Fuzzy Evaluation of Social Exchanges Between Personality-based Agents

G.P. Dimuro[1], A.V. Santos[1], B.C. Bedregal[2], and A.C.R. Costa[1]

[1] PPGINF, Universidade Católica de Pelotas, 96010-000 Pelotas, Brazil
[2] DIMAP, Universidade Federal do Rio Grande do Norte, 59072-970 Natal, Brazil
{liz,avs,rocha}@ucpel.tche.br,{bedregal}@dimap.ufrn.br

Abstract. Social interactions can be seen as service exchanges, followed by the qualitative evaluation of those exchanges by means of social exchange values. This paper introduces an approach based on Fuzzy Logic for the evaluation of the investment and satisfaction values generated in personality-based social exchanges in multiagent systems. The fuzzy equations of material social equilibrium, associated to the first stage of a social exchange between agents, are analyzed in detail. A case study is presented to illustrate the proposed approach.

1 Introduction and Related Work

According to [1], it is possible to distinguish between three coordination models in Multiagent Systems (MAS): hierarchies, markets and networks, which result in different frameworks for agent societies, driving the way the social interactions between agents are analyzed. This work is in the context of the agent-based simulation [2, 3] of network-oriented societies with collaboration-based social control, based on Piaget's theory of *social exchanges* [4], in the line of the works in [5–12].

In Piaget's theory, social interactions are seen as service exchanges between pairs of agents, followed by the qualitative evaluation of those exchanges by the agents by means of *social exchange values*: the *investment* value for performing a service or the *satisfaction* value for receiving it, called *material values*. The exchanges also generate values of *debts* and *credits* that help to guarantee the continuity of future interactions. A MAS is said to be in *social equilibrium* if the balances of investment and satisfaction values are equilibrated for the successive exchanges occurring along the time.

Social exchange values are of a qualitative nature, since they represent subjective values with which everyone judges the daily exchanges he has (*good*, *bad*, *better than*, *worst than* etc.), which usually cannot be faithfully represented quantitatively, due to the lack of neat objective conditions for their measurement. In fact, one of the main contributions of the exchange values approach to social exchanges, in comparison to the classical, quantitative utility function based approach, is precisely the introduction of the possibility of taking care of the variety of such subjective values.

Notice that the notion of exchange in Piaget's theory, which can be related to the work of Homans [13], in some sense refers to the notion of an exchange viewed as "adoption conditional to reciprocation" of the cognitive model of exchange of Conte and Castelfranchi [14], since the realization of a service by an agent in behalf of other agent presupposes that the first adopts the latter. However, in [14] there is no concern neither with the evaluation of the services performed nor with the generation of debts and credits, as a foundation for the continuity of future interactions.

In [6, 9], agents were modeled with the help of a set of simple *social exchange personality traits* (e.g., egoism and altruism),[3] in such way that the performance of the same service could be evaluated by the agents differently according to their various social exchange personality traits (e.g., the performance of a service that seems to be "good" for an altruist agent may be classified as "bad" by an egoist agent). This way of characterizing agent social exchange behaviors was said to be *personality-based*.[4]

In [6], a representation based on Interval Mathematics [20] was used to capture the qualitative nature of Piaget's concept of scale of exchange values [4]. Although this representation seems to be a compromise between a qualitative and a quantitative representation, making it mathematically operational, and the decision process computationally viable, it lacks the subjectiveness of personality-based evaluations.

The work presented in [10–12] introduced a methodology for the evaluation of services in non-economics exchange processes, in order to propose a mechanism for partner selection and coalition in the context of bioinformatics exchange services. In [7, 8], social exchange values were used to incorporate sociability as a means to improve coordination mechanisms in a virtual agent environment. However, in both works we do not find an effective qualitative, subjective representation of exchange values.

On the other hand, the Fuzzy Set Theory [21] introduced in 1965 by Zadeh [22] offers a natural way of representing vagueness and subjectiveness in everyday life. It is based on the idea that several elements in human thinking are not exact data, but can be approximated as classes of objects in which the transition from membership to nonmembership is gradual rather than abrupt. Besides that, human reasoning sometimes does not follow the two-valued or multivalued logic, but logic with fuzzy truths, fuzzy connectives, and fuzzy rules of inference.

Fuzzy logic has been largely used in Soft Computing, with application in different areas, as, e.g., in the context of Social Simulation. In [23], it was observed that simple agent models, as those normally used with exiting tools, are neither sufficient nor adequate to deal with the uncertainty and subjectiveness that have to be considered in the analysis of values (like, e.g., trust) in human societies. Then, in the agent-based social modeling and simulation presented in [23], Fuzzy Logic was used to naturally specify attributes of the agents representing individuals, the evolution of the agent minds, the inheritance, the relationship and similarity between individuals, etc.

