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A linguistic consensus model for Web 2.0 communities

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ABSTRACT

Web 2.0 communities are a quite recent phenomenon which involve large numbers of users and where communication between members is carried out in real time. Despite of those good characteristics, there is still a necessity of developing tools to help users to reach decisions with a high level of consensus in those new virtual environments. In this contribution a new consensus reaching model is presented which uses linguistic preferences and is designed to minimize the main problems that this kind of organization presents (low and intermittent participation rates, difficulty of establishing trust relations and so on) while incorporating the benefits that a Web 2.0 community offers (rich and diverse knowledge due to a large number of users, real-time communication, etc.). The model includes some delegation and feedback mechanisms to improve the speed of the process and its convergence towards a solution of consensus. Its possible application to some of the decision making processes that are carried out in the Wikipedia is also shown.

1. Introduction

Making decisions, that is, the cognitive process leading to the selection of a course of action among several alternatives according to a set of criteria, is a common activity that appears in almost any human endeavour [1]: from choosing what to eat, what to wear and what to buy to selecting a representative or voting in an election. Group decision making (GDM) is a particular case of decision making where the final selected choice has to be done by multiple persons. GDM presents several special characteristics that distinguishes from individual decision making. For example, on the one hand, the total knowledge about a particular decision problem of a complete group of persons is usually higher than the knowledge of a particular individual, and thus, the group final decision may be better justified. On the other hand, the heterogeneous nature of the persons involved in the decision may introduce additional difficulties like very different points of view, specially on topics where feelings or beliefs are present.

One of the fields where GDM is a fundamental matter is politics. As political decisions may influence lots of people, during all history it has been necessary to develop different forms of government to make decisions. One of those forms of government is democracy, where usually a set of elected officers undertake to represent the interests and/or views of citizens within a framework of the rule of law. However, as this kind of system only requires a periodic involvement in the elections of the majority of the citizens, the electorate is almost excluded from the political decision making, which can derive into a lack of political interest, knowledge and responsibility among the non-participant population [2].

It is clear that involving a very large number of individuals in a decision process is a difficult task but, with the appearance of new electronic technologies, we are in the beginning of a new stage where traditional democratic models may leave some space to a more direct participation of the citizens. In the specialized literature some efforts about the use of these new technologies are found in what it is being called e-democracy [2], e-participation [3], e-Governance [4] and public deliberation [5,6].

In fact, new Web technologies have allowed the creation of many different services where users from all over the world can join, interact and produce new contents and resources. One of the most recent trends, the so-called *Web 2.0*, which comprises a set of different web development and design techniques, allows the easy communication, information sharing, interoperability and collaboration in this new virtual environment. Web 2.0 communities, that can take different forms as Internet forums, groups of blogs, social network services and so on, provide a platform in which users can collectively contribute to a Web presence and generate massive content behind their virtual collaboration [7]. In fact, Web 2.0 represents a paradigm shift in how people use the web as nowadays, everyone can actively contribute content online.

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It is thus clear that to develop more sophisticated GDM models and schemes that can be applied into the new Web 2.0 communities is a current necessity. In fact, there have been several efforts in the specialized literature to create different models to correctly address and solve GDM situations. Particularly, the fuzzy theory [8] introduced by Zadeh has been shown to be a good tool to model and deal with vague or imprecise opinions (which is a quite common situation in any GDM process) [9–11]. Many of those models are usually focused on solving GDM situations in which a particular issue or difficulty is present. For example, there have been models that allow to use linguistic assessments instead of numerical ones, thus making it easier for the experts to express their preferences about the alternatives [12]. Other models allow experts to use multiple preference structures (and even multi-granular linguistic information) [13–15] and other different approaches deal with incomplete information situations if experts are not able to provide all their preferences when solving a GDM problem [16] or when a consensus process is carried out [17].

Moreover, usual GDM models have been complemented with consensus schemes that allow users to interact until there is a certain degree of agreement on the selected solution [18–20]. This consensus models allow not only to provide better solutions to decision problems, but also to increase the users satisfaction with the decision process as all the opinions are reconsidered to achieve a high enough level of consensus.

However, those approaches are not usually well suited to be used by Web communities due to some of their inherent properties. For example, due to the diversity of the users backgrounds, using numerical preferences might be not adequate (and thus, linguistic assessments should be used [21]) or dynamic situations in which some of the parameters of the problem, as the set of experts, the set of alternatives and even the set of criteria to select the solutions change, have not been modelled. This kind of situations are quite common in other environments: in [22] the problem of managing time-dependent preferences (that is preferences expressed at different periods) is presented; the problem of dealing with dynamic real-time information to choose the best routes is shown in [23], and a practical example about resource management where the criteria to make decisions (climate) changes over time can be found in [24]. Thus, it is important to develop new models that take into account this kinds of dynamical situations to solve realistic GDM problems [25].

For the particular case of Web Communities, dynamic situations in which the group of experts vary over time are quite common: a new expert could incorporate to the process, some experts could leave it or a large group of experts could be simplified in order to minimize communications and to ease the computation of solutions. This behaviour is usually found in democratic systems where the individuals delegate into a smaller group of experts to make decisions (it is usually not possible to involve everyone in each decision). There have been some efforts to model this kind of situations. For example, in [26] a recursive procedure to select a qualified subgroups of individuals taking into account their own opinions about the group is presented. However, there is still a big necessity of creating new consensus models that suit Web Communities characteristics appropriately.

