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TECHNOLOGICAL SUPPORT OF AN INQUIRING ORGANIZATION: MOVING FROM CONCEPTUALIZATION TOWARD IMPLEMENTATION

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Abstract

Organizations are operating in increasingly complex environments. Simply functioning effectively in these environments requires increasing amounts of information; creating, storing, and retrieving this information is of paramount importance. To effectively manage these tasks, organizations must adopt flexible technology capable of withstanding dynamic environments and which enable the organization to maintain and evolve a reliable data store. A framework for such an organization is based on the philosophies underlying inquiring systems (Churchman, 1971) and is known as an inquiring organization (Courtney, 1998). These organizations require specific components to enable them to sustain themselves in a dynamic environment. Some of the necessary components are defined in this paper, and software technology capable of performing the functions of these components is discussed. Available and feasible agent techniques are listed as evidence of the feasibility of this approach.

Introduction

Various systems have been used to support organizational processes. There is a need, however, for providing support in a more active, proactive, and interactive manner. Furthermore, in ill-structured problems, more than one perspective should be included in order to achieve a more comprehensive understanding of the problem at hand. A system that can work with more than one perspective and where applicable knowledge and information are available is capable of functioning in a scenario of complex and fuzzy problems. Inquiring systems begin to approach this level. Inquiring systems are characterized by the properties of the five inquirers described by C. West Churchman (1971). They have the ability to gather and model evidence in a way that represents the system's view of reality. Inquiring systems provide support for various organizational processes such as decision-making or goal setting. This is done partly by facilitating and encouraging member communication, providing feedback throughout the process (especially with temporally or contextually relevant information), and by providing access to reliable organizational memory in a way that facilitates retrieval. Inquiring systems also create and manage knowledge (Courtney, 1998; Hall, Paradise, & Courtney, 2000; Kienholz, 1999). Organizations based on the philosophies underlying inquiring systems are called inquiring organizations (Courtney, 1998).

In his work on inquiring systems, Churchman (1971) summarized inquirers into five categories based on the underlying philosophies of Leibniz, Locke, Kant, Hegel, and Singer. These inquirers share components and work together to comprise an inquiring system, which is the fundamental basis of an inquiring organization. The Leibnizian inquirer maintains a set of elementary axioms and stored knowledge. After the system identifies a potential truth (candidate), it uses the fact net to deduce the candidate's legitimacy. If legitimacy is found, the candidate is added to the knowledge store. In the Lockean inquirer, external/internal observations can become "knowledge" (asserted into a classified observation store) by consensus. The Kantian inquirer is an extension to the Leibnizian inquirer with the addition of a multiple model generator that incorporates various perspectives. The Hegelian inquirer can be thought of a system consisting of opposing Leibnizian inquirers with a synthesizing component that combines the strongest assumptions of each Leibnizian inquirer. The Singerian inquirer is the most comprehensive; it incorporates multiple perspectives and provides a highly organized process of validating information. In the face of no information inconsistencies to eliminate, the Singerian system challenges existing knowledge and works to refine the measures on which that knowledge is based. Along with various characteristics unique to each philosophical basis, each inquirer utilizes five components that together act as integrity checks. These checks serve to protect the system by ensuring that the system maintains its integrity despite changing environmental variables or temporal effects. The flexibility inherent in this series of

components makes inquiring organizations in general, and the higher order inquirers particularly, suited to functioning with ill-structured or wicked problems, which are common in political, dynamic organizational settings (Hall et al., 2000).

This paper begins by developing some concepts that support the functionality of the inquiring organization and applicable components are produced. Next, the application of agent technology to serve as a basis for implementing those concepts is considered, both from a general standpoint and then by discussing three special applications of agent technology that is applicable to inquiring organizations. The paper ends with a discussion of the direction of research in the area of supporting inquiring organizations with agent technology.

