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Coordinated Persuasion with Dynamic Group Formation for Collaborative Elderly Care

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Abstract—Ageing in place demands a new paradigm of in-house caregiving allowing many aspects of daily lives to be tackled by smart appliances and technologies. The important challenges include the effective provision of recommendations by multiple parties of caregiver constituting changes of the user's behavior. In this multiagent environment, interdependencies between agents become major issues to tackle. This paper presents an approach of dynamic group formation for autonomous caregiving agents to collaborate in recommending different aspects of well-being. The approach supports the agents to regulate the timing of their recommendations, prevent conflicting messages, and cooperate to make more effective persuasions. A simulation of virtual elderly-care system demonstrates how dynamically grouped and collaborating agents can imply improvements in persuasive recommendation.

I. INTRODUCTION

A growing number of smart appliances and technologies for ageing in place have become popular in the past decade. The disproportionate population of caregivers has initiated the use of technologies to carry out many parts of the caring tasks like ambient assisted living for in-house daily monitoring and intervention [6], [13], [14]), and smartphones apps for evaluating overall aspects of personal well-being [5], [10], [17]. In this case, a caregiving technology can be considered as an autonomous agent that assesses and changes the user conditions towards improvement or sustenance of the one's well-being.

When multiple parties of caregiver are employed to persuade the user, complications may arise since some of the advices may interfere with each other as in a scenario as follows :

> *A fitness trainer application reminds the user to do a programmed exercise for certain period of time, while a cognitive advisor suggests the user to take a nap at the same time as follows:*
>
> **Fitness**:*"you should do the abs workout now for 10 minutes"*
> **Cognitive**:*"taking a nap now for a half hour can refresh your mind"*
> *Listening to both advices, the user seems interested to follow the taking-a-nap suggestion, and eventually forgets to do the routine exercise.*

Taken individually, each advice sounds reasonable and useful. However, when they are given together at the same time, their intended effects may instead cancel each other out. A recommending agent should take the other's advice into consideration besides the user condition alone.

In this paper, a framework for multiagent persuasion and recommendation is presented. It is made to handle inter-dependencies among persuasive agents as illustrated above. Particularly, it is emphasized on how an agent becomes aware of the others' presence that is relevant, how does it know what the others are doing, and how it can get the most from their co-existence. Each agent is considered as an independent and fully functional piece of program or application for addressing particular issues on the user well-being. Specifically, a persuasive agent is the one that monitors the user for the need of any behavioral change, and give some advices accordingly. The issue of how to determine which agents should be co-present can be considered as *coalition formation*.

The Dynamic formation of groups is taken as the mean to enable different agents to coordinate with each other. Since coordinated activities comprise exchanges of information among agents, a group represents information about objects and activities in the domain agreed by all the members. It can be formed whenever potential interdependencies among different agents are identified like possible conflicts or opportunity for cooperation so that the agents can resolve the issue or gain more from the opportunity. A group is the basic unit of coordination instead of an individual agent. This contrasts with most other existing frameworks for coordination in multiagent systems (e.g [12], [11], [21]) that aim for optimizing the agents' own activities or processes in terms of throughput and correctness. In a conventional approach of coordination, an agent may be selected on behalf of a group or the entire system by a single mechanism or a managing agent (e.g Contract Net [20]).

The proposed framework suggests that a new task can be allocated to an agent if all group members agree with it. A single persuasive agent may be designed to have a particular role or task in persuading a person for a particular aspects of living. The preference to allocate a task may change as the group expands and shrinks. This approach is particularly adopted to handle persuasion to change the user's behavior regarding the factors influencing the effectiveness of persuasion. According to Fogg [9], the success of persuasion to change the user's behavior depends on the user motivation and ability to realize the target behavior. It also depends on whether the persuasive message can be properly delivered and interpreted by the user which also involves the ability and motivation to comprehend the message [18]. Consequently, the effectiveness of delivering the message also depends on the agents' co-

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presence as a group. How a group is formed determines how effective different persuasive recommendations are delivered.

The framework consists of a shared knowledge base system letting different persuasive agents to share information and be aware of what the other agents believe and plan to persuade. The framework also specifies the mechanisms for dealing with different types of situation wherein the agents must coordinate with each other either to resolve or to enhance the effectiveness of persuasion. In this paper, the focus is on addressing particular issues as follows:

1) how to avoid the user being distracted by too many agents advising different messages within a narrow time frame;
2) how to prevent conflicts between different advices that their intended effects may cancel out each other;
3) how to make the agents help each other to persuade the user to achieve a particular target behavior.

In this paper, we also take the interdependence of the three individual issues to tackle above into consideration. Solving an individual issue above may introduce another one to tackle. We compare the group formation approach with a basic task allocation procedure (dynamic group selector vs single agent selector) to see how one particular issue above depends to another. we present a case study using a simulation of elderly caring for well-being domain to demonstrate our coordinated persuasion model.