In this paper a consensus model in which preferences are expressed in a linguistic way and that has been designed taking into account the characteristics of Web 2.0 communities is presented. In particular, it has been designed considering that the number of users of this kind of communities is usually large [27]. For example, online music communities usually gather hundreds or even thousands of individuals that share an interest about particular bands or music genres. To reach a consensual decision with such a large user base is not an easy task because, for example, not every member of the community is willing to participate and contribute to solve the problem [28] or maybe because the topic being discussed is controversial and involves individual feelings or beliefs [29]. In addition, this model allows dynamic sets of users, that is, the users set to solve the decision problem may change in time. Moreover, by means of a delegation scheme (based on a particular kind of trust network [30]) an important simplification in the obtaining of a proper consensus level may be achieved. The model also incorporates a feedback mechanism that helps the users to change their preferences towards a higher consensus level solution. In addition, a trust checking procedure allows to avoid some of the problems that the delegation scheme could introduce in the consensus reaching model. Finally, a brief discussion about the applicability of the model to increase the consensus level in the decision making processes of the Wikipedia is also presented. It is important to remark that this model is one of the first efforts in introducing the fuzzy logic theory and the fuzzy linguistic modelling into the field of Web 2.0 communities.

To do so, the paper is set as follows: in Section 2 some preliminaries are presented, that is, some of the most important characteristics of Web 2.0 communities and the basic concepts that are used in the paper. In Section 3 the new consensus model with linguistic preferences that helps to obtain consensual decisions in Web 2.0 communities as well as its possible application to the Wikipedia is introduced. Finally, in Section 4 some conclusions are pointed out.

2. Preliminaries

In this section some preliminaries are presented: first some of the main characteristics of Web 2.0 communities that have to be taken into account when designing any tool for them are described; second, some groundwork about the use of linguistic preferences in consensus models is presented.

2.1. Web 2.0 communities

New Web 2.0 technologies have provided a new framework in which virtual communities can be created in order to collaborate, communicate, share information and resources and so on. This very recent kind of communities allows people from all over the globe to meet other individuals which share some of their interests. Particularly, some of the most common activities in which the different users in online communities participate are:

- *Generate online contents and documents*, which is greatly improved with the diversity and knowledge of the involved people. One of the clearest examples of this kind of collaboration success is Wikipedia [31], where millions of articles have been produced by its web community in dozens of different languages [32]. It is clear that in a massive service as Wikipedia many situations where it is necessary to make decisions about its inner workings and the contents that are being created arise [33].
- *Provide recommendations* about different products and services. Usual recommender systems are increasing their power and accuracy by exploiting their user bases and the explicit and implicit knowledge that they produce [34,35]. This kind of systems represent a quite powerful addition to Web 2.0 systems where decisions have to be made. A clear example of recommender systems success, which exploits its users community knowledge to provide personalized recommendations, is the Amazon online store [36].
- *Participate in discussions and forums*. Many online communities have grown around a web forum or some discussion boards where users share information or discuss about selected topics. In many of these communities some simple group decision

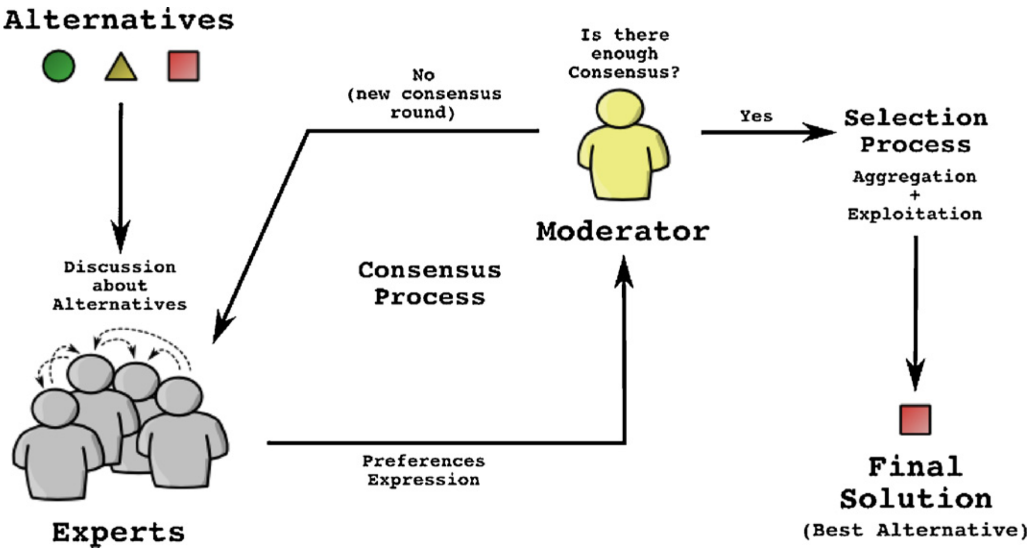

Fig. 1. Typical scheme of GDM models.

making schemes, as referendum or voting systems are usually used. For example, services like PollDaddy [37] allow to create online surveys and polls where users can vote about the best alternative to choose for a given decision problem.