Zadeh has pointed out the incompatibility principle, which states that "complexity and precision are incompatible properties", arguing that the conventional numerical-based approaches are inadequate to model human knowledge in complex processes, like, for example, human personality traits. Then, [17, 18] specified human personality

[3] See [15, 16] for a discussion on applications of personality-based agents in the context of MAS.

[4] The notion of egoism (altruism) in social exchange personality traits is not related to the usual concept of selfish (altruist) agents as in [14], since here those personality traits are simply different forms of evaluating social exchanges. For the same reason, the social exchange personality traits can not be compared to patterns of behavioral, temperamental, emotional, and mental traits that are used in several works in social and human simulation, as, e.g., in [17–19].

facets and traits (according to the Big Five and OCEAN models) as conditional rules in fuzzy agentes (agents that can perform qualitative uncertainty reasoning), in order to perform human behavior simulation. See also [24] for an application of Fuzzy Logic in the simulation of human behavior and social networks, representing behavioral elements, such as stress, motivation or fatigue, and sociological aspects.

Differently from [17, 18], in our previous works [6, 9] the social exchange personality traits were defined by means of probability state transition functions, specifying the way the agents increase or decrease their exchange results, by accepting or refusing exchanges proposals according to their preferences on exchange stages (see Sect. 2 for the two different kinds of exchange stages). However, there was no qualitativeness in the evaluations of the exchanges performed by the agentes. In this paper, those social exchange personality traits are enriched by endowing the agents with a fuzzy mechanism to perform qualitative evaluations of social exchanges, according to tendencies specified by their different personalities.

The aim of this work is then to introduce an approach based on fuzzy logic for the evaluation of the material social exchange values generated in the first stage of the social exchanges between personality-based agents, with the analysis of the fuzzy equilibrium equation associated with this stage. This is the first step for the simulation of self-regulation of social exchanges using personality-based MAS [9], where the social equilibrium is treated as a fuzzy concept.

This paper is organized as follows. Section 2 presents a brief description of the model of social exchanges that we adopt in this work. The fuzzy approach for the evaluation of the material exchange values generated in the first stage of a social exchange process between personality-based agents is introduced in Sect. 3. A case study in presented in Sect. 4. Section 5 is the Conclusion with final remarks.

2 The Modelling of Social Exchanges

According to Piaget's approach to social interaction [4], a *social exchange* between two agents, α and β, is seen as an exchange of services between those agents joint with the subjective evaluation of the services by the agents themselves, by means of the so-called qualitative exchange values.

A social exchange involves two types of stages. In stages of type $\mathrm{I}_{\alpha\beta}$, α realizes a service for β. The *exchange values* involved in this stage are the following: $r_{\mathrm{I}_{\alpha\beta}}$, which is the value of the *investment* done by α for the realization of a service for β; $s_{\mathrm{I}_{\beta\alpha}}$, which is the value of β's *satisfaction* due to the receiving of the service done by α; $t_{\mathrm{I}_{\beta\alpha}}$ is the value of β's *debt*, the debt it acquired for its satisfaction with the service done by α; and $v_{\mathrm{I}_{\alpha\beta}}$, which is the value of the *credit* that α acquires for having realized the service for β. In stages of type $\mathrm{II}_{\alpha\beta}$, α asks the payment for the service previously done for β, and the values related with this exchange have similar meaning. The order in which the stages may occur is not necessarily $\mathrm{I}_{\alpha\beta} - \mathrm{II}_{\alpha\beta}$.

The values $r_{\mathrm{I}_{\alpha\beta}}$, $s_{\mathrm{I}_{\beta\alpha}}$, $r_{\mathrm{II}_{\beta\alpha}}$ and $s_{\mathrm{II}_{\alpha\beta}}$ are called *material values* (investments and satisfactions), generated by the evaluation of *immediate exchanges*; the values $t_{\mathrm{I}_{\beta\alpha}}$, $v_{\mathrm{I}_{\alpha\beta}}$, $t_{\mathrm{II}_{\beta\alpha}}$ and $v_{\mathrm{II}_{\alpha\beta}}$ are the *virtual values* (credits and debts), concerning exchanges that are expected to happen in the future [4].

A *social exchange process* is composed by a sequence of stages of type $\mathrm{I}_{\alpha\beta}$ and/or $\mathrm{II}_{\alpha\beta}$ in a set of discrete instants of time. The *material results*, according to the points of view of α and β, are given by the sum of material values of each agent. The *virtual results* are defined analogously. A social exchange process is said to be in *material equilibrium* [5, 6] if in all its duration it holds that the pair of material results of α and β encloses a given equilibrium point[5]. If just the internal equilibrium of an exchange is considered, then the following equilibrium equations [4] are taken into account:[6]

