



Integrating Fuzzy Logic and PageRank Algorithm for Agent Selection in Multi-Agent Systems

Ayman M Mansour

Department of Computer and Communication Engineering, Tafila Technical University, Tafila, Jordan

Abstract: Multiple researchers have developed fuzzy logic-based active and reactive controllers in multi-agent systems to help agents act intelligently. Some researchers have been adding the PageRank Algorithm into the fuzzy logic controller in robot soccer during the evolutionary process. It is known that the PageRank Algorithm is focused on the selection of a website to search by means of hyperlinks; popular websites are commonly selected by more users because they usually contain good content. Taking the PageRank Algorithm idea, we will develop a new agent selection method in multi-agent systems.

Multi-agent system definition MAS can be defined as a society of agents that interact with one another according to certain rules in order to accomplish some sets of goals autonomously. In a multi-agent system, four types of agent interactions can be established: Interaction, Coordination, Collaboration, and Coalition. These types of interactions are explained in the work of Wooldridge (2002). According to Omicini et al., the cooperation and coordination capabilities inside the multi-agent systems have been improving through the use of new technologies, like the Java language. For instance, the Java Agent Development framework can be used to develop a multi-agent system from Java beans.

Key Words: Fuzzy logic, Page Rank, Multi-Agent Systems, JADE, Agent Communication, Agent Selection

FUZZY LOGIC

The term "fuzzy" refers to things which are not clear or are vague. Fuzzy sets generalize the classical set theory. The membership of an element to a set is represented by a membership function rather than by a single value, either 0 or 1 as in the classical set theory. Since the debut of fuzzy set theory, many generalized phenomena have been modeled by the theory, including multi-valued logic, multi-dimensional geometry, and linguistic approximate reasoning. Such work not only establishes a more flexible and powerful mathematical theory, but also supports the microscopic philosophy of many real-world problems. Based on fuzzy sets, Zadeh proposed a new methodology of analysis and decision-making, namely fuzzy reasoning or fuzzy logic. Fuzzy logic provides an approximate reasoning framework. In this system, factors dependent on one sort of degree upon another are modeled by fuzzy set themselves.

Fuzzy logic encompasses the ideas of fuzzy sets and approximate reasoning techniques to provide a method of inference that assesses linguistic rules and conclusions. The operations of fuzzy logic, together with the linguistic descriptions for fuzzy sets, define the logic of fuzzy if-then rules which provide a rational basis for approximate reasoning about imprecise states. There are four main components of fuzzy logic systems. They are fuzzy interfaces, the rule base, the inference engine, and the defuzzification units. There are various ways of combining the output of rules, most often using the major preposition - a fuzzy union. The language of fuzzy logic is closely associated with linguistic variables, which are mapped to an underlying metric space. The associated question "how is the set in the sentence described?" is crucial; different interpretations will give different fuzzy sets for the sentence.

The popularity and decreasing costs of the high-speed World Wide Web have meant that many of today's websites contain data that is interrelated, for example, hyperlinked documents. Internet expansion has resulted in a growing need for complex and specialized information gathering services, such as multi-agent systems running within local inferno sectors. A multi-agent system is one that consists of a set of agents that share a common goal but act as independent entities. Each of these agents also has a particular scope of interest. Related to these interests, there are different ways in which a selection mechanism for a multi-agent system can be used.

Search engines deal with such data made available through indexing of internet sites, further serving this demand. Today's search engines apply web crawlers that store the internet's documents as a large and ever-increasing database. Required search engine data is then retrieved through the response of queries fed to the search engine via a web interface. However, often search engines do not supply the depth of information offered by comparison of these. Potential real-time search is



possible in an environment where complex information gathering occurs via multi-agent systems exercising intelligent, independent selection of data.

