A Group Catalog Mechanism to Promote Knowledge Sharing in Open Virtual Communities

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***Abstract*—In open virtual communities, thematic groups promote mutual cooperation among their members in order to reach specific targets. To this purpose, users share portions of their knowledge in a reciprocal understandable manner. For this aim, personal software agents are able to assist users by encoding personal information about preferences and goals into suitable profiles. In this work we present a multi-agent solution to manage knowledge shared by users across a number of common thematic groups. A common catalog is created for each thematic group of interest that, in turn, is associated with a group agent. The group agent is devoted to support the group by interacting with personal agents in order to manage the group affiliation process and enrich the common thematic catalog of its own group. In presence of heterogeneous agents, such a common group catalog is a key element to provide knowledge sharing and agent interoperability with both other personal and the group agents. In the proposed approach each user agent is able to personalize its own catalog and contribute to enrich that of its own group by collaborating with its group agent.**

***Keywords*—Open Virtual Communities, Knowledge Sharing, Common Thematic Catalog, Intelligent Agents, Thematic Groups.**

I. INTRODUCTION

In open virtual communities [1]–[5] users having an interest for a common topic (e.g. sports, food) look for a profitable opportunity to collaborate in order to satisfy their needs. In such environments a common way to promote these activities consists of creating thematic groups formed by users sharing common interests.

To maximize the quality of interactions within each thematic group, software agents may be employed to assist users [6]–[9], in order to carry out important tasks related to knowledge sharing that may result heavy and boring [10]. Each software agent is able to build a personal profile for its own user by monitoring the user's activities carried out within the community. Therefore, every thematic group will correspond to a group of software agents on which a group agent will manage the group itself. In this context, software agents shall adopt different descriptions to describe the same topic of interest. When a common representation of the users' knowledge is not available, then such interactions among users (i.e. agents) could be not possible. Conversely, when a representation of knowledge which results mutually understandable, quality relationships and cooperations among users (i.e. among the associated agents) will result improved. Therefore, it is convenient to support users' interactions within a virtual community (i.e. a thematic group) by means of some mechanisms capable to provide a suitable representation of personal knowledges in a mutually understandable manner.

Given the premises above, we propose to adopt a specialized thematic catalogue storing topics (i.e. names, things, concepts and so on) of interest in thematic groups in order to provide potentially heterogeneous agents with a mutually understanding common knowledge. The catalog is publicly available by all the agents affiliated with that thematic group and represents the common knowledge with respect to all the topics dealt within that group. At the same time, users' agents are provided with individual knowledge deriving by the analysis of both the past and the current behaviors of their users. In order to include individual knowledge, the common shared catalog of a thematic group can be enriched by means of the mutual cooperation between the users' agents affiliated with that community and the group agent managing it which, periodically, provides to update such a common catalog.

The remainder of the paper is as follows. Section II contains the reference scenario, while in Section III we discuss the structure of the designed catalogue. In Sections IV and V the profiles of the personal and the platform agents are described. Section VI presents some related literature and the novelties provided by this work. Finally, in Section VII we draw our conclusions and introduce our future works.

II. THE OPEN MULTI-AGENT ARCHITECTURE

The proposed model considers a number of thematic groups within several open *Virtual Communities* (V), each one specialized on a specific topic or set of topics (hereafter only topic). Furthermore, each thematic group can affiliate users belonging to different open virtual communities and each user, in turn, can be member of different thematic groups, each one potentially belonging to a different open virtual community.

Each user u is supported by a software agent a, called *Personal Agent*, which is specialized on the *topic* t characterizing a specific group G. Therefore, when a user is joined with more thematic groups, he/she will be supported by a set of Personal Agents, one for each group (i.e. topic). In order to support its owner in performing his/her activities within a group, his/her Personal Agent suitably encodes in its profile all the information necessary to manage the user's interests for the specific topic of that group. Similarly, each group is managed by the *Group Agent* A devoted to provide some basic services to its affiliated users by cooperating with their associated Personal Agents. The proposed model architecture is graphically depicted in Figure 1.