$$\text{Rule } \mathbf{I}_{\alpha\beta} : (r_{\mathbf{I}_{\alpha\beta}} = s_{\mathbf{I}_{\beta\alpha}}) \wedge (s_{\mathbf{I}_{\beta\alpha}} = t_{\mathbf{I}_{\beta\alpha}}) \wedge (t_{\mathbf{I}_{\beta\alpha}} = v_{\mathbf{I}_{\alpha\beta}}) \tag{1}$$

$$\text{Rule } \mathbf{II}_{\alpha\beta} : (v_{\mathbf{II}_{\alpha\beta}} = t_{\mathbf{II}_{\beta\alpha}}) \wedge (t_{\mathbf{II}_{\beta\alpha}} = r_{\mathbf{II}_{\beta\alpha}}) \wedge (r_{\mathbf{II}_{\beta\alpha}} = s_{\mathbf{II}_{\alpha\beta}}) \tag{2}$$

$$\text{Rule } \mathbf{I}_{\alpha\beta}\mathbf{II}_{\beta\alpha} : \ r_{\mathbf{I}_{\alpha\beta}} = s_{\mathbf{II}_{\alpha\beta}} \tag{3}$$

3 Fuzzy Evaluation of Material Exchange Values

Fuzzy sets constitute the oldest and most reported soft computing paradigm, used to modeling different forms of subjectiveness, uncertainties and ambiguities, often encountered in real life. A fuzzy set is a class of objects characterized by a membership function that assigns to each object a degree of membership ranging from 0 to 1. The algebra and other concepts of classical sets were extended to fuzzy sets, and the various properties of these notions were well established. Fuzzy logic, which is the logic underlying fuzzy set theory, was also deeply discussed in the literature [21, 22].

Definition 1. *Let X be a (classical) set. A* fuzzy subset $\mathbb{F}$ *of X is a set of ordered pairs $\mathbb{F} = \{(x, \mu_{\mathbb{F}}(x)) \mid x \in X\}$, where $\mu_{\mathbb{F}} : X \to [0, 1]$ is the* membership function *that gives the* membership degree *of x in $\mathbb{F}$, with the degrees 1 and 0 representing, respectively, the full membership and the non-membership of the element to $\mathbb{F}$.*

3.1 Services and Scales of Values for the Fuzzy Evaluation of Service Attributes

The performance of a service by an agent α to an agent β generates the material values of investment $r_{\alpha\beta}$ (from α's counterpart) and of satisfaction $s_{\beta\alpha}$ (from β's counterpart). For the evaluation of a service, according to those different points of view, one has to take into account all the factors that may influence such evaluations. It follows that:

Definition 2. *A* service in a social exchange *is defined as a tuple $\mathbb{S} = (a_1, \dots, a_n)$, where each a_i, with $1 \leq i \leq n$, $n \in \mathbb{N}$, is a* service attribute *representing an aspect of the service to be analyzed in the evaluation process of the material values generated by the performance of $\mathbb{S}$. The service is denoted by $\mathbb{S}_r(\alpha)$ when the evaluation process of the investment value $r_{\alpha\beta}$ of an agent α is considered. Whenever the evaluation process of the satisfaction value $s_{\beta\alpha}$ of an agent β is analyzed, the service is denoted by $\mathbb{S}_s(\beta)$.*

[5] Notice that Piaget's notion of equilibrium has no game-theoretic meaning, since it involves no notion of game strategy, and concerns just an algebraic sum.

[6] See also [5, 6, 9–11], for more details on this modeling.

The set of attributes is application dependent, and may be different for the evaluation of the service from de points of view of either the agent that performs the service or the one that receives the service. An attributes is represented by a *linguistic variable*, whose value is expressed qualitatively by a *linguistic term* specified by a membership function μ, which constitutes the *fuzzy scale* for the qualitative evaluation of the attribute (see, e.g., the fuzzy scale for the evaluation of the attribute *complexity*, shown in Fig. 1, where the possible values for the complexity are: *low*, *medium* and *high*).[7] The limit value of the x-axis in an evaluation scale is denoted by $N \in \mathbb{N}$.

A fuzzy scale is said to be *decrescent* if greater the measure in the x-axis, worse the attribute evaluation based on the linguistic terms of the scale (see, e.g., the scale of Fig. 1). Otherwise, the fuzzy scale is said to be *crescent*. A fuzzy scale for the evaluation of an attribute a (linguistic variable), with possible values (linguistic terms) $T_1, \ldots, T_m$ is denoted by $T^a = \langle T_1, \ldots, T_m \rangle$, where $m \in \mathbb{N}$ is the fuzzy scale cardinality. The notation $T_k \in T$ means that "the linguistic term T_k is in the fuzzy scale T".

3.2 Social Exchange Agent Personality Traits

The modeling of agent social exchange personality traits considered in this paper is inspired on [6, 9], where the authors introduced a set of agent personality traits for the application in the context of social exchanges in MAS, determining the way the agentes decide on accepting or refusing an exchange proposal. In this paper, those social exchange personality traits also determine different forms in which the agents evaluate the services exchanged, generating qualitative fuzzy exchange values.

