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Efficacy of Fuzzy Representation of Knowledge for Integrated Management of Networked Systems

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Abstract
For most modern networked systems, the traditional element-based management views are replaced by integrated management structures that take the nature of the enterprises and the services they provide into account. These complex systems need capabilities to accommodate for diverse areas, ranging from administration of elements to provision of services and management of the enterprise itself. This is not an easy task. While many automated approaches are in use, to a large extent the effectiveness of the integrated management depends on understanding the functions of its components and their relations with one another. For most organizations, it is impossible to ascertain models that describe various roles, functions, and interactions of such components in a precise and yet useful manner. As such, human interactions are crucial for their proper operations. Human intelligence is for instance needed to deal with the incoherent and conflicting data with varying degrees of relevance for managing the tasks in hand. Such a need is also a direct consequence of the extensive utilization of linguistic variables in communication amongst staff and managers. In this work, these points are further discussed leading to elaboration of ways to utilize fuzzy modeling to improve integrated management effectiveness. We propose an integrated management design framework, which is based on multiple agents, where each human role is supported by an agent. It will be shown that through facilitating the cooperation among the entities involved in a given task, the framework can result in improving the effectiveness of the integrated management.

Keywords: Fuzzy logic, Fuzzy Modelling, Integrated Management, Knowledge Granulation, Networked Systems.

Introduction

Successful management of any complex system or large enterprise is dependent upon cooperation amongst a number of individual and entities. As discussed by Wang and Cheng (2004), one of the basic difficulties in achieving robust analytical solutions in cooperative management environments relates to the difficulty in quantifying cooperation and awareness levels (AL). Modern organizations are heavily dependent on proper utilization of IT and particularly on the use of networks, networked resources, and connectivity to the Internet. These now constitute vital parts of these organizations.

It is also well established that for most modern networks, the centralized management is no longer viable and a fully distributed architecture is forecast. As it will be discussed in later parts of this paper, artificial intelligence (AI) techniques can find various uses in distributed and flexible management areas. Conventional IT solutions provide some degree of automation for processing and filtering the data. But human interactions remain essential, as the data is often incomplete and conflicting or the information may be

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irrelevant to the task in hand. These issues have been discussed in our previous works, for instance see Shahrestani (2008). Furthermore, the ever-increasing complexity of the networks has some intense technical implications for management systems. Network management requirements have rapidly evolved from those relating to administration of equipment to efficient provision of solutions addressing the concerns related to a combination of services, applications, and enterprise management issues. Additionally, modern systems result in an overwhelming amount of data as a result of comprehensive monitoring abilities.

In principle, AI techniques are designed and implemented to overcome such predicaments and to limit the system dependency on human involvement. In particular, several characteristics of fuzzy modeling make it suitable for enhancing the efficiency of integrated network management systems. Such characteristics include flexibility in dealing with imprecision and vagueness, as well as the capabilities to coordinate and manage several models and rules. But perhaps the most powerful aspect of such modeling relates to the capabilities it provides for computing with words and the use of natural language in complex analysis. Zadeh (1965) introduced the notions of computation with words and the use of linguistic variables to manage the inherent fuzziness in human queries, representation of concepts and coordination, properly and efficiently.

In practice, humans acting as operators, experts, managers and the like, describe these concepts in linguistic terms and analyse them qualitatively. As we have discussed in our previous works, Shahrestani (2003), this leads to imprecise descriptions, models, and required actions. In that sense, uncertainty permeates the entire management process. The information regarding the context of needed support and the type of awareness models that can be built to represent them are among crucial aspects of an efficient management system. While traditionally and in general the main components used in the definition of a context are observations or facts, the data on relevance and confidence may add precious information. The latter piece of information can be easily amended and handled by fuzzy logic based approaches.

One of the available solutions is based on the so-called intelligent agents. Benech (1996) has shown that, this allows for the system management to reflect on the changes of the managed entities dynamically. These can also be used in taking the further steps to improve cooperation needed in achieving better service levels, amongst the entities making up an integrated management system. Provision of collaborative services requires cooperation among various entities of an organization. One of the core difficulties in analysis and finding better solutions in integrated management environments stems from the inherent issues in modeling collaboration and quantifying awareness levels.

This work will further discuss the utilization of soft computing and fuzzy system concepts to identify a fuzzy framework to quantify awareness levels to facilitate their implementation. In particular, this work proposes a design framework and describes several ways that fuzzy representations and knowledge granulations can be used to identify or to improve the solutions to problems encountered in an integrated network management environment. As with other fuzzy systems, this framework will accept crisp measurements, as inputs and produce crisp outputs, e.g. awareness levels, while fuzzy logic operations are used internally to reach inferences for effective cooperative management.