Apart from the obvious advantage of meeting new people with similar interests, Web communities present some characteristics that make them different from other more usual kinds of organizations. In the following some of those characteristics and how they can affect in the particular case of GDM situations are discussed:

- *Large user base*: Web communities usually have a large user base [27] (it is easy to find web communities with thousands of users). This can be seen from a double perspective. On the one hand, the total knowledge that a large user base implies is usually greater and more diverse than in a small community. This can be seen as a clear advantage: taking decisions is usually better performed when there is a rich knowledge on the evaluated subject. On the other hand, managing a large and diverse amount of opinions in order to extract and use that knowledge might be a difficult task: for example, some of the users might not find easy to use typical numerical preference representation formats and thus, linguistic ones should be implemented.
- *Heterogeneous user base*: not only the user base in Web communities is large, but it is usually heterogeneous. This fact implies that it cannot be easily assumed that all the individuals may find easy to use the tools that are being developed and introduced in the websites. A clear example is the use of numerical ratings: some users may find difficult to express their preferences about a set of alternatives using numerical ratings and thus, it may be interesting to provide tools which can deal with natural language or linguistic assessments. Moreover, tools that allow to group, cluster or measure distances among expert preferences need to be developed [38].
- *Low participation and contribution rates*: although many Web communities have a quite large user base, many of those users do not directly participate in the community activities. Moreover, encouraging them to do so can be difficult [28]. Many of the users of a web community are mere spectators which make use of the produced resources but that does not (and is not willing to) contribute themselves with additional resources. This can be a serious issue when making decisions if only a small subset of the users contribute to a decision and it does not reflect the overall opinion of the community.
- *Intermittent contributions*: partially due to the fast communication possibilities and due to a very diverse involvement of the different members, it is a common issue that some of them might not be able to collaborate during a whole decision process, but only in part of it. This phenomenon is well known in web communities: new members are continuously incorporated to the community and existing users leave it or temporarily cease in their contributions.
- *Real time communication*: the technologies that support Web communities allow near real time communication among its members. This fact let us create models that in traditional scenarios would be quite impractical. For example, in a referendum, it is not easy at all to make a second round if there has been a problem in the first one due to the high amount of resources that it requires.
- *Difficulty of establishing trust relations*: as the main communication schemes in Web communities use electronic devices and, in the majority of the cases, the members of the community do not know each other personally, it might be difficult to trust in the other members to, for example, delegate votes. This fact implies that it might be necessary to implement control mechanisms to avoid a malicious user taking advantage of others.

2.2. Consensus models with fuzzy linguistic preferences

Usual GDM models follow a scheme (see Fig. 1) in which two phases are differentiated: the first one consists in a *consensus process* in which the users (that will be called *experts* in the following), discuss about the alternatives and express their preferences about them using a particular preference representation format. A special individual (the moderator) checks the different opinions and confirms if there is enough consensus among all the experts. If there is not enough consensus, the moderator urges the experts to rediscuss about the alternatives and to provide a new set of opinions to improve the consensus level in a new consensus round. Once the desired consensus have been reached (or a maximum number of consensus rounds has been reached) the second phase (the *selection process*) starts and the best solution is obtained by aggregating the last opinions from the experts and applying an exploitation step which identifies the best alternative from the aggregated information.