Then, an agent is said to be *egoist* if it overvalues the investment for the performance of a service and depreciates the satisfaction for a service received from other agent. On the contrary, an agent is said to be *altruist* whenever it overestimates its satisfaction due to a received service and undervalues its investment when performing a service for other agent. A *tolerant* agent is the one that realizes evaluations according to the common sense, that is, according to the average of the evaluations realized by the local people in analogous situations (obtained by, e.g., an statistical analysis).

A *personality factor* is associated to each agent personality trait, determining the influence of such personality trait in a attribute evaluation. For a decrescent fuzzy scale, the personality factors of tolerance, egoism and altruism, denoted by γ_{tol}, γ_{ego} and γ_{alt}, respectively, satisfy the following constraints:

$$0 \leq \gamma_{ego} < 1 - \delta \quad \text{(depreciation factor)} \tag{4}$$

$$1 - \delta \leq \gamma_{tol} \leq 1 + \delta \quad \text{(neutral factor)} \tag{5}$$

$$1 + \delta < \gamma_{alt} \leq 2 \quad \text{(overvaluation factor)} \tag{6}$$

where $0<\delta<1$ are the variation limits. The inferior limite equal to 0 in Eq. (4) means a depreciation of 100%, and the superior limit equal to 2 in Eq. (6) represents a overvaluation of 100%. The personality factors for a crescent fuzzy scale are defined analogously.

3.3 Fuzzy Evaluation of de Services

For the evaluation of a service attribute a using a fuzzy scale it is necessary first to realize a *normalization* process, which takes into account the personality factors.

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[7] We use trapezoidal-shape membership functions in the configuration of fuzzy scales.

Definition 3. *Let $V(a)$ be the measured value of a service attribute a, N be the limite value of the x-axis of a decrescent fuzzy scale and* max *be the limit value of* a *according to the common sense. The normalized value of the service attribute* a*, for an agent with personality factor γ, is defined as:*

$$V_{nor}(a) = min\{N, V'(a)\}, \text{ where } V'(a) = \frac{V(a) \times N}{\max} \times (2 - \gamma). \tag{7}$$

The service attribute normalization for a crescent fuzzy scale is defined analogously.

The normalized value of the service attribute a is then evaluated in a fuzzy scale, obtaining the fuzzy evaluation of the service attribute, denoted by $\mu(a)$ (see Fig. 1).

Consider a social exchange between a pair of agents α and β, which is started with a service $\mathbb{S}_r(\alpha)$, performed by α to β, defined as $\mathbb{S}_r(\alpha) = (a_1, \ldots, a_n)$. Then, a set of conditional rules is obtained through the crossing of the individual fuzzy evaluation results of the service attributes $a_1, \ldots, a_n$, using the MAX-MIN inference rule [21].

Let $T^i = \langle T^i_1, \ldots, T^i_{k_i} \rangle$ be the fuzzy scale for the evaluation of the attribute a_i of the service $\mathbb{S}_r(\alpha) = (a_1, \ldots, a_n)$ that an agent α performs to an agent β. Let $T^r = \langle T^r_1, \ldots, T^r_m \rangle$ be the fuzzy scale for the evaluation of the investment value $r_{\alpha\beta}$ by α. Then, the fuzzy evaluation of the investment value $r_{\alpha\beta}$ is determined by the MAX-MIN inference rule applied over a rule base "**If** ... **Then**" of type:[8]

If a_1 **is** T^1_j **and** a_2 **is** T^2_l **and** $\ldots$ **and** a_n **is** T^n_p
Then $r'_{\alpha\beta}$ **is** T'^r_q

with $T^1_j \in T^1, T^2_l \in T^2 \ldots T^n_p \in T^n, T^r_q \in T^r$.

For the evaluation of a certain rule, firstly we evaluate each condition of type a_i **is** T^i_k, with $i = 1, \ldots, n$, as been $\mu_i(V_{nor}(a_i))$, that is, the fuzzy evaluation of the normalized value of the service attribute a_i using the fuzzy scale T^i, where $V_{nor}(a_i)$ is determined by Eq. (7). From those values, the evaluation of $r'_{\alpha\beta}$ **is** T'^r_q is obtained as:

$$\min\{\mu_1(V_{nor}(a_1)), \ldots, \mu_n(V_{nor}(a_n))\}. \tag{8}$$

The investment fuzzy value $r_{\alpha\beta}$ is then determined from the evaluation of all rules of such type. For each term T^r_v, with $v = 1, \ldots, m$, one obtains then value

$$\max\{T'^r_v, T''^r_v, \ldots, T^{\omega r}_v\}, \tag{9}$$

where $\omega \leq k_1 \times \ldots \times k_n$, and k_i is the cardinality of the fuzzy scale T^i for the evaluation of each service attribute a_i. These values give rise to a cut in the linguistic term T^r_v, and, therefore, a fuzzy region in T^r. In this region, if necessary, according to the application, it is possible to apply a method of *defuzzification* (e.g., the *centroid* method [21]), in order to obtain a crisp value for the investment $r_{\alpha\beta}$.