However, we still assume that the persuasion message in the study is represented as a data structure conveying the recommended target behavior rather than as a generated natural language message. The issue of properly generating a natural language message for persuasion is outside the scope of this paper. Some examples showing natural language advice from the agents are manually mapped from the data structure as mentioned. The scope of this paper does not include how agents monitor the activity and resolve the inconsistency among them. It is assumed that some perception or beliefs about the user regarding the achievement of the persuaded target (e.g. motivation, ability) can be obtained straightforwardly. The scope does not cover how the agents manage consistent views about the domain problem and meanings (e.g. ontology, agreed semantics) as well.

This paper is organized as follows: Section II discusses related work. Section III provides illustrative examples of the issues tackled in brief. Section IV presents the representation of the user's activity of daily living and how it can support reasoning and inference about activity. Section V explains how persuasion is incorporated in the model and its relation to co-ordination. Section VI describes the case study demonstrating the realization of coordinated persuasion.

II. RELATED WORK

Presenting information by multiple agents to a single user has been investigated in [1] suggesting that information can be conveyed more effectively if the agents present it from different perspectives. Similar effects can be produced if they employ a certain dialog strategy in which the agents talk to each other about the recommended behavior letting the user see and reflects on it [16]. Most of these studies are still limited to investigating human factors without really involving

software agents that autonomously generate the dialogs. The conversations are still handcrafted or generated offline.

Some studies have also looked at the use of relational agents in which persuasive virtual agents are designed to maintain long-term social relationship with the user [19], [2] including particularly to provide companionship to elderly [22]. Based on some prescribed ontology and a hierarchical dialogue planner, the agent can converse fluently with the user according to its domain objective [3]. Complex but natural flows of dialog can be achieved thanks to the *SharedPlan* collaborative dialog model [11] adopted in which the conversation can be made goal-directed. Although the approach taken is promising, the work mostly looks only to a single agent conversing with a user. The approach does not take interdependencies among multiple agents into consideration during conversation or persuasion.

Studies on multiagent systems, on the other hand, mostly assume rational solutions for collective desires or preferences. In multiparty persuasion, the concern is mainly on the regulation of argumentation involving multiple agents with diverse and independent objectives. Persuasions are provided towards changing the beliefs or preferences of each other and to arbitrate among conflicting ones [15], [4]. An agent being persuaded is considered to be rational or a utility-maximizer. Similarly, it is also commonly adopted in many practical frameworks for cooperation (e.g [7]) with optimizing objective like improving the throughput of the overall processes or ensuring the robustness or correctness of the team activities.

When the target of persuasion is a human user, rational thinking may only apply when the user is strongly motivated with the ability to deeply comprehend the message. In Elaboration Likelihood Model (ELM), peripheral route to persuasion will be taken instead if the user has a lower motivation or a lack of ability [18]. In this peripheral path, persuasion depends on more pragmatic, emotional, intuistic, and social judgement. In the proposed framework, the focus is not on how to provide the appropriate ontology or knowledge to persuade the user. It is assumed that some of the agents involved have the appropriate knowledge to generate the appropriate message and persuasion. Instead, the emphasis is on regulating, coordinating, and recruiting agents to act in unison to persuade the user.

III. MOTIVATING EXAMPLE

In this section, we illustrate the multiparty persuasion issues tackled in this paper. Consider multiple smart applications, appliances, or embedded devices that can talk to the user to advise better activities or ways of living. Each of them has its own mean to observe the environment and the user and accordingly respond to it by persuasively providing some advices. Although, their main concern is the well-being of the user, putting together many of them with different aspects of well-being to address (e.g physical, cognitive, emotion, social) may introduce some complications.

Figure 1(i) illustrates that too many advices provided at the same time or within a narrow time window may confuse the user. In relation to that, two (or more) advices may have opposing intended effects to one another. As shown in Figure 1(ii), one advice from one advisor can have the effect

of cancelling out the intention of another. There must be some means to regulate those advisors based on how one action may affect the others.
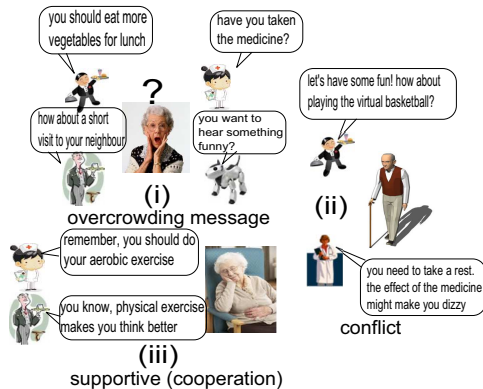

Fig. 1. Cases of persuasion interferences: (i) overcrowding message; (ii) conflicting effects; (iii) supportive advices.