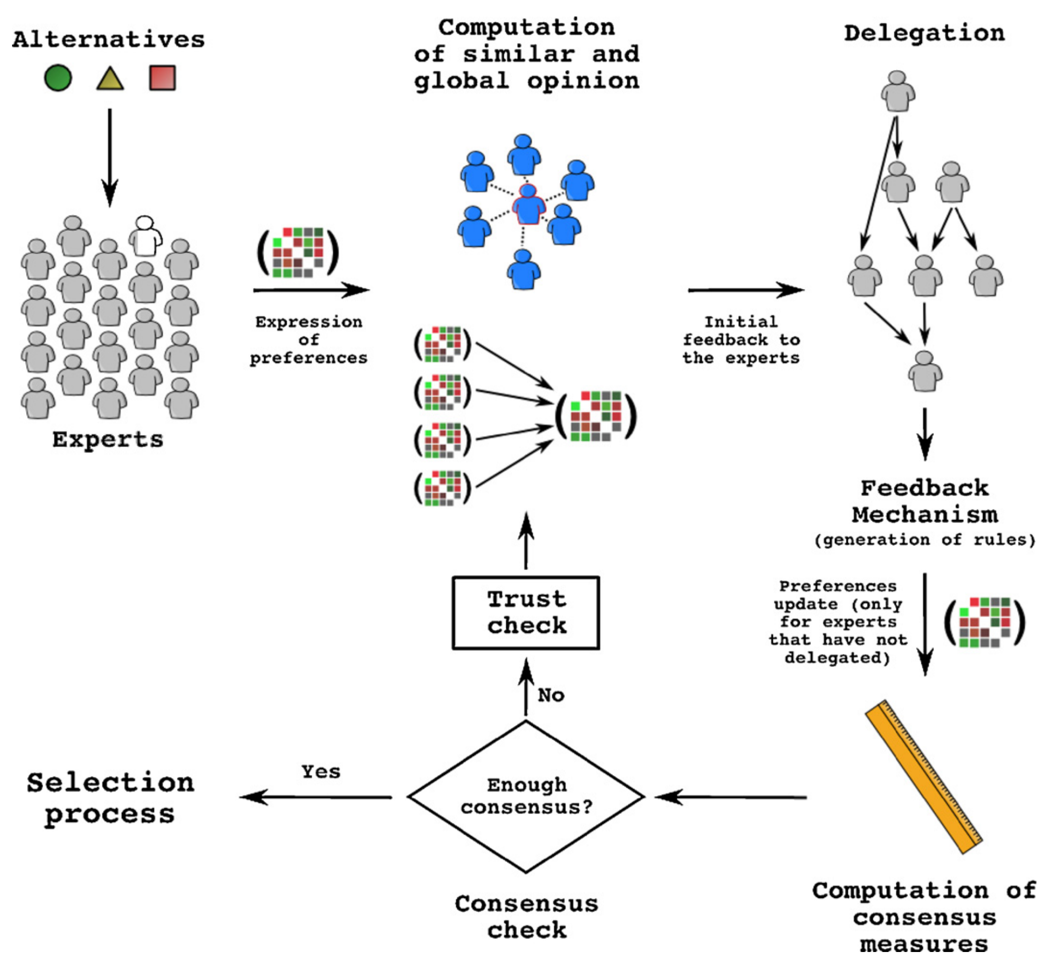

Fig. 2. Scheme of the presented consensus model.

This paper focuses only in the consensus process, where the experts are supposed to narrow their different opinions about the alternatives to obtain a final solution with a high level of consensus. In the consensus model that we propose, the experts $E=\{e^1, \ldots, e^m\}$ will provide their preferences about the set of alternatives $X=\{x_1, \ldots, x_n\}$ in form of fuzzy linguistic preference relations [39]. In particular, we will use the 2-tuple linguistic computational model [40], in which the linguistic information is represented by a 2-tuple (s, α), $s \in S$, where S is a usual term set with odd cardinality and where the terms are uniformly distributed.

Definition 1. Let $\beta \in [0, q]$ be the result of an aggregation of the indexes of a set of labels assessed in a linguistic term set $S=\{s_0, \ldots, s_q\}$, i.e., the result of a symbolic aggregation operation. Let $i = round(\beta)$ and $\alpha = \beta - i$ be two values, such that, $i \in [0, q]$ and $\alpha \in [0.5, 0.5)$, then α is called a symbolic translation.

The model also defines two functions Δ^{-1} and Δ to transform 2-tuples to numerical values and viceversa [40].

Definition 2. A 2-tuple linguistic preference relation P^h given by expert e^h on a set of alternatives X is a set of 2-tuples on the product set $X \times X$, i.e., it is characterized by a membership function $\mu_P^h : X \times X \to S \times [0.5, 0.5)$.

3. A linguistic consensus model for Web 2.0 communities

In this section a new consensus model that can be applied in Web 2.0 communities to reach solutions in GDM environments and its possible application to the Wikipedia is presented. It takes into account the different characteristics of this kind of communities (see Section 2.1) in order to increase the consensus level of the users when making a decision on a set of alternatives. Some of the properties of the model are:

- it does not require the existence of a moderator,
- it allows to work in highly dynamical environments where participation and contribution rates change,
- it uses linguistic information to model user preferences and trust relations,
- it allows to weight the contributions of each user according to some degree of expertise,
- it offers a feedback mechanism to help experts to change their preferences about the alternatives and
- it can be easily adapted to real world Web 2.0 communities.

Its operation implies several different steps that are repeated in each consensus round:

1 first preferences expression, computation of similar opinions and first global opinion and feedback,
2 delegation,
3 change of preferences (feedback mechanism),
4 computation of consensus measures and
5 consensus and trust checks.

In Fig. 2 the main steps of the model have been depicted and in the following they are described in more detail.

3.1. First step: first preferences expression, computation of similar opinions and first global opinion and feedback

In this first step the different alternatives in the problem are presented to the experts (note than in Fig. 2 only a small amount of experts have been represented, but when applied to a Web 2.0 community the number of users will usually be larger). Once they know the feasible alternatives, each expert $e^h \in E$ is asked to provide a fuzzy linguistic preference relation P^h that represent his opinions about the alternatives. Although every single member of the community has the opportunity of expressing his preferences about the alternatives, as it has been previously mentioned, only a subset of those experts $\tilde{E}$ will really provide preference relations. We will note $\tilde{e}^h$ to the experts that have provided a preference relation. It is important to note that if an expert at this stage does not provide a preference relation the model will still allow him to contribute in the consensus process in a later stage. Once a certain amount of time has passed (to allow a sufficient number of preferences to be provided) we compute the distance among each pair of experts $\tilde{e}^h$ and $\tilde{e}^g$ in the following way:

$$d^{hg} = d^{gh} = \sqrt{\sum_{i=1} \sum_{\substack{j=1 \\ j \neq i}} \left(\frac{\Delta^{-1}(p_{ij}^h) - \Delta^{-1}(p_{ij}^g)}{q} \right)^2}$$