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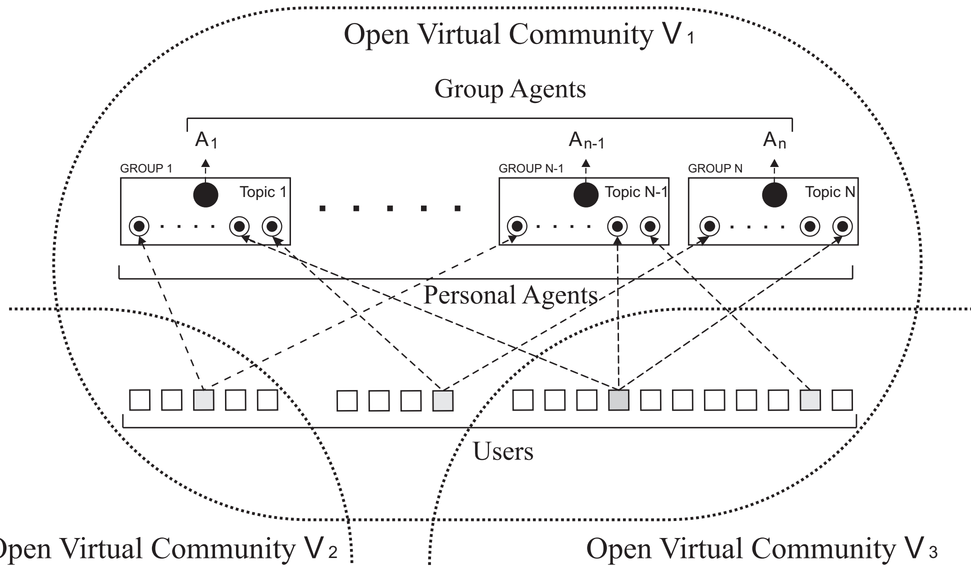

Fig. 1. The proposed Open Virtual Community architecture.

Given the open nature of the proposed architecture, Personal Agents coming from different virtual communities could encode their knowledge with different modalities. This implies that different agents may represent the same topic by using different terms as well as the relationships linking it to other topics may be different between two agents. Consequently, in order to promote a better reciprocal understanding it is necessary to provide each thematic group with some suitable mechanism in order to give a common knowledge, specialized for that group, to the agents.

To this purpose, in this paper for each thematic group it is proposed the adoption of a *Thematic Catalog* ($\mathcal{C}$) storing all the topics and their mutual relationships which form the common knowledge for all the agents affiliated with that thematic group. Such a *Thematic Catalog* is publicly available at all the Personal Agents of a thematic group and it is periodically updated by the associated Group Agent. Therefore, Personal Agents in managing their users profiles, in order to mutually cooperate with the other members of their group, can directly represent the topics of interest, already present in $\mathcal{C}$, by using the corresponding terms associated in $\mathcal{C}$. Moreover, Personal Agents, by monitoring their users, can acquire new knowledge referred to a thematic group (i.e., those topics currently not belonging to $\mathcal{C}$) and can use $\mathcal{C}$ also to represent it into their personal knowledge by means of a general relationship between each "personal" topic with at least another topic already present in $\mathcal{C}$ to allow the interoperability among all the agents of the same group also on such personal topics.

III. The Thematic Catalog

This section provides a formal description of the *Thematic Catalog* ($\mathcal{C}$) which permits to the Personal Agents of interacting with the other Personal Agents affiliated to the same thematic group. As described above, each of these catalogs is associated with a thematic group and shared among all its members and stores all those topics (i.e. names, things, concepts and so on) and their mutual relationships resulting of interest for the group members. We assume that the catalog $\mathcal{C}$ contains the common knowledge of a group. It is publicly available to all the members of this group and each Personal Agent can enrich it with further knowledge, also including any new relationships among the new entries and the past common knowledge.

A. Components of $\mathcal{C}$

A Thematic Catalog $\mathcal{C}$ consists of a set of topics *i*) $\mathcal{C}_{topic}$ *ii*) a set $\mathcal{C}_{link}$ of *links* which represents the relationships existing among the topics belonging to $\mathcal{C}_{topic}$. A link between the two topics t_i, $t_j \in \mathcal{C}$ is described by a tuple in the form of $\langle t_i, t_j, L_{i,j}, p_{i,j} \rangle$ where:

- t_i and t_j are the topics which are identified by two lexical terms that are linked in the thematic catalog $\mathcal{C}$;
- $L_{i,j}$ identifies the type of the *link* involved in the relationship occurring between t_i and t_j;
- $p_{i,j}$ is a parameter giving information on some characteristics of the link, by means of a numerical value ranging in $[0, 1] \in \mathbb{R}$.

More in detail, we introduce two types of category links, namely:

- **I** : this type of link connects two topics t_i and t_j iff the terms belonging to t_i have a different meaning of those belonging to t_j (for instance, the terms painting and sculpture). In this case, the value of $p_{i,j}$ represents the degree of interest that a user interested in t_i has about t_j which can vary from null (i.e, $p_{i,j} = 0.0$) to maximum (i.e., $p_{i,j} = 1.0$).