On the other hand, the multiplicity can also be advantageous. Figure 1(iii) shows that the advice from one agent may motivate the user to do the one as advised by another. Telling the user about one behavior from different perspectives gives more chances that the user will adopt the target behavior (as a cue for peripheral route of reasoning [18]). However, it should be noted that even though multiple advices positively support a single message to the user, some of them may still have an opposing effect to another. For example, if another agent provide a meant-to-be motivating advice like "*aerobic relieves you from thinking too much*" to the dialog in Figure 1(iii), it may instead be counterproductive since it may oppose another motivating message (e.g "*you know, physical exercise makes you think better*" in Figure 1(iii)). In this case, as one tenet in this paper, helping another is not just about supporting the one that needs help but may also depend on those who already offering the help. As mentioned above in a previous section, conventional approaches of allocating the supporting messages to particular agents may not be effective in this case. Selecting the supporting agents by the group currently formed rather than a single manager is the proposed solution.

In this paper, we intend to tackle the above issues of coordinating multiparty persuasion. We devise a shared memory system to let the agents share information and know each other actions. By imposing some coordination protocols on the use of the shared memory, it is expected that those interferences can be regulated.

IV. INFORMATION SHARING

To know, understand, and help each other, agents need to share what they know, what they are doing, and what they think will happen. In this section, we present a shared memory system to let persuasive agents share information and their plans of persuasion.

The shared memory (shared Knowledge Base or KB) contains group beliefs B and group intentions I (Figure 2). Group beliefs B consists of assertions representing what groups know about the user and what would follow from them as

predictions. On the other hand, assertions in group intentions I describe what the agents (groups) want to achieve and what action of recommendation they want to deliver. Through this structure, the agents share information to each other while advising the user towards persuasive objectives.
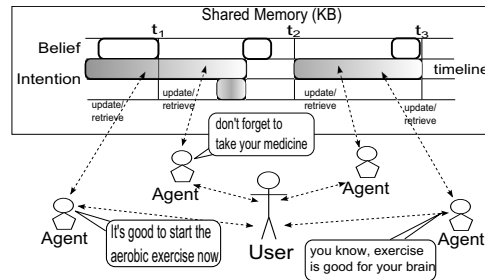

Fig. 2. Shared memory system for multiparty persuasion.

The elementary part of an assertion in KB is an event. An event is the basic informational unit specifying what happens to agents or what activity the agents do within a particular time interval. The agents associated with the event can be represented as a singleton referring to a single agent (or user). As shown in Figure 3, an event (white-rounded rectangle) specifies the time interval, agents (or user) as the subject, and a set of attributes. With time intervals, the shared memory contains activity descriptions within a timeline. When an agent posts an event description, it will be put in the timeline structure. For example, in the belief part (Figure 3), it is believed that `user01` perform `cleaning-up` activity from time t_1 to t_2. In the intention part, it is shown that there is an intention of an agent that `user01` has a lunch with vegetables within the time as given. The `exec:true` attribute indicates that the activity is executed at the given time as specified. Without the `exec:true` attribute , the activity is only described as to have the characteristics as mentioned in the event attributes. For example, another event in the belief part suggests that between t_3 and t_4, `user01` has no motivation (`motivation:0`) to have lunch with `vegetables` diet. The main concern in the event is not about the activity but is something to do with no or minimum motivation related to the activity.
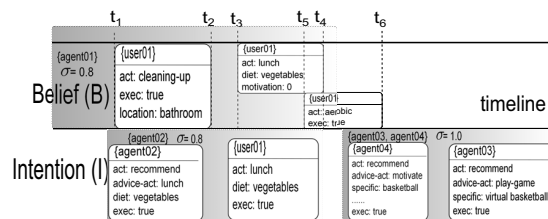

Fig. 3. (i) the structure of the shared memory with belief, intention, and elementary event representation; (ii) implication relations of time intervals, overlapping intervals and *event-density function*.

More formally, an event can be defined as a tuple $\varepsilon = (G_r, \mathcal{V}, \overline{T})$ wherein G_r is a set of agents (or a singleton of user), $\mathcal{V} = \{v_1, v_2, ..., v_p\}$ is a set of attributes, and $\overline{T} = (t_{start}, t_{end}, \mathcal{Q})$ is the time interval from t_{start} to t_{end}. The quantifier $\mathcal{Q}$ indicates if the event occurs `some` of the

time or `all` of the time within the interval. An event in KB is contained in its assertion structure shown as a gray rectangle in Figure 3. An assertion specifies whether an event is in B or I in KB. It also indicates which group of agents (or a singleton) this assertion belongs to or which group has asserted, subscribed, or updated it. For example, one assertion of {agent01} (a singleton) in Figure 3 consists of an event about {user01} doing `cleaning-up` from time t_1 to t_2 and another one about {user01} that has no motivation to have lunch with `vegetables` from time t_3 to t_4.

An assertion can be expressed as $\beta = (\mathcal{G}, \varphi, \overline{\varepsilon}, \sigma)$. $\mathcal{G}$ is the group of agents in which the assertion belongs to. φ determines whether it is in B (belief) or I (intention). $\overline{\varepsilon}$ is the set of events contained in the assertion. σ is the level of confidence (for belief) or urgency (for intention) where $0 \leq \sigma \leq 1$. An assertion may describe a plan of agents to persuade the user. For example, one intention (assertion) of {agent02} in I (intention) is to recommend the user to have lunch with `vegetables` to achieve the condition that {user01} eventually have lunch with the diet specified. It may also specify how the members in the group coordinate. For example, in Figure 3, the assertion of {agent03,agent04} in I specifies that {agent04} motivate the user to have an interest in playing basketball which will be followed by {agent03} triggering the recommendation of playing of virtual basketball.

V. PERSUASION AND COORDINATION

In [9], the success of persuasion to change the user's behavior depends on whether the user is well motivated or willing to change, whether the user can realize the behavior without burden or obstacle, and the triggering condition of when the change can be started or initiated. It is also suggested that there are three phases in finding the right kind of persuasion [8]:

1) Identify the user's target behavior.
2) Determine the trigger to initiate the behavior.
3) Plan specific steps of persuasion.

It can be inferred that, similar phases should be followed by persuasive agents to come up with the most suitable recommendation and persuasion strategy. In the beginning, the agent identifies the needs of the user and determines the target behavior to achieve or to change. In the next stage, the agent decides the trigger, or the message to be delivered according to the goal of target behavior. In Fogg's model of persuasion [9], a trigger can be used not just to initiate the target behavior, but also to leverage the motivation (Spark), to convince the user that the target behavior is achievable and/or easy to do (Facilitator), or just as a reminder (Signal). When all those targets and triggers are set, the agent can just follow the schedule of persuasion that has been set up.

Based on the Fogg's model, a persuasive agent may collect information in the beginning phase of the caring system. It then shares the assertions about what the user would do and what recommendations to provide. Meanwhile, a group is formed as the content of the shared memory is added. However, some members may also be in conflict.

A. Group Formation

Retrieving and updating information in the shared memory or KB requires some means of comparing two events within different assertion structures. When an existing event ε^x of assertion x implies another event ε^y of an incoming assertion y (or $\varepsilon^x \to \varepsilon^y$), the agent asserting y may become a member of the group that assertion x belongs to and the other members are notified about the change. On the other hand, retracting a belief assertion in the group may cease the group membership of the agent initiating the retraction if the other members of the group disagree (Figure 4(i-ii)). The implication $\varepsilon^x \to \varepsilon^y$ holds if $G_r^y \subseteq G_r^x$, $\overline{T}^y \to \overline{T}^x$, and $\mathcal{V}^y \to \mathcal{V}^x$. Figure 5 shows different types of temporal relationships including the temporal implication between events given the specification of intervals and the quantifier (`all` or `some`).

Asserting an event ε^y that $\varepsilon^x \to \varepsilon^y$ (ε^x is an existing assertion) like above provides the functionality of belief subscription that the agent will receive any update to the corresponding group assertion in the future. This can happen since any change to the existing assertion will be notified to all members of the group. On the other hand, when a member of the group or a non-member asserts an event ε^y but $\varepsilon^y \to \varepsilon^x$ holds instead, the group formation depends on the agreement from the existing members of the group. Once agreed, the asserting agent will be added to the group and all members must update their beliefs (Figure 4(iv)). Otherwise, the new assertion should be abandoned or held as an independent entry in the shared memory (KB).

The mechanism of group formation above suggests that each coalition of agents also represent a consistent view of assertions. In this way, any change that may lead to inconsistency indicates potential conflicts for which the agents must resolve.
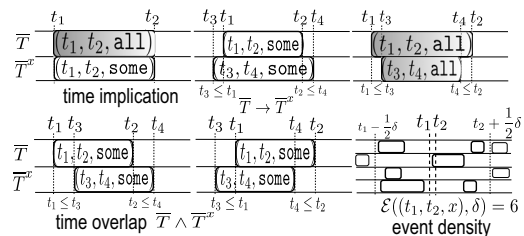

Fig. 5. Different kinds of temporal relations.

B. Conflict

Besides the implication relations between events that facilitate the group formation, potential conflicts between assertions can also be detected when an agent is asserting a new entry in I (intention) to KB. Figure 5 shows temporal overlapping ($\overline{T} \wedge \overline{T}^x$) relationship between two different events. *Potential-opposite* or $\mathcal{V} \not\approx \mathcal{V}^T$ can be defined as the existence of attributes in both $\mathcal{V}$ and $\mathcal{V}^T$ of events with the same name but different values. A conflict situation, like in Figure 1(ii), can be identified whenever a newly asserted event is temporarilly overlap ($\overline{T} \wedge \overline{T}^x$) and there is a potential opposite among attributes $\mathcal{V} \not\approx \mathcal{V}^T$ within the overlapping interval.

To resolve this condition, one or more agents in conflict must be selected to concede or to abandon their original intentions. Once selected, one agent may change its own intention without changing its main goal. For example, if the main intention is to let the user to have fun and the
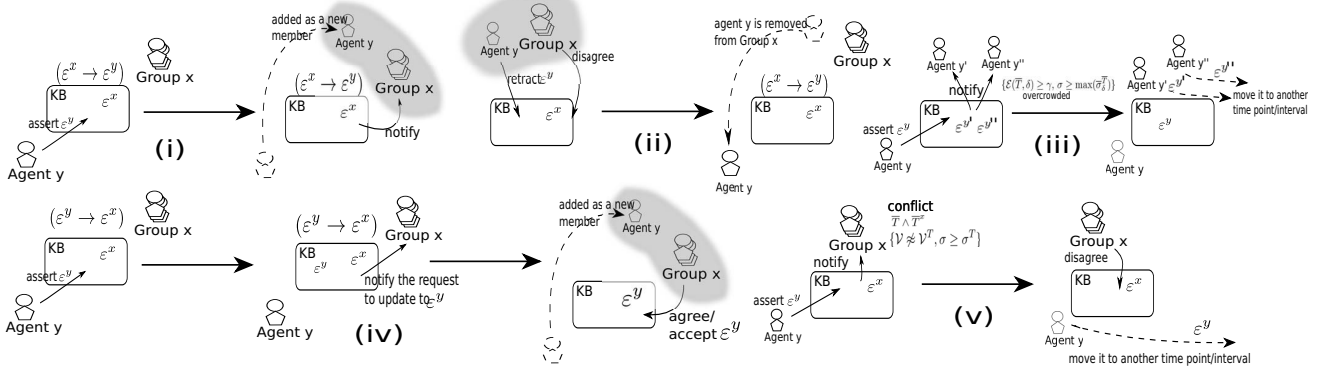
Fig. 4. (i) Asserting an event implied by an existing assertion in KB automatically puts the agent as a member of the group; (ii) Retracting an event would remove the agent from the membership of the group if the other members disagree with the removal; (iii) Asserting an intention to recommend the user within an overcrowded interval will make all agents in the interval with lower urgency of intention move their intentions away; (iv) Asserting an event that implies an existing assertion in KB will initiate the request for agreement to the other members of the group for the new assertion. If accepted, the asserting agent is recruited as a new member and the group replaces its assertion with the new one; (v) when a new assertion is potentially in conflict with another existing one in KB, the one with a lower urgency level must be moved to another time slot.

recommendation to conduct a dancing practice is conflicting with another intention (e.g avoiding too much user physical activities), changing the recommendation to listening some music can resolve the conflict without changing the main intention. In a more restricted case, the agent may need to suspend or change the timing of the recommendation such that no conflict occurs from another intention. This can be done, for example, by shifting the time interval to another time slot in which interferences with another intention no longer exists. Figure 4(v) shows a conflict situation that the agent must move its intention to another time slot because of its lower urgency (σ). In the worst case, the agent must totally abandon its main intention.

Figure 5 also shows the *event-density* function $\mathcal{E} : 2^{\overline{T}} \times \mathbb{R} \to \mathbb{N}$ which is defined as the number of existing events that occur around a particular time interval. Overcrowded trigger like in figure 1(i) can be detected by checking the condition that *event-density* $\mathcal{E}(\overline{T}, \delta) \geq \gamma$ where γ is the maximum number of triggers allowed to be together within the time slot. The overcrowding number of trigger can be considered as a particular type of conflict that some agents must change their time slots to recommend their user. In the case of overcrowded messages, it can also be considered that all events within the overcrowded interval are in-conflict.

To select which agents to concede or abandon, the criteria of the importance level $\sigma \geq \max(\overline{\sigma}_\sigma^{\overline{T}})$ can be used to determine that the corresponding trigger can stay. On the other hand, those assertions with $\sigma < \max(\overline{\sigma}_\sigma^{\overline{T}})$ can be the candidates to concede. $\overline{\sigma}_\sigma^{\overline{T}}$ is the set of all importance values of triggering (advising) intentions that are in conflict. This condition is illustrated in Figure 4(iii).

