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A Coordination Framework for Multi-Agent Persuasion and Adviser Systems

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Abstract

Assistive agents have been used to give advices to the users regarding activities in daily lives. Although adviser bots are getting smarter and gaining more popularity these days they are usually developed and deployed independent from each other. When several agents operate together in the same context, their advices may no longer be effective since they may instead overwhelm or confuse the user if not properly arranged. Only little attentions have been paid to coordinating different agents to give different advices to a user within the same environment. However, aligning the advices on-the-fly with the appropriate presentation timing at the right context still remains a great challenge. In this paper, a coordination framework for advice giving and persuasive agents is presented. Apart from preventing overwhelming messages, the adaptation enables cooperation among the agents to make their advices more impactful. In contrast to conventional models that rely on natural language contents or direct multi-modal cues to align the dialogs, the proposed framework is built to be more practical allowing the agents to actively share their observation, goals, and plans to each other. This allows them to adapt the schedules, strategies, and contents of their scheduled advices or reminders at runtime with respect to each other's objectives. Challenges and issues in multi-agent adviser systems are identified and defined in this paper supported by a survey study about perceived usefulness and user comprehensibility of advices delivered by multiple agents. The coordination among the advice giving agents are investigated and exemplified with a simulation of activity of daily living in the context of aging in place.

Keywords: persuasive agent, virtual companion, multi-agent systems, coordination

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1. Introduction

Recent improvements in intelligent agent technologies have made products and applications related to companion agents become popular. Different related fields have emerged like ambient assisted living (Cook et al., 2013; Kidd et al., 1999; Mozer, 2005), personalized mobile assistants (Campbell & Choudhury, 2012; Gaggioli & Riva, 2013; Akker et al., 2014), sociable robots for companionship (Piore, 2014) and companion technology (Honold et al., 2014). Assistive agents may provide cares to their users by pro-actively recommending options or activities that may improve well being. In this case, they can be persuasive agents that non-coercively change a person's behavior or habits. Fogg (2002) suggests that the technology can be used to persuade people. In education, healthcare, or aging-in-place (elderly care) domain, persuasive technology is used as a mean to encourage the user towards a better living. As the technology becomes pervasive, different agents are likely designed with distinct techniques, strategies, purposes, or heuristics to serve the user. They may also be produced by different vendors or third parties independent from each other. Despite the hype and the growing adoption, there are still little attentions on integrating these agents to serve a single user in the same context and environment.

Studies have shown the potential benefits of using multiple agents to deliver advices to persuade a single user. The user's motivation, attention, and attitudes can be directed towards the main target of persuasion if the object of discourse is presented from different perspectives by different agents (Andre et al., 2000). The multiplicity of the advisers can also make the user pay more attention to the content of the advice, especially when the agents can talk to each other rather than just converse with the user (Swartout et al., 2010). Despite the potential benefits, giving advices to the user by multiple agents can also be irritating and patronizing if not properly arranged (Nguyen et al., 2007). Non-deliberated interrupts by peer agents when a dialog is on-going may instead disturb and distract the user from what he or she is supposed to listen to or to do. Besides turn-takings in the dialog, dealing with unwanted interruptions or overlapping utterances requires the consideration of multiple roles and types of dialog in the conversation by the agents as dialog participants (Traum, 2004; Knott & Vlugter, 2008). Each participant must be aware of the presence and states of the others and must anticipate the effect of different utterances to the flow of the dialog. In this case, persuasion becomes a more complex and challenging when it is delivered by multiple agents.

In this paper, a framework for multi-agent persuasion and advice giving is presented. It is focused on multiple companion agents that together advise and persuade the user towards a better living (e.g getting healthier, lesser stress, feeling happier). The agents may be designed separately and built as independent companion systems resided in different (hardware or software) platforms. Each agent is assumed to address a particular aspect of the user's well-being distinct from the others. The main objective is then to make the persuasions more effective in maximizing the likelihood that the user adopts and follows the target behavior while minimizing the negative impacts from improper planning of giving multiple advices.

The proposed framework is designed to be practical that adapting existing adviser or companion agents to include them in the system does not require a major overhaul nor significant extension of technology. Rather than focusing on all the computational processes for identifying cues about dialog turns, interruptions, and natural language processing within each individual agent, all agents are facilitated to actively exchange and share their goals and plans to each other so that their persuasions can be coordinated. We cast light on various situations that different persuasive advices can be conflicting with each other when they are presented together within the same range of time. We also show some potential conditions for the agents to cooperate with each other to give advices more effectively and make the persuasion more impactful.

As parts of the contribution in this paper, the model of coordinating multiple advices are presented. In contrast to conventional frameworks for persuasive agents, the advisers can exchange information about the user and their plans before giving the advices. In particular, they can share predictions about the user's beliefs regarding his or her own motivation and ability to reach the targets or to understand the messages. They also exchange their plans and schedules of when the advices will be given to the user and when the user is expected to adopt the advice and achieve the target. Based on the shared information, some meta-heuristics and strategies are applied to resolve conflicts among the advices and targets when they occur. The strategies can also be applied to initiate cooperation among the adviser agents to persuade the user. Derived from Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986) and Fogg's persuasion model (Fogg, 2009; Fogg & Hreha, 2010), the strategies are applied taking the user's motivation and ability into consideration.

To illustrate the model, we use aging-in-place (home-based elderly care) as a domain problem and develop an agent-based model to simulate and exemplify cases of distraction, cooperation, and how to handle them. The framework includes a virtual user as the advice recipient in which different advices can be provided and tested. To evaluate the effectiveness of the strategies, we conduct a survey study to see if the persuasion strategies applied in the framework can also be recognized and perceivable by human subjects in regard to the factors of usefulness and ease-of-use. The result of the study can be useful not just for evaluating the proposed coordination model in particular, but also as guidelines for designing and integrating different recommender systems (with multiple heterogeneous agents), persuasive applications, or user-centered services in general.

The paper is organized as follows. Section 2 discusses some similar works and studies. Section 3 discusses and formulates the issues of multi-agent persuasion and the related effects regarding the effectiveness of multiple advices. Section 4 discusses the computational framework for the coordinated multi-agent persuasion based on the proposed model of multiple advices. Section 5 describes the case study that includes an agent-based model of multiple persuasion and a survey study about the in-house caregiving domain.

2. Related Work

It has been demonstrated that virtual agents can be made to engage in a long-term social relationship with the user (Schulman & Bickmore, 2009; Bickmore & Schulman, 2009) and act as companions (Vardoulakis et al., 2012). Believable and realistic fluency in dialogs can be achieved by a carefully designed ontology and hierarchical planning to direct the conversation. Based on *SharedPlan* model of collaborative planning process (Grosz, 1996), a dialog interaction is modeled as a goal directed joint planning wherein the participants exchange and adapt their partial plans to come up with a global solution. A plan, in this case, consists of turn taking steps in the dialog interaction between the agent and the user. These works focus on achieving a global solution as the result of the collaboration. However, the model does not consider the interaction beyond two participants (the agent and the user) and neither deal with the context of the dialog that may affect the user's comprehension and motivation. In another work, multiple agents autonomously interact and negotiate with each other to come up with a global recommendation to satisfy their users (Rossi et al., 2017). In this extreme case, the interaction between agents and humans can be considered minimal although every agent operates on-behalf of its corresponding user.