Support Components for Inquiring Organizations

The design of an inquiring system based on the five philosophical approaches must include components derived from the philosophy underlying each system. For instance, Churchman writes about the need for an inquirer to routinely examine itself in order to assure validity (1971, p. 129) and that an inquirer must contain a filter that ensures that valid assumptions are stored (1971, p. 96). From these (and other) statements, one can conceptualize integrity components such as basis, environmental, self-adaptation, and analysis integrity verifiers. Additionally, Churchman (1971) is particularly concerned with the idea of temporal integrity – that an organization be able to track its progress toward a goal and to know when each step must be completed or when a goal cannot be met before a time constraint has arrived. This concern gives rise to a fifth component, a time/space assessor (Courtney et al., 1998, Hall et al., 2000).

The first four components listed above are concerned with integrity of knowledge stored and knowledge generated within the system. A *basis verifier* is critical to all the inquirers, as they depend on their knowledge bases to create new knowledge and analyze information. If any of the information in a knowledge base is incorrect, the system will reach the wrong conclusion about any item compared to the incorrect base item. Additionally, it will reach the wrong conclusion with all items subsequently compared to any aspect of the base built upon the initial erroneous conclusion. An *environmental verifier* is also critical for much the same reasons. It varies from a basis verifier in that, rather than continuously comparing knowledge in the store against itself, it reviews incoming information or newly created knowledge to determine whether changes have occurred in the environment that would, in turn, affect the validity of other stored knowledge components. Commonly, knowledge becomes outdated as an organization's processes or resources (particularly technology) mature. A *self-adaptation verifier* allows the system to support management by preparing reports of recommended action in the face of new knowledge, especially in response to changing environmental variables, which makes this component a critical facet of functioning in a turbulent environment. This component monitors knowledge base changes to identify new relationships or new knowledge that arise from newly stored knowledge or changing information. Prevention of storage or use of knowledge based on error is inherently obvious; however, many systems have been designed that do not verify the accuracy of their internal models and therefore propagate incorrect information. A component such as an *analysis integrity verifier* can warn a user of potential problems with information or knowledge that the user wants to store.

A component such as the *time/space component* plays an important role in the efficiency of the organization as well as integrity of the organization's knowledge base. Its primary function is to follow time-critical missions of the organization, and to ensure that all temporal considerations of the organization are met. Additionally, it works to maintain time-sensitive knowledge and information such that outdated information is removed and information nearing its expiration is flagged and possibly sent to the self-adaptation verifier for action. Together, these five components comprise the integrity process that surrounds the inquirers, forming the basis of an inquiring organization.

In order to support the dynamic nature of a wicked environment, a system must be able to go beyond a functional (action-oriented) process and toward an achievement (goal-oriented) process. Huff and Lesser (1988) demonstrate how non-monotonic reasoning can be used to assess the credibility of complex alternatives. Their system works with assumptions and is capable of revising assumptions through the use of its truth maintenance system. The same need for reasoning in a complex and dynamic environment exists for inquiring organizations. Agent technology is an example of existing technology capable of addressing this need.

A Multi-level Multi-Agent Architecture for Inquiring Organizations

An agent, primarily a software agent in our context, is defined as "a self-contained program capable of controlling its own decision making and active, based on its perception of its environment, in pursuit of one or more objectives" (Jennings & Wooldridge, 1996). Agents can exist in an environment that may dynamically affect the agents' problem-solving behavior and strategy (non-monotonic reasoning). Further, agents are capable not only of functioning autonomously, but also of collaborating with other agents. For example, Bui and Lee (1999) proposed a framework for a cooperative decision support system that incorporated

cooperating agents (either human or not). Based on their description of an Internet-based DSS being a form of Cooperative Information Systems, their framework relates primarily to situations in which the task, although possibly complex, is likely pre-determined. While this framework is appropriate for that context, a multi-agent framework may be necessary to support components underlying an inquiring organization. Originally considered to be from the domain of Artificial Intelligence, agents are now being applied across domains. Agent technology can be used to implement components that support inquiring organizations. The design question becomes how to apply existing agent technology to achieve that goal, or whether to design new agents with these tasks in mind. We begin to answer this question by first proposing a multi-agent architecture with multiple levels for inquiring organizations in this section, then examining existing agent technology to support one core function (integrity checking of inquiring agents) in next section.

