Prioritizing Quality Specifications of Multi-agent Systems

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Abstract— **Agents are being recommended as a next generation model for revising and restructuring the complex distributed applications. So the task of engineering quality for agent systems has also become significant. As different stakeholders such as project managers, users, and practitioners have different interpretations of quality; an integrated specification of MAS quality that could satisfy all the stakeholders in the project is required. The quality specifications of stakeholders are subjective and, there is a fair chance of non-zero hesitation part in recommending quality specifications; Intuitionistic Fuzzy Sets (IFS) have been used to capture the uncertainties associated with stakeholders' recommendations. IFS are generalization of fuzzy sets having membership, non-membership and hesitation, and this paper proposes a methodology to obtain prioritization of quality specifications that assists quality engineer in achieving the desired level of quality for Multi-agent systems.**

Index Terms—**Intuitionistic Fuzzy Set (IFS), Multi-agent system (MAS), Quality criteria, Quality factor**

I. INTRODUCTION

Advances in network and distributed systems have revolutionized the advent of Multi-agent systems. A Multi-agent system is a loosely coupled network of software agents that can move throughout a network of agent aware computers [12] and interact to solve problems, which are beyond the individual capacities or knowledge of each problem solver, while software agent is a computer program that is situated in some environment, and is capable of autonomous action to meet its design objectives. Agents are characterized as goal-oriented, situation aware and proactive as well as reactive [3].

An MAS models problems in terms of autonomous interacting component-agents, which is proving to be a more natural way of representing task allocation, team planning, user preferences, open environments. MASs have been applied in a variety of domains, including monitoring complex chemical processes [11], maintaining cellular switching systems [13], servicing mobile manipulator robot [14], etc.

During the life cycle of MAS, many stakeholders contribute from their own objectives, perspectives and interests [16]. Examples follow. Managers would primarily be concerned with meeting the requirements within the assigned cost and schedule. Practitioners would want the system built as per functional requirements. Users would want the product easy to use, difficult to misuse, and to work as intended. A maintainer would want the system to be easier to repair and fix.

Thus, MAS would have several quality-related specifications such as knowledgeability, persistence, availability, extensibility, collaboration [1][2][10][15] etc. Several aspects of quality may conflict with each other and may be difficult to achieve.

In this paper, we study quality of MAS from the viewpoint of various stakeholders, like project manager, software engineer, user and maintainer. As the opinions of stakeholders regarding quality specifications are subjective, Intuitionistic fuzzy sets are being used to give an integrated view that satisfies each of the stakeholders involved.

Intuitionistic Fuzzy Sets (IFSs) are one of the interesting and useful generalizations of fuzzy set theory introduced by Atanassov [9] having membership, non-membership and hesitation part. Fuzzy sets are IFS but the converse is not

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necessarily true. In fact there are situations where IFS theory is more appropriate to deal with [5]. In these situations, along with fuzziness, a hesitation part is also present.

This paper proposes an application of IFS to software engineering domain by achieving consensus among stakeholders' opinions for quality specifications and hence prioritizes them to achieve desired MAS quality. The organization of this paper is as follows: Section 2 presents Intuitionistic fuzzy sets in a brief way. Section 3 prioritizes quality specifications for MAS and a case study illustrating the application of proposed methodology has been presented. Section 4 concludes the paper.

II. BRIEF INTRODUCTION TO INTUITIONISTIC FUZZY SETS

Intuitionistic fuzzy sets based models may be adequate in situations where we face human testimonies, opinions, etc. involving two (or more) answers of the type:

- Yes
- No
- I am not sure

Voting may be a good example [5] of such a situation as the human voters may be divided into three groups of those who:

- Vote for,
- Vote against
- Abstain or giving invalid votes.

This third area is of a great interest from voter behavior analysis because people from this third undecided group after proper enhancement (e.g. different activities) can finally become sure i.e. become persons voting for (or against).

Here we give some basic definitions [9], which are used in the next section.

Definition i: Let a set E be fixed. An IFS A in E is an object of the following form

$$A = \{(x, \mu_A(x), \nu_A(x)) \mid x \in E\}$$

Where the functions

$$\mu_A: E \to [0,1]$$

and

$$\nu_A: E \to [0,1]$$

define degree of membership and degree of non-membership of the element $x \in E$, respectively.

And for every $x \in E$,

$$0 \le \mu_A + \nu_A \le 1$$

Definition ii: The value

$$\Pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$$

is called the hesitation part that may cater to either membership value or non-membership value or both.

Definition iii: Let X and Y be two sets. An intuitionistic fuzzy relation (IFR) R from X to Y is an IFS of X × Y characterized by the membership function μ_R and the non-membership function ν_R and is denoted as R (X → Y).

Definition iv: If A is an IFS of X, then the **max-min-max composition** [17] of the IFR R (X → Y) with A is an IFS B of Y denoted by B = R o A, and is defined by the membership function.

$$\mu_{RoA}(y) = \bigvee_x [\mu_A(x) \wedge \mu_R(x, y)]$$

and the non-membership function given by

$$\nu_{RoA}(y) = \bigwedge_x [\nu_A(x) \vee \nu_R(x, y)]$$

$$\forall\, y \in Y$$

(Here $\vee$ = max, $\wedge$ = min)

Definition v: Let Q (X → Y) and R (Y → Z) be two IFRs. The **max-min-max composition** R o Q is the intuitionistic fuzzy relation from X to Z, defined by the membership function

$$\mu_{RoQ}(x, z) = \bigvee_y [\mu_Q(x, y) \wedge \mu_R(y, z)]$$

and the non-membership function given by

$$\nu_{RoQ}(x, z) = \bigwedge_y [\nu_Q(x, y) \vee \nu_R(y, z)]$$

$$\forall\, (x, z) \in X \times Z \text{ and } \forall y \in Y$$

Definition vi: Distance between Intuitionistic Fuzzy Sets

Two of the most popular distances [5] the normalized Hamming distance $l_{IFS}(A,B)$ and the normalized Euclidean distance $e_{IFS}(A,B)$ between intuitionistic fuzzy sets A, B in X = { $x_1, x_2, x_3, \ldots, x_n$} are defined as follows:

$$l_{IFS}(A,B) = 1/2n \sum_{i=1}^{n} (| \mu_A(x_i) - \mu_B(x_i)| + | \nu_A(x_i) - \nu_B(x_i)| + | \pi_A(x_i) - \pi_B(x_i)|)$$

$$e_{IFS}(A,B) = 1/2n \sum_{i=1}^{n} ((\mu_A(x_i) - \mu_B(x_i))^2 + (\nu_A(x_i) -$$

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$\nu_B(x_i))^2 + (\pi_A(x_i) - \pi_B(x_i))^2)^{½}$

Also $0 \leq l_{IFS}(A,B) \leq 1$ and

$0 \leq e_{IFS}(A,B) \leq 1$

Applications of IFS theory have been presented in various areas such as, decision-making problems [6][8], medical diagnosis [17].

III. PRIORTIZING QUALITY SPECIFICATIONS OF MAS

Researchers in software engineering have examined MAS quality from different ways. Quality of MAS has been addressed in terms of knowledgeability, complexity and uncertainty [2], non-functional properties that include performance, scalability and stability [10] and decision making mechanisms in uncertain environments [1].
This section presents an application of intuitionistic fuzzy sets to quality model of MAS [15] that address various dimensions of quality in terms of factors and criteria. Criteria are stakeholders' view of quality. By contrast, factors are system-oriented characteristics that indicate product quality [7]. Factors and criteria tend to have a cause-effect relationship. IFSs have been employed to capture the subjectiveness associated with quality criteria specified by various stakeholders.

In a Software Engineering environment, suppose

C = a set of quality criteria;
F = a set of quality factors;
S = a set of stakeholders involved;

Determination of prioritized quality specifications for MAS involves mainly the following steps:

1. Determination of quality criteria C, quality factors F and stakeholders S in MAS.
2. Formulation of intuitionistic fuzzy relation Q between criteria C and stakeholders S.
3. Formulation of intuitionistic fuzzy relation R between factors F and criteria C.
4. Determination of intuitionistic fuzzy relation T = R o Q, consisting of values for quality factors corresponding to various stakeholders obtained from composition of Intuitionistic Fuzzy Relations R and Q.
5. Compute distance among the stakeholders' recommendations regarding MAS quality.
6. Arrange factors of quality in descending order of distance to obtain list of quality factors in increasing order of consensus.

Let A be an IFS of the set C, and R be an IFR from C to F. Then max-min-max composition (defn. iv) B of IFS A with the IFR R(C → F) denoted by B = A o R signifies the state of the stakeholder in terms of quality factors as an IFS B of F with the membership function given by

$$\mu_B(f) = \bigvee_{c \in C} [\mu_A(c) \wedge \mu_R(c, f)]$$

And the non-membership function is given by

$$\nu_B(f) = \bigwedge_{c \in C} [\nu_A(c) \vee \nu_R(c, f)]$$

$\forall f \in F$. (Here $\vee$ = max, $\wedge$ = min)

If the quality specifications of a given stakeholder S is described in terms of an IFS A of C, then S is assumed to be assigned factors in terms of IFS B of F, through an IFR R from C to F which is assumed to be given by a quality engineer/a team of quality engineers who is/are able to translate their own perception of association and non-association respectively between criteria and factors.
This concept can be extended to a finite number of stakeholders. Let there be n stakeholders s_i, i= 1,2,..n in software project. Thus $s_i \in S$. Let R be an IFR(C → F) and construct an IFR Q from the set of stakeholders S to the set of criteria C. Clearly, the composition T (defn. v) of IFRs R and Q (T = RoQ) describes the state of the stakeholder in terms of the factors as an IFR from S to F given by the membership function

$$\mu_T(s_i, f) = \bigvee_{c \in C} [\mu_Q(s_i, c) \wedge \mu_R(c, f)]$$

And the non-membership function given by

$$\nu_T(s_i, f) = \bigwedge_{c \in C} [\nu_Q(s_i, c) \vee \nu_R(c, f)]$$

$\forall\ s_i \in S$ and $f \in F$.

For a given R and Q, the relation T = RoQ can be computed. For this relation T, normalized Hamming distance and/or Euclidean distance among the stakeholders' opinion for quality factors can be found. Quality engineer can sort these values corresponding to various factors in descending order of distance. This sorted list will give most desired quality factor first and the least preferred in the end, enabling quality engineer to choose the important factors to be considered for achieving quality in MAS. This will not only simplify quality analysis of MAS but will also satisfy all stakeholders involved in the project.

3.1 *Case Study*

To see the application of the method, a survey was administered to obtain an integrated view of quality for a Intelligent Travel Planning System (ITPS) that solve Web problems in the e-tourism Domain for moving from the origin to the destination town, lodging at the destination, local transport at target town and returning to initial town [4]. ITPS is composed of UserAgents, PlanningAgents, WebBots and CoachAgents. This study aimed to focus on the perceptions of respondents regarding quality of ITPS.

The survey was held with 27 project managers and 51 developers (that are associated with the projects of e-commerce, web engineering, agent-mediated software engineering); 31 travel agents of agencies *Radisson, Swan Tours, Cox & Kings, Spring Travels and Flexi Tours*. All the respondents were familiar with the operations and the working of ITPS.

Quality measures for ITPS were drawn from the quality model of MAS [15] as well as from survey items in the literature. Five quality criteria namely *communicative richness, decisiveness, goal driven, m*achine independence *and average response time* and five quality factors such as *Collaboration, Knowledgeability, Performance, Persistence and Extensibility* were selected to simplify the study. The stakeholders were asked to give their recommendation about quality criteria using Intuitionistic Fuzzy Sets that capture the recommendation in form of a triplet (μ,ν,π) where

μ represents the stakeholders who voted in favor of quality criteria;

ν represent the stakeholders who did not vote for quality criteria;

and π represents the stakeholders who were indecisive for quality criteria;

Let E1 is the set of all team members corresponding to stakeholder1, e.g., travel agents. Suppose x members of E1 say that a particular criteria like *communication richness* is required for ITPS, y members of E1 say that *communication richness* is not necessary and rest are not able to decide, then Q (Table 1) contains entries of the form (x/E1, y/E1, 1-(x/E1+y/E1)). e.g. Q [3, 1] i.e. (0.2, 0.2, 0.6) signifies that 20 percents of users voted for *communication richness*, 20 percent users did not vote for *communication richness* and rest 60 percent were indecisive about the quality criteria *communication richness.*

Table 2 presents the relation R regarding opinion of quality expert regarding association of quality criteria to quality factors using IFS. Table 3 obtains the relation T containing stakeholders' opinion in terms of quality factors using Table 1 and Table 2 (step 4 of the algorithm, defn. v). Table 4 gives the intuitionistic distance among the stakeholders' opinions (defn. vi). Two or more factors having the same Hamming distance are sorted according to Euclidean distance. The factors having the same Hamming and Euclidean distance are treated at the same level, i.e. either all or none would be included. Table 5 sorts the quality factors in decreasing order of distance (ascending consensus), this gives the integrated opinion of stakeholders for ITPS.

In this study, if quality engineer wants to include one factor, then **Extensibility** should be chosen as it contributes maximum to stakeholders' consensus for ITPS quality. If two factors are to be included, then **Performance** is to be considered next and likewise, more factors can be added in integrated quality specifications for ITPS.

IV. RELATED WORK

The application of Intuitionistic Fuzzy Sets to group decision making, negotiations and other situations are presented in [5], [6], [8] and [17].

In [5], a method for the evaluation of a degree of agreement in a group of individuals by calculating distance between intuitionistic fuzzy preference relations has been presented.

Szmidt et al. [6] present a similarity measure to assess an extent of agreement in a group of experts giving their opinions expressed by intuitionistic fuzzy preferences relations.

Atanasov et al. [8] propose an intuitionistic fuzzy interpretation of multi-person multi-criteria decision-making concerning the selection of best alternatives among a set of predefined ones.

An application of intuitionistic fuzzy set theory for medical diagnosis has been proposed by De et al. [17]. The methodology formulates medical knowledge based on intuitionistic fuzzy relations that have been used to determine diagnosis.

In our paper, an application of intuitionistic fuzzy sets in the software engineering domain has been presented. To achieve the desired quality of MAS, it is essential to develop integrated quality measures that could satisfy all the stakeholders

Table 1: Stakeholders' opinion of quality criteria for ITPS

Q	Communication richness	Decisiveness	Goal driven	Machine Independence	Average response time
Project manager	(0.4,0.2,0.4)	(0.5,0.2,0.3)	(0.8,0.1,0.1)	(0.2,0.6,0.2)	(0.8,0.1,0.1)
Software engineer	(0.8,0.1,0.1)	(0.8,0.2,0.2)	(0.8,0.1,0.1)	(0.4,0.3,0.3)	(0.6,0.2,0.2)
User	(0.2,0.2,0.6)	(0.5,0.3,0.2)	(0.9,0.0,0.1)	(0.2,0.7,0.1)	(0.8,0.1,0.1)
Maintainer	(0.4,0.2,0.4)	(0.7,0.1,0.2)	(0.9,0.1,0.0)	(0.8,0.1,0.1)	(0.4,0.3,0.3)

Table 2: Contribution of each criterion to quality factors obtained from quality expert

R	Collaboration	Knowledgeability	Performance	Persistence	Extensibility
Communication richness	(0.7,0.2,0.1)	(0.8,0.1,0.1)	(0.6,0.3,0.1)	(0.4,0.3,0.3)	(0.2,0.6,0.2)
Decisiveness	(0.5,0.2,0.3)	(0.6,0.1,0.3)	(0.5,0.2,0.3)	(0.3,0.3,0.4)	(0.1,0.8,0.1)
Goal driven	(0.4,0.3,0.3).	(0.5,0.2,0.3)	(0.2,0.2,0.6)	(0.1,0.3,0.6)	(0.2,0.2,0.6)
Machine Independence	(0.1,0.5,0.4)	(0.1,0.6,0.3)	(0.3,0.2,0.5)	(0.2,0.4,0.4)	(0.7,0.2,0.1)
Average response time	(0.5,0.2,0.3)	(0.4,0.2,0.4)	(0.8,0.0,0.2)	(0.2,0.2,0.6)	(0.3,0.4,0.3)

Table 3: Stakeholders' opinion of quality factors for ITPS

T	Collaboration	Knowledgeability	Performance	Persistence	Extensibility
Project manager	(0.5,0.2,0.3)	(0.5,0.2,0.3)	(0.8,0.1,0.1)	(0.4,0.2,0.4)	(0.3,0.2,0.5)
Software engineer	(0.7,0.2,0.1)	(0.8,0.1,0.1)	(0.6,0.2,0.2)	(0.4,0.2,0.4)	(0.4,0.2,0.4)
User	(0.5,0.2,0.3)	(0.5,0.2,0.3)	(0.8,0.1,0.1)	(0.3,0.2,0.5)	(0.2,0.2,0.6)
Maintainer	(0.5,0.2,0.3)	(0.6,0.1,0.3)	(0.5,0.2,0.3)	(0.4,0.3,0.3)	(0.7,0.2,0.1)

Table 4: Distance among stakeholders' opinion for ITPS

Distance	Collaboration	Knowledgeability	Performance	Persistence	Extensibility
Hamming	0.1	0.2	0.25	0.1	0.3
Euclidean	0.0707	0.1288	0.1547	0.065	0.212

Sorting this list in descending order, we get

Table 5: Prioritized factors in ascending order of stakeholders' consensus (descending order of distance)

Distance	Extensibility	Performance	Knowledgeability	Collaboration	Persistence
Hamming	0.3	0.25	0.2	0.1	0.1
Euclidean	0.212	0.1547	0.1288	0.0707	0.065

involved in the project. Prioritization of quality specifications based on the Euclidean/ Hamming distance among stakeholders' opinion has been achieved that would assist quality engineer in accomplishing the quality specifications by taking most desired factors while ignoring the factors with least preference and support developers in meeting explicit quality needs of the MASs and stakeholders.

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