When two or more agents are involved in a conversation with humans, Traum (2004) suggests that different roles and identities of the participants in the dialog must be taken into account. Who is speaking to whom and whether one participant has an active role in the dialog or just only as an overhearer determine how the dialog engagement is developed. What and how the participants (or non-participants) view the situations become crucial. Beyond simply turn taking between two participants, in which one replies to the other or initiate the talk, other parties may interrupt or initiate the dialog in the middle of conversation. Knott & Vlugter (2008) developed a dialog management system for handling and generating utterances from multiple speakers. The dialog is mainly conducted via textual media, in which the user keys in the textual input and may receive the responses as textual messages. The natural language processing used in the model can derive some contextual information to detect the addresse(s) of a utterance when it is implicit in the text (Knott & Vlugter, 2008). Beyond individual participants, the system is also able to track which group a participant belongs to based on the history and context of the dialog.

Similar approaches have been used in multi-party interactions among human users, humanoid robots, and virtual characters (Yumak et al., 2014). Unlike dialog systems that purely involve virtual agents, real-world aspects in the environment must be taken into account when robots and humans are involved as participants. Identifying who is the speaker and who is (are) the attendee(s) of the utterances can only be done by observing the physical locations and orientations of each corresponding participant. Aside from the clues in the context of the dialog, physical features derived from computer vision (e.g facial features, gaze direction, gesture/activity recognition) are also important to predict the participants' roles, intentions, and attentions in the dialog.

In any case, all the approaches of multi-party dialog and interaction above are proposed to make the conversation flows more natural and believable. In the context of Ambient Intelligence, Homola et al. (2015) suggest that in order to incorporate different autonomous entities to behave in synchronized and coherent manner, they need to be equipped with knowledge to handle different types of conflict. The conflicts can be in multiple levels including sensory, contextual, domain knowledge, goal, and action conflict. Based on a survey conducted on different research areas and contexts, the conflicts can be addressed in different ways which can be categorized as *context modelling*, *multi-context systems*, *belief change*, *ontology evolution*, *ontology debugging*, *argumentation*, and *preferential reasoning* (Homola et al., 2015). Omari & Mohammadian (2016) put the conflict resolution in interacting with humans further by incorporating moral and ethical dimensions. Using Rule-Based Fuzzy Cognitive Map to represent the situation, an agent is demonstrated to come up with a decision to resolve a dilemmatic situation by regarding some ethical principles like justice, veracity, autonomy, beneficence, and non-maleficence (Omari & Mohammadian, 2016).

The most similar application to the concept and functionality of the system presented in this paper is the eMate intelligence coaching system as described by Klein et al. (2013). eMate is designed to be a virtual persuader to encourage behavior change. Based on the so called *Combi* model which combines different influential theories of behavior change, the system can choose the strategy of persuasion to apply according to the stage of change mostly suitable for the intervention (Klein et al., 2013). The combined model is applied to describe the internal states of the user with respect to different phases of behavior change. This contrast with the proposed system presented in this paper in which the particular persuasion model, which is based on the combination of Fogg's model (Fogg, 2009) and Elaboration Likelihood Model (Petty & Cacioppo, 1986), emphasizes the stage of intervention from the perspective of the persuader rather than modeling the internal state of the user. The user's mental state is assumed to be modeled and utilized independently by each individual agent. Based on Homola et al. (2015) categorization, the proposed conflict resolution approach in this paper is used to address action and goal conflicts.

As has been pointed out previously (Andre et al., 2000; Nguyen et al., 2007; Swartout et al., 2010), advising a recommendation to the user by multiple agents can leverage the effectiveness of persuasion, but must be carefully conducted in a way that not to overwhelm the user in comprehending the message nor to discourage the user to adopt the target change of the persuasion. A similar study also reveals that the existence of a peer agent besides the one delivering the message in human-agents dialogs can improve the user's satisfaction significantly and stimulate the user's active participation in the dialog (Dohsaka et al., 2009). Despite the advantage of multi-party dialogs, another challenge to address in the model is the heterogeneity of the participating agents in which they may individually have different expertise and knowledge regarding the contents and strategies they use to persuade.

3. Advice Giving and Persuasion

For advice giving agents, dialog engagements with the user can be minimal since the advices may be given as reminders or recommendations without requiring any direct reply from the user. However, the purpose of providing the advice can be persuasive that the user is encouraged to do some activities or to change his or her behavior. In that case, the agent may later evaluate the following user's conditions or activities as feedbacks so that the achievement or failure of the persuasion can be determined. Assuming all agents are designed to be cooperative and not against one another in convincing the user, different agents can be made to support each other to increase the chance that the user eventually adopts the target. However, delivering too much incoherent information may also overwhelm, confuse, or distract the user from the target.

In this paper, advice giving is modeled as persuasion wherein multiple agents have different targets and agendas towards the user. In this section the model of interaction in persuasion comprising the states of comprehension and motivation is presented. It sheds some light on possible interdependencies among different persuasive agents.

3.1. Triggers and Persuasion

According to Fogg et al. (2003), persuasion is a non-coercive way to change attitudes or behaviors. The main part of persuasion is *trigger* which is the message that tells people to perform or initiate a behavior (Fogg, 2009). A *trigger* can take many forms depending on the purpose (e.g prompts, calls, cues) and be conveyed in different modalities (e.g text message, sound, human voice, animation). In this paper, an advice refers to a trigger wherein its content can be delivered to the user at a particular time or condition. In this paper, the term trigger has a more specific meaning as the message that is made to serve a particular goal of persuasion. On the other hand, the term advice has a more general meaning referring to the entire content of the message regardless its persuasiveness.

In order to appropriately produce a trigger, a persuasive system must conduct at least three phases of information search (Fogg & Hreha, 2010):

1. *Identify the target.* This phase is to determine what is the target change of behavior to achieve by the user. For example, at this stage the agent may seek information to determine if the user needs to have a more active lifestyle, prefer a healthier diet, learn more information, or conduct particular workouts.
2. *Determine the trigger.* In this phase, the agent selects the type of trigger to advise to achieve the target. Depending on the context and the user conditions, it may include the time or another cue condition wherein the trigger will be delivered besides the main content (later in this section, types based on the role of persuasion will also be described).
3. *Plan specific steps to apply the trigger.* In this phase, specific contents, steps, cues, and conditions of the selected triggers are elaborated and set or committed to be active.

The phases above are followed by the presentation of the advice at the particular time or condition as planned. In this case, Fogg's model of persuasive system involves strategic planning process to generate persuasion messages. Figure 1 shows the flow of activity in generating triggers by a single persuasive system. The activity flow includes the execution of the planned trigger and the evaluation of its success. If the trigger fails to achieve the persuasion objective, the phase repeats to select another type of trigger in trigger determination phase.