Part of what makes the agent concept worthy of consideration is that it is a good abstraction tool. Sometimes treated as a natural extension of objects, agents are capable of concurrent actions and semantic knowledge, and of exhibiting social behaviors (Wooldridge, 1997), which make agents suitable for higher-level tasks. Furthermore, agents can work with each other to perform a multitude of functions. Multi-agent systems are collections of agents with emergent behaviors. Thus, an inquiring organization can be conceptualized as a multi-agent system -- a collection of inquiring and supporting agents.

In an inquiring organization, there are five types of inquiring agents, corresponding to the five philosophical inquirers; each inquirer has its own collection of integrity checking components. We argue that an inquiring organization needs all five types of inquirers and their support components, working primarily in a collaborative mode (Figure 1). That is, within an organization, these agents do not generally possess conflicting goals or compete over resources, although some competition may arise because of the lack of availability of critical resources. The need for coordination of resources calls for a resource agent (RA in Figure 1), which is in charge of breaking down tasks, making assignments, allocating resources, and attending to conflict management as necessary. Of course, the role of a resource agent can be strong or weak, depending on the level and type of coupling among agents. A strong resource agent (such as the one show in Figure 1) may not be necessary if the agents will solve resource coordination issues among themselves through friendly negotiation. There is also a need for an interface agent (the smiling face in Figure 1), which is responsible for handling the interaction /communication between the human user and the system, so that human agents are included as part of the system. The collective goal is to provide relevant, accurate information by maintaining a consistent knowledge base and providing organizational strategies for processes such as decision-making or goal setting.

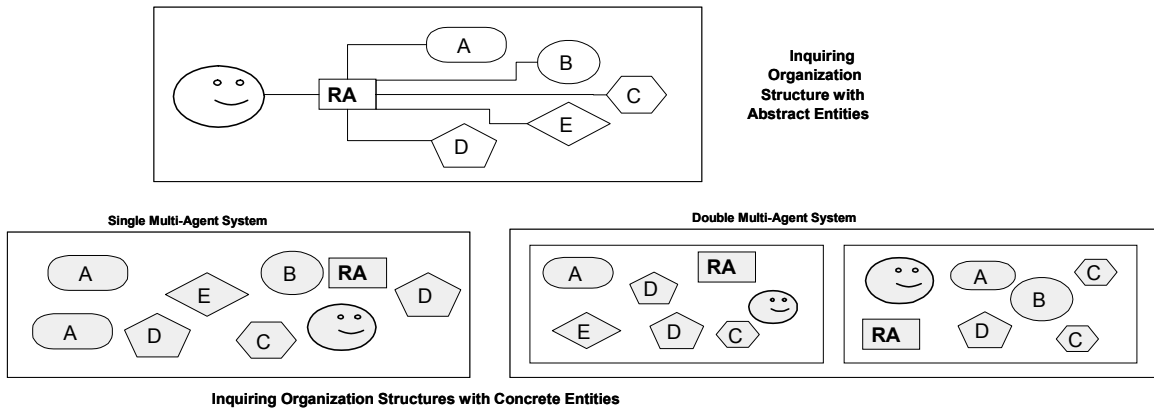


Figure 1. Inquiring Organizations as Multi-Agent Systems

An organization is an arrangement of relationships between components and therefore dynamic. Using the terminology of Ferber (1999), a multi-agent system itself is an organization. The structure of organization expresses the static part; thus, defines characteristics of a class of organizations on the abstract plane (p. 88). The same organizational structure can act as a basis for the definition of a multitude of concrete organizations; that is, a particular concrete organization is one possible instantiation (p. 89). These five types of inquiring agents are abstract entities (Figure 1, A to E, unshaded). Relationships among them comprise an abstract organization. For a particular/concrete organization, there may be different numbers of each type of inquiring agents or support components (Figure 1, left side, shaded). Furthermore, a concrete organization can consist of more than one group of various agents for example, two organizations (Figure 1, right side, shaded). This exemplifies the recursive property of the “multi-agent system” concept. Thus, these present two special cases for inquiring organizations, each as a special implementation or configuration suited to unique requirements of a particular organization.