This distances will be used to provide information to each expert about the experts that share a similar opinion about of the alternatives. In fact, for each $\tilde{e}^h \in \tilde{E}$ his *set of neighbours* is defined as

$$N^h = \{\tilde{e}^{\beta_1}, \ldots, \tilde{e}^{\beta_{nnh}}\} \mid d^{h\beta_i} < \delta$$

where *nnh* is the number of neighbours that will be presented and e^{β_i} is the i-th nearest expert to $\tilde{e}^h$. Note that the number of neighbours presented to each expert may vary according to a predefined proximity threshold δ.

It is important to note that the model does not impose a particular amount of time in which the experts are forced to express their opinions. This question is purposedly left open because due to the highly dynamical environment in which users interact and due to some of the problems that this kind of online communities have (for example, intermittent contributions) it may desirable to establish a different criteria depending on the problem and the necessity for a fast or not fast answer. For example, if a tight time restriction appears, this amount of time may be shortened and fixed. However, if there is no time restriction, this amount of time may be increased or even changed into a different criteria like waiting until a percentage of users that have participated in the process. However, this particular matter does not interfere at all in the exposed model.

As it happens in many real world GDM problems, it is possible that the preferences of every different expert may be weighted differently. This may be interesting in situations where some of the experts have a great reputation or expertise in the problem field. Thus, for every expert in the problem a *trust weight* τ^h is assumed to be given. If for a particular problem the preferences of every expert are considered equally important, then all the trust weights will be initialized to 1: $\tau^h = 1$. It is interesting to note that many existing online communities do have some reputation mechanisms that can be used to weight the expertise degree of each one of its members. If so, those mechanisms can be used to initialize the trust weights of the experts to initially provide more importance to the most relevant users. However, how this initialization is done will completely depend on the existing mechanism of the online community that is implementing this model.

The last task at this first step is to compute the current global preference as an aggregation of all the provided preference relations. To do so, a weighted average is applied to compute it:

$$p_{ij}^c = \Delta \left(\frac{\sum_{\tilde{e}^h \in \tilde{E}} \tau^h \cdot \Delta^{-1}(p_{ij}^h)}{T} \right) \quad (1)$$

Once the distances among experts, the neighbours of each expert and the global preference relation have been computed, this information will be presented to the experts. After receiving this feedback, an expert will know if his opinions are very different to the current global preferences and he will also know which are the experts that share similar opinions. Apart from just his neighbour list, an expert is also able to check the particular preference relations that his neighbours have introduced in order to really check the preferences expressed by his neighbourhood.

3.2. Second step: delegation

In this second step the model incorporates a delegation scheme in which experts may choose to delegate into other experts (typically experts from their neighbourhood, with similar opinions). This mechanism is introduced to soften the intermittent contributions problem (because an expert who knows that he will not be able to continue the resolution process may choose to delegate into other experts instead of just leaving the process) and to decrease the number of preference relations involved in the problem. To make the delegation scheme flexible enough and to be able to cover a wide range of different delegation proposals, an expert $\tilde{e}^h$ that decides to delegate has to provide a set of trust evaluations of other experts $t_j^h, j \in \{1, \ldots, m\}$. In this proposal, this trust evaluations are assumed to be given using a linguist terms set in the form $TS = \{ts_{-3} = total\ distrust, ts_{-2} = high\ distrust, ts_{-1} = low\ distrust, ts_0 = neutral, ts_1 = low\ trust, ts_2 = high\ trust, ts_3 = total\ trust\}$. Note that as a result of the usually large number of experts that may take part in the resolution process, many of the trust evaluations t_j^h of expert $\tilde{e}^h$ will be neutral (ts_0) as the expert may not be able to evaluate all the rest of experts. However, he might know some experts that he trusts or distrusts, and thus, those trust evaluations are the ones that the system will take into account. This implies that the user does not have to provide trust evaluations for all the rest of experts, but only of those that he really trusts or distrusts. Once an experts has provided his trust evaluations for some other experts he will not be required to update his preferences to improve the consensus level.

Once a certain amount of time have passed (enough time for the experts to decide if they wanted to delegate or not), the system will re-compute the trust weights τ^h for every expert according to the trust evaluations of the rest of the experts. To do so, for every expert $\tilde{e}^h$ that has provided his linguistic trust evaluations t_j^h a $tt^h = \sum_{j=1}^m |\tilde{t}_j^h|$ is computed where $\tilde{t}_j^h$ is the index of the linguistic term t_j^h in *TS*. Then, for each $t_j^h \neq ts_0$ an increment of the trust value $\Delta\tau^j = \tau^h \cdot (\tilde{t}_j^h / tt^h)$ is obtained. At this point, every trust weight τ^j can be updated adding this increment: $\tau^j = \tau^j + \Delta\tau^j$ and the trust value for the expert that delegated becomes 0: $\tau^h = 0$. If, after the all the trust updates have been done an expert has a new trust value less than 0, the system should round it to 0. A trust value of 0 means that the opinion of that expert is not trusted enough to take part in the process (and, in fact, in expression (1), a trust weight equal to 0 is not taken into account in the global preferences relation).