Fuzzy Awareness Modeling and Knowledge Granulation

In general, awareness relates to possession of relevant information for a given task. Normally, this information is made available to certain entities for some specific purpose. Awareness modeling is an area that has witnessed significant research to define various types of

awareness and supporting awareness. In most of these works, it is argued by Grudin (1994) that an individual's level of awareness is increased by perception of information about a given event or object, rather than by receiving that information. At any case, to be of practical value in any collaborative environment, a design methodology incorporating a reasonable approach for utilization of awareness levels is a prerequisite.

From a practical point of view, the assignment of the AL of each role for a given task is more conveniently achieved with words like *minimal* or *high.* This can be related to the fact that humans (operators, experts, managers, customers…) prefer to think and reason qualitatively, which in turn leads to imprecise descriptions, models, and required actions.

Associations and collaborations of humans are partially or fully dictated by their level of awareness of the ability of others to support them to fulfill their responsibilities, as explained by Grudin (1994) and Lim, et al (2009). In general, awareness relates to being cognizant and possessing the relevant information or informed. Information itself is not necessarily equivalent to awareness. Wang (2004) defines awareness as the knowledge or facts which are normally acquired from some form of study or observation. As such, awareness modeling and levels can play significant roles in improving the management efficiency. The awareness levels in human beings and managers have a fuzzy nature with linguistic variables extensively used in their characterizations and communications. For instance, Table 1, adapted from our previous works Ray et al (2005), shows the required awareness levels and satisfaction levels for a number of interactions.

The granulation involves the replacement of awareness level, *AL*, of a particular role, for instance technician D, defined in the crisp terms, e.g., between 0 and 4 in the form

AL (D) = a (where a is crisply defined as a member of {0, 1, 2, 3, 4})

by

AL (D) is A.

Where *A* is a fuzzy subset of the universe of the awareness levels of the roles. For instance, the technician's lowest awareness level may be represented by

AL (D) is minimal.

Given the semantic definitions that are actually based on the use of linguistic variables this notion of fuzzy logic is obviously more appropriate. In this sense, while AL (D) = *a* is a particular characterization of the possible values of the technician's awareness level, the fuzzy set *A* represents a possibility distribution. Now, the possibility of the *linguistic variable* AL (D) is represented by a *linguistic value* as the label of the fuzzy set taking a particular (*numerical*) *value b.* In this sense, while *AL (D) = a* is a particular description of the technician's awareness level, the fuzzy set *A* represents a possibility distribution taking a particular numerical value *b* given by

Possibility {AL (D) = b} = μ_A *(b).*

The membership function μ, represents the grade of membership of *b* in *minimal,* as the technician's Awareness Level. This is mainly related to the complex nature of the dependencies of these levels and the knowledge required at each level on the variables that actually quantify them. For instance, they could include contact address and actions of others involved in that task. Even for rare cases that such dependencies can be identified, the use of linguistic variables to make use of the tolerance for vagueness it is still advantageous, as it allows for more intelligent explanations leading to lower solution costs. This will furnish for designing systems for most practical situations, where the awareness levels are expressed vaguely by supervisors and others involved.

The knowledge about AL of each role for a given task that is based on linguistic variables can act as a descriptive and flexible profile for that role. More specifically, the fuzzy values signify a technician's AL that can be used for

Table 1: Awareness and satisfaction levels, adapted from Ray et al (2005).

Interaction	Awareness Required	Awareness Supported	Awareness Gap	User Satisfaction level
1	1 for each role	1 for each role	No	8 (High)
2	3 and 2	1and 2	Yes	3 (low)
3	4 and 1	3 and 0	Yes	3 (low)
4	3 for each role	1 and 0	Yes	3 (low)
5	3 and 4	1 and 3	Yes	3 (low)
6	4 and 3	3 and 1	Yes	2 (low)

different purposes. The profiles can be used for identifying and ranking of suitable technicians for a given task. Furthermore, the profile for a given technician provides a means for easy identification of the additional knowledge that the technician needs to carry out a given task. Furthermore, through forming of fuzzy clusters of profiles, one can establish aggregate profiles. Such aggregate profiles can be used an overall picture of the AL of the technicians within the organization.

One can now characterize interactions with fuzzy-based definition of the awareness levels. Zadeh (1994) shows how this will provide for the description of the complex systems and interactions using the knowledge and experience of customers, managers, and other involved people in simple English-like rules. Given the range of tasks and the required awareness levels, each human role will need to have a software agent to implement the desired awareness level for an interaction. The implementation of such a multi-agent framework mentioned by many researchers, including Nuansri et al (1997), needs to consider a range of intelligent techniques, such as case-based reasoning, active directories, neural networks, and appropriate rules and policies

This coordination process is closely related to de-fuzzification procedure that maps the resulting output fuzzy set B into a crisp output u. Various methods have been nominated in the literature with a possibility for the output membership function is based on considering singleton output membership functions. That is, the output MF is considered as a single spike rather than a continuous distribution. With fuzzy sets A_1^i to A_n^i and $\mathbf{x}=[x_1 \ldots x_n]^T$ the (crisp) input, a general typical inference based on m fuzzy rules in this model can be described by

IF x_1 is A_1^i … AND x_n is A_n^i THEN $u^i=f^i(x_1,\ldots, x_n)$, i=1, 2,…, m.

Where $f^i(.)$ is defined crisply. This approach proposed by Mamdani (1977) is a highly efficient approach as the weighted average

of at most m data points needs to be calculated, that is

$$u(x) = (\sum_{i=1}^{m} u^{i}(x) \mu_{A}^{i}(x)) / (\sum_{i=1}^{m} \mu_{A}^{i}(x))$$

Where μ_A^I represents the multivariable MF resulting from evaluation of the n conjunction parts in the antecedent of the rule. The linear dependence of each rule on the system input variables combined with the efficient centroid calculation, make this approach ideal for supervisory level construction. That is, for systems that are considered by several models the interpolative capabilities of the described fuzzy system can be efficiently utilized for modeling the overall behavior of the system. At the higher layer, it can be effectively used to supervise and coordinate multiple control actions and tasks that have been designed or identified for different conditions of a system.

At the management level, the discussed coordination process can be effectively used to supervise and coordinate multiple entities that possess different pieces of information, collectively needed for achieving a task in an integrated management environment. The fuzzy-based characterization results in models that are easy to understand, use, and expand even by non-experts. Clearly, the fuzzy-based methodology offers significant benefits. In this case, an obvious advantage is related to simplification of modeling process. We have already discussed in Shahrestani (2005) that several automated approaches for classification of dynamic fuzzy models have been developed. In addition, as the fuzzy systems are rule based, the system designer can focus on the actual design process. The abstract system design involves the realization of appropriate awareness levels for every interaction by designing appropriate group repositories, appropriate group communication mechanisms and tools.

Fuzzy-based Management and Collaborative Works

The need for distribution of network management is already well established, for instance see Shahrestani (2003). This is evident by the approaches such as definitions of remote monitoring management information base (MIB) or mid-level manager MIB, for example. In general, the integrated network management is concerned with a combination of issues relating to equipment, services, applications, and enterprise management. In this context various new requirements need to be met by network management solutions. Some of these requirements are mentioned in this section, while some possible enabling approaches for complying with them are discussed in later parts.

Within a cooperative environment, an intelligent system can be built upon the collaborative nature of the queries by noting the implicit connection between the individuals. The system should be capable of taking into account the individuality of different users; e.g. different people will generally use different keywords for the same query. Therefore, the emphasis should be on concepts, structure and connection of keywords as well the behavior and awareness levels of the individuals using those keywords. One of the main applications of the awareness model of the user (or its agent) is related to the use of the awareness level terms as part of the query (resulting in an expanded query). The intelligent information system will then be able to elevate the awareness levels of the individuals by pointing to them the data set items they might have been missing otherwise.

Consider the hierarchical model for network management discussed by Bakser et al (2002). At the highest layer the problems can be associated with an overwhelming amount of data. The AI techniques should process the data and present only the relevant information by acting as a decision-support tool. At this layer, the response time is important but not critical. This type of task is well suited

for techniques that implement search techniques, e.g. genetic algorithm. Also, model-based expert systems can be used to hide the network complexity behind several abstraction levels. In this context soft computing can be used to handle model/data uncertainties and ambiguities, while interpolating between possibly several emerging models. The resultant aggregate model will also have some degree of confidence attached to it that will assist the operators in dealing with the presented information.

While in the following parts we take a closer look at some of the tasks in the service layer, it can be noted that the above discussion holds for both service and network management layers. For example, as mentioned by Huang et al (2008), AI based network management systems that deal with the problems at network layer, are mostly based upon expert system techniques. From a broader point of view, the ability to handle huge amounts of information is a prerequisite for management of complex systems. The experience gained on a problem represents the knowledge that can be of value in the future. Information retrieval (IR) tools are the very bases for any process that deals with large databases. In a standard IR context, uncertainty pervades the behavior of both the system and the users. To undertake uncertainty problems in an adaptive manner, soft computing offers excellent solutions. For instance consider the problem of information retrieval, possibly in a cooperative manner, or possibly to achieve some collaborative tasks.

Administering the Awareness Levels

Within a cooperative and management environment, an intelligent system can be built upon the collaborative nature of the queries by noting the implicit connection between the individuals. The system should be capable of taking into account the individuality of different users; e.g. different people will generally use different keywords for the same query. Therefore, the emphasis should be on concepts, structure and connection of keywords as well the behavior and knowledge levels of the individuals using those keywords. One of the main advantages of such a system is therefore, related to its ability to elevate the awareness levels of the individuals by pointing to them the data set items that they might have been missing otherwise.

Most current search engines or systems for retrieval of information from knowledge bases in corporate environments function through utilization of keywords and unstructured phrases. Such approaches are based on identifying all documents that contain the information indexed by the used keywords. They would then rank the results by some degree of relevance according to the query made by an individual. In most of these approaches, the presence or absence of the keywords in the query and the indexing terms of the documents form the basis for evaluation of the relevance of a document to the query. However as pointed out by Horng et al (2005), and Shirvanian and Lippe (2009), basing IR systems on such approaches will have fundamental shortcomings. Among the basic deficiencies that need to be dealt with here, is the lack of ability to express the linguistic based queries made by humans in a formal way needed for machine interpretation and processing. Another and probably more fundamental problem relates to identifying suitable ways for representation and inference of concepts and the context in which they appear. In machines, the concepts need to be precisely defined; leading to lack of generalization that in turn causes the number of cases that need to be dealt with increase rapidly.

To make the discussions more concrete consider for instance, a query with regard to '*heavy traffic*' on a link in a computer network. Obviously, there is no clear boundary that can be used to distinguish between 'heavy traffic' and let's say 'moderate traffic'. Here, the problem can be related to vagueness and lack of specificity. Additionally, the level of traffic that is considered as 'heavy' on a particular link is not necessarily considered as such on another link. Moreover, the term 'heavy traffic' may be used in contexts other than those related to the link traffic, e.g., 'the

students are late due to heavy traffic'. In this case, the problem is related to the vagueness of the meaning and ambiguity in the language.

To address the lack of flexibility in representing documents and queries, fuzzy systems that deal with this type of problem for individual users have also been studied and developed by several researchers, for example see Radecki (1976). In such approaches, a fuzzy set will represent each keyword. The membership value of each piece of information or document indicates its degree of relevance to the fuzzy set denoted by the keyword. In this way, it is easy to use linguistic qualifiers for computing with words to enhance the information retrieval process. While this can help in indexing and the querying process, users can also employ it to provide feedback information. Such information can be used to evaluate the retrieval system and in turn for evaluation of the search engine. Although in some simple cases simple fuzzification of numerical terms can address this problem, the general solution needs to be based on fuzzification and processing of *concepts*.

In an integrated management environment, an intelligent system can be built upon the mutual character of the inquiries, taking into account the implicit association between the individuals. The system should be capable of taking into account the obvious fact that different people generally use different keywords for the same inquiry. That is, the prominence should be on connection of keywords and the performance and awareness levels of the individuals using those keywords. The methodology involves the access to the desired documents, e.g., trouble-tickets, rules or policies based on queries using keywords, a common mechanism for accessing knowledge over the web. The intelligent information system will then be able to elevate the awareness levels of the individuals by pointing to them the data set items they might have been missing otherwise. Obviously, the situation could be vastly improved by improving the awareness of various levels by providing the appropriate knowledge or information for each role in an interaction through compound documents searched by agents against certain criteria. That is, provided the required knowledge is available somewhere on the network. While a trouble-ticket provides an artifact for sharing management information, there a number of other documents and repositories that help in diagnosing a problem and in developing an organizational knowledge-base for efficient problem management.

Concluding Remarks

Efficient management of any complex system, such as large enterprises or modern enterprise networks, depends on understanding the roles of its constituents and their interactions with one another. The management system for modern complex networks must be capable of dealing with an overwhelming amount of data that may be incoherent and inconsistent or unreliable. Furthermore, provision of collaborative services requires cooperation among various entities of an organization. Interaction of humans is partially or fully dictated by their level of awareness of the capacity that others have in supporting them in fulfilling the tasks at hand. As such, awareness modeling and levels can play significant roles in improving the management efficiency. The awareness levels in human beings and managers have a fuzzy nature with linguistic variables extensively used in their characterizations and communications. Compared to more conventional techniques, AI approaches are more suitable for this type of task. Hence we have proposed a cooperative management design framework based on multiple agents, each human role being supported by an agent. This paper has explored the use of fuzzy logic for the development of this multi-agent cooperative management system where each agent uses some fuzzy processing to achieve the desired awareness levels for each human role in the cooperative management process. The design of the framework utilizes the capabilities of soft computing in handling vague concepts and the use of fuzzy modeling to facilitate the incorporation of linguistic variables. One of

the main advantages of such solutions is that they are based on processing of structural concepts. This work described several ways that fuzzy representation and knowledge granulation can be used in identifying or improving the solutions to problems encountered in integrated network management environments.

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