C. Coordinated Persuasion Model

To improve and sustain the user's well-being, the effectiveness of persuasion is determined not just by the correct identification of the target behavior and the right planning of triggers but also the user motivation and ability to perform the target behavior. When the user is less motivated and has
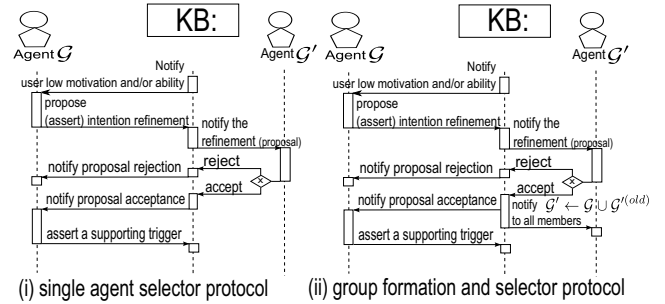

Fig. 6. (i) Proposal selection by a single manager or agent; (ii) The proposed incremental group formation and selection for cooperation

difficulties to perform what has been suggested to do, different agents may take different roles in persuasion to ensure the achievement of the target behavior. Cooperation and support can be identified based on the type of motivation and ability of the subject to change attitudes (e.g ELM persuasion strategy that takes central and peripheral influences [18]). Cooperation between persuasive agents, as illustrated in Figure 1(iii) can be realized as a division of labor of conveying the message in different ways to give more chances that the subject accepts the recommendation.

At some stage, an agent may intend to trigger a reminder for a target behavior, but the user's motivation or ability for it is still low. If the agent is unable to change the user's motivation (or ability), other persuasive agents more capable to leverage it may be able to help. The motivation and ability can be measured by detecting if the user follows or confirms the agent recommendations indicating attention. When the user does not respond to the agent for the same kind of message, it can be inferred that the motivation or ability of the user towards the particular type of recommendation is low [1]. As a feature of the shared memory KB, whenever `motivation` or `ability`

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[1] Although measuring the user motivation and ability is supported in the framework, the detail of how to obtain it is outside the scope of this paper.

towards a targeted activity is low as detected in B, all agents are notified about the condition and requested to support or help. An agent that is capable of motivating or guiding the user in performing the activity may further assert a new intention and form a group. Those stages are shown in Figure 6(ii) as the proposed cooperative persuasion model. As the proposal is sent to group $\mathcal{G}'$, it may be accepted or rejected which is then fed back to to pass it to $\mathcal{G}$. Until the rejection, the process is mostly identical to the common task allocations (see the single-manager task allocation in Figure 6(i)). However, when the proposal (assertion of intention) is accepted, it is not just the selection result that is informed back to the bidder, but the bidder is also recruited as a new member. In the next time round of the selection process, the new recruited members will be biasing the selection criteria.

The proposed method enables the selector to adapt incrementally to the recruited members. This feature is important when a supporting recommendation from one agent depends can be supported by another.

VI. SIMULATION AND CASE STUDY

The model is applied in a simulation of elderly caring in a virtual home environment. The virtual home is built with a virtual elder user residing as the subject initially built to follow a routine habit of daily task. There are nine main activities of daily routines (e.g waking up, taking a bath, having breakfast/lunch/dinner, spending spare time, sleeping). In a finer detail, each activity may have a number of configuration features. For example, having a breakfast may include the type of menu (e.g eat with eggs, bread, or milk) and spare-time activity may include doing physical exercises, playing video games, or get connected with friends through a social network.

The virtual user is made to follow the daily routine as specified. It follows the prescribed main activities but randomly selects the detail configuration. The virtual user can be advised anytime to change its main core activities or the detail configuration of activity directly based on the event structure representation as described above. In the study, virtual user has a motivation-ability attribute to determine the level of chance it follows the advice. Here, motivation-ability is considered as the same attribute to simplify the matter. When motivation-ability is less than a threshold η the virtual user does not follow what has been adviced by particular agents. In other words, there is η chance that the virtual user does not follow the advice from the persuasive agent whenever the agent recommends it.

Four persuasive agents are included to advise the user to do or change the one's activities to improve well-being. Each agent tackles one aspect of well-being. There are four aspects in this study: physical (phs), cognitive (cog), emotion (emo), and social (social).

The level of well-being is measured according to each aspect taken by each agent individually. The level of well-being for i aspect can be measured as follows $Q_i(t) = Q_i(t-1) + \sum_j^N \delta_{ij}(t).W_j$ where $Q_i(t)$ is the quality of well-being for aspect i, $\delta_{ij}(t)$ indicates the presence of the jth key indicator of i at time t (0 or 1), and W_j is the weight for the key indicator j wherein $W_j \in [-1, 1]$ and Q_i is bounded between 0 and 1.