The same methodology is applied to obtain the fuzzy satisfaction value $s_{\beta\alpha}$ of the agent β for receiving the service $\mathbb{S}_s(\beta) = (b_1, \ldots, b_n)$, with attributes $b_1, \ldots, b_n$.

4 A Case Study

Consider a pizza delivery system, where there are two points of view for the evaluation: (i) of agent α, which performs the service of delivering a pizza for an agent β, generating an investment value $r_{\alpha\beta}$, where the aspects to be considered in the evaluation of

[8] In this paper, we consider the Gödel t-norm. [21]

Table 1. Rules for the fuzzy evaluation of the investment value $r_{\alpha\beta}$ and the satisfaction value $s_{\beta\alpha}$

$r_{\alpha\beta}$ $(d \times cl)$	low	medium	high	$s_{\beta\alpha}$ $(t \times ct)$	cheap	medium	expensive
close	low	medium	medium	fast	high	high	medium
far	medium	medium	high	medium	high	medium	low
very-far	medium	high	high	slow	medium	low	low

Table 2. Equations of the fuzzy material equilibrium of the stage $I_{\alpha\beta}$ $(r_{\alpha\beta} \times s_{\beta\alpha})$

$I_{\alpha\beta}$	low	medium	high
low	$r_{\alpha\beta} = s_{\beta\alpha}$	$r_{\alpha\beta} < s_{\beta\alpha}$	$r_{\alpha\beta} << s_{\beta\alpha}$
medium	$r_{\alpha\beta} > s_{\beta\alpha}$	$r_{\alpha\beta} = s_{\beta\alpha}$	$r_{\alpha\beta} < s_{\beta\alpha}$
high	$r_{\alpha\beta} >> s_{\beta\alpha}$	$r_{\alpha\beta} > s_{\beta\alpha}$	$r_{\alpha\beta} = s_{\beta\alpha}$

the service are the *complexity* (cl) of the pizza elaboration process and the *distance* (d) of β's residence, where the pizza should be delivered; (ii) of agent β, which receives the service, generating a satisfaction value $s_{\beta\alpha}$, where the aspects to be considered in the evaluation are the *delivery time* (t) and the *cost* (ct) (the amount paid by β for the pizza). Then, this service is defined by: $\mathbb{S}_r(\alpha) = \{d, cl\}$ and $\mathbb{S}_s(\beta) = \{t, ct\}$.

Agents with different personality factors are considered, and we analyze in detail the evaluations realized by α_3 (with egoism personality factor $\gamma_{\alpha_3} = 0.3$) and β_{15} (with altruism personality factor $\gamma_{\beta_{15}} = 1.5$).

4.1 Fuzzy Evaluation of the Investment Value

For the fuzzy evaluation of the investment value of the pizza delivery service $\mathbb{S}_r(\alpha) = \{d, cl\}$, let the fuzzy scales for the evaluation of the service attributes d (delivery distance) and cl (complexity), and of the investment value $r_{\alpha\beta}$, be given, respectively, by:

$T^d = \langle \texttt{very-close}, \texttt{close}, \texttt{far}, \texttt{very-far} \rangle$; $T^{cl} = \langle \texttt{low}, \texttt{medium}, \texttt{high} \rangle$;

$T^r = \langle \texttt{low}, \texttt{medium}, \texttt{high} \rangle$.

The rule base for the fuzzy evaluation of the service investment value $\mathbb{S}_r(\alpha) = \{d, cl\}$, based on the fuzzy evaluation of its service attributes, is shown in Tab. 1.

Consider an instance of the service $\mathbb{S}_r(\alpha) = \{d, cl\}$, whose attributes are measured as $V(cl) = 40$ and $V(d) = 5$. The normalization process of these service attributes, realized by the egoist agent α_3 (with egoism factor $\gamma_{ego} = 0.3$), using Eq. (7), results, respectively, in $V_{nor}(cl) = 6.80$ and $V_{nor}(d) = 5.66$, for $\max_{cl} = 70$ and $\max_d = 15$. For the tolerant agent α_{11} (with tolerance factor $\gamma_{tol} = 1.1$), the normalization process of those same attribute values results in $V_{nor}(cl) = 3.6$ and $V_{nor}(d) = 3$, respectively.