Example. Suppose that a particular expert participating in the decision process $\tilde{e}^1$ whose current trust weight is $\tau^1 = 2$ decides that he will no longer take part in the process, and thus, he wants to delegate in other experts. He decides that experts $\tilde{e}^2$ and $\tilde{e}^3$ (whose

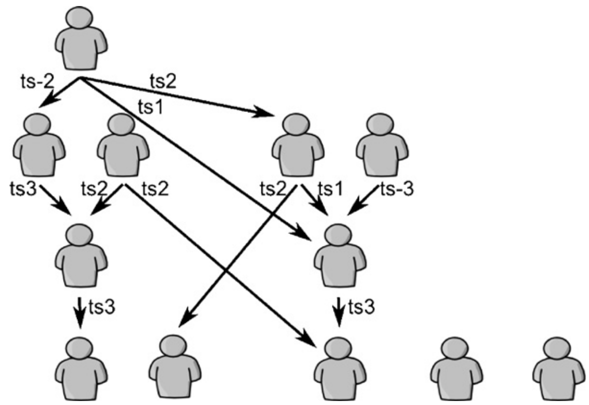

Fig. 3. Example of the delegation scheme.

current trust weights are $\tau^2 = 2$ and $\tau^3 = 1$) can be trusted but, on the other way, $\tilde{e}^4$ (whose current trust weight is $\tau^4 = 1.5$) can not. Thus, he provides the following trust evaluations: $t_2^1 = ts_1$, $t_3^1 = ts_2$ and $t_4^1 = ts_{-2}$. Then, the system computes $tt^h = |1| + |2| + |-2| = 5$; $\Delta\tau^2 = 2 \cdot (1/5) = 0.4$; $\Delta\tau^3 = 2 \cdot (2/5) = 0.8$ and $\Delta\tau^4 = 2 \cdot (-2/5) = -0.8$. Finally, the system updates the trust weights of $\tilde{e}^2$, $\tilde{e}^3$ and $\tilde{e}^4$ by adding the increments: $\tau^2 = 2 + 0.4 = 2.4$, $\tau^3 = 1 + 0.8 = 1.8$ and $\tau^4 = 1.5 - 0.8 = 0.7$.

Note that the expressed trust evaluations may be seen as a directed graph structure among the set of experts. This directed graph structure conforms a kind of trust network which can be used to stablish a kind of delegation scheme in which some transitivity conditions occur: if an expert $\tilde{e}^h$ delegates in an expert $\tilde{e}^k$ and $\tilde{e}^k$ delegates in $\tilde{e}^j$ the situation would be similar as if both $\tilde{e}^h$ and $\tilde{e}^k$ would have directly delegated in $\tilde{e}^j$. Note that the model should avoid cycles in the trust network. If an expert tries to delegate in another one and this delegation would produce a cycle in the trust network, the system should alert him about this situation and ask him to reconsider his trust evaluations. In Fig. 3 a group of experts in which some of them have delegated by expressing some trust evaluation over other experts have been depicted. The two experts on the right have not delegated in any other expert and have neither been chosen by other experts to delegate in them. In addition, a similar situation to the example above has been depicted with experts in the upper left part of the image.

It is clear that with this kind of trust evaluation to delegate it is easy to replicate more typical delegation schemes. For example, if an user wants to delegate its entire trust weight into another expert, he might just provide a positive trust evaluation for that expert. Or, if an expert wants to delegate his opinion into a group of experts equally, he just have to provide equal positive trust values for each one of the delegates. Finally, if an expert is not sure about whom to delegate in, but he knows that he does not trust a particular expert, he can reduce the trust weight of that expert by giving him a negative trust evaluation.

This delegation mechanism provides several advantages to the model: first of all, it allows experts not to provide their preferences in every consensus round. If an expert delegates in another one, he will not have to update his preferences but, in a certain way (through the delegate), his opinion will still influence the consensus state. Thus, the consensus rounds may be carried out faster as only a subset of experts will have to change their preferences. Moreover, the computations will also be reduced as the system will not have to deal with a large amount of preference relations. Additionally, as the mechanism allows to give different trust evaluations to multiple experts, it is possible to delegate into a group of experts that *as a whole* have a similar opinion to the expert, not conferring too much weight to a single person.

3.3. Third step: change of preferences (feedback mechanism)

Once the trust weights have been re-computed the system will ask the remaining experts to update their linguistic preference relations P^h in order to achieve a greater level of consensus. This experts will conform the new $\tilde{E}$ subset. As in some cases changing the linguistic preference relations may not be an easy task, the model includes a feedback mechanism that identifies which experts and preference values should be changed to increase the level of consensus and which advices the corresponding experts about it. To do so, the system computes several proximity measures [41] at three different levels: pair of alternatives, alternatives and relations levels.