Ferber (1999) points out that “an agent then being considered as a multi-agent system in its own right when the concept of a multi-agent system is applied to the definition of the architecture of the agent” (p. 140). This multi-agent concept then is applied to inquiring agents and supporting agents in Figure 1. A multi-agent structure for one inquiring agent is pictured in Figure 2. The

strategy provider’s function is to differentiate between five inquirers and their representative agents. The knowledge base can be centralized or distributed over the organization, but each inquiring agent can have “local memory.” Integrity checking (or truth maintenance) in this leveled environment is a challenge. The interface agent is included here to present the need for human-computer interaction, as it is important to recognize the importance of the human agents’ input into an inquiring system. Even though the system may be multi-agent, one interface agent may well be able to carry out the task of facilitating the interface between the human and non-human agents. The integrity-checking agent will carry out the tasks of the components we discuss in next section to ensure the validity of the knowledge base. In turn, it can be treated as a multi-agent system with its own five agents, which are the basis verifier, environmental verifier, self-adaptation verifier, analysis integrity verifier, and time/space assessor as discussed above. The technological support for these components is the focus of next section.

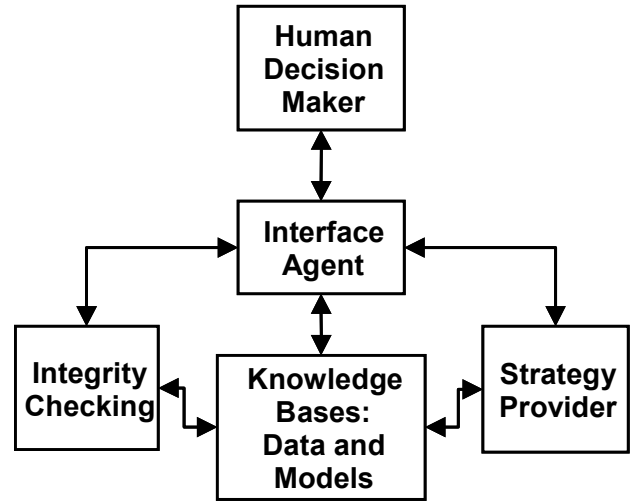


Figure 2. An Inquiring Agent as a Multi-Agent System

Conceptualizing an inquiring organization into a multi-level multi-agent system simplifies and clarifies the architecture of such a complex systems, summarized in table 1. Use of such architecture helps conceptualize mapping available technology to implementation of the system, and analyzing the technological feasibility of a multi-agent system approach to developing support for inquiring organizations.

Table 1. Summary of Multi-Agent Architecture for Inquiring Organizations

Level	Multi-Agent System	Components
Level 1	Inquiring organization	Inquiring agents and supporting agents
Level 2	Inquiring agents	Interface agent, integrity-checking agents, strategy provider, etc.
Level 3	Integrity checking	Basis verifier, environmental verifier, self-adaptation verifier, analysis integrity verifier, and time/space assessor, etc.

Existing Agent Technology to Support Integrity Checking

The components listed above can be conceptualized and implemented into multi-agent systems that provide support for inquiring organizations because 1) the knowledge is continuously checked for integrity and continuously generated, and 2) each of the components offers assistance in a unique (but sometimes collaborative) way. This approach has been proven to be constructive in many cases (for instance, Bose and Sugumaran, 1999; Chuang and Yadav, 1998; Vahidov and Elrod, 1999). Once a component’s function has been defined for a inquiring organization, it is reasonable to examine existent technology to determine whether that component is available to use either “as-is” or with moderation necessary to infuse that technology into the organization’s existing technology. This task is facilitated by the flexibility and portability of the concepts behind agent technology. Agents currently exist that parallel most, if not all, of the functions listed in the above components.