Let X be a set of values or linguistic terms in a universe of discourse, and let A be a statement of fuzzy knowledge defined over the set of values X . Let $M(a, b)$ be the membership value of a , a statement of fuzzy knowledge, characterized by a linguistic variable in the set of values X , for b , a set of finite fuzzy logical connectives. A one-variable function $m: [0, 1] \rightarrow [0, 1]$, defined $m: [0, 1] \rightarrow [0, 1]$ is a membership function if, for each x in the universe of discourse, $m(A, x) = M(A, x)$. Several different membership functions are proposed in the reviewed literature. The most common is triangular, which gives lower performance but the advantage of parametric tuning. The Gaussian membership function produces the highest performance due to its two parameters, but lack of parameter-tuning restricts its application. Membership functions are crucial to the Fuzzy Logic System approach. They return the degree of membership of a linguistic variable to a fuzzy set, based on its property or characteristics.

One of the most common membership functions for fuzzy sets is the triangular function. The performance of the triangular function, however, depends heavily on the correct selection of its parameters. More complex membership functions, such as Gaussian and Trapezoidal, are already known for offering more precise representation by taking into account other features of a variable, but require a deep search for parameter tuning. Gaussian functions have been proposed mainly because of their theoretical foundations, because they can approximate any finite-valued membership function, and because they produce longer membership values and therefore more pronounced intersection with other fuzzy sets. The reason for considering other more complex membership functions is their obstructive characteristic to extend other membership values, requiring deep search for parameter tuning. That is, the main drawback is that they do not generate very similar fuzzy values, but learned rules that accept different parameter settings. Other researchers consider quantum membership functions and non-parametric fuzzy membership functions. They also address geometrical, logical and symmetrical constraints by combining the properties of different membership functions such as Singleton, Trapezoidal, Trapezoidal, and Trapezoidal.

PAGERANK ALGORITHM

The World Wide Web is a system of interlinked documents that share information with each other. The relationships between the pages are usually obtained by applying a search engine to find the pages. The search engine ranks these pages according to their importance and returns a list of web pages. To date, several efficient algorithms have been developed to compute how important a page is [1-3]. In developing these algorithms, the so-called link analysis has been performed based on the relationship between the pages. The link analysis returns the list of pages in decreasing order along with their membership number. When X is a set of documents in a certain domain, these sets of documents are referred to as collections and can be represented as their own links.

The main point of the PageRank algorithm is to calculate iteratively. Given a transition matrix M , which results from the link matrix L by dividing the entries of a column of L by the nonzero part of that column. The transition matrix M is made by the link matrix. Step 1: We initially assign a score for each page or document, up to being $1/N$ where N is the total number of documents. Another initial assignment of a page score is also possible if we have different values on each document. In fact, a proper value of the starting rank is important since it sometimes affects the numerical convergence of the PageRank algorithm.

PageRank is the algorithm used by the Google search engine that orders pages based on their importance. The key idea behind this algorithm is to consider the number of links pointing to a document and the importance of these documents. This last concept is fundamental in the context of the Web, since there are web pages with more quality than others. One of the most original ideas of the algorithm is that of thinking of links as votes, assigning a weight equal to the PageRank of the page of origin of the link and distributing this value among the destination pages of the link. The PageRank of pages is adjusted iteratively using some damping factor. It is also important to mention the random surfer model because it has a prominent role in the algorithm. This model states that users start on a web page and, after some time, finish their navigation by going to another web page through a link or by typing an address on the address bar. The model also considers the possibility of the user stopping navigation, generating a jump from the current page to any other page of the Web. The pages will have a rating based on the frequency with which this model visits them.

To use the PageRank algorithm, we first have to model the Web as a graph $G = (V, E)$. In this graph, $V = \{v_1, \dots, v_n\}$ represents the collection of n web pages and $E = \{e_1, \dots, e_m\}$ denotes all links between the pages represented by the edges of the graph. The random surfer model allows us to introduce a damping factor (sometimes called teleportation probability) in the PageRank vector that penalizes linking cycles that are derived from fierce competition for Rank and follow their continuation. This damping factor makes some contribution of other pages possible, even if there is no link



to the original page (jump to other pages). Since users usually close open windows and access another page using the address bar provided for that, this damping factor will help the teleportation to any page that the user wishes. The original PageRank algorithm uses a damping factor equal to 0.85.