Level (1) *Proximity measure on pairs of alternatives*: the proximity measure of an expert $\tilde{e}^h$ on the pair of alternatives to the group one, denoted pp_{ik}^h is calculated as

$$pp_{ik}^h = 1 - \frac{|\Delta^{-1}(p_{ik}^h) - \Delta^{-1}(p_{ik}^c)|}{q}$$

Level (2) *Proximity measure on alternatives*: the proximity measure of an expert $\tilde{e}^h$ on alternative x_i to the group one, denoted pa_i^h is calculated as

$$pa_i^h = \frac{\sum_{k=1;k \neq i}^{n}(pp_{ik}^h + pp_{ki}^h)}{2 \cdot (n-1)}$$

Level (3) *Proximity measure on the relation*: the proximity measure of an expert $\tilde{e}^h$ on his preference relation to the group one, denoted pr^h, is calculated as

$$pr^h = \frac{\sum_{i=1}^{n} pa_i^h}{n}$$

Using these proximity measures an *APS* set that contains 3-tuples (h, i, k) symbolizing preference degrees p_{ik}^h that should be changed because they affect badly to the consensus state is defined. To compute the *APS* set we follow a three simple step process:

Step (1) The set of experts *EXPCH* that should receive advice on how to change some of their preference values is identified. The experts that should change their opinions are those whose proximity level on the relation is lower than a certain threshold γ (set prior to the beginning of the decision process):

$$EXPCH = \{h \mid pr^h < \gamma\}$$

Step (2) The alternatives that the above experts should consider to change are identified. This set of alternatives is denoted as *ALT*. To do this, the alternatives with a proximity level lower than the γ threshold are selected:

$$ALT = \{(h, i) \mid h \in EXPCH \wedge pa_i^h < \gamma\}$$

Step (3) Finally, the preference values for every alternative and expert $(x_i; \tilde{e}_h | (h, i) \in ALT)$ that should be changed according to their proximity measures on the pairs of alternatives is also identified:

$$APS = \{(h, i, k) \mid (h, i) \in ALT \wedge pp_{ik}^h < \gamma\}$$

Once the feedback mechanism knows which preference values are contributing less to the consensus state (p^h_{ik} | $(h, i, k) \in APS$), it generates some easy to follow rules which are presented to the experts that should change their opinions. For each $(h, i, k) \in APS$ the generated rule for expert $\tilde{e}^h$ has the following form: *"You should change your preference value* (i, k) *to a value close to* p^c_{ik}*"*.

Note that this rules are just recommendations that are offered to the experts to increase the consensus level in a fast way but, in any case they are ever forced to follow them.

3.4. Fourth step: computation of consensus measures

Once the updated preferences have been given some consensus degrees can be computed. To do so, for each pair of experts $(\tilde{e}^h, \tilde{e}^l)$ $(h < l)$ of the new $\tilde{E}$ a similarity matrix $SM^{hl} = (sm^{hl}_{ik})$ is defined where

$$sm^{hl}_{ik} = \tau^h \cdot \tau^l \cdot \left(1 - \left|\frac{\Delta^{-1}(p^h_{ik}) - \Delta^{-1}(p^l_{ik})}{q}\right|\right)$$

Then, a collective similarity matrix, $SM = (sm_{ik})$ is obtained by aggregating all the $(\#\tilde{E} - 1) \times (\#\tilde{E} - 2)$ similarity matrices using following expression:

$$sm_{ik} = \frac{\sum_{h,l \in \tilde{E} | h<l} sm^{hl}_{ik}}{T \cdot (T-1)/2}$$

where $T = \sum_{i=1}^{m} \tau^i$.

Once the similarity matrices are computed the consensus degrees at the three different levels are obtained:

L. 1. *Consensus degree on pairs of alternatives*. The consensus degree on a pair of alternatives (x_i, x_k), denoted cop_{ik}, is defined to measure the consensus degree amongst all the experts on that pair of alternatives:

$$cop_{ik} = sm_{ik}$$

L. 2. *Consensus degree on alternatives*. The consensus degree on alternative x_i, denoted ca_i, is defined to measure the consensus degree amongst all the experts on that alternative:

$$ca_i = \frac{\sum_{k=1; k \neq i}^{n} (cop_{ik} + cop_{ki})}{2(n-1)}$$

L. 3. *Consensus degree on the relation*. The consensus degree on the relation, denoted *CR*, is defined to measure the global consensus degree amongst all the experts' opinions:

$$CR = \frac{\sum_{i=1}^{n} ca_i}{n}$$

3.5. Fifth step: consensus and trust checks

In the end of each consensus round the current consensus state must be checked. If it is considered a high enough consensus value the consensus process would finish and a selection process would be applied to obtain the final solution for the decision problem. To do so, the check $CR > \gamma$ is performed, being γ a threshold value fixed prior to the beginning of the GDM process. In the case that the level of consensus is not high enough the trust check that is described in the following is applied. Note that in real applications it might be desirable to include a *maximumRounds* parameter to control the maximum consensus rounds that can be executed in order to avoid stagnation.