Agent technology was developed in the artificial intelligence (AI) discipline and AI techniques are commonly embedded in agents. For example, Lamirel and Crehange (1994) describe an object-oriented system built on a design that emphasizes components. The system, called NOMAD, exhibits several of the features we describe. NOMAD works with thematic knowledge that is synthetically constructed primarily in an unsupervised mode. The themes enable different perspectives of a particular domain. A thematic knowledge manager (i.e., component) controls the thematic reasoning of the system, which includes abilities to complete thematic queries, “recenter” thematic queries (i.e., find the best theme connected to an original query), and “reformulate” thematic queries (i.e., find a new set of relevant themes based on user decisions). While some may argue that this level of performance is more the exception than the rule (Mingers, 2001), technology and AI research continue to advance. For instance, Bradshaw et al. (1999) are working on standardized tools to facilitate the development of sophisticated agents.

A common objective between AI research and inquiring organizations is knowledge facilitation (Fowler, 2000). Knowledge engineering, an AI sub-field, focuses on systematically capturing and representing domain knowledge. Because it is impractical to list all the AI/agent techniques that may potentially be applied to building or selecting agents for inquiring organizations, some regular techniques are assumed herein and not directly addressed. For example, search algorithms, planning, inferring logical

languages, and resource model representations are widely used in various agents, such as Retriever (Fragoudis & Likothanassis, 1999) and Softbot (Etzioni & Weld, 1994). Three techniques with special applications are discussed below. Table 2 summarizes the discussion.

Table 2. Summary of AI/Agent Techniques to Support Integrity Checking

Agents of the Integrity Checking Component	Critical Requirements	Techniques
Basis Verifier	Accuracy of system basis	Truth maintenance
Environmental Verifier	Knowledge store continually reviewed for accuracy in changing environments	Perception, learning, and mobility
Self-adaptation Verifier	New action requirements	Default reasoning, learning
Analysis Integrity Verifier	Prevents assimilation in error; prevents other knowledge store components from being assimilated because of an error	Proof and explanation
Time/Space Assessor	Time/Space Assessment	Temporal logic

The integrity checker is concerned about the validity of knowledge created and stored. Techniques to maintain truth in a knowledge base are the basis for any evolving system and any inquirer with a locally operated knowledge base. Truth Maintenance System (TMS) techniques have been studied and developed since the late 1970s (Russell & Norvig, 1995) and can be used to improve knowledge base integrity. We can conceptualize a knowledge base in its simplest form as a collection of logical sentences. Some sentences become outdated or not applicable due to the passing of time or changes that have occurred. Therefore, in addition to retrieving information, we also want to have the ability to remove outdated information or information that is no longer valid. The challenge is to not introduce any inconsistencies or degrade the system when deleting sentences. In AI, the process of keeping track of which additional propositions that need to be retracted is the principle behind truth maintenance (Russell & Norvig, 1995). TMS is capable of keeping track of dependencies between sentences so that retraction will be more efficient. Naturally, the major task of such a program is to use dependency-directed backtracking and avoid inefficient chronological backtracking. A second task is to provide explanations of propositions, which is critical to analysis integrity verifier. A proof is one kind of explanation. If the proof is not accomplished successfully, assumptions are provided to explain why the proof is not possible. A third task of TMS is default reasoning, which is useful for self-adaptation verifier. A last task for TMS is to ameliorate possible inconsistencies by adding sentences.

Self-adaptation verifier not only passively produces reports at arrival of new information, but also actively makes recommendations. In order to do so, it needs to be able to learn over time. Although Mae’s agent (1994) is a personal assistant agent designed to control incoming emails, learning via a neural network makes this agent a perfect example of what a self-adaptation verifier should do to achieve the goal of learning. There are many techniques developed in machine learning, either from data (data mining and neural networks), observation and human feedback, or from other artificial entities (Hu & Wellman, 1998) that can be used to implement the self-adaptation verifier. It is quite possible that an environmental verifier will also have learning capability. Because the environment is essentially dynamic, it is impossible for an agent to consider and respond to every stimulus. A more desirable behavior is to focus on the relevant information and be proactive in the search for information. Learning is needed for an agent to find out what is relevant to the current context and what is not.