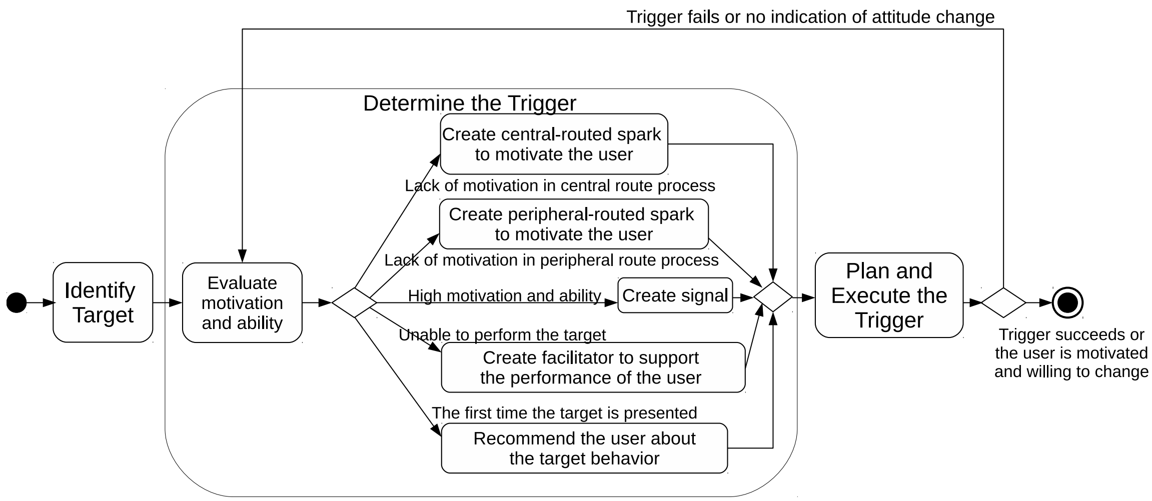


Figure 1: Persuasion Activity Flow

However, depending on the particular type of persuasion system, the evaluation step in the trigger determination phase can be skipped so that the activity flow can just proceed without a loop or repetition. For example, a reminder agent may act as a simple alarm system that the target is to set off the alarm at a particular time for a certain duration or until the user switch it off manually. No feedback information is required for evaluation in this case. On the other hand, a persuasive agent may take a model about the user and situation into account in order to decide whether to update the trigger or not. For instance, a health coaching agent that has provided some advices about a workout may evaluate the status of the user's acceptance to the recommendation in order to know if another kind of trigger must still be made to persuade the user.

3.1.1. Types of Persuasion Triggers

There are different types of triggers for persuading the user. In Fogg's model of persuasion (Fogg, 2009), triggers can have different functionalities apart from just telling the recipient about the target response. The types of trigger based on Fogg's model are as follows:

- *Spark*. A spark trigger is used to motivate the user to do or to start changing its behavior to realize the target. This kind of trigger is suitable only when the user lacks the motivation to realize the target. A spark may motivate the user based on the following core motivators

  - Pleasure (or pain). A spark can indicate a direct pleasure, reward, or relief following the realization of the target. For example, a spark trigger may show or indicate that taking a nap after a housework can relief the recipient from dizziness or omitting heavy lifting can avoid back pain.
  - Hope (or fear). A spark may suggest something that can happen in the future as a consequence of the target behavior. It can initiate the anticipation of an outcome that something good (or bad) will happen if the recipient accept (or refuse) the target behavior.
  - Social acceptance (or rejection). A spark may also be used to motivate the recipient to adopt (or avoid) the target behavior so that he or she gains social acceptance. Just being rejected by the community or relatives can be a severe punishment for a person.

- *Facilitator*. A facilitator informs or convinces the recipient that the target behavior can be easily realized or achieved with no much efforts. The simplicity of the target behavior can be based on time, cost (e.g financial), efforts (physical and mental), social deviance from norms and habits, and other challenges in achieving the target.

- *Signal*. A signal trigger serves as a reminder about the target behavior given that the user has been highly motivated with the ability to perform the target. A signal can be effective if well-timed but mixing it with a spark or a facilitator may instead distracting or even annoying to the user.

In Fogg's model, the motivation and ability are about the realization of the target behavior. However, motivation and ability may also reflect the individual capacity to comprehend the message. Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986) is a theory of thinking processes when one is persuaded to change one's attitudes or behavior. ELM concerns more on what and how a person thinks when receiving a communication message or a persuasion trigger. According to this theory, when different people are receiving information delivered to change their attitudes, they can have different levels or routes of comprehension processing as follows:

- *central* route of processing in which the person is well motivated to think about the message presented and has enough resources or skills necessary to understand it carefully and thoughtfully; and

- *peripheral* route of processing which is characterized by the person's lack of motivation and/or ability to think and understand carefully about the information presented.

When a person is in the central route, it is more effective to persuade him or her using strong arguments. If the arguments are weak or not convincing enough, the person may have unfavourable thought to the message and will make no attitude change or even rejection. However, if the arguments are convincing enough, the person will generate favourable thoughts regarding the message and the expected attitude change can be relatively enduring. The arguments can be logically sound, reasonable, or backed up with facts, examples, or evidences. The central route also requires the recipient to be free from distractions. The route will not work properly when the environment is noisy.

On the other hand, if the person is in the peripheral route, the strength of the arguments in the message may no longer influence the person's attitudes. Instead, he or she processes simple cues in the messages without any careful consideration. The cues can be something that the person already liked (e.g personal preferences), arising emotional states (e.g happinesss, sentiment), and containing social proofing or believed authority judgements.

Although ELM and Fogg's model of persuasion adopt different meanings for motivation and ability, in this paper, the ELM types of trigger are considered as refinements of the spark triggers in Fogg's model.

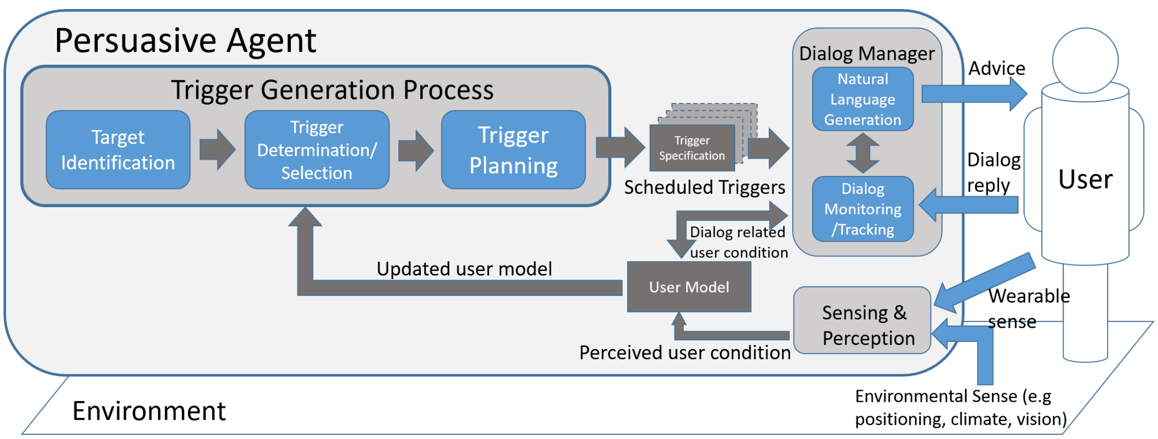


Figure 2: Architecture of Persuasive Agent

4. Coordinating Multi-Agent Persuasions

4.1. Generic framework for persuasive agent

ELM has been applied to a persuasive virtual agent that can adapt its persuasion strategy based on the user's different routes of processing (Kang et al., 2015). In this case, the agent classifies the user based on his or her motivation and ability in understanding the messages and provides the advice accordingly to better persuade the user. In this paper, the conceptual model of ELM-based persuasive agent is extended to incorporate Fogg's persuasion model to make it more generic. In that case, Figure 1 shows a generic process of persuasion as a combination of Fogg's process of persuasion and strategies in ELM.

In order to determine the target, an agent may observe the user from time to time to determine what change of behavior or attitude is needed. After the target change or behavior is identified, the kind of trigger to deliver is determined based on the persuasion context, the user's motivation, and ability. Depending on the motivational and ability conditions of the user, a trigger may be created either as a *spark*, *facilitator*, *signal*, or as an initial *recommendation* when the persuasive target is advised for the first time. A *spark* trigger can be an argument given to the person if the one is in a central-route of understanding and processing the advice. When the person is still with the peripheral route, the *spark* can also be as shortcut cues. Moreover, following Fogg's model of persuasion, a *facilitator* is particularly made to inform and support the user's effort in realizing the target behavior while *signal*s serve as reminders.

A *recommendation*, on the other hand, is a distinct type of trigger from either Fogg's model or ELM in which the message is used initially to introduce the significance of the target. It is an additional type of trigger for the proposed generic framework which is still unavailable in the original Fogg's model.

Based on the process of generating a persuasion trigger, a general architecture of a persuasive agent can be shown in Figure 2. As parts of the abstract architecture, a trigger can be specified or updated within the trigger generation process after the steps of target identification, trigger (type) selection, and planning. The specific trigger can be timed or contextualized so that it will be advised to the user at the appropriate time or condition. In a single iteration or cycle in the trigger generation process, more than one triggers may be scheduled depending on the targets identified.

Dialog Manager produces an advice and delivers it to the user in natural language (either via a speech synthesizer or a textual display). The user's response or reply to the advice, if available, is handled by the dialog manager to track the dialog process. The reply may indicate the effectiveness of the trigger, but it can also be the user's state of motivation and ability. For example, an agent may recommend the user (e.g as an elderly occupant) to join a social event so that she or he can be more socially active and would not feel lonely. The response made by the occupant can be favorable, negative, but can also be less concerned which may indicate the motivation and ability in terms of achieving the target behavior or in understanding the message. Another source of information regarding the user's motivation is the activity (or inactivity) of the user performed towards the achievement of the target at the expected moment. This status of user's activity is captured by Sensing and Perception part in Figure 2. For instance, based on the sensory reading, if there is no indication that the user has done something (inactive) towards the target, even though formerly has provided a favorable response to the trigger, then her or his motivation may still be lacking.

Either the explicit reply from the user in the dialog or the status of the following up activity may update *User Model*. Changes in the user model may initiate further trigger generation process, like when the persuasion target is not yet achieved following the previous advice.

4.2. Multi-Agent Persuasion and Distraction

In a multi-party interaction setting, a trigger should be associated with the information about the producer of the message and its recipient or addressee. Similar requirements exist in multi-party dialogs or interactions (Traum, 2004) that one participant in the dialog needs to identify either the speaker or the addressee of the advice in order to understand a utterance and the context when multiple participants are present.

Even though the strategies of persuasion above can effectively change the user attitudes when delivered by a single agent, they may not be so when multiple independent agents are employed together. The advice given by one agent may instead distract the user from comprehending another message delivered by another agent when their timing is not properly set. In another case, the targets of different triggers may be perceived as contradictory by the user which may affect her or his ability or motivation against the attitude change.

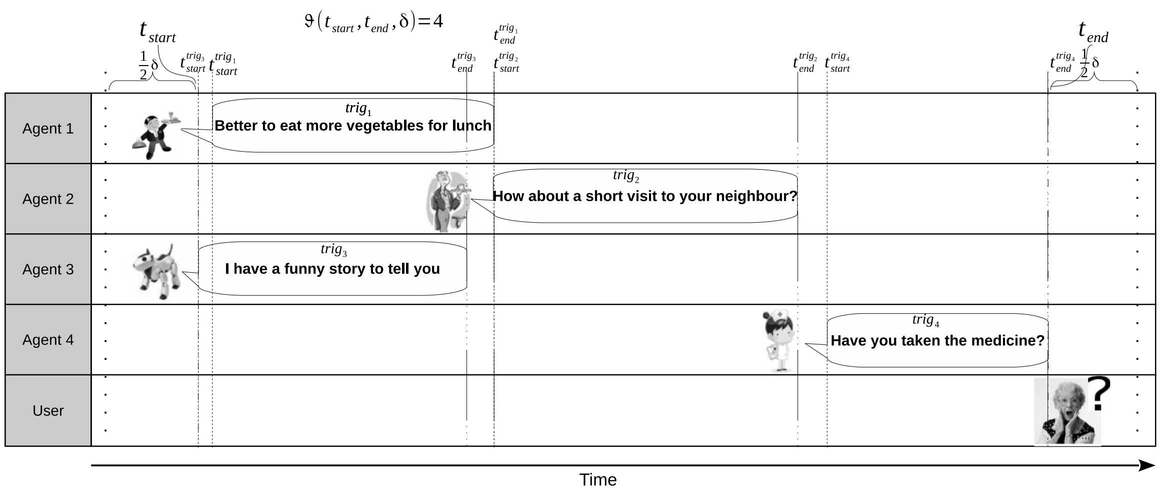


Figure 3: Overcrowded advices

4.2.1. Distraction by overcrowding

When multiple persuasive agents are included but independently make their own decision, many messages can be delivered that interfere with one another. The best trigger may become the worst choice if the user is distracted by its co-presence with the others. In other words, too much information presented within a short period of time simply overwhelm the user especially, if the advices are given as voiced utterances.

As illustrated in Figure 3, four different agents present different advices independently from one another. There are four different triggers ($trig_1$, $trig_2$, $trig_3$, and

$trig_4$) made by different agents. Assuming the presentation method is through voice interface, a trigger can be presented as a utterance starting at a particular time and taking some time to end. Each trigger is attributed with a time interval to mark the start and end of the voice. Let $t^x_{start} \in \mathbb{T}$ and $t^x_{end} \in \mathbb{T}$ be the starting time and the ending time of trigger $x \in \mathcal{T}$ respectively, where $\mathbb{T}$ is the set of time points and $\mathcal{T}$ is the set of all possible triggers. Some triggers overlap the others so that $t^x_{start} \leq t^{x'}_{start} < t^x_{end}$ and $x \neq x'$. By presenting all the advices together in this way, the user hardly can comprehend or catch any of the message provided by the agents.

In Figure 3, the user is hardly able to get any of the message given by Agent 1 and Agent 3 as they are delivered mostly overlapping with each other. The non-overlapping message in $trig_2$ by Agent 2 may still be difficult to catch since no delay is given during its turn after $trig_1$. On the other hand, the user may likely can get the full message of $trig_4$ as it starts after a short delay from $trig_2$, which gives her enough time to comprehend the utterance. In this case, the overall confusion and distraction produced by too many advices delivered in a narrow time window reduce the effectiveness of each individual persuasion message as the user can hardly adopt or commit to the target of persuasion.

Presenting independent advices in this way will likely distract and confuse the user in understanding the meaning of the messages. To avoid such overlaps, an agent must schedule its trigger so that some delays can be put between different triggers. More formally, trigger x can be delivered so that $\forall y \in \mathcal{T}$, if $t^y_{start} < t^x_{start}$ then $t^y_{end} < t^x_{start}$, and $t^y_{start} > t^x_{start}$ then $t^x_{end} < t^x_{start}$.

In relation to this overcrowding messages, *trigger-density* function ϑ can be defined as the number of triggers that are active within a time interval. As shown in Figure 3, ϑ can be defined as $\vartheta : \mathbb{N} \times \mathbb{N} \times \mathbb{R} \rightarrow \mathbb{N}$, and $\vartheta(t_{start}, t_{end}, \delta)$ is the number of triggers that set between the time interval $t_{start} - \frac{1}{2}\delta$ and $t_{end} + \frac{1}{2}\delta$, wherein δ is the extended interval for all events before t_{start} and after t_{end}. Triggers within the interval between t_{start} and after t_{end} should not be put too close or coinciding with each other. Given that $|X|$ denotes the cardinality of set X, the trigger density can be obtained as follows:

$$\vartheta(t_{start}, t_{end}, \delta) = |T|, T \subseteq \mathcal{T}, \tag{1}$$

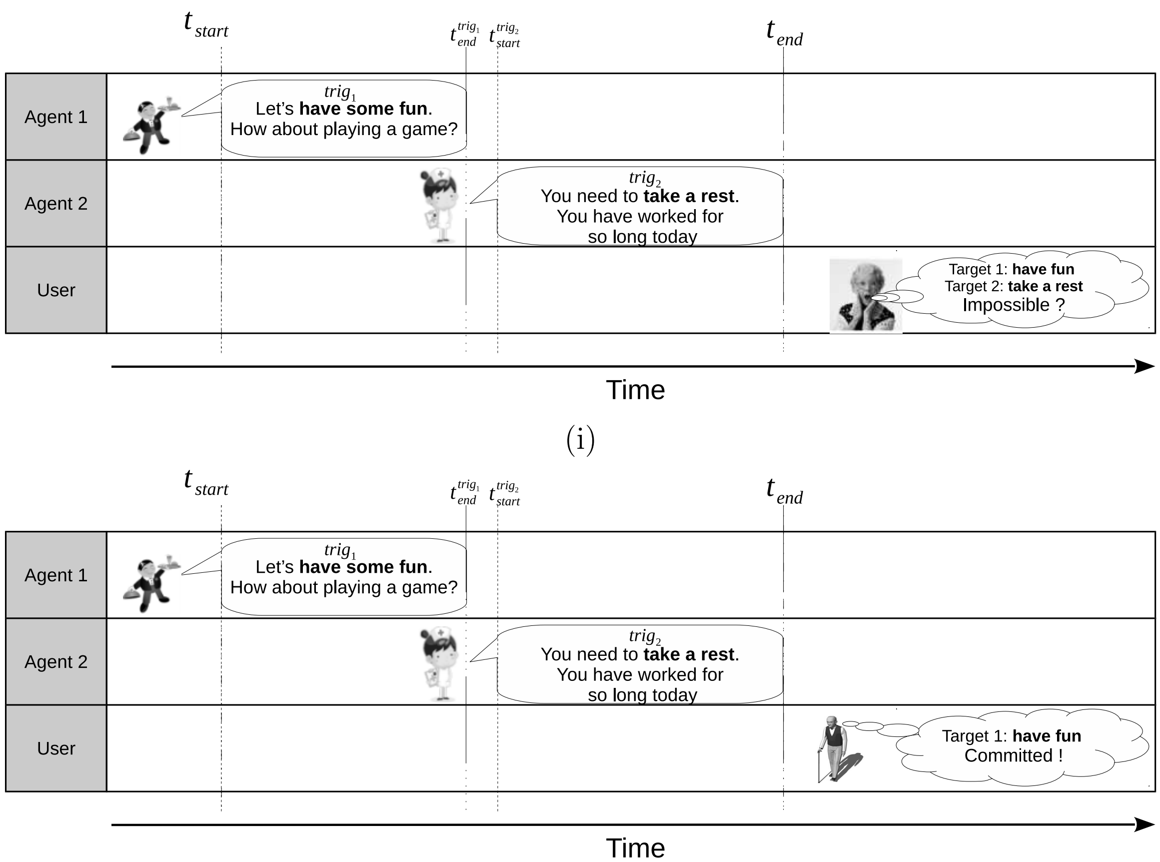
$$T = \{x | \forall x \in T, t^x_{start} > t_{start} - \frac{1}{2}\delta \texttt{ and } t^x_{end} < t_{end} + \frac{1}{2}\delta\}. \tag{2}$$

To avoid distraction, a maximum density level of an interval can be set so that γ can be defined as the maximum number of triggers allowed to be in the interval and the user may still be able to understand clearly every advice presented by different agents. The interval or period of time can be considered overcrowded with persuasions when $\vartheta(t_{start}, t_{end}, \delta) \geq \gamma$ holds.

According to Equation 2, every trigger counted in the density function must strictly be enclosed within the interval. In this case, only a trigger that is scheduled to start after the beginning of the interval and ends before it finishes will be counted. The assumption is that the content of the triggers can normally be presented in a relatively short time and most of them have a uniform interval length. However, in some cases, this assumption may not hold especially if the lengths of the advices are varied. In that case, the criteria in Equation 2 can be made less strict so that the triggers accounted for the interval becomes as follows.

$$T = \{x | \forall x \in T, t^x_{start} > t_{start} - \frac{1}{2}\delta \texttt{ or } t^x_{end} < t_{end} + \frac{1}{2}\delta\}. \quad (3)$$

Based on the loosened constraint of triggers for the density function, it is possible to include a long trigger that its start or end overlaps with the start or end of the given interval.



(ii)

Figure 4: Conflicting dialog

4.2.2. Mental Conflicts in persuasions

Beyond overwhelming the user, different advices from different agents may still be confusing to the user even though she or he can comprehend all the messages. The user may think that the effects of the targets in the advices are contradictory or one may cancel out or reduce the chance of achieving the other. Figure 4(i) illustrates this situation that one agent recommends the subject to do something (e.g "let's have some fun...") but the user may think that it can cancel out the desired effect of another recommendation (e.g "you need to take a rest..."). The condition of conflict may not be in real or actual but only occur potentially in the user's mind.

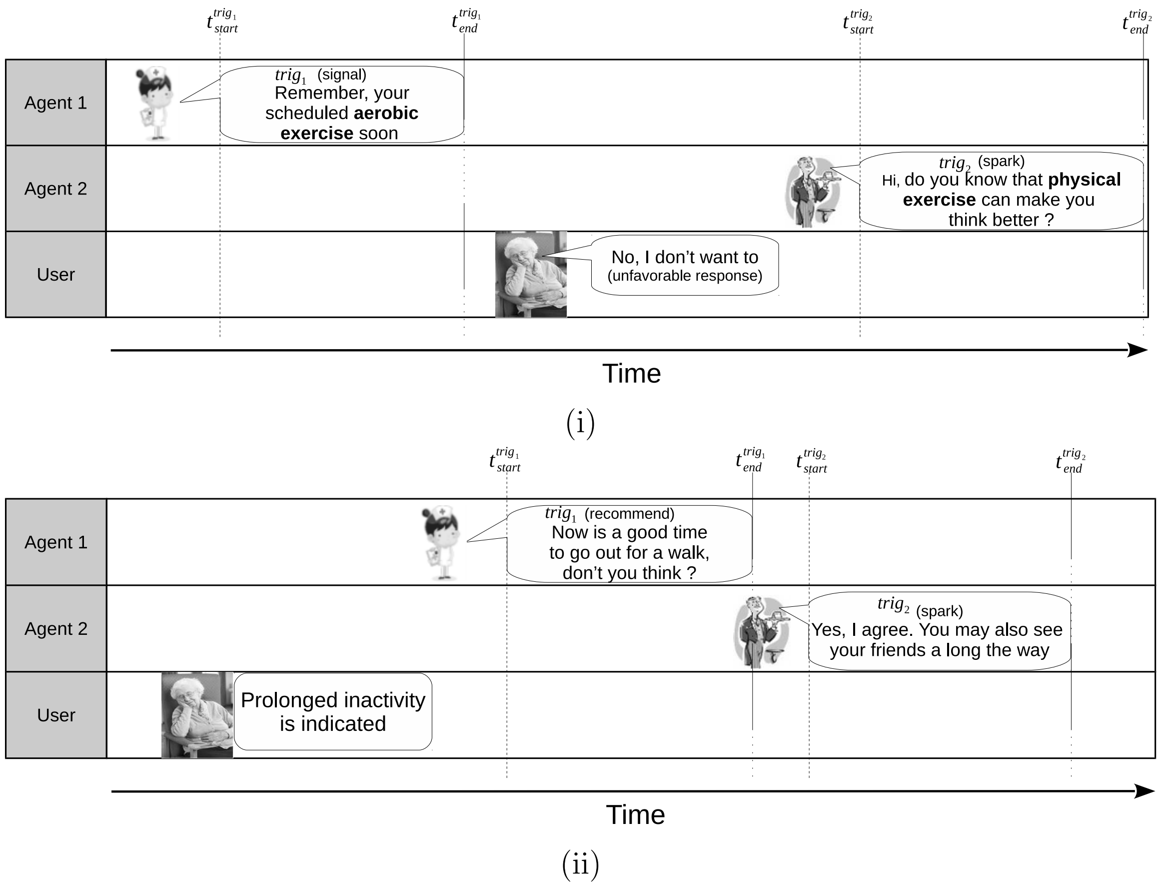


Figure 5: Coordinated persuasion (i) and dialog cue engagement (ii)

More formally, let ψ_t^x be the target change of trigger x expected to occur at time t. The mental conflict situation is a condition that the human recipient believes that ψ_t^x of trigger x advised by agent a is contradictory, may cancel out, or reduce the chance of achieving target $\psi_t^{x'}$ of x' presented by agent b, wherein $x \neq x'$ and $a \neq b$. In that case, the user believes that probability $P(\psi_t^x|\psi_t^{x'})$ (or $P(\psi_t^{x'}|\psi_t^x)$) is very low or even zero. The example in Figure 4 shows that the trigger for having fun reduces the feeling of ability to be on rest as advised by another agent in a different trigger. The mental kind of conflict can be resolved by presenting additional *facilitator* to the user, clarifying that both targets are not contradictory and still possible to achieve (e.g conducted at different time, having fun in relaxing way). Another way is to adapt the contents of the message using different terms that will not puzzle the user before presenting it. In any case, the conflict situations can only be addressed if every agent is aware of the others' on-going or scheduled triggers and the user's attitudes towards them.

4.2.3. Target conflicts in persuasions

It is also possible that rather than inside the user's mind, the conflict is potentially occured in reality. Besides distracting the user to choose which action to take, the user may also ignore one or some of the triggers for certain targets. This may also happen without the user knowledge or awareness. The user may miss some advices without notice. Although this conflict may not affect the user motivation or ability, the forgotten advices may still affect the overall effectiveness of the system. In this case, the agents still need to change their strategies to advise the user or put extra signals to remind the user.

The case illustrated in Figure 4(ii) can be regarded as an example of a target conflict when the user forgets or ignores one trigger and adopts the other. In this case, the main risk is that the user may miss a crucial advice that may be important. More formally, given different targets ψ_t^x and $\psi_t^{x'}$, the target conflict happens when after the presentation of triggers x and x', only either one target ψ_t^x or $\psi_t^{x'}$ is remembered and committed. This may also happen when the user is given so many advices so that she or he may ignore or forget some of the confusing triggers and take the less important ones instead.

4.2.4. Generalized Formalism of Conflicts

Subagdja & Tan (2014) developed a formal specification for pervasive adviser agents which then becomes the basis of conflict and cooperation defined in this paper. The specification defines interdependencies among the agents in a group when they are advising the user. Using BDI (Belief, Desire, and Intention) logic formalism, inconsistency and conflict conditions are defined in more elaborated ways as follows.

- *Inconsistent* belief about φ in a group of agents g occurs when one agent in the group believes that φ holds but at the same time there is another agent in the group that believes it is not the case that φ.

- *Weak conflict* occurs when there are at least two agents in the group that intend to achieve different conditions and one of them believes that the achievement of one will cancel out the other's achievement.

- *Strong conflict* occurs when there are at least two agents in the group that intend to achieve contradictory conditions (one is the negation of the other).

- *Hard conflict* occurs when at least two agents in the group have contradictory intentions and at least one of them has the goal to make the achieved condition persistent.

Besides the abstraction of conflict conditions above, potential condition for cooperation is also defined as a condition that when one or more agents are unable or do not know how to achieve their goals, there is at least one cooperative (willing to help) agent in the group that can achieve the goals or an intermediate condition that enables the others to achieve the main ones.

Coordination, in this case, is regarded as the process of detecting the situations or conditions above and the agents involved take particular actions to resolve them. For instance, when the system detects a *Weak conflict*, one of the agents can resolve it by re-scheduling the timing for achievement of the goal at a different time when the other agent would have no conflicting intention anymore. Similarly, the re-scheduling strategy can also be applied to *Strong conflict*. However, *Hard conflict* can only be resolved if one of the agents drop or change the content of its original goal to conform with the other conflicting ones.

In this paper, the general formalization of the conflicts and cooperation from (Subagdja & Tan, 2014) is adopted and derived as the classification of conflict and cooperation as described previously. Since, the focus of this paper is the persuasive and advice giving agents, modeling and resolution of inconsistency are not included and considered as outside of the scope.

4.3. Coordinated Persuasion

Despite the distraction and confusion, the provision of multiple targets by heterogeneous agents can still be beneficial in encouraging or motivating the user's towards the targets. Agents may cooperate to make their advices more impactful. Figure 5(i) shows an example of coordinated persuasion between multiple agents. Depending on the condition of the user, different agents may use different types of persuasion trigger and take different routes of process either central or peripheral to persuade the user towards the same target. For example, agent 1 presents a reminder to the user about a routine event or activity. When the user's unfavourable response has indicated the lack of her or his motivation towards the reminder's target, another agent (agent 2) joins the conversation and provide a *spark* trigger supporting agent 1 in motivating the user.

More formally, a supportive coordinated persuasion can be defined as a situation that a negative or unfavorable response to trigger $x \in \mathcal{T}$ presented by agent a is made or indicated by the user. Another spark or facilitator trigger x', in which $x \neq x'$, is presented by agent b where $a \neq b$ but the target $\psi_t^{x'} = \psi_t^x$. Besides producing the new trigger x', agent b also adopts the same persuasion target with agent a for that particular case of persuasion. Rather than having a single agent to advise lengthy information, two agents or more can take turn to deliver different persuasive messages to encourage the user to adopt the target of persuasion. In this case, short delayed, coinciding, or even overlapping intervals between triggers may be advantageous in terms of the user attention, comprehension, and continuity of the conversation. Figure 5(ii) shows an example of dialog engagement in which one agent explicitly demonstrates the connection with a trigger from another agent (explicit agreement "yes, I agree. ...."). Similar to the supportive coordinated persuasion above, the supporting agent must adopt the same or a compatible target.

To enable the agents to work together, each of them needs to be aware of the others including their triggers and persuasion targets. Thus, they need to share what they know and what they need to do in order to adapt their strategies of persuasion. In this section, we propose a coordination framework for multiple agents to make more effective persuasions. Unlike other state of the arts of multi-party dialogs that concern more on efficient algorithms to recognize or predict intentions of the dialog participants accurately, our focus is on providing a framework for different persuasive agents that can be heterogeneous. In this case, each may be developed independently from each other.

4.4. Multi-Agent Persuasions

Each persuasive agent should be able to know what the others want and do. In that case, a shared data structure can be made to let the agents access and exchange the necessary knowledge and information about the whole situation. Figure 6 illustrates the shared data structure that includes the shared situation model and the triggers that have been scheduled or planned by the agents. They are parts of *collaboration proxy* which includes protocols for communication and coordination.

In Figure 6, an adviser agent may insert or update its belief about the user into the shared knowledge. A belief assertion indicates what the agent has observed, known, or predicted about the situation and the user at a particular moment or period (shown in white rounded rectangle). The agent may also share its planned or scheduled triggers in a timeline representation (illustrated as grey rounded rectangles). Following the triggers posted in the shared knowledge, the submitting agent is committed to advise or talk to the user according to the timing and the content of the corresponding trigger.

An agent can retrieve the information from collaboration proxy to search for the target behavior or to plan the triggers. When a trigger has been set but there is a potential conflict that can lead to the user distraction, the agent may re-plan the content of the trigger or re-schedule it. Similarly, an agent may be able to get the information that another agent needs some support in motivating the user so that a spark or facilitator trigger can be made. In this way, the proposed shared knowledge model allows the agents to regulate their advices on temporal and contextual basis according to what the others want to achieve.

Table 1 shows the detail representation of a trigger that is posted and shared in Collaboration Proxy. The trigger is a data structure consisting of several attributes including the name of the agent that posts or create the trigger (`Creator`), the type of the trigger (`Trigger_Type`), the route of elaboration (`Route_of_Elaboration`), the period of time that the trigger will be given (`Time`), the content of advice of the

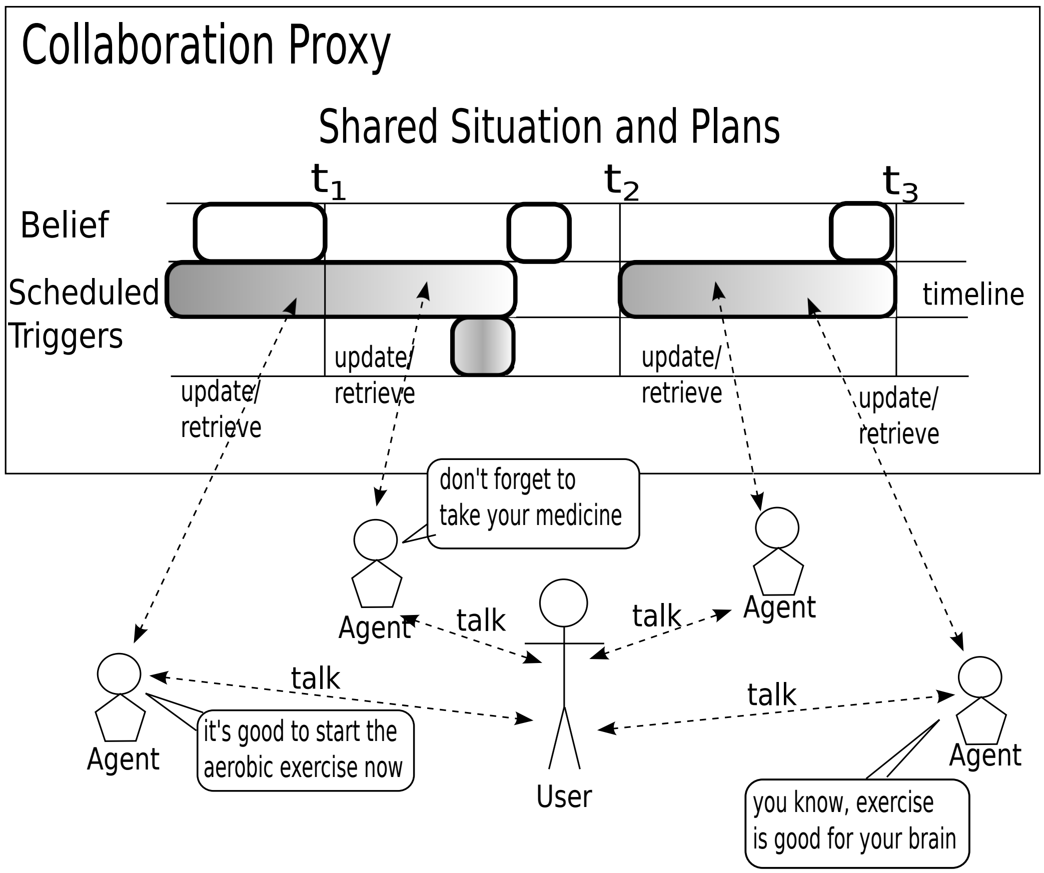


Figure 6: Shared knowledge structure of Collaboration Proxy consisting of belief and scheduled triggers represented in timelines. A belief, shown as a white rounded rectangle, indicates what the agents have observed, known, or predicted about the situation and the user at some moments. Schedules for triggers to deliver are shown as grey rounded rectangles. Based on the shared beliefs, an agent may plan to deliver a trigger to the user at particular times. Based on the triggers allocated in Collaboration Proxy, the agents advise the user (e.g "don't forget to take your medicine", "you know exercise is good for your brain")

trigger (`Advice`), the associated key terms (`Context`), the intended effect after the trigger is given (`Effect`), and the level of importance (`Importance`). Each trigger is associated with a unique identifier (`Trigger_ID`). When an agent asserts a new trigger to Collaboration proxy, it may receive a list of potentially conflict trigger based on the density level within the period or mental (target) conflicts. The potential conflicts can be identified based on the key terms included in the corresponding attribute of trigger. The agent then may update the trigger (the timing or the content) when necessary and re-assert it to the proxy. This can be conducted iteratively until no other potential conflicting triggers are returned. A trigger is considered successful if its target or intended effect (`Effect`) is achieved. In this case, the evaluation of `Effect` condition is still domain specific and tied to a particular vocabulary or ontology of a certain field. For example, attribute `med` and `status` under the `Effect` attribute in Table 1 refer to a particular code of the prescribed antibiotic medicine and the condition that it is taken by the user respectively.

Besides the triggers, the agent may also use *belief* to assert and share information with the others as shown in Table 1 in the belief part of the structure. Similar to trigger, it has the information about the creator and the timing. However, it also includes the object (or the user) being described, the related activity, and a confidence level to indicate the significance or importance of the information. Every agent in the framework can assert and retrieve beliefs from collaboration proxy using a query containing some partial cues. For example,

```
{Object: USER001, Activity: {act:exercise}, type:jogging}
```

can be used as a cue to retrieve all asserted belief about user `USER001` regarding an exercise activity (jogging).

4.4.1. Coordination strategies

To overcome the possible distractions and opportunity to cooperate, a set of coordination strategies can be made. The strategies are meta-heuristics that may provide a sufficiently fair solution given a limited information. They are also considered to be independent from the particular domain where the persuasive system is applied.

The heuristics for coordinating persuasive agents can be described as follows.

- *Distraction Prevention.* Several ways can be devised to address the possible distractions as follows.
  - Avoiding overcrowded advices by planning sparse timing for triggers. This can be achieved, for example, by ensuring that the *trigger density* ϑ allocated between the starting time t_1 and ending time t_2 of the trigger satisfies $\vartheta(t_1, t_2, \delta) < \gamma$.
  - Avoiding mental conflict by putting a facilitator trigger to clarify the user about the misunderstanding that one has regarding own ability to address multiple targets.

Table 1: Attributes of trigger and belief as the main message representation structure exchanged and stored in collaboration proxy

Trigger

```
{
Trigger_ID:   TRIG0001,   /* Trigger ID or name */
Creator:      AGENT01,    /* Agent ID */
Trigger_Type: signal,     /* one of recommendation, signal, spark, or facilitator */
Route_of_Elaboration: peripheral,   /* central or peripheral */
Time:         {start: 08:00:00AM, end: 08:01:00}, /* time interval: start time and end time */
Advice:       "Don't forget to take your prescribed antibiotic after breakfast",
/* the content of the message or advice */
Context:      [medicine, health, infection, memory], /* key terms related to the message */
Effect:       [{med:PREANTIBIO001, status: taken}], /* conditions as the target of the trigger */
Importance:   0.8         /* value or level of importance or significance or the target */
}
```

Belief

```
{
Belief_ID:   BEL0001,   /* Belief ID or name */
Creator:     AGENT02,   /* Agent ID */
Time:        {start: 09:30:00AM},     /* time interval: start time and end time */
Object:      USER001,   /* Object or User ID of the one being described */
Description: [{motivation:low}], /* related key attributes or other IDs describing the condition */
Activity:    {act:exercise, type:warmup}, /* key attributes or terms about activity related
to the condition */
Confidence:  0.75 /* value or level of confidence or significance of the information */
}
```

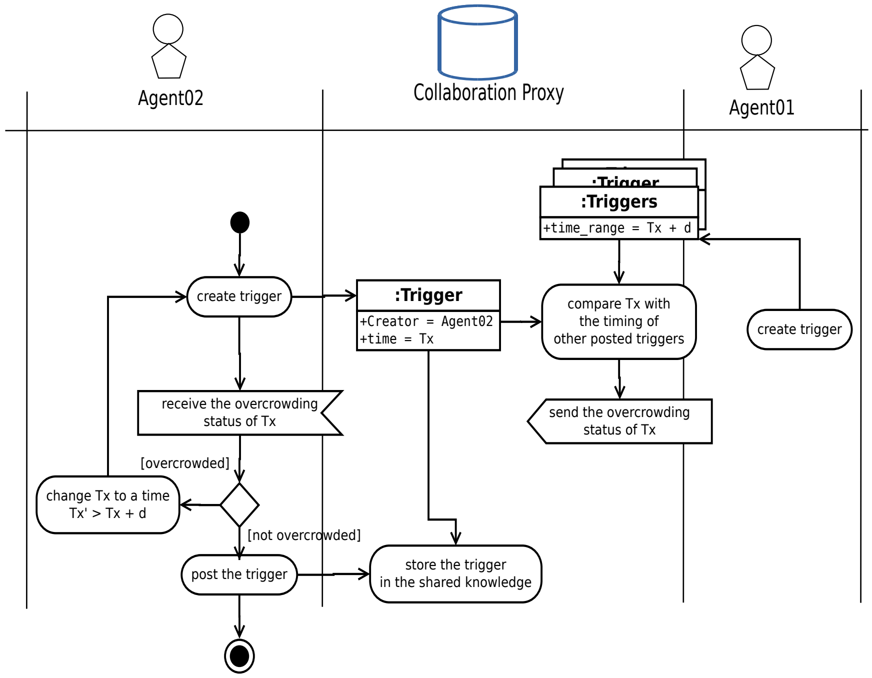


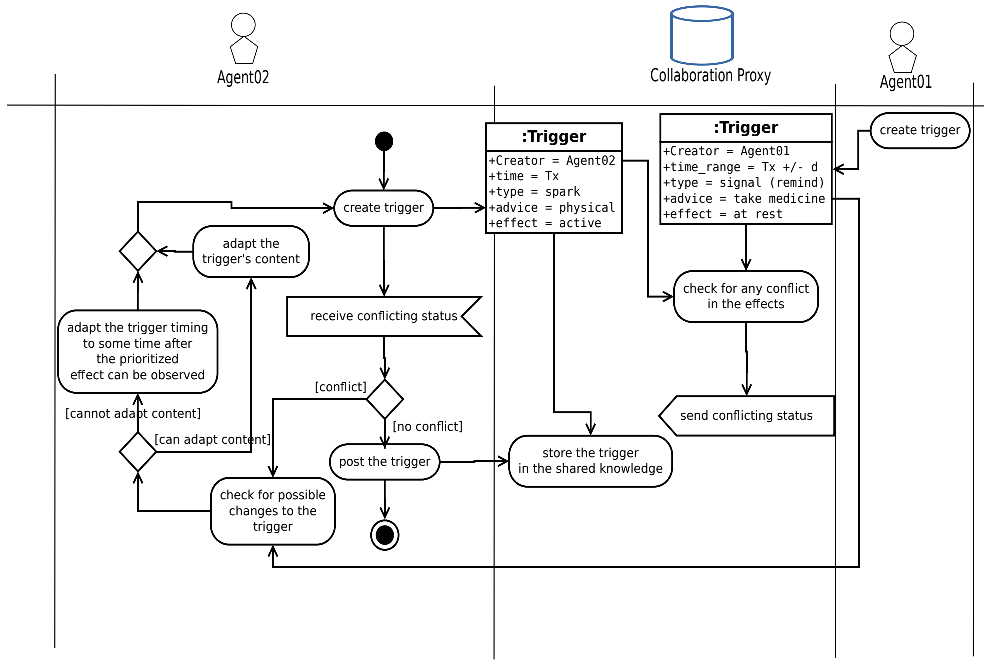
Figure 7: The trigger re-scheduling heuristic to avoid overcrowded messages. To submit a trigger to Collaboration Proxy, the timing of the given advice is compared to existing posted triggers within the period. If the number of advices exceeds the limit ($> \gamma$), the trigger should be re-scheduled by the agent.

  - Avoiding target conflict by re-scheduling the trigger. When the target does not require to be held at a particular time, the trigger can be suspended until later when no conflict occurs.
  - Avoiding target conflict by modifying the content of the trigger. If re-scheduling is not possible, the content of trigger can be modified to avoid conflicts with the others.

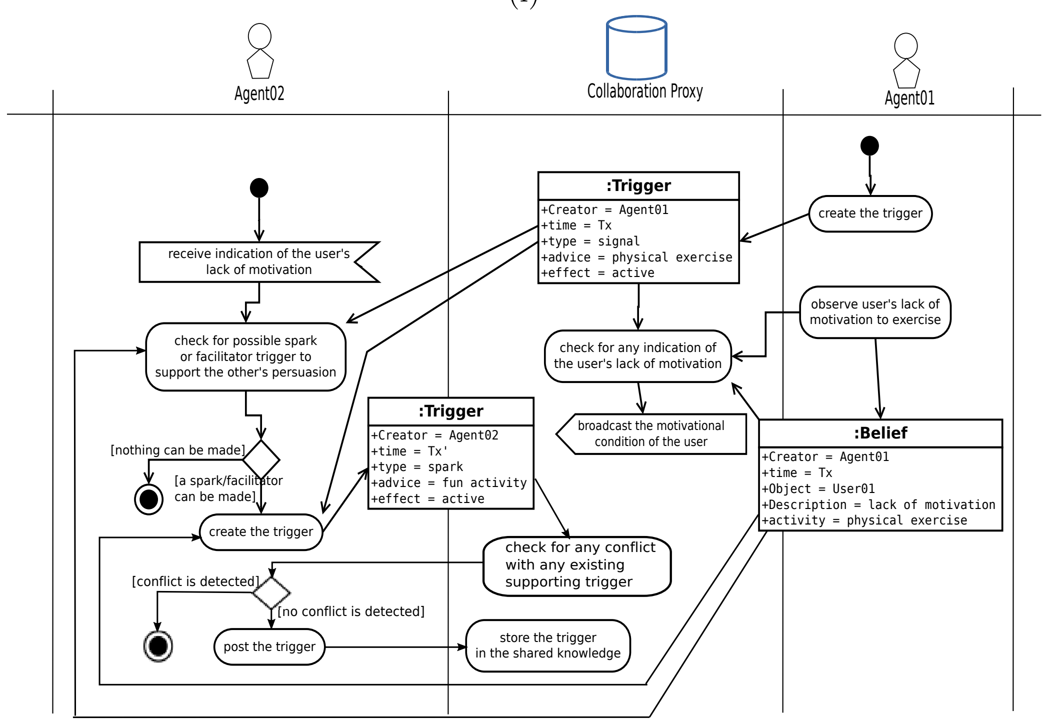
- *Cooperative persuasions.* When a lack of motivation or ability of the user to achieve the target is detected, that condition can be advertised to other agents so other spark or facilitator triggers can be included to better persuade the user.

Figure 7 shows an example of the heuristic to deal with the overcrowded advices in activity diagram. The process involves the interaction between the agents and the collaboration proxy. When an agