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Trust Based Quantification of Quality in Multi-agent Systems

Punam Bedi and Vibha Gaur
Department of Computer Sciences, University of Delhi, Delhi-11007, India

Abstract: Agent technologies have been revitalized for engineering complex distributed software systems. Conventional software quality models such as ISO 9126 address quality in terms of factors. Since distinct quality factors have dissimilar units, comprehensive quality can't be computed just by adding them. But, a mechanism to determine quality is needed to guide developers in achieving the desired product quality. This research proposes evolution levels of stakeholders' trust namely a priori belief, indirect trust, proximity trust, transitive trust and intentional trust which are used to quantify quality of Multi-agent system. Since trust is subjective in nature and Intuitionistic fuzzy sets are most suited for capturing subjectiveness, these have been adopted to evaluate multi level measure of stakeholders' trust.

Key words: Multi-agent system (MAS), intuitionistic fuzzy sets (IFS), proximity trust, transitive trust, intentional trust, trust wheel

INTRODUCTION

Software agents have been used to control translation of messages, representing buyers and sellers in e-commerce transactions and managing the database queries and updates.

Multi-agent systems consist of an environment populated with a set of autonomous entities known as software agents that cooperate to solve a complex problem in decentralized way. Software agents are autonomous program units that act on behalf of their users, across open and distributed environments. Software agents solve a growing number of complex problems and can move throughout a network of agent aware computers (Luiqi and Wictor, 2001). Agents are characterized as autonomous, goal-oriented, situation aware and proactive as well as reactive. 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 and so on. MASs have been applied in a variety of domains, including aircraft maintenance, wireless collaboration and communications, financial portfolio management, supply chain management etc. An application of MASs to monitor complex chemical processes has been presented (Bunch *et al*., 2004). An application of MAS to a service mobile manipulator robot that interacts with a human during an object delivery and hand-over task has been presented by Erden *et al*. (2004). Guiagoussou and Said (1999) present the implementation of a maintenance application for cellular switching system using the Multi-agent paradigm.

MASs pose challenges for software engineers, as the quality in MAS is not straightforward. However, both researchers and practitioners are lacking a comprehensive framework that would help them evaluate the quality of MAS and there is a pressing need for software-engineering techniques that allow quality of MAS to be effectively managed.

We found a little guidance in literature on what constitutes a comprehensive quality in MAS. Far (2002) defines knowledgeability and complexity issues in MAS. A method for measurement of quality of Java agents using extreme programming, which depends only on code, has been presented (Luiqi and Wictor, 2001). Far and Wahono (2003) has defined mechanisms for decision-making by software agents in uncertain environments.

Conventional software quality models such as McCall's *et al*. (1977) and ISO 9126 (based on 6 factors: functionality, reliability, usability, maintainability, efficiency and portability) addresses quality of software in terms of factors and criteria. Thus quality is a function of combined attributes that represents some aspect of quality. But substituting the values of these attributes to compute quality is not possible (Voas *et al*., 2004) because units of each attribute are not equal. By adding distinct quality factors will give a new entity with different units than those used in the computation of quality. So a mechanism to determine quality of MAS is needed to guide developers and researchers to achieve the desired product quality.

In literature, researchers in software engineering have tried different ways of defining quality. They have adopted product-based view (Boehm *et al*., 1976;

Corresponding Author: Vibha Gaur, Department of Computer Sciences, University of Delhi, Delhi-110007, India
Tel: 91-011-27667591 Fax: 27662553

McCall *et al.*, 1977; Kitchenham and Walker, 1986), the manufacturing view (Paulk *et al.*, 1991; Dowson, 1993). But quality has not been examined from viewpoint of stakeholders' trust. Since one of the prime goals of achieving quality is to build stakeholders trust in the system, this paper uses this perception to define quality in MAS.

Trust and quality are inter dependent terms. As quality based system induces stakeholders' trust in the system and likewise if a stakeholder trusts a system, the system is more likely to satisfy quality parameters of their interest. Trust is a complex, multifaceted and context-dependent notion (Bhargava and Lilien, 2004). Sloman (2004) defines trust as the quantified belief by a trustor with respect to competence, honesty, security and dependability of a trustee within a specified context. It is also defined as the trusting peer's belief in the trusted peer's willingness and capability to behave as expected by the trusting peer in a given context at a given time slot in a particular association relationship (Rehman and Hailes, 2000; Hussain *et al.*, 2004).

Relationship between stakeholders' trust and quality is required to achieve quality goal in MAS. Firstly, this paper explores evolution levels of stakeholders' trust namely A priori belief, indirect trust, proximity trust, transitive trust and intentional trust; secondly, it defines quality as a function of distinct levels of trust and finally quantifies quality from trust.

Since trust is subjective in nature and the manner in which the human mind deals with subjective concepts such as yes, no, can't say (linguistic terms), the Intuitionistic Fuzzy Sets (IFS) are most suited for capturing such subjectiveness. An IFS based method has been adopted to quantify distinct levels of stakeholders' trust.

MAS Quality: Quality in software system is defined as the degree to which a system, a component or process conforms to specified requirement (David *et al.*, 1990) or fitness for use. ISO Standard 8402 defines quality as; the totality of features and characteristics of a product or services that bears on its ability to satisfy stated or implied needs. A quality based product results in better user satisfaction. Conventional software quality models such as McCall's (1977) and ISO 9126 (based on 6 factors: functionality, reliability, usability, maintainability, efficiency and portability) addresses quality of software in terms of factors and criteria.

Far (2002) define quality in MAS from various viewpoints such as:

- Conformance: Conformance to customer's requirements; conformance to standards;
- Development process quality: requirement, design, implementation, test and maintenance quality;
- End-product quality: reliability, usability and availability;
- Relativity: advantage over similar products;

Lee *et al.* (1998) define non-functional properties of MASs which includes

- Performance: It is a measure using a set of statistical indicators of the system's major outputs and its consumption of resources, where typical indicators of performance in MAS include throughput, response time, number of concurrent agents/tasks, computational time and communication overhead.
- Scalability: It is the average measure of the degree of performance degradation of individual agents in the MAS as their environmental loading, caused by an expansion in the size of MAS increases.
- Stability: It is defined with respect to perturbations of some sort such as noise, variations in parameter values, addition or disablement of agents, etc. Should a small disturbance at a given instant grow and become significant such that after a long time the behavior of the system depend substantially on the initial disturbance, the system is then considered unstable.

Relationship between stakeholders trust and quality is required to achieve quality goal in MAS. Therefore quality of MAS can be defined as achieving high levels of stakeholders' trust.

Basics of 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 (Szmidt and Kacprzyk, 2002) 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 (Atanassov, 1999), which are used, in the next section.

Definition 1: Consider a set E. An intuitionistic fuzzy set (IFS) A in E is defined as an object of the following form

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

Where the functions

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

and

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

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

$$0 \leq \mu_A + \nu_A \leq 1$$

Obviously, each ordinary fuzzy set may be written as

$$\{(x, \mu_A(x), 1 - \mu_A(x)) \mid x \in E\}$$

Definition 2: The value of

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

is called the degree of non-determinacy (or uncertainty) of the element $x \in E$ to the intuitionistic fuzzy set A. This may cater to either membership value or non-membership value or both.

Definition 3: If A and B are two IFSs of the set E, then

$$A \subset B \text{ iff } \forall x \in E, \ [\mu_A(x) \leq \mu_B(x) \text{ and } \nu_A(x) \geq \nu_B(x)],$$

$$A \supset B \text{ iff } B \subset A,$$

$$A = B \text{ iff } \forall x \in E, [\mu_A(x) = \mu_B(x) \text{ and } \nu_A(x) = \nu_B(x)],$$

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

$$A \cap B = \{(x, \min(\mu_A(x), \mu_B(x)), \max(\nu_A(x), \nu_B(x))) \mid x \in E\}$$

$$A \cup B = \{(x, \max(\mu_A(x), \mu_B(x)), \min(\nu_A(x), \nu_B(x))) \mid x \in E\}$$

Definition 4: Let X and Y be two sets. An intuitionistic fuzzy relation (IFR) R from X to Y is an IFS of X x Y characterized by the membership function μ_R and the non-membership function ν_R and is denoted as

$$R\,(X \rightarrow Y)$$

Definition 5: If A is an IFS of X, then the max-min-max composition (Szmidt and Kacprzyk, 2002) of the IFR R $(X \rightarrow Y)$ with A is an IFS B of Y denoted by B = RoA 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 6: Let $Q(X \rightarrow Y)$ and $R(Y \rightarrow Z)$ be two IFRs. The max-min-max composition RoQ 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

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

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

Also, if R and S are two IFRs on $X \times Y$ and $Y \times Z$ respectively, then

- $(R^{-1})^{-1} = R$
- $(S \text{ o } R)^{-1} = R^{-1} \text{ o } S^{-1}$

LEVELS OF TRUST IN MAS

Trust plays a key role in MASs as agents will be representing or acting on behalf of users or owners with different goals and motivations. Tasks are delegated to software agents that achieve their common goals based on interaction among themselves. Barber and Kim (2002) define trust as confidence in the ability and intention of an agent to provide correct information or perform promised actions. We define trust in MAS as the dynamic entity that is a positive belief at the initial stage, it grows on the basis of some rational belief or justification of external resources with whom the system interacted in the past, gets ascertained with objective knowledge of MAS in terms of qualitative characteristics, becomes conceptualized with use of logical inference such as extrapolation or interpolation to predict system behavior and reaches at apex with MAS's tendency to behave honestly toward achievement of goals. Trust evolution pyramid is shown below in Fig. 1.

The above definition of trust assumes that trust can be decomposed into high-level trust factors and these factors may be defined in terms of criterias which can be measured. Since defining trust in terms of criterias is a user oriented view of trust while trust levels indicate trust from evaluation point of view. Following section addresses distinct levels of trust in terms of factors and the relationship between trust levels, their respective factors and criterias have been presented in Table 1.

Rudimentary trust/A priori belief: In the initial bootstrapping stages, where little information is available about the MAS then one must depend upon a priori belief. A priori belief is a state of mind in which rudimentary trust is formed without any previous interactions. This is placed without an underlying rational or verifiable method or established theories and is crucial in explaining validity of MAS in novel applications (Kashyap, 2004). A priori belief in MAS requires an element of Familiarity in order to develop.

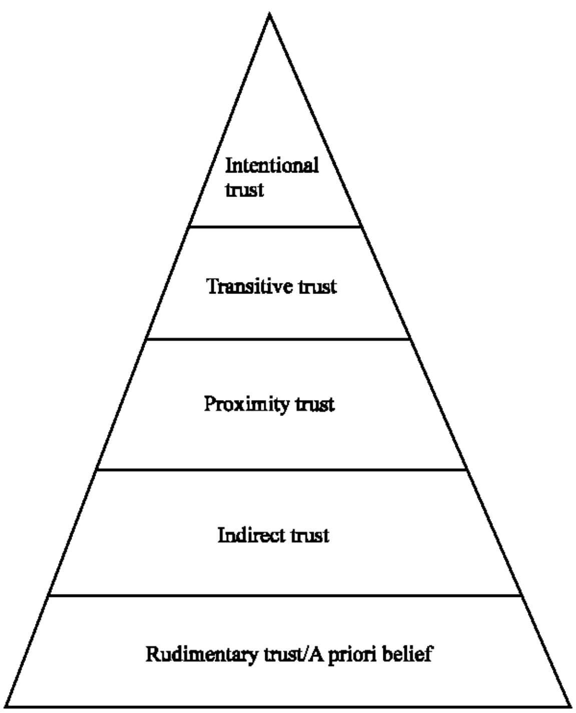

Fig 1: Trust evolution pyramid

Table 1: Relationship between trust levels, factors and criteria

Trust levels	Trust factors	Trust criterias
A priori belief	Familiarity	Autonomy Sociability Proactiveness Decisiveness Reasoning Collaboration
Indirect trust	Reputation	Competence Quality of service Consistency Complete, Correct and relevant info.
	Credence	Trust certificate Reputation of organization owning the MAS
	Risk management	Goal driven Uncertainty handling Recovery Fault tolerance Stability
Proximity trust	Knowledgeability	Communicative richness Correctness Completeness Consistency Recentness and relevance
	Realism	Correctness Self-descriptiveness Cost effectiveness Interactive Achievement of goals
	Feasibility	Cost effectiveness Technical competence Social acceptance Goal driven
	Persistence	Distilled information Knowledge acquisition Stability Acceptability True identity
	Performance	Response time Turnaround time Execution time Resource management Frequency of defects
	Integrity	Availability Confidentiality Security Fault tolerance Recovery
	Usability	Interface design issues Proper navigationallinks Comfortable system's dialogue to users Ease of use
Transitive trust	Predictability and behavioral experience	Inferences of past experience Duration of relationship in past Consistency Reinforcements and restraints Stability of environment
Intentional trust	Intention	Benevolence Desires Committal in achieving goal Collaboration for achieving goals

The Familiarity in MAS can be defined as the cognitive capabilities of agents that every one believes in. Features such as autonomy, sociability, proactiveness, decisiveness, reasoning and collaboration often characterize the software agents.

Indirect trust: Indirect trust is based on external resources e.g., past experience with the MAS (the way others interacted to system). This is formed when we assume the validity of MAS on the basis of some rational belief or justification e.g., Reputation of MAS, Credentials that it had acquired from trusted authorities, Risk Management as trust is required most in risky situations. Indirect trust might be measured objectively or empirically.

Reputation: Robinson (1996) states reputation as one builds probabilistic beliefs about the [other] party based on rational reasons, such as the past behavior of or experience with that other party. Reputation of MAS is directly influenced by characteristics such as competence, quality of service, consistency in achievement of goals and quality of information brought by MAS.

Credence of MAS can be measured by Trust certificate issued by trusted party like CMM, ISO etc. and reputation of organization owning the MAS.

Risk Management affect the stakeholders' trust immediately as trust is required most in risky situations.

Proximity trust: Proximity refers to high level of direct interaction in which the behavior of MAS can be observed and evaluated. It assumes a long enough relationship to allow for a detailed analysis of MAS. Proximity trust is placed in MAS with objective knowledge of successes in terms of qualitative attributes and is induced as a result of direct communication of users with MAS. Proximity facilitates the formation of trust because of transparent behavior of MAS revealed to users. Factors that affect proximity trust in MAS are as follows:

- Knowledgeability
- Realism
- Feasibility
- Persistence
- Performance
- Integrity
- Usability

The relationship between the quality characteristics and trust can be viewed as a wheel shown in Fig. 2, where MAS can be regarded as hub and quality characteristics

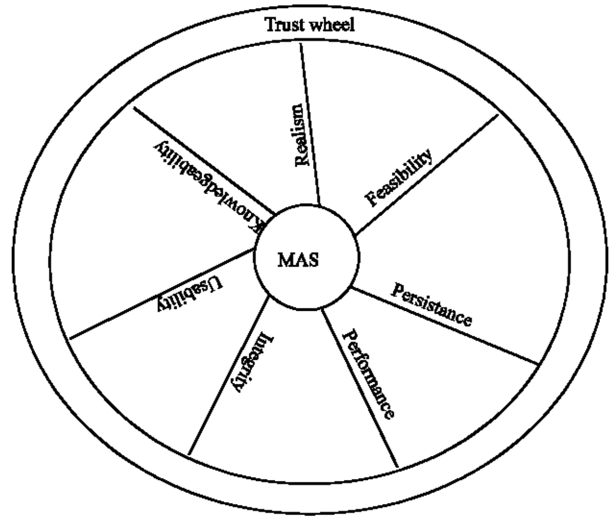

Fig. 2: Trust wheel driven by qualitative characteristics of MAS

as spokes that drive the trust as rim. More the quality characteristics driving the rim, stronger is trust of the user in MAS. And if any of these quality characteristics degrade over a period of time, it will affect the bondage between trust and MAS.

Knowledgeability: It is the extent to which MAS acquires knowledge from its environment, peer agents and users to achieve the goals. A software agent performs a task that requires particularly large amount of knowledge and reasoning using that knowledge. For example, it may be required to have knowledge of daily routines, habits and preference of the users on behalf of whom it is simulating the behavior. Clearly, an agent that deemed knowledgeable will find it easier to establish trust relationship with its users and peer agents. Communicative richness, correctness, completeness, consistency, recentness and relevance are the criterias for assessing knowledgeability.

Realism: It is the extent to which the performance of MAS matches with that of human agents in terms of problem solving and hence achievement of goals. Correctness, self-descriptiveness, cost effectiveness, goal achievement and interactivity affect the realism.

Feasibility: It is the extent to which MAS is economically, technically and socially accessible to the user community. When a number of MASs in same domain are available with same capabilities, the one that is economical, technically sound and acceptable to users will find it easier to establish trust. Cost effectiveness, goal achievement, social acceptance and technical competence characterize the feasibility of the system.

Persistence: It is the consistency with which an agent achieves its goals. It designates identity to software agents and in turn helps in establishing and extending the relationship with peer agents and users. These interacting agents form social structures to facilitate mutual assistance in achieving the goals. So with persistence the MAS can earn reputation for competence, timeliness and ease of use and trust worthiness. The MAS that deems trustworthy will find it easier to establish the relationship with other agents and this relationship provides access to resources that can assist the MAS with its tasks at hand and finally in mutual assistance. An agent with a reputation for conducting thorough search will be trusted by peer agents wishing to use the results obtained by this MAS (Buhler and Huhns, 2001). Distilled information for making the decisions, knowledge acquisition, recovery, stability, acceptability and true identity have an effect on persistence of MAS.

Performance: It has multi facets e.g., response time (Patrick, 2002), quality of service, value of response etc. Clearly, Performance of MAS affects the user trust directly. Turnaround time, response time, execution time resource management and frequency of defects characterize the performance of MAS.

Integrity: An integrity characteristic deals with the authentication, security and privacy issues of parties involved in online transaction. Integrity and confidentiality of agent information affects the availability of information in MAS. Integrity is defined as the protection of MAS against eavesdropping and modification when an agent migrates from one host to another and protection of agent when resident on a host (Sheldreup and lnes, 1999).

Availability, confidentiality, security, fault tolerance and recovery affect integrity of MAS (Fig. 3).

Usability: It deals with interaction issues of agents with users. Usability is the ease with which the users can utilize the services of MAS and hence nurture trust of users in MAS. Interface design issues, proper navigational links, comfortable system's dialogues to users and ease of use influence usability of MAS.

Transitive trust: It is conceptualized as combination of indirect and proximity trust together with use of logical inference such as extrapolation or interpolation. This trust is based on predictability, behavioral experience of MAS so that the behavior of system could be anticipated for future use.

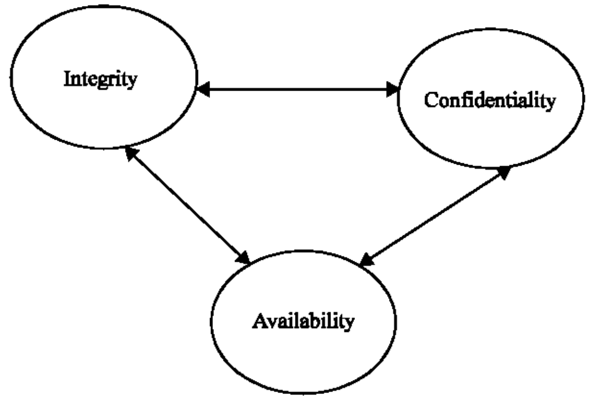

Fig. 3: Interrelation of availability, integrity and confidentiality

Predictability in MAS can be defined as stakeholders' expectations about system's future behavior, based on inference from observed past behaviors. Predictability in MAS is facilitated if one possesses specific information about MAS such as consistency in behavior, reinforcements and restraints. Inference from past experience, consistency of behavior, stability of environment, reinforcements and restraints and duration of relationship in past affect predictability of MAS.

Behavioral Experience also leads to predictability. Inferences of experience and duration of relationship affect behavioral experience.

Intentional trust: An MAS's tendency to behave honestly toward achievement of goals builds intentional trust in stakeholders. It may be defined as the extent to which users believe a system is honest and concerned about them. Examples of honest behavior include MAS providing information it believes to be truthful (Barber *et al*., 2003). Benevolence, desires, committal in achieving goals and collaboration for achieving the goals induces intentional trust in MAS.

INTUITIONISTIC INTEGRATED TRUST MEASUREMENT IN MAS

Here we presents how intuitionistic fuzzy set theory can be used in the implementation of integrated trust measurement for MAS.

In a Software Engineering environment, suppose

C = A set of trust criteria,
L = A set of trust levels,
S = A set of stakeholders.

Intuitionistic Integrated Trust measurement for MAS involves mainly the following steps:

- Identify trust criterias C and levels of trust L in MAS from Table 1.
- Input stakeholders S.
- Formulations of Intuitionistic fuzzy relation Q between trust criteria C and Stakeholders S.
- Formulation of Intuitionistic fuzzy relation R between trust criteria C and trust levels L.
- Determination of Intuitionistic fuzzy relation T = RoQ that consisting of values for trust levels corresponding to various stakeholders' on the basis of composition of Intuitionistic Fuzzy Relations R and Q.
- Compute the effective stakeholders opinion (without hesitation) by subtracting the product of nonmembership and uncertainty part from the membership part ($\mu(x)$-$\nu(x)$* $\pi(x)$) (Bedi and Kaur, 2005).
- Find weighted average of values for each level giving weights w_i to various stakeholders s_i, i.e., calculate $\Sigma w_i\ \mu_T(s_i,\ l)/\Sigma w_i$. This gives integrated views of Intuitionistic trust in MAS for various stakeholders.

Let R be an intuitionistic fuzzy relation (IFR) from the set of trust criteria C to trust levels L (i.e., on C x L). Then R reveals the degree of association and degree of non-association between trust criteria and level.

Let state of a given stakeholder S is described in terms of an IFS A of C. Then max-min-max composition (Defn. 5) B, o f IFS A with the IFR R(C→L) denoted by B = RoA signifies the state of the stakeholder in terms of levels of trust as an IFS B of L with the membership function given by

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

And the non-membership function is given by

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

$\forall l \in L$ (Here $\vee$ = max, $\wedge$ = min)

The value of R (Table 3) is to be specified by a quality engineer/a team of quality engineers who is/are able to translate their own perception of intuitionism involved in degrees of association and non-associations respectively between trust criterias and levels.

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→L) and construct an IFR Q (Table 2) from the set of stakeholders S to the set of criteria C. Clearly, the composition T (Table 4) of IFRs R and Q (T = RoQ) describes the state of the stakeholders in terms of the trust levels as an IFR from S to F given by the membership function

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

And the non-membership function given by

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

Table 2: Stakeholders' opinion for influence of trust criterias on trust

Q	Proactive-ness	Collaboration	Quality of service	stability	Cost effectiveness	Ease of use	Turn around time	Consistencey	Commitruent
Academicians	(0.9, 0.1)	(0.8, 0.2)	(0.7, 0.2)	(0.8, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.6, 0.1)	(0.7, 0.1)	(0.7, 0.1)
Practitioners	(0.9, 0.1)	(0.9, 0.1)	(0.8, 0.1)	(0.9, 0.1)	(0.8, 0.1)	(0.6, 0.2)	(0.8, 0.1)	(0.9, 0.1)	(0.9, 0.1)
User	(0.8, 0.2)	(0.5, 0.3)	(0.5, 0.5)	(0.7, 0.3)	(0.6, 0.2)	(0.8, 0.1)	(0.6, 0.3)	(0.7, 0.2)	(0.6, 0.2)

Table 3: Quality expert opinion for contribution of trust criterias to trust levels

R	A priori trust	Indirect trust	Qualitative trust	Transitive trust	Intentional trust
Proactive-ness	(0.9, 0.1)	(0.5, 0.5)	(0.7, 0.2)	(0.6, 0.2)	(0.5, 0.3)
Collaboration	(0.7, 0.1)	(0.5, 0.5)	(0.6, 0.2)	(0.7, 0.1)	(0.6, 0.3)
Quality of service	(0.6, 0.1)	(0.7, 0.1)	(0.2, 0.2)	(0.6, 0.1)	(0.1, 0.5)
stability	(0.3, 0.5).	(0.3, 0.2)	(0.7, 0.1)	(0.6, 0.2)	(0.8, 0.1)
Cost effectiveness	(0.2, 0.5)	(0.1, 0.6)	(0.7, 0.1)	(0.6, 0.2)	(0.1, 0.5)
Ease of use	(0.2, 0.4)	(0.4, 0.3)	(0.8, 0.1)	(0.6, 0.1)	(0.3, 0.2)
Turn around time	(0.1, 0.4)	(0.3, 0.2)	(0.7, 0.1)	(0.5, 0.2)	(0.2, 0.4)
Consistency	(0.3, 0.2)	(0.5, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.6, 0.1)
Commitruent	(0.3, 0.1)	(0.5, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.9, 0.1)

Table 4: Stakeholders opinion in terms of trust levels obtained from Table 2 and 3

T	A priori trust	Indirect trust	Proximity trust	Transitive trust	Intentional trust
Academicians	(0.9, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.8, 0.1)
Practitioners	(0.9, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.7, 0.1)	(0.9, 0.1)
User	(0.8, 0.2)	(0.5, 0.2)	(0.8, 0.1)	(0.7, 0.1)	(0.7, 0.2)

Table 5: Effective stakeholders opinion (without hesitation) for trust levels

C_R	A Priori trust	Indirect trust	Proximity trust	Transitive trust	Intentional trust
Academicians	0.9	0.68	0.68	0.68	0.79
Practitioners	0.9	0.68	0.68	0.68	0.9
User	0.8	0.44	0.79	0.68	0.68

Table 6: Degree of membership of various trust levels in MAS

A Priori trust	Indirect trust	Proximity trust	Transitive trust	Intentional trust
0.86	0.584	0.724	0.612	0.779

$\forall s_i \in S$ and $l \in L$.

The weighted average of values for each level can be obtained by giving weights to various stakeholders.

Experimental study: An experimental study of Online Stock Market (OSM) was performed to assess the relationship of quality and trust. OSM is an open system that we model as MAS, with traders, brokers, buyers, sellers, price analyzers and negotiators are software entities (agents) that act on behalf of their human owners by autonomously carrying out the negotiation and the exchange of stocks. All the entities are distributed, each connecting to Internet from a different location, with agents entering and leaving the system as they wish.

For an intelligent seller agent to return the most relevant stocks, it must understand the nature of order placed by buyer agent and the context of the search. It must also understand the content of web search it indexed and be able to reason what led it to serve the order in this way. Knowledgeability of software agents will identify which of stocks are in demand while persistent identity of software agents will help in establishing relationship with other agents and can result in increased turnover of MAS application. Integrity authenticates the parties involved in transaction and protects the software agents against the alteration in code or its malicious behavior. Usability of MAS signifies ease to use, easy to learn system for users and realism emphasizes the performance of trading system as if it is being performed by human agents.

A survey was conducted to find the quality from various levels of trust and participants were from three groups; 8 academicians (who are working in the areas of software quality, agent oriented software engineering, trust, web engineering), 6 practitioners (that are practicing as quality engineers, members of SQA team and testing professionals) and 21 users of Stock Market. Nine trust criterias namely proactiveness, collaboration, quality of service, stability, cost effectiveness, ease of use, turn around time, consistency and commitment were selected to simplify the study. Each group of members was requested to give their opinion about influence of trust criterias on stakeholders' trust using IFS. e.g., Users believe that ease of use contribute towards trust in MAS by 0.8 value and it does not contribute for formation of trust by 0.1. And hesitation part can be computed by subtracting the sum of membership and nonmembership from one (1), i.e., (1-0.8-0.1 = 0.1). The value of hesitation signifies the indecisiveness regarding building of trust from ease of use. Quality expert was consulted to obtain degree of association of these criteria with trust levels (Table 3). The IFS relation (Table 4) between stakeholders and trust levels was formed using Table 2 and 3. And finally, effective stakeholders' opinion without hesitation about trust levels in MAS has been obtained by subtracting the product of nonmembership part and hesitation part from membership part (Table 5). If we assign weights 0.3, 0.3 and 0.4 to academician, practitioners and user respectively then the weighted degree of membership of trust levels for the quantification of MAS quality is calculated (Table 6).

Table 6 shows that A priori trust, Indirect trust, Qualitative trust, Transitive trust and Intentional trust contributes 86, 58.4, 72.4, 61.2 and 77.9%, respectively for the quantification of quality.

MAS QUALITY MEASUREMENT

Large scale MAS based software development will require support for a quality metric that will guide the developers in choosing the techniques to achieve the desired product quality. Conventional software quality models Boehm's (1989), McCall's (1977) and ISO 9126 addresses quality in terms of quality attributes and criteria to represent the attribute. Thus quality is a function of combined attributes say $A_1, A_2, A_3 \ldots A_n$ and would be

$$Q = f(A_1, A_2, A_3 \ldots A_n) + \epsilon$$

Where ϵ represents error term that represents quality aspects that $A_1, A_2, A_3 \ldots A_n$ could not define.

This metric is simplistic, impractical and not even accurate (Voas *et al*., 2004) because units of each attribute are not equal. By adding distinct quality factors will give a new entity with different units than those used in the computation of quality. But, a mechanism to determine quality of MASs is needed to guide developers and researchers to achieve the desired product quality.

The American Heritage Dictionary defines quality as a characteristic or attribute of some thing. Since multiple levels of stakeholders trust are influenced by one or the other characteristics of agents, so quality in MAS may be defined as

Quality = f (A priori belief, Indirect Trust, Proximity Trust, Transitive Trust, Intentional Trust)

Quality = α* A priori belief+β* Indirect Trust+χ* Proximity Trust+δ* Transitive Trust+η* Intentional Trust.

Where

α-Coefficient of Familiarity;

β-Coefficient of Trust of indirect references;

χ-Coefficient of Transparency that will depend on information revealed to users while problem solving and will be decided by quality expert depending on the application requirements;

δ-Coefficient of Consistency based on past and present interaction of MAS with stakeholders;

η-Coefficient of Sensitivity of application towards honesty in MAS and will be decided by quality expert.
Such that sum of weights $\alpha,\beta,\chi,\delta,\eta$ is 1.0.

For a safety-critical system, weights for qualitative trust will be more than a priori belief or indirect trust. For an e-commerce system, weights of a priori belief, indirect trust and transitive trust would be higher than proximity and intentional trust. Quality expert will decide weighing in computation of quality for each MAS application.

The values of coefficients α, β, χ, δ and η (which are project dependent) have been obtained from quality expert for Online Stock Market as 0.3, 0.2, 0.3, 0.1 and 0.1, respectively. Substituting these coefficients and the values of A priori belief, Indirect Trust, Proximity Trust, Transitive Trust and Intentional Trust obtained earlier, in Eq. 1, we obtain

Quality = 0.86* 0.3+0.584* 0.2+0.724* 0.3+0.612* 0.1
= 0.7312

The value of quality obtained for, OSM is quite satisfactory as the minimum value of quality is zero and maximum value is 1. The quantification of quality helps to compare the different MAS and will be beneficial in deciding which of the MAS will gain popularity among the users as all the trust levels have been defined keeping in mind the users opinion of trust.

CONCLUSIONS

This study explores the evolution process of stakeholders' trust in MAS. Various levels of trust namely A priori belief, Indirect trust, Qualitative trust, Transitive trust and Intentional trust have been identified that are then addressed in terms of non-quantifiable factors and factors have further been addressed in form of quantifiable criterias. Since defining trust in terms of criterias is a user oriented view of trust while trust levels indicate trust from evaluation point of view. The relationship between trust and quality is required to define comprehensive quality. As quality instill trust in the users of the system and likewise if a user trusts a system, the system is more likely to satisfy quality parameters of user interest. This paper explores the relationship between stakeholders' trust and quality of MAS. An IFS based method has been used to quantify various levels of trust that have been used in computation of quality. The quantified quality thus helps in deciding that whether MAS will be acceptable to user community.

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