- **II** : this type of link connects two topics t_i and t_j which can belong to three categories based on the value assumed by the parameter p, namely (*i*) *isa*, (*ii*) *overlapped* or (*iii*) *synonymous*. In particular, for the three considered categories we have that:
  - ***isa***, iff the terms belonging to t_i also belong to t_j and in this case $p_{i,j} = 0.0$. For instance, with respect to the terms bust (t_i) and sculpture (t_j) it means that each bust is also a sculpture.
  - ***overlapped***, iff some terms of t_1 also belong to t_2 and vice versa, in this case $p_{i,j}$ ranges in the domain $]0,1[$. For instance, the two terms cup and goblet are partially synonymous because a cup could not be exactly a goblet and vice versa.
  - ***synonymous***, iff the terms belonging to t_i have the same meaning of those belonging to t_j, in this case $p_{i,j} = 1.0$. For instance, the terms statue and sculpture identify the same type of artistic artifact.

B. Representation of the Thematic Catalog $\mathcal{C}$

A Thematic Catalog $\mathcal{C}$ is representable by using a direct graph $T^{\mathcal{C}} = \langle T^{\mathcal{C}}_{topic}, T^{\mathcal{C}}_{link}\rangle$, where $T^{\mathcal{C}}_{topic}$ is the set of nodes, each one associated with a different topic. Similarly, $T^{\mathcal{C}}_{link}$ represents the set of arcs of the graph, where each link in $T^{\mathcal{C}}_{link}$ is associated with a relationship $\langle t_i, t_j, L_{i,j}, p_{i,j}\rangle \in \mathcal{C}$, with $L \in \{\text{I, II}\}$ and $p_{i,j} \in [0,1] \in \mathbb{R}$, as explained in Section III-A. In the following of this paper, we will refer to the Thematic Catalog as $T^{\mathcal{C}}$ or $\mathcal{C}$ in an interchangeable manner. Figure 2 shows an example of a Thematic Catalog $\mathcal{C}$ concerning Art. In particular, links that belong to more than one category have multiple labels. Note that in Figure 2 all the arcs are depicted without orientation but, in order to take into account the different possible characteristics of the links, for convenience both the links of type I when $p_{i,j} = 1.0$ (i.e., the two topics are not disjointed) and of type II when $p_{i,j} = 0.0$ (i.e., the topics are isa) are depicted as oriented.

Moreover, we define that two categories t_i and t_j are in a *t-relationship* when in $\mathcal{C}$ there exists a path $\langle t_i, t_k, L_{i,k}, p_{i,k}\rangle \dots \langle t_m, t_j, L_{m,j}, p_{m,j}\rangle$. Differently, if the links of this path joining the nodes t_i and t_j belong to different topics links, we say that they are *generally related*.

IV. THE PERSONAL AGENT

Each user u_k is assisted by several Personal Agents $(a_{k,1}, a_{k,2}, \dots, a_{k,n})$, where n is the number of groups to which the user u_k is affiliated (i.e. topics of interest for u_k). More in detail, for each group where a user is affiliated his/her associated Personal Agent will manage his/her affiliation with that group (and with other groups focused on the same topic).

User Profile. The Personal Agent a_k monitors all the activities of its own user u_k referred to a specific group in order to maintain the user's profile P^C_k. To represent the profile P^C_k for the user u_k, the same notation of $\mathcal{C}$ is adopted, i.e. a graph $T^{P^C_k} = \langle T^{P^C_k}_{topic}, T^{P^C_k}_{link}\rangle$ where $T^{P^C_k}_{topic}$ is the set of topics and $T^{P^C_k}_{link}$ is the set of links.

Moreover, each topic $t \in \mathcal{C}$ of interest for u_k is associated in $T^{P^C_k}_{cat}$ with a tuple $\Gamma_k = \langle i_k, v_k\rangle$, where $i \in [0,1] \subset \mathbb{R}$ represents the *interest* of u_k for t (respectively, $0/1$ denotes the minimum/maximum interest for t), while v is a flag which specifies the type of *visibility* that u_k desires to give to his/her own interest for t (respectively the value $0/1$ corresponds to a $public$ or $private$ visibility). Figure 3 reports an example of agent profile derived from the example proposed in Figure 2. Note the categories (in bold) are not present into figure 2.