Figures 1 and 2 show, respectively, the fuzzy evaluations of the normalized values $V_{nor}(cl) = 3.6$ and $V_{nor}(d) = 3$ of the attributes cl and d, according to their respective fuzzy scales[9], realized for agentes with different personality factors. In particular, compare the neutral evaluation realized by the tolerant agent α_{11} with the overvalued evaluation realized by the egoist agent α_3, in order to see the influence of the personality factors in the agent evaluations. The fuzzy evaluations of the service attributes cl and d, realized by the egoist agent α_3, result, respectively, in the following fuzzy values:

[9] In all fuzzy scales we adopt $N = 10$.

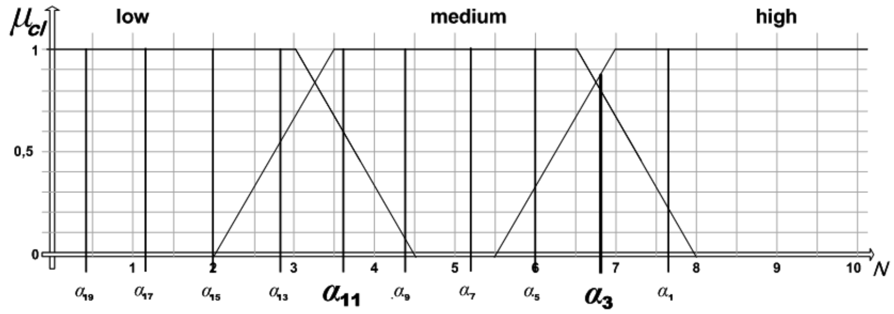

Fig. 1. Fuzzy evaluation of the service attribute *complexity* (cl)

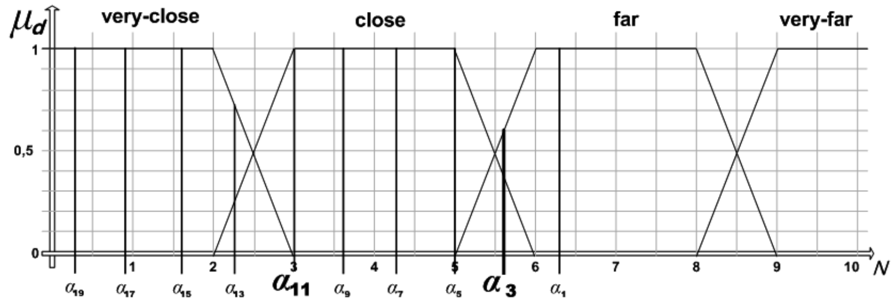

Fig. 2. Fuzzy evaluation of the service attribute *delivery distance* (d)

"cl **is** `medium`" with degree 0.8 and "cl **is** `high`" with degree 0.86
"d **is** `close`" with degree 0.34 and "d **is** `far` " with degree 0.66.

With those fuzzy values, we then evaluate the rules of Tab. 1 that are applicable in this case. Then, using Eq. (9), the fuzzy value of the investment of α_3 is obtained as:

"$r_{\alpha_3\beta}$ **is** `medium`" with degree $\max\{0.34, 0.34, 0.66\} = 0.66$ and
"$r_{\alpha_3\beta}$ **is** `high`" with degree 0.66,

generating the fuzzy region of Fig. 3. The output crisp value of the investment, if necessary, can be obtained by using the centroid method, resulting in 6.852866.

4.2 Fuzzy Evaluation of the Satisfaction Value

For the fuzzy evaluation of the satisfaction value of the pizza delivery service $\mathbb{S}_s(\beta) = \{t, ct\}$, let the fuzzy scales for the evaluation of the service attributes t (delivery time) and ct (cost), and of the satisfaction value $s_{\beta\alpha}$, be given, respectively, by:

$$T^t = \langle \texttt{fast}, \texttt{medium}, \texttt{slow} \rangle; \;\; T^{cl} = \langle \texttt{cheap}, \texttt{medium}, \texttt{expensive} \rangle;$$
$$T^s = \langle \texttt{low}, \texttt{medium}, \texttt{high} \rangle.$$

The rule base for the fuzzy evaluation of the service investment value $s_{\beta\alpha} = \{t, ct\}$, based on the fuzzy evaluation of the respective service attributes, is presented in Tab. 1.

Consider an instance of the service $s_{\beta\alpha} = \{t, ct\}$, whose attributes are measured as $V(t) = 30$ e $V(ct) = 40$. The normalization process of these attributes, realized by the