As for the application of fuzzy theory to the weighted average of the matrix W , the proposed Fuzzy Weighted Matrix Averaging (FWMA) method will be presented. From (1), to rank the web pages in a web where website structure is represented in a transition probability matrix A and the relevance of the web pages on the web are represented in a web page relevances probability matrix Y , the weighted matrix W is defined to be AY . Suppose a random surfer randomly selects links from the web pages on the web until infinity. According to the probability, when the random surfer visits different web pages, the probability that the random surfer visits a specific web page is estimated from the steady-state of the Markov chain formed by the web pages on the web. To implement random surfer, using PageRank algorithm to compute the web page clicking rank for each web page is a technique that can be employed.

The article titled "The PageRank Citation Ranking: Bringing Order to the Web" introduces the concept in 1999. In the article, the PageRank of web pages is defined at the term of web pages, the authors consider the pages linking to the page and denote as parents while the pages which are being linked are called as children. Further, the authors prove the PageRank value can be calculated by iterating an iterative formula.

MULTI-AGENT SYSTEMS

Although the first multi-agent systems (MAS) are thought to be sports simulations described during the eighties Christopher Langton defined an agent as "a computational-executive composite character residing in a CIM environment which is capable of flexible autonomous action situated in unpredictable, dynamic environments that have to be tackled using processes such as analogy, ambiguity, learning, perception, and uncertainty. Following these definitions, modern multi-agent systems (MAS) can be defined as a logical conjunction of agents, situated in some environment, having characteristic skills like learning, perception and decision making, and sharing dynamics based on communication, cooperation, coordination, negotiation and benevolence, either with humans or among themselves, in attempts to achieve their goals [4-6].

The current section presents a summary of the major issues that concern multi-agent systems, encompassing: architectures and interaction; issues of expressiveness and representation of the agents' knowledge, beliefs and goals, that concepts like goals, plans and rules rely upon; the mechanisms for the agents' communication, that comprise negotiation policies, semantic knowledge between agent pairs, social commitments, social attitudes and agent conversation protocols; and finally the ways that agents are aggregated to form the organizational structures they usually encompass, to coordinate their actions.

This paper addresses the problem of agent selection in a multi-agent environment, where agents are considered as web services. In many industries, web services are increasingly becoming cleverer, more autonomous, and capable of performing complex tasks. Currently, web services are manually managed through centralized infrastructures, which over time would become cumbersome and impractical. On the other hand, they can be widely deployed within software agents, where footprints and capabilities of agents are recorded by brokers, which offer matching services for developers to dynamically locate, select, couple, and deploy agents able to perform task ensembles.

The selection of a particular agent in a multi-agent society is crucial for the success of the overall system. An agent is selected not only to be able to carry out a certain task but also it must possess particular qualities such as trustworthiness, valued reputation, system qualities, resource consumption criteria, and task matching performance. These qualities can be conflicting with each other, making the selection process difficult. Furthermore, when the user is not an expert in a certain domain, these criteria can be subjective, imprecise, and uncertain. In this paper, we propose to combine the strengths of fuzzy logic and the PageRank algorithm to provide an intelligent agent selection mechanism, tailored to multi-agent users who are not domain experts.

A multi-agent system (MAS) is a system composed of many agents (organizations, individuals, or entities). These agents interact with one another by using communication, cooperation, negotiation, precise states, and complex welfare intended for the composition of a task or autonomy. Agents have diverse traits determined by features including sovereignty, responsiveness, rouge, flexibility, practical rationality, social capacity, and learning. Moreover, transports are profound, adding prevailing social and technical networks that operators propose and employ, including a variety of principles as a broker, creating coalitions, and exploring a common bottom.



Game theory is the distortion of studying zero-sum games, which cooperate with pragmatics, a sequence of repeated games, and the internal organization of the agency. Kolari and Mermaid investigated important precise subjects such as the inefficiency of the agency: the noticeable reduction in decision rules and outcome biases, the inconvenience of cooperating results of the agency from declaration fallacies and statistical discrimination. Cultural progress and the audience have also been articulated in the psychological literature concentrating in actible mistakes. Non-coordinated communication can happen from the fallacy of declaration settlements, but disgracing reviews can lead to ethnic and sex-based divisions that are well exterior what would be captivating grounded on the genuine distributions.