Determining topics of interest. The Personal Agent $a_{k,i}$ monitors the activities of its user u_k within the thematic group G_i and periodically provides to evaluate the interest of u_k in the topics belonging to its profile $P^{C_i}_k$. To this purpose, for each topic in the profile $P^{C_i}_k$ the agent a_k, by collaborating with the other agents which u_k belongs to and from which it collects all their catalogs, computes the index $I_{k,t}$ as:

$$I_{k,t} = \frac{1}{1 + e^{-\frac{\sum_{\forall t \in \{S_k \cap C_{u_k}\}} i_t}{\|S_k \cap C_{u_k}\|}}} \tag{1}$$

where $S_k = \{t_1, t_2, \dots, t_n\}$ is a set of topics of interest for u_k that belong to P^C_k and C_{u_k} is the set of catalogs of all the groups where u_k is member. For each topic t belonging to S_k is determined the average interest shown by u_k (i.e., $I_{k,t}$) with respect to the domain $[0,1]$. More in detail, when the interest of the user u_k in a topic t decreases then, consequently, the value of the associated interest i_t for that topic decreases and, as a result, also the value of $I_{k,t}$ will decrease. Conversely, for any group concerning the same topic managed by the agent a_k, their computed values of $I_{k,t}$ will increase.

Group affiliation. Based on a threshold $\psi \in [0,1] \in \mathbb{R}$ fixed by the user, each Personal Agent provides to identify those groups potentially of interest for its own user as well as to require the affiliation to their respective Group Agents. Similarly, the Personal Agent also suggests to leave a group as well as to send a leave message to the Group Agents managing those groups for which the interest of its user is low.

More in detail, with respect to the Personal Agent $a_{k,i}$ after that the index $I_{k,t}$ has been computed, when $I_{k,t} > \psi$ for a topic if interest for u_k, if there is a group focused on that topic then it becomes a candidate for the user to join with (and a new Personal Agent of u_k could be activated to deal with all the activities of u_k within this group). At the same way, when for a group for a topic of interest it results that $I_{k,t} < \psi$, if u_k is affiliated with a group focused on that topic then its Personal Agent recommends to the user of leaving that group and, if required by its user, it provides to send a leave request to the Group Agent associated with it and the associated Personal Agent will be stopped.

Matching category links. Another activity is executed by the Personal Agent on existing connections between topics $t_1 \in \{S_k \cap C_{u_k}\}$ and $t_2 \in \{S_k - C_{u_k}\}$, with respect to the links of type II — i.e., *synonymy* (s) and *overlap* (o). In particular, the parameter H_k is computed as:

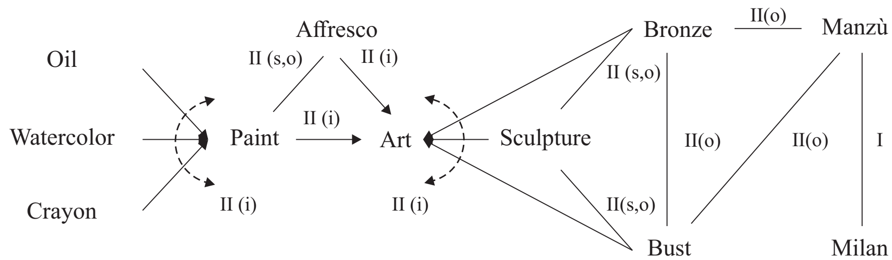

Fig. 2. A part of a CTD about "Art". Note that for the type II, the links isa, synonymous, overlap have been respectively identified as i, s and o.

$$H_k(t_1, t_2) = \frac{1}{N_{t_2}} \cdot \sum_{m \in \{s,o\}} v^m_{t_1,t2} \cdot N^m(t_1, t_2)$$

where $t_1 \in \{S_k \cap C_{u_k}\}$, $t_2 \in \{S_k - C_{u_k}\}$, $v^m_{t_1,t2}$ represent the parameters $v^s_{t_1,t2}$and $v^o_{t_1,t2} \in [0,1] \subset \mathbb{R}$ as well as $N^m_{t_1,t2}$ represents $N^s(t_1, t_2)$ and $N^o(t_1, t_2)$, which are the number of synonymy and overlap connections between t_1 and t_2, respectively. Moreover, N_{c_2} is the total number of links of the topic $t_2 \in \{S_k - C_{u_k}\}$ and since $N^s(t_1, t_2) + N^o(t_1, t_2) \leq N_{t_2}$, it will be $H_k < 1$.