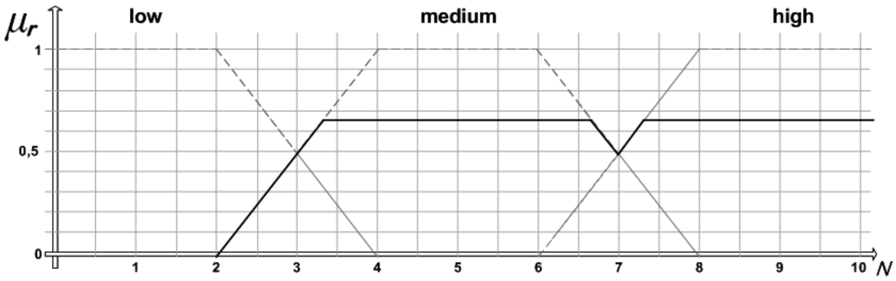

Fig. 3. Geometric representation of α_3's fuzzy investment value

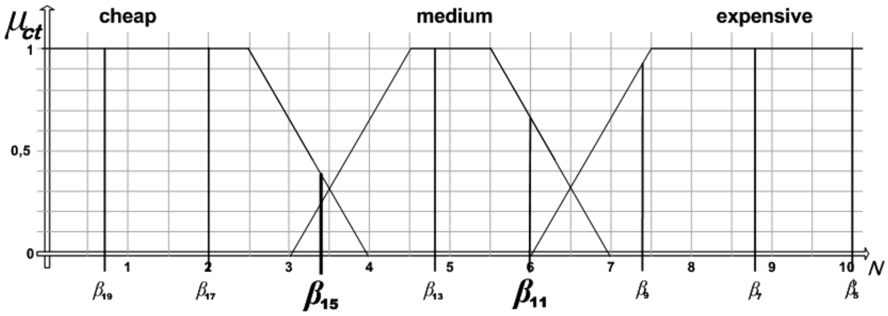

Fig. 4. Fuzzy evaluation of the service attribute *cost* (ct)

altruist agent β_{15} (with altruism factor $\gamma_{alt} = 1.5$), using Eq. (7), results, respectively, in $V_{nor}(t) = 2.5$ and $V_{nor}(ct) = 3.33$, for $\max_t = 60$ and $\max_{ct} = 40$. For the tolerant agent β_{11} (with tolerance factor $\gamma_{tol} = 1.1$), the normalization process of those same attribute values results in $V_{nor}(t) = 4.50$ and $V_{nor}(ct) = 5.99$, respectively.

Figures 4 and 5 show, respectively, the fuzzy evaluations of the normalized values $V_{nor}(t) = 4.50$ and $V_{nor}(ct) = 5.99$ of the attributes t and ct, according to their respective fuzzy scales, realized for agentes with different personality factors. In particular, compare the neutral evaluation realized by the tolerant agent β_{11} with the underestimated evaluation realized by the altruist agent β_{15}, which is another example of the influence of the personality factors in the agent evaluations.

The fuzzy evaluations of the service attributes t and ct, realized by the altruist agent β_{15}, result, respectively, in the following fuzzy values:

"t **is** `fast`" with degree 0.75 and "t **is** `medium`" with degree 0.25,
"ct **is** `cheap`" with degree 0.44 and "ct **is** `medium`" with degree 0.22.

With those fuzzy values, we then evaluate the rules of Tab. 1 that are applicable in this case. Then, using Eq. (9), the fuzzy value of the satisfaction of β_{15} is obtained as:

"$s_{\beta_{15}\alpha_3}$ **is** `high`" with degree $\max\{0.44, 0.22, 0.25\} = 0.44$ and
"$s_{\beta_{15}\alpha_3}$ **is** `medium`" with degree 0.22,

generating the fuzzy region of Fig. 6. The output crisp value of the satisfaction, if necessary for any application, can be obtained by the centroid method, resulting in 2.866667.

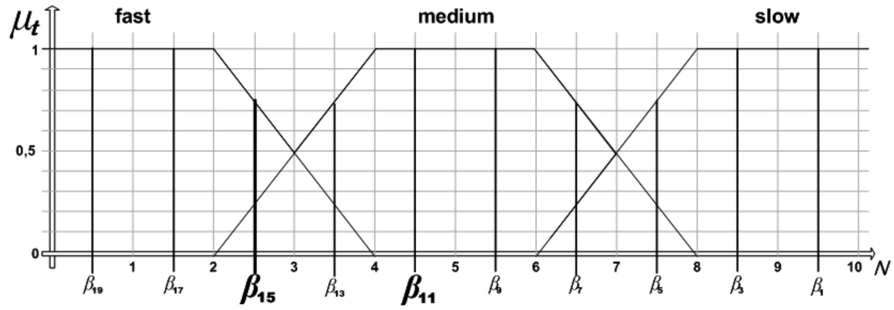

Fig. 5. Fuzzy Evaluation of the service attribute *delivery time* (t)