INTEGRATION OF FUZZY LOGIC AND PAGERANK ALGORITHM FOR AGENT SELECTION

In this study, a new approach is proposed that integrates fuzzy logic technique with PageRank algorithm. In this respect, agents are selected considering their expertise on doing different tasks and a fuzzy logic system that takes expertise degrees of agents on doing those tasks as input and gives weights of agents as output is used. In eliciting weights of agents, both weights of tasks determined by human experts and expertise degrees of agents on doing those tasks are utilized. The model proposed is simulated by using Matlab programs and expertise degrees of agents are determined according to the competence of agents. In the literature part, the fuzzy logic is implemented as Mamdani for the first time and Criteria Weight Consistency Index and Evaluation Ratio are used to equalize the weight of tasks. According to the results, as the proficiency, the expertise degree of a reviewing agent on a review task and the degree of association of that agent with the user to be evaluated increases, the achieved weight of the agent is increased. These findings show that this proposed model operates satisfactorily and it can be employed in review agent selection applications.

In this research, the shortcomings of the PageRank algorithm are intended to be removed and these credentials are proposed. In this respect, the proposed approach is prepared by modifying the PageRank algorithm and using a fuzzy parameter instead of constant convergence coefficient. The consistency, time and number of iterations of the algorithm implemented are controlled by integrating the fuzzy logic parameter instead of the convergence coefficient. With the presented approach, the weights of the agents can be determined by considering the task weights and their expertise degrees with a new point of view without reducing the efficiency of the PageRank algorithm. Also, as a result of the model and examples presented, a recommendation model has been developed that takes into account the previous accomplishments, expertise, and task weights of agents in the M-task in an expanding artificial intelligence environment. Fuzzy logic represents a flexible formalism which models human reasoning, based on their experience, feelings and intuitions in linguistic terms. In the context of agent communication, fuzzy logic increases system adaptability by incorporating trust measure as one of the selection criteria. The intelligence of agents is encoded by firms through soft constraints, which characterize the level of confidentiality and reliability in performing delegated tasks. Fuzzy rules extract the portal by integrating expert advice on the relevance of discovered links for correct result identification. The algorithm to identify semantic portals through intelligent agents exploits the properties of fuzzy reasoning. It contains several phases: portal selection, web page evaluation and selection of the most relevant links to portals in the query results. Fuzzy logic principles can also exploit the coefficients determined from the agent past experience on the specific query domain. In order to further enhance task delegation capabilities of intelligent agents, we named this model FireNYx by integrating PageRank algorithm within Fuzzy logic for the fuzzy agent selection process. Selective agent ranking is proposed as a new entity, which encapsulates agentarium level and portal level where the agent can reason effectively and answer any user query. With selective agent ranking, the system retains the adaptive nature and improves the task matching performance, by training agentarium agents through agent-based simulation methods to fit the intentions of web users. Agents are classified into semantic similarity categories according to their performance in relation to an initial user request; these classes provide a feedback mechanism to the agent ranking and rating scheme.

The proposed methodology uses fuzzy logic to calculate the overall grade based on several criteria identified through the classification of the developers themselves. The model developed will objectively identify the knowledge of the developers through their participation in similar developments, whether it be technological development or software testing. This will help assess the overall score. The degree of knowledge of the developers will assist in their participation and facilitate the choice of the profile of developers who will select the agent to execute the actions or tasks. The method of selecting agents or competing for tasks is based on the principles of trust and reputation, knowledge-sharing, and collaborations. These principles are characterized by indexes that demonstrate the level of performance and availability. This approach aims to evolve in decision making agent selection, which is based on the overall degree rating of the knowledge that each individual has.

The performance of the proposed model measures the degree of knowledge in both software development and software testing. It is linked to the performance where the developer can really assist in shared knowledge, collaboration, and trust for communication and group participation. This takes into account the phases of development and possibly testing. It is



important to note that the proposed model and the Leader/Expert operational model aim to form developers with good skills and knowledge in software development, as demonstrated in the previous sections. The experimental results show that the Leader/Expert integration model does not exceed one position in the ranking. This demonstrates that it already has good collaborators and trusted agents. It is worth noting that the trust computation demonstrated results in reduced influence of the test in terms of robust testing tool.