The purpose of the computation of H_{k,C_j} is to select those topics belonging to users catalogs, in order to enrich the catalog of the group with further users categories, as explained in the following.

Catalog enrichment. Let be j^* a group to which user u_k is affiliated. Firstly, the u_k Personal Agent a_{k,j^*} provides to calculates the value H_k for all $t_1 \in \{S_k \cap C_{u_k}\}$ and $t_2 \in \{S_k - C_{u_k}\}$. After this, the agent a_{k,j^*} calculates the index $\widehat{H}_k(t_2)$ $\forall t_2 \in \{S_k - C_{u_k}\}$ as:

$$\widehat{H}_k(t_2) = \frac{1}{||S_k \cap C_{u_k}||} \sum_{t \in S_k \cap C_{u_k}} H_k(t, t2)$$

Moreover, the Personal Agent a_{k,j^*} sets the threshold $\phi \in [0,1] \subset \mathbb{R}$ such that it is $\widehat{H}_k(t_2) \geq \phi$, then the topic $t_2 \in \{S_k - C_{u_k}\}$ is sent to the group agent in order to enrich the catalog of the group. When the Group Agent receives the topic t_2 then it will be a potential candidate to be added to the catalog of own group by means of the selection of other parameters, as the frequency of the involved terms (see Section V).

V. The Group Agent

Group Agents are the counterparts of the Personal Agents (i.e. users) with respect to the activities of group affiliation and enrichment of the *Thematic Catalog* $\mathcal{C}$ management. To support such activities the Group Agent adopts specific data structures able to encode the group profile.

More in detail, (see Section III), the *Thematic Catalog* $\mathcal{C}$ of the group stores all those topics of interest for the group members, as well as all the relationships taking place among them (see Section III). A *White Pages* service is provided to the agent affiliated with the group in order to provide the identifiers of all the group members. A third data structure, named *Yellow Pages*, is devoted to store all the public interests of the group members in order to allow each agent to find in the group other agents (i.e. users) sharing similar interests in the same topics. The *Yellow Pages* data structure is formed by a set of lists, each one referred to a single agent (i.e. user) resulting affiliated with the group.

A. Group Agent behavior

Group affiliation. When a user joins with the group assisted by the Group Agent, he/she receives an identifier for that group and, consequently, the White pages of the group are updated. Similarly, when a user leaves the group then its associated Group Agent will prune all the information referred to that user from his/her data structure.

Dictionary enrichment. The Thematic Catalog of a group is periodically updated by the associated Group Agent basing on the knowledge of the affiliated Personal Agents (see Section IV). Indeed, the Group Agent will collect all the topics $t \notin C_{u_k}$ sent to it by Personal Agents affiliated with its group because $\widehat{H}_k$ is greater then the ϕ parameters set by their owners (see Section IV). Note that when an agent is interested to enrich the catalog of its group with a new topic t it is "quite connected" with other categories belonging to the set of topics S_{u_k}. The information H_k is for the Group Agent a first set of candidate topics from which it will extract those topics having the highest frequency f [1] or, in other words, those sent by the higher number of Personal Agents in order to use that knowledge resulting really shared among the groups members.

VI. Related Work

A wide body of studies investigated on the various modalities to promote interactions and mutual cooperation in heterogeneous environments [12]–[14]. Consequently, in this section only those approaches which comes closed to the arguments proposed in this paper will be cited. The interested reader can refer to [15]–[18] for a more complete overview on the matter.

The capability of a mutual collaboration among agents usually implies a mutual understanding ability, and in this context a common way is that of providing agents with some form of knowledge shared by all the cooperating agents [19].

[1]The frequency is computed among all the used terms which fall into these topics

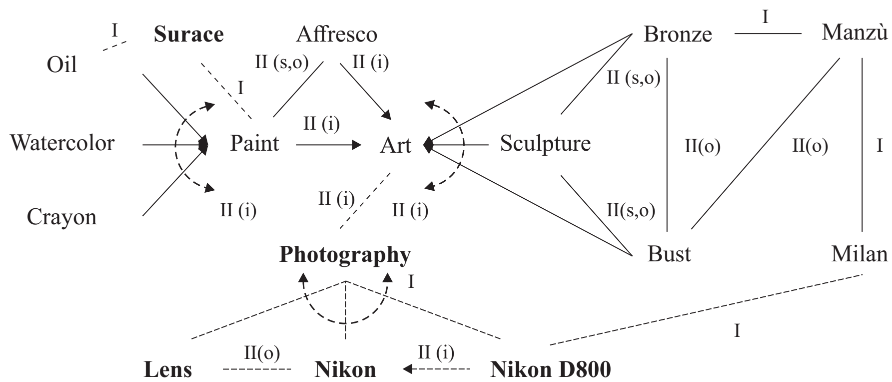

Fig. 3. An example of Personal Agent profile based on the Catalog of Figure 2 (new topics are represented in bold and new links are represented with dashed lines).

A similar approach has been adopted in [1] where agents share a common hierarchical ontology representing a close domain of interest. In fact, in this proposal the agents have not the opportunity to represent their individual knowledge and, therefore, in a more general context it results highly limited to support emerging user's needs.

Other approaches where a common and shared ontology is unnecessary are proposed in [20]–[23]. More specifically, the authors of [20] in a message-based mechanism propose a meta-ontology for translating the presuppositions extracted by a message in order to make understandable its meaning to the receiver agent. This target is obtained by means of a common vocabulary shared between the sender and the receiver agents. Moreover, in presence of conflicts, inconsistencies or ontological gaps in the incoming message then the receiver agent has the possibility to change its personal ontology in order to overcome such problems, while other systems have chosen to adopt semantic negotiation approaches as in [14], [24]

In a similar way, the paper [22] presents a domain-specific ontology, called *global ontology*, which allows a matchmaking system to be used by agents. This approach gives the advantage of not adopting shared ontologies. More precisely, each agent provides to its platform the map of its ontology which is integrated in that of the platform. This task is executed by using a suitable extraction engine which provides to identify relevant information present into the personal agent ontologies. Therefore, the aim of the common ontology shared on the platform is only that of a dictionary for translation and each agent can use its personal conventions. Other solutions adoptable when it is needed to represent wide and specialized knowledge contexts, as in the e-Commerce, are those adopted in [25] and [26] where the interacting agents have to perform the task of realizing their mutual understanding by allowing them the capability to build rich and detailed XML users' profiles.

The authors of [27] studied the problem of the potential heterogeneities existing in digital libraries. To this purpose they designed a P2P agent framework by associating each library with a software agent aimed to realize a common dictionary (i.e. ontology) capable to support the agents in semantic communications. Another technique is presented in [28] and consists of using shared keys, which are semantically negotiated by agents, to solve the problem deriving by the presence of synonymies in order to avoid the adoption of different terms for the same objects and, in this way, permitting the mutual agent understanding.

Finally, in [29] and [30] users are supported by a set of personal agents. More in detail, in a benevolent environment, they adopt an approach inspired to the biologic evolution where the best performing agents can be cloned and the worst agent can be deleted. Similarly to the proposal presented here, each user is supported by more agents, potentially heterogeneous for knowledge representation modalities, that, differently from this proposal, act autonomously and therefore they do not need to communicate. However, a similar approach could receive great benefits from the adoption of a common catalog which can be enriched by the individual and potentially heterogeneous agent knowledges, although these proposals implement a not explicit knowledge sharing on the basis of the cloning process. In this overview we presented some approaches implementing mutual collaboration among software agents on the basis of their mutual understanding and other implementing a multiple agent support for each user. The most part of them implement some form of shared knowledge as dictionaries, common/global ontologies more or less versatile.

In particular, our proposal is based on a dictionary approach to promote agent cooperation in a simple and versatile way. Indeed, the proposed catalog natively permits to the agent of enriching it in order to include both the common and the personal knowledge which give to the groups the dynamic capability of easily evolving. Currently, a prototype of a framework based on the proposal presented in this paper is in an implementation phase in order to test its real performance.

VII. Conclusions and future work

This paper discussed the problem to promote mutual users interactions and cooperation within thematic groups in open virtual (agent) communities in presence of heterogeneous knowledges among the affiliated users (i.e. the associated agents). To this aim, a framework is proposed such that each thematic group is assisted by a Group Agent and, in turn, each user is assisted by a Personal Agent. More in detail, each Personal Agent is specialized only on a specific theme (i.e. topic) and manages a personal profile (resp. catalog) of its owner's knowledge and interests, such that users are supported by one or more Personal Agents. In such a context, Group Agents provide to their affiliated Personal Agents some basic services. Each group catalog is extensible by the delegated Personal Agent in order to take into account other topics of interest for its user. Then such further knowledge can be exploited by the Group Agents to enrich their respective common Thematic Catalogs of their groups. As future work, we will perform a number of simulations in order to verify the effectiveness of this proposal.

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