TABLE I
EXAMPLES OF KEY INDICATORS AND THE CORRESPONDING WEIGHTS IN ASPECTS OF WELL-BEING

Activity	key indicator	physical	cognitive	emotion	social
waking up	stretching and exercise	+0.001	+0.0001	0	0
taking a bath	-	+0.0003	+0.0001	0	0
breakfast	toast bread and eggs	+0.0005	-0.0001	0	0
	american breakfast	+0.0005	-0.0001	0	0
	....				
lunch/dinner	salad	+0.007	+0.0005	0	0
	....				
	junk food	-0.0001	-0.0001	0	0
	drink only	-0.005	-0.003	-0.003	0
spare time	aerobic	+0.005	-0.0001	0	0
	treadmill	+0.009	+0.001	-0.0005	0
	....				
	social media	-0.005	+0.0001	+0.0001	+0.005
	chatting with relatives	-0.0001	+0.001	+0.001	+0.009
sleeping	-	+0.001	+0.001	+0.0001	0

Table I shows examples of key indicators and their valuation of weights for the corresponding aspect associated with the corresponding activity. A single indicator may contribute positively or negatively to different aspects. For the reason of space, only few key indicators associated with different activities from around 42 used in the experiment are shown. All key indicators above are still based on intuitive valuations about daily activities for the purpose of only demonstrating the coordination. To the best of our knowledge, no standardized scoring system is available which is based on sensory readings and realtime acquisition. The current valuations can still be improved to be more realistic by collecting samples from the real settings of human daily living and applying some statistical techniques to adjust the key indicator valuations.

In this paper, we put four different configurations of experimental runs to compare the level of well-being in 14 consecutive days (virtual time) of virtual living:

1) Daily living without any recommendation;
2) Daily living with recommendation from four agents with no coordination;
3) Daily living with recommendation from four agents with coordination;
4) Daily living with coordinated recommendation but with a single selector agent to select the supporting agents.

Each configuration is measured based on average from 50 independent experiment runs. Figure 7(i) shows decreasing overall score of well-being (only total average is put for the reason of space). When agents are included to give advices, with $\eta = 0.25$, the well-being score increases to reach about 0.7 score in average. Other parameter settings include $\sigma = 1,800,000$ (30 minute) and $\gamma = 7$ to avoid overcrowded advices. The figure also shows that in the first day the agent does not provide any recommendation since it is in the phase of determining the target behavior. After the first phase, the agents provide triggers or recommendations. Without coordination, there are about 9 trigger messages or advices from all agents. Although the first day is dedicated to determine the targets, an agent may still modify its scheduled activities or make new targets in the following days as the user's behavior may also change.

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Figure 8(ii) shows the average scores of various η values. For $\eta = 0$ in which the user always follows the advices, the score marginally reaches the highest with the proposed approach (reaches almost 0.85). In comparison, very small differences in score can be seen between $\eta = 0.25$ and $\eta = 0.5$. It is also shown that even though $\eta = 0$, the score still relatively low for uncoordinated persuasion. This can happen since overcrowding advices and conflicts reduce the score in general. So, although the virtual user can accept and follow every advice, it still missed the important or good ones when they are overcrowded or in conflict. The scores for all with the single selector mode produce marginally lower scores than the group ones even though both have similar profiles.

When the shared memory and coordination protocols are employed, the overall well-being score is improved and reaching about 0.8 as shown in Figure 7(ii). The coordinated model also reduces the number of trigger at one time to reach about 5 messages daily. This result indicates that, even though the score can be much improved by a set of persuasive agents in the second configuration, some interferences occur that makes some of the recommendations ineffective without coordination. A closer look at particular traces of data reveals that many triggers from different agents are made at a narrow time frame such that the virtual user may miss the important trigger that may significantly produces a greater score. Note that the virtual user can only follow a trigger presented immediately with no memory extension to hold multiple messages. Thus, a trigger message may override another when presented shortly after another or simultaneously. Similarly, Figure 7(ii) shows that the one with the single agent selector protocol produces marginally lower performance than the group one since there are still conflicting advices during cooperation.

The protocol to handle overcrowding triggers reduces the number of messages at a particular time. It can be observed in Figure 8(i) as the daily projection taken from the averaged score of a single day (averaged over 50 trials for every 2 consecutive hours) that conflicts occur at particular times (e.g around 06:00 to 08:00). Handling them with the conflict handling mechanism implies more reductions on the number of triggers at one time and significantly improves the score. It is also shown that some agents are starting to help one another by proposing additional supporting triggers around the time of conflict resolutions causing the continuation of the score improvement.

Figure 9(i) and (ii) compares the supporting advices produced by the single agent selector and by the group selector. In Figure 9(i),"Let's play monopoly" and "Have lunch in cafe" recommendation are irrelevant as supporting advices. They can trigger another activity that instead produces lower score. On the other hand, Figure 9(ii) shows that the proposed method can filter those irrelevant intention during the selection process.