EXPERIMENTAL EVALUATION

In this section, we evaluate the performance of the proposed agent selection methods with several different scenarios. We compare the proposed three methods, i.e., the constant selection probability method, the linguistically weighted method, and the PageRank with the proposed constant selection probability method using particle swarm optimization method. The simulation platform MATSim 0.3 is employed in our simulations. The running environment is a machine with 64-bit Windows 7, quad-core Intel i7-740QM @ 1.73 GHz CPU, and 6 GB memory.

In the simulation, we assume that there are 20 driver agents, each of which employs the identical agent selection method and randomly changes the current method in every 20 iterations in order to ensure the randomness of the results. Through the specified platform, after approximately 500 iterations, driver agents evolve the target path decision model and then converge to a stable state depending on the interaction among agents. The frequency of selecting each of 20 possible methods is subsequently counted.

In the study, two types of road network scenarios are evaluated: 10-20 with different costs and 20-40 with different costs, where cost is defined as the driving time for the road, which comprises the mean time in heavy traffic, congestion, and so on. The first group is a simple square road network scenario, which comprises 10 local roads in that network. The second group of cost-criteria scenarios is a cross-shape road network with 20 crossed large roads. Among those 20 roads, 2, 3, 5, 6, 8, 13, 15, 18, and 20 incur the identical driving time through each of the 20 cases.

The integration of fuzzy logic and PageRank for selecting helpful agents is evaluated based on two sets of multi-agent systems available in the literature: one designed for learning scenarios, called the ALMAS-game, and a second one developed in the computer science field, called the Complexity-CS domain. ALMAS-game is more focused on learning and educational purposes, whereas Complexity-CS is designed for education in the computer sciences. The characteristics of the evaluated agents present on both datasets can be seen in reference tables, and the applied metrics, which are precision and reduction, are aimed at reducing initial effort and can be found as well. The results demonstrate that it is possible to develop an intelligent system for offering agents' selections by considering alternative search strategies, which can optimize the assistance provided with the suggestion of agents available in the multi-agent system. It is also observed in this work a relatively low complexity mainly due to its feasibility.

The experimental results in this simulation show the advantages of Fuzzy Agent Selection (FAS) over PageRank or Random Agent Selection technique. As explained earlier, the agents consult the environment to independently provide status data for gates present in the environment. The effectiveness of the agents to provide credible status is given by its credibility level. Based on the status of the gates received from the environment, an experimental set is generated to calculate the resulting effectiveness of each technique. Many combinations of int and presence for individual gates of each scenario are generated to allow all the decision rules to fire at least once. Both linguistic and fungible interpretations are considered to be able to accurately determine which technique yields better results. After calculating the effectiveness using different combinations, the main experimental set is used. According to this latter set, two main scenarios were considered in order to allow the agents to consult the environment using information or prompting the environment to give out false information.

Another experiment was conducted to find similarities between patients, where each agent possesses a set of similarity rules that reflect varying levels of physician experience. The rules differ among agents, as it is realistic to assume that a universally accepted set of rules does not exist for all users (i.e., physicians). However, there are key rules that all agents share, which are essential for basic similarity detection, such as calculating Total Laboratory Similarity and Global Similarity. Agents formulate their rules based on the experience of their human users, and since the number of patients seen by different physicians (and their agents) varies, this affects both the experience levels of the physicians and the number of rules their agents employ. For any individual agent, these experience-based rules are incomplete, potentially leading to inaccurate identification of signal pairs. Over time, as physicians encounter more patients, more comprehensive and accurate rules become available, which should be reflected in the behavior of the agent system.

To enable agents to benefit from each other, it is crucial to develop a strategy to represent the experience level of each agent's rules. In this paper, we propose assigning a confidence level, a value between [0, 1], to each rule. This confidence level is determined by the agent's experience with that rule, essentially reflecting how often the rule has been applied to



patient records. The confidence level is calculated as the fraction of patient records in the set that trigger the rule, indicating how confident the PAAs are in their rules. Rules that have been frequently used should have higher confidence levels than those that have not been applied.