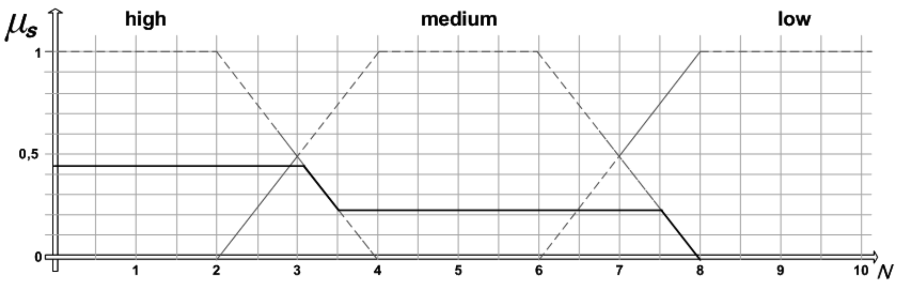

Fig. 6. Geometric representation of β_{15}'s fuzzy satisfaction value

4.3 Equations of Fuzzy Equilibrium

With the results obtained in Sections 4.1 and 4.2, we evaluate the *fuzzy material equilibrium* in the first stage of a social exchange between the agents α and β, generalizing the first equality of **Rule** $\mathbf{I}_{\alpha\beta}$ (Eq. (1)), whose rule base is given in Tab. 2. In this table, it is possible to observe the notion of *fuzzy equilibrium* (the case in which the investment of agent α and the satisfaction of agent β are "equivalent" with a certain degree) or the two notions of *fuzzy disequilibrium* (the cases in which the investment of α is either "less than" or "much less than" the satisfaction of β with a certain degree, or vice-versa). Let the fuzzy investment and satisfaction values be given, respectively, by:

"$r_{\alpha_3\beta_{15}}$ **is** `medium`" with degree 0.66 and "$r_{\alpha\beta}$ **is** `high`" with degree 0.66, and
"$s_{\beta_{15}\alpha_3}$ **is** `medium`" with degree 0.22 and "$s_{\beta_{15}\alpha_3}$ **is** `high`" with degree 0.44.

We evaluate the rules of Tab. 2 that are applicable in this case, using Eq. (9). Then, the equations of fuzzy material equilibrium of the stage $I_{\alpha_3\beta_{15}}$ are evaluated as follows, generating the fuzzy region of Fig. 7:

"$I_{\alpha_3\beta_{15}}$ **is** $r_{\alpha_3\beta_{15}} < s_{\alpha_3\beta_{15}}$" with degree 0.44 and
"$I_{\alpha_3\beta_{15}}$ **is** $r_{\alpha_3\beta_{15}} = s_{\alpha_3\beta_{15}}$" with degree $\max\{0.22, 0.44\} = 0.44$ and
"$I_{\alpha_3\beta_{15}}$ **is** $r_{\alpha_3\beta_{15}} > s_{\alpha_3\beta_{15}}$" with degree 0.22.

5 Conclusion

Social exchange values have been applied in different contexts in MAS [5–12]. However, since social exchange values are qualitative values for subjective concepts, one

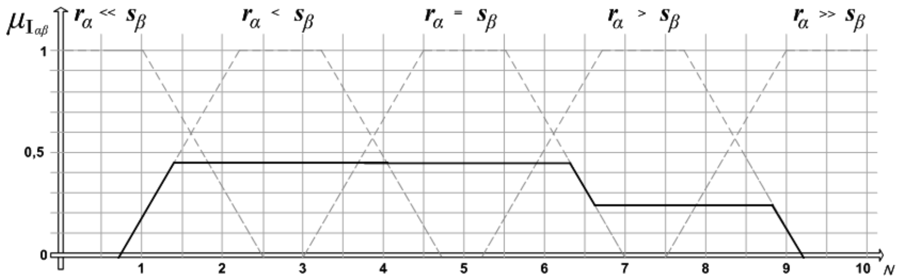

Fig. 7. Fuzzy material equilibrium of the stage $I_{\alpha_3\beta_{15}a}$

has that their computational representation is not so trivial, as discussed in Sect. 1. On the other hand, Fuzzy Sets constitute the oldest and most reported soft computing paradigm, been well-suited to model different forms of uncertainties, ambiguities and subjectiveness, often encountered in real life. Fuzzy Logic has been applied in Social Simulation in order to cope with complex agent-based models for the simulation of human behavior [23, 24], and, in particular, human personality traits [17, 18].

This work introduced an approach based on Fuzzy Logic for the evaluation of the material social exchange values generated in the first stage of a social exchange, with an application in personality-based MAS, where social exchange personality traits are defined as the way the agents qualitatively evaluate the services performed and/or received, after the decision on accepting or refusing an exchange proposal. The equations of fuzzy material equilibrium associated to this stage were also established. A case study was analyzed allowing to evaluate the potentiality of the proposed approach.

Although for simplicity just a small number of service attributes were considered, we remark that the approach is flexible enough to allow the addition of other different attributes. Moreover, the approach can be applied for the subjective, imprecise or vague evaluation of any other kind of service performable by agents.

Ongoing work is concerned with the fuzzy evaluation of the virtual values, which we intend to do using linguistic modifiers [21], and then the three equations of fuzzy equilibrium may be established. Future work will be concerned with the development of a fuzzy perception mechanism for BDI agentes [25], in order to incorporate fuzzy perception in the social exchange simulator described in [9].

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