VII. CONCLUSION

We have presented a model of coordination for persuasive agents using a shared memory and specifically designed protocols to make multiparty persuasions more effective. The design of the coordination mechanism constitutes the notions of the user motivation, ability, and persuasion triggers. The
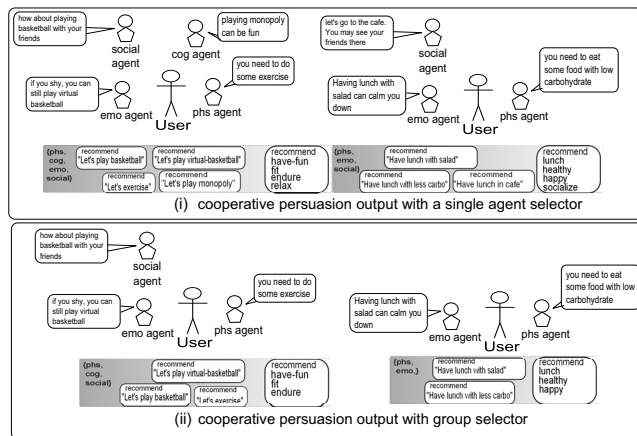

Fig. 9. (i) Some output of coordinated (team) persuasion using the single agent selector. Many proposed targets of persuasion are accepted by the selector model (have-fun, fit, endure, relax in the first example and lunch, healthy, happy, socialize in the second example) although some target may be inconsistent or opposing to each other. (ii) Some output of coordinated (team) persuasion using group selector. Some proposed targets can be pruned away when they are already inconsistent with the pre-selected ones

timeline structure of the shared memory and the coordination protocols enable the agents to dynamically and instantaneously form groups on demand. A case study using a simulation of persuasion in a caregiving task shows that the model can make multiparty persuasion more effective by preventing overcrowding recommendation messages due to multiple persuasions within a close time interval, avoiding conflict of effects, and dynamically form teams to achieve a persuasive task. It is also shown that the dynamic group formation in the proposed method can be beneficial to handle conflicts caused by the generation of multiparty advices.

In the future, other features like dealing with beliefs inconsistency and full-featured cooperation strategy should be included in the model. The integration with natural language generation and understanding is also necessary to make the model more practical. More variations on the virtual user behavior including capabilities of learning or memorizing what have been recommended can be incorporated to see how the agents and the shared memory handle the user adaptations. From all these configurations, however, real tests involving real human subjects in a realistic settings should be achieve to obtain more understanding of the model in general.

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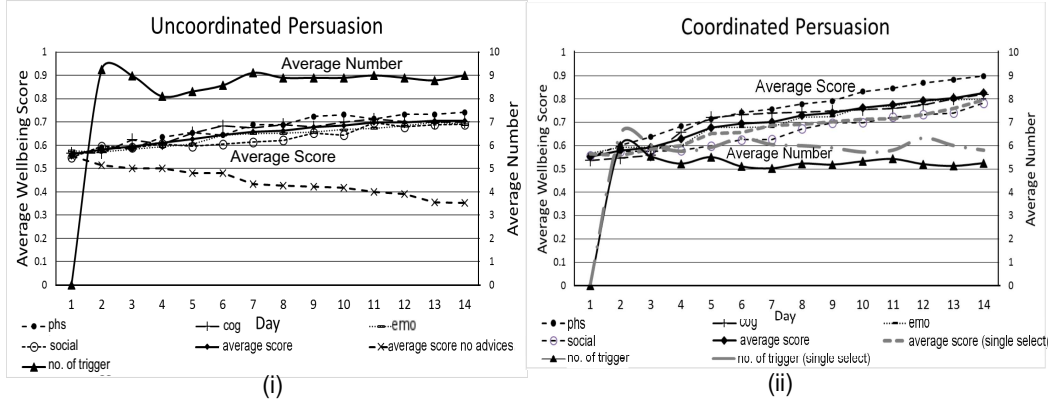
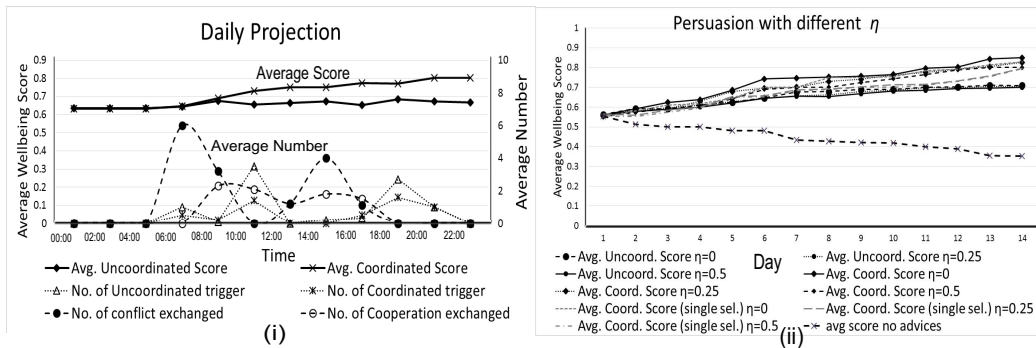Fig. 7. (i) no persuasion vs uncoordinated persuasion in 14 days; (ii) Coordinated persuasion in 14 days

Fig. 8. (i) Daily projection of coordinated vs uncoordinated persuasion. (ii) Average score of well-being over 14 days for different multiagent configurations and different user's advice-following rate or η.

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