These confidence levels play a critical role in the process of updating and exchanging similarity rules between agents. An agent can randomly contact one or more available PAAs during a conversation. When PAAs collaborate to find similar patients, each PAA shares its similarity rules with the others. The agents begin a learning process by comparing their similarity parameters with those of other agents. If a parameter is missing from its Experience Knowledge Base, the agent will compare the confidence levels of the rules associated with that parameter found in other agents and add the rules with the highest confidence levels to its own base. Afterward, the agent updates the parameters already existing in its knowledge base by comparing the confidence levels of its rules with those of other PAAs. The agent will adopt the rules with the highest confidence levels, thereby improving its similarity task performance. Each time a new case is presented, the confidence levels of the rules are updated. Additionally, the agent has the option to update its rules during a conversation. The overall process of similarity finding is illustrated in Figure 1.

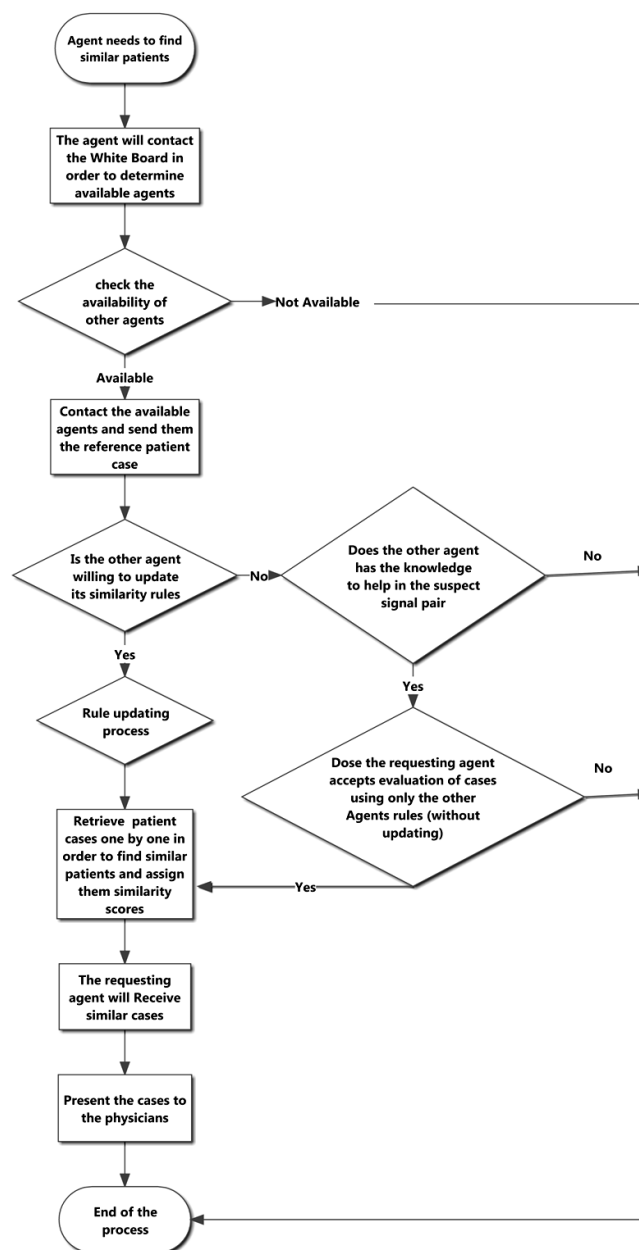


Figure 1: Similarity finding process.



In this scenario, three Patient Assistance Agents (PAAs) collaborate to find patients similar to a specific case. PAA1 needs to identify patients who match a particular profile, so it sends a request to the White Board, asking for available PAAs in the system that can assist in this task. The White Board then consults its agents, identifying those equipped with the necessary skills to help PAA1. If no suitable agents are found, the White Board responds with "impossible to do," indicating that no assistance is available. Otherwise, it sends an "acknowledgment of acceptance" to PAA1, listing the available agents. For instance, if PAA2 and PAA3 are available, the White Board provides PAA1 with their contact information, enabling direct communication among the agents.

PAA1 then sends individual requests to PAA2 and PAA3, seeking their collaboration. Each agent responds with either "agree to do" or "reject to do," depending on their current availability. If PAA2 is available and agrees to assist, while PAA3 is busy and declines, PAA1 proceeds by sending patient information to PAA2. The agents then exchange their similarity rules to enhance their search criteria.

For example, if PAA1 uses similarity rules based on Age and Medications, and PAA2 uses rules based on Laboratory Tests and Medications, PAA1 will integrate PAA2's Laboratory Tests rules into its knowledge base, as it lacks such criteria. For Medications, PAA1 compares the confidence levels of its rules with those of PAA2. If PAA2's rules have higher confidence, PAA1 will adopt PAA2's Medication rules, replacing its own. PAA2 follows a similar process for updating its rules based on Age and Medications.

Finally, PAA1 and PAA2 search their respective patient databases using the newly updated rules. PAA2 forwards the cases it finds to PAA1, but only those with similarity scores above a threshold specified by PAA1 and the overseeing physician.

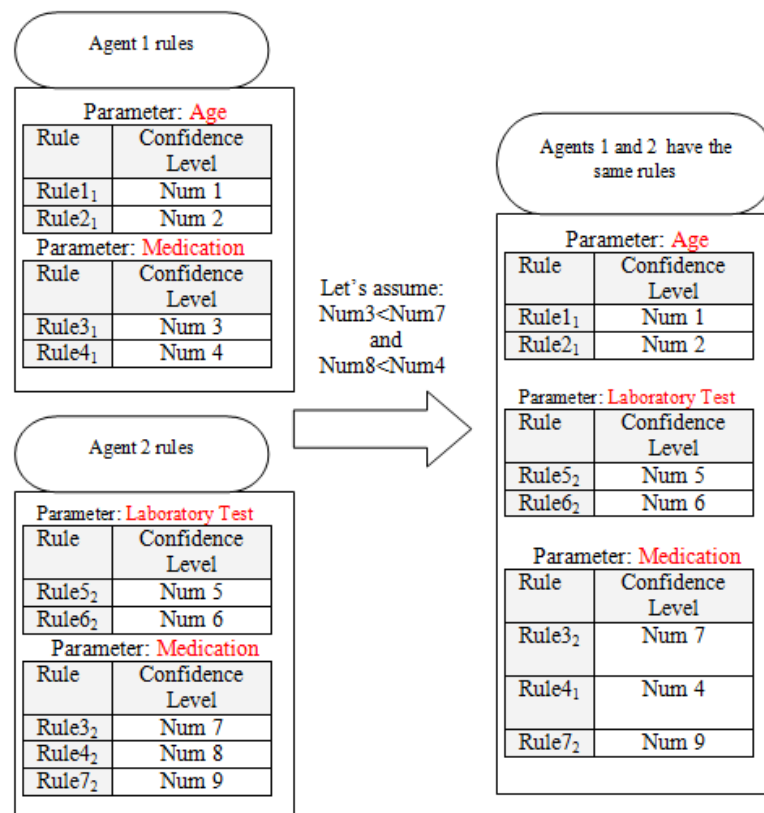


Figure 1. Updating similarity rules in two PAAs using confidence levels.

CONCLUSION AND FUTURE WORK

In this paper, we proposed a solution for tackling the difficult task of finding, among the agents in the system, the ones more fitted to perform a job. We imbued each agent with a score which was a combination of its ability to perform actions and an estimation of its potential communication load. This information was produced using fuzzy logic. We then used an adaptation of the PageRank algorithm to calculate and assign a final authority score to each agent.



To test the solution, we defined a concrete scenario which demanded agents to perform a special kind of web service, namely to interact with entities, like people or objects, present in an urban scenario to implement a smart cities application. We then designed the multi-agent system and implemented the agents. We finally executed several experiments and analyzed the results. The proposed solution delivered quite good results, as the best agents were being correctly selected. However, we could still note some issues with some configurations of the fuzzy sets used to calculate the communication load parameter.

A stronger point of the solution is the fact that the calculations to produce the necessary information and to assign the final scores to the agents were quite efficient. The calculations of the estimates of the communication load of agents could be quite complex and take more time than the job itself. As a consequence, the multi-agent system could spend lots of time trying to assess each candidate agent, every time a new role candidate agent was needed.

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