The trust check is introduced to avoid some of the problems that can be derived to one of the characteristics of Web communities: the difficulty of establishing real trust relations. It is not difficult to imagine an scenario where some experts delegate into another that shares a common point of view on the decision that has to be made and in a certain consensus round, this expert decides to drastically change his preferences, probably not reflecting the other experts opinions any more. To avoid this kind of situations the trust check will compare the last preference relation expressed by expert $\tilde{e}^h$ with the last preference relations of the experts that delegated in him (direct or indirectly). This comparison can be made by applying a distance operator (as the euclidean or cosine distances) over the preference relations or computing proximity measures similar to the ones presented in Section 3.3. If this distance is greater than a certain established threshold, the expert that delegated in $\tilde{e}^h$ would be informed with a special message to warn him about this problematic situation and thus allowing him to take a different course of action in the next consensus round if appropriate.

At this point a new consensus round begins: a new global preference will be computed with the new preferences of the experts and their new trust weights, and new distance measures will be obtained. New experts may join the new round (by giving their preference relations), some other experts may decide to delegate on others, and all previously involved expert may change their preferences or their trust evaluations over other experts.

It is important to emphasize that in each new consensus round all the members of the Web community can participate, independently of what they did in the previous rounds. For example, an expert that delegated in a previous consensus round may decide not to continue delegating (maybe because the trust check mechanism has warned him that the expert in which he delegated has drastically changed his preferences) and thus to provide again a new fuzzy linguistic preference relation or to delegate in a different individuals; an expert which had not delegated in any of the previous rounds might decide to delegate in the current consensus round or even an expert which has not participated until this moment in the consensus process (he did not provide any preference relation in the first step of the model) could join the process by providing his initial preferences.

3.6. Possible application of the consensus model to an existing Web 2.0 community: Wikipedia

Wikipedia [31], as almost any other Web 2.0 service is a very recent phenomenon that has attracted a lot of attention from the public and the media. Its main purpose is to create an online freely available encyclopedia. One of its revolutionary aspects is that the contents, contrary to other more conventional encyclopedias, are created and updated in collaborative way by any of its users. In fact, it follows a similar tendency present in the Web where anyone can freely create and publish content without any need of third-party control, which has not been the case in the traditional models of publishing and broadcasting, which are usually governed by centralized organizations [32]. Despite the decentralized nature of the Wikipedia, there are currently some studies that analyse the quality of the contents of the Wikipedia that assure that its quality is almost as good as other well reputed encyclopedias [42,43].

In such a vast environment, where millions of encyclopedical entries and millions of users interact it has been necessary to introduce new tools and features [44] to improve not only the quality of the entries, but the coordination [45,29], cooperation [46] among the users, the social transparency of the articles [47] and the semantic annotation of the contents [48].

However, it is still necessary to develop new tools to avoid conflict [49] and increase the consensus of the decisions taken in Wikipedia. As the Wikipedia covers conflictive and controversial topics (political and religious ones are a clear example where there is no clear neutral point of view) this kind of tools may help to reach better decisions about the contents presented in such topics.

The consensus model proposed in this contribution may be appropriate for some of those situations. For example, lets imagine a particular conflictive topic covered in the Wikipedia. Suppose that in the discussion page for that topic have been proposed four different alternatives to solve the discussion in the topic: to completely remove the article, to rewrite it according to a particular point of view, to split it in several articles that can be managed separately and that do not provoke too much controversial or to leave it as it is in its present state. Applying our model, would allow to choose a solution of consensus among the alternatives in which:

- every user that is willing to participate can do it (thus increasing the level of confidence in the final decision making),
- new users may incorporate in the middle of the consensus process,
- participating users will not be forced to finish the consensus process, as they may choose to delegate into other users,
- some users may have higher weight than others (for example, Wikipedia administrators or the users that have actively contributed to the conflicting article),
- the consensus status may be reached faster than using traditional discussion mechanism (due to the incorporation of the feedback mechanism),
- the preferences of the users are given in a linguistic way increasing their understandability.

4. Conclusions

In this contribution a novel consensus model which has been specially designed to be applied in Web 2.0 communities has been presented. Particularly, it uses fuzzy linguistic preference relations for the expression and management of experts' preferences and it has been designed to manage a large users base by means of a delegation scheme. This delegation scheme is based in a particular kind of trust network created from linguistic trust evaluations given by the experts that simplifies the computations and the time needed to obtain the users preferences. Moreover, this delegation scheme also solves the intermittent contributions problem which is present in almost any online community (that is, many of the users will not continuously collaborate but will do it from time to time). The model also incorporates a feedback mechanism to help the experts in changing their preferences in order to obtain a high level of consensus rapidly.

In addition, the model allows to incorporate new experts to the consensus process, that is, the model is able to handle some of the dynamic properties that real Web communities have. Finally, the model incorporates a trust check mechanism that allow to detect some abnormal situations in which an expert may try to take advantage of others by drastically changing his opinion and benefiting from the trust that the other experts might have deposited in him in previous consensus rounds.

It has also been shown that this model can be used in existing Web 2.0 communities as the Wikipedia to reach consensus in difficult decision making situations.

Finally, it is important to remark that the proposed model is one of the first attempts to introduce the fuzzy logic theory and fuzzy linguistic modelling tools into the novel field of Web 2.0 communities.

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