Because its task involves monitoring changes occurring in environment, there is a need for the environmental verifier be able to move through different environments and through different perspectives. Mobility of agents is a popular area in agent research and predicted as the future of the Internet (Kotz & Gray, 1999). The environmental verifier can send smaller applets to retrieve new information from relevant locations in a distributed inquiring organization. Mobility is also valuable for the basis verifier that is in charge of maintaining global consistency across a decentralized knowledge base. There are arguments for the trade-off between the increased complexity of mobility and the benefits that mobility provides. These tradeoffs must be considered before mobile agents are implemented.

Because we conceptualize the inquiring organization as a multi-agent system, one of the challenges is communication among agents due to its distributed nature. We believe that a communication architecture, such as one based on the blackboard architecture, will be sufficient to support the agents. Blackboard systems were first developed in the context of traditional artificial intelligence for speech recognition in early 1980s, but have been applied to distributed artificial intelligence and multi-agent systems because of their flexibility and powerful parallelism. The coupling among inquiring agents and among verifiers is variable and not heavy in an inquiring organization, which makes a blackboard-based structure suitable. A traditional, typical blackboard system consists of three parts: a set of separated knowledge bases (KS), a shared base (“board”), and a control device. The board encompasses the partial states of the problem in the process of solution and is the place where the separated knowledge

bases exchanging data. The control device manages conflicts of access between the separated knowledge bases. After twenty years, blackboard systems have been extended and applied to many domains successfully. For example, Pinson et al. (1997) built a distributed decision support system for strategic planning using four blackboards to facilitating communication among decision support agents. Blackboards would be used as part of data exchanging mechanism among inquiring agents and among various integrity checking agents during implementation of a multi-agent system to support an inquiring organization. For instance, if the basis verifier detects an inconsistency, it can post the finding onto the board for other agents to “see”. Multiple blackboards may be required in such a system.

Conclusions and Further Research

A review of extant literature indicates that agent technology is a widely researched topic in a variety of domains. Likewise, the problems that arise in organizations from inaccurate, untimely, or difficult to find information are an issue. Combining the framework of inquiring organizations with agent technology will give rise to technological support of components designed to work in turbulent environments. While existing agent technology can and probably would be used in various design projects, it is not unreasonable to consider developing agents that specifically function as support components for inquiring organizations although attention must be paid to appropriate agent design.

According to Kautz et al. (1994), a difficulty in agent design is the specification of the proposed agent’s task and along with that, consideration of the complexity of the necessary technology and whether that technology is available. Technology is continuing to produce platforms capable of supporting a wide range of agents and generally is not a problem if the task is within that technology’s bounds. Task specification, on the other hand, is certainly critical. However, when designing agents for an inquiring organization, one need only look to the underlying philosophies of Churchman’s (1971) inquirers to find the functions and tasks necessary. In fact, the components outlined in this paper are not exhaustive of the possibilities for agents inherent in an inquiring organization. A secondary problem that arises when designing agents for a multi-agent system is that of coordination of agents. A component of the inquiring organization not addressed specifically in this paper is the guarantor, which guides processes along the proper path according to the context and complexity of the problem being addressed. In this manner, this component acts similarly to a coordinator of agents. The strategy provider from Figure 2 would be a sub-agent to the coordinator. Barbuceanu and Fox (1997) conceptualize coordination as a series of structured conversations between agents.

Clearly, both the technology and the foundation for implementing existing agents or newly designed agents for use in inquiring organizations exist. The task of the researcher now is twofold. The first task is to continue to investigate Churchman’s (1971) inquirers for components necessary to support the underlying philosophical bases. The second task is to begin to conceptualize, select or build, and implement those components into a comprehensive system that will support an inquiring organization, or indeed, any organization faced with a constantly changing landscape.

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