them. Bombara et al., offer details of a multi-agent based system called KORE that aims to address the above need and provide a 'personal guide' to assist museum visitors through the visitor's wireless connected handheld device [19]. KORE was developed as a prototype using Java Agent Development Environment (JADE) to work on Palm m505 PDA and consists of:

- Main museum server, that has global information database with details of all the works of art in the museum

- Information service agents that provide access to main museum database
- A set of zonal servers that have a database with details on works of art in that particular zone along with zone information agents that are responsible for managing the database
- Beamer agents that drive the IR beamers
- User mobile agents that use WAI (Work of Art Identifier) from IR beamers and provide information based on 'Users Preferences.'

Tourists visiting a particular city would like to dynamically receive details such as places to visit, restaurants nearby, visiting hours of a tourist spot, etc., on their mobile devices.

Lopez and Bustos describe a multi-agent system architecture that provides services like obtaining up-to-date information on places of visit and planning for a specific day in tourism industry [20]. This MAS system architecture consists of broker agents, sight agents, user agents and a planning agent. Communication among these agents is based on a common ontology. Various services like search, reserve, plan a specific day and register have been provided to the users. When a user requires details on places of visit, she uses various services provided by a user agent. Then the user agent sends a REQUEST message to a broker agent, that in turn processes and forwards message to sight agents that match the parameters and return a set of results that match the user's requirements containing relevant information about each site. In order to reserve, the user agent sends PROPOSE message with required information to a sight agent, which then reserves the bookings or sends refusal if reservation is not possible. A plan agent presents plans on receiving a REQUEST message from the user agent such that time can be managed efficiently throughout the day. The authors have developed a prototype and implemented it using JADE-LEAP platform on Hewlett Packard iPAQ 5450 that has Bluetooth and 802.11b onboard to run the user agents.

Similarly, Balachandran and Enkhsaikhan present the use of MAS technology in automating various services in travel industry involving airline tickets, hotel accommodations, taxi services, etc [21]. These agents communicate with each other and negotiate the services to provide an optimal solution to a customer. The different types of agents used in creating this MAS based application are:

- Business agents such as travel agents, flight agents, hotel agents, car agents that are specialized assistant agents for the customer using this system

- Database agents that are responsible for performing all database operations such as queries and updates.

Transportation Services

Increasing population has led to increase in traffic. There are limited parking spots in busy commercial localities, malls, offices and colleges. People spend a lot of time finding a parking space.

To address this problem of finding parking space Ganchev et al., have demonstrated a multi-agent based system solution wherein a set of different types of agents collaborate to automatically and dynamically locate a parking space in a university campus. These ideas can be extended to offer similar service in other locations of public interest. The system can inform the user through her mobile wireless

connected device [22]. The authors presented a detailed three tier architecture of this solution consisting of: user mobile devices, geographically dispersed InfoStations and a central InfoStation center. Different types of agents mounted on these devices or systems collaborate through WPAN or Wi-Fi or Wi-Max connections. In this solution, a user makes a request for a parking slot through the mobile device. This request will be forwarded to the nearest InfoStation by the personal agent residing on the user's mobile device. If the nearest InfoStation cannot confirm a parking slot in its geography, it escalates the request to the InfoStation center which then locates the near optimal parking slot if available and informs the personal agent of the user. This system was implemented using JADE framework and LEAP module that facilitate implementation of agents on mobile devices. One can imagine that, in future, it is possible to make such a personal agent intelligent and proactive whereby (i) it can examine the plans of its owner in advance and proactively collaborate with appropriate InfoStations and reserve parking slots, and (ii) dynamically negotiate changes to these reservations by sensing changes / delays to the plans of its owner.

Roozemond and Rogier discuss the use of intelligent agents to build traffic control systems that pro-actively bring changes in real time to various traffic scenarios [5]. Information agents collect information about weather, traffic jams, public transport, route closures, best routes and various parameters that control traffic via a secure network and send it to the user and the control stations. Signal durations would hence be determined based on the measured and predicted data. Traffic regulation and tuning is done with coordination among adjoining agents.

Bioinformatics

The adoption of multi-agent systems constitutes an emerging area in bioinformatics [23]. In fact, a working group on Agents in Bioinformatics (BIOAGENTS) was founded during the first AgentLink III Technical Forum meeting held in July 2004, with a purpose to explore agent technology and develop new flexible tools for (a) analysis and management of data, and (b) for modeling and simulation of computational biology.

GeneWeaver is a multi-agent system comprising of a community of agents, having five distinct roles, that collaborate with each other in order to automate the processes involved in bioinformatics [24].

Armano G et al., describe a multi-agent system for Protein Secondary Structure Prediction (PSSP) by a population of homogenous 'experts' [25]. The authors discuss how multi-agent technology is a very good fit to address the problems of PSSP.

Telecommunication

The advent of wireless connected mobile devices has enabled human beings to be connected with other humans and information systems anytime, anywhere. Such a paradigm shift in connectivity coupled with the MAS technology is showing a phenomenal potential for a new set of social and business applications.

Bryl et al., have used multi-agent technology and Bluetooth enabled mobile devices to create and use ad-hoc social networks [6]. These social networks can hence be used to provide access to a variety of services that allow users of a locality to interact and transact in areas of mutual interest, such as 'buy and sell books in a university campus.' A generic architecture of independent servers is presented where multi-agent platforms can be installed

and agents can act on behalf of their users. Each server is meant to offer one or more specific services (e.g., buy and sell books) of interest to the geographic area in which it is located (e.g., a university campus). The strength of this architecture is that it is (a) domain independent where each server can offer different services relevant to its location, and (b) independent of the MAS technology used (one can use different MAS technologies such as JADE on each server). A prototype with 'buy/sell books' service has been developed and implemented using JADE and tested using Nokia 6260 and PC/Server equipped with Tecom Bluetooth adapter. Bluetooth communication has been implemented using Blue Cove which is an open source implementation of the JSR-82 Bluetooth API for Java.

Application of MAS Technology in Horizontal Business Segments

Knowledge Management

Knowledge Management (KM) is gaining importance in large organizations owing to their geographically distributed operations spread across different time zones. Such organizations are increasingly tapping into global markets on the one hand and resources on the other. KM systems attempt to offer the latest knowledge of the enterprise – knowledge extracted and created from structured and unstructured sources - to the employees who need it.

Houari and Far offer a comprehensive methodology to build such a sophisticated KM system using the multi-agent systems technology [26]. They discuss how a KM system built using agents with distinct roles, cooperation and communication capabilities, intelligence, autonomy and shared ontologies can be used to achieve better utilization of knowledge in decision-making.

Supply Chain Management

A typical supply-chain manager is responsible for (a) managing the optimal arrival and stocking of a range of input materials from different sub-contractors, and (b) the integration and processing of the input materials to produce and deliver a variety of finished products to the clients. The management of this responsibility in today's world is still human centric. The supply chain manager and her team interact with the teams representing the sub-contractors, enterprise production units and the clients. These interactions are known to involve many tedious tasks that are error prone. In addition to that, the lack of latest information from all these sources can impact cost, productivity and quality of products delivered to the clients.

To achieve better coordination in the flow of information among the sub-services of a supply chain management, Wang et al., propose the use of a variety of software agents [7]. The problem of coordination among sub-services is modeled as a distributed constraint satisfaction problem which is solved collaboratively by the group of software agents. The steps involved in this solution methodology are as follows:

- Decomposing customer requirements into a set of services represented by a business process or plan. This can be achieved by means of any workflow representation or hierarchical task network (HTN) wherein each task is broken down into sub-tasks and uses task-reduction rules to decompose abstract goals into lower level tasks.

- Find and coordinate the actors that would be fulfilling these services.

These steps are achieved by creating multiple service dispatcher agents, service broker agents and service provider agents. The requirements are initially analyzed by the dispatcher agent, based on the customer's requirements and history of customer requests. Following this, each service broker agent forwards the request to service providers for collecting bids or solutions to the request. Once all the bids are received, the next step is to filter the dominated solutions and then identify compatible and promising solutions. The final step is to refine constraints for a global solution by means of communications between the various service broker agents, thereby achieving coherence and coordination.

Kern et al., discuss on how intelligent software agents can help humans in carrying out different tasks involved in supply chain management [8]. Their project, titled as MobiSoft, proposes a new form of supply-chain management. In their approach, a mobile device based software agent that performs the role of a personal assistant is provided to each of the humans involved in the supply-chain process flow. These personal assistant agents interact and collaborate to reduce human errors and provide latest information to their owners anytime, anywhere thereby enabling the teams to achieve higher levels of productivity and quality.

Software Project Management
An important characteristic of business management is the use of dialogues by a community of professionals to solve problems. One of the serious problems confronting the business managers, in their problem solving and decision making endeavor, is the high degree of dependency on human interactions and the high degree of manual interpretation

of dialogues by humans. Such a dependency on manual intervention lends itself to problems that can result from (i) the unpredictable, inconsistent egoistic behavior of humans that one witnesses time to time, (ii) the drop in efficiency of humans under stressful situations, or (iii) the use of less experienced/qualified humans for managing tasks due to lack of sufficient number of adequately skilled human resources.

Sethuraman et al., illustrate the application of MAS technology to one such business management task, viz., software project management (SPM) [27]. The authors discuss the various sub-tasks of SPM that can get benefitted from the use of MAS technology. They use the task of 'Quality Review' which is initiated and completed at the end of each phase of the software lifecycle and demonstrate how a set of personal assistant agents assigned to each (a) software engineer, (b) quality assurance reviewer, (c) quality assurance manager and (d) software project manager, collaborate among themselves and manage the 'Quality Review' task efficiently. The agents manage many steps of the process of 'Quality Review' but do not perform the sub-task of actually reviewing the artifacts. The main advantages brought out by this research are (i) productivity improvement, as the agents perform many mundane tasks that otherwise consume the time of experienced software professionals, and (ii) consistency of ensuring that the task of 'Quality Review' is initiated and completed at the right time and any incompleteness is recorded and escalated in time.

Petrie et al. illustrate how MAS technology can be utilized for propagation of dynamic knowledge, such as designs and plans that are changed according to the status of project execution, between the project

designers and planners, such that the effects of changes are communicated properly [28]. The effort is concentrated on provision of support for complex projects, where it is crucial to communicate changes to necessary actors on time, also termed as Distributed Integrated Process Coordination. The authors characterize their coordination model as a logical set of dependencies among the project elements that can be used to determine the effects of changes within the project. To implement this, Redux dependencies model was used, which tracks validity within the dependency model and notifies designers as and when changes occur. They exhibit this by means of a central facilitating event which uses these Redux dependencies for decision making and propagation. They conduct a case study by means of a building construction example.

Nienaber et al., talk of a comprehensive black-box model of a generic agent framework that could be used in different phases of software project management [29]. The paper discusses the creation of personal assistant (PA) agents, messaging agents, task agents, monitoring agents and team manager agents. A multi-agent system comprised of these types of agents is used in the framework to support various aspects of SPM, such as scope management, time management, cost management, quality management, human resource management, communication management and risk management. The paper discusses the prototype design of the system and proposes the development of the same using JADE framework.

Pitt et al., describe the design and implementation of a 'CEC GOAL' project, that aims at development of generic software tools to support distributed project management, which is collaborative, decentralized and inter-

organizational [30]. The authors propose the use of autonomous software agents to provide for normalization of inter-organizational terminology and flow of information, structuring of inter-organizational interactions with respect to contracts and working practices and also to enable each organization to provide or use services required or offered by other organizations. It uses a distributed review process as an example to exhibit the application of an agent system with behavior specified by means of decision logic. They consider a quality control scenario, where the deliverables are largely technical papers. The project office aims to assure quality of the papers by means of getting them reviewed by at least three reviewers. Hence a call for participation for performing this review is sent out, followed by an 'announce and negotiate' way of aiding this review process.

CONCLUSION

MAS is found to be increasingly adapted by various industry verticals and horizontal business segments. There is an important need to present a comprehensive survey of the current and potential future applications of MAS technology, which is undertaken in this paper. The landscape of case studies discussed in this survey points to a host of new opportunities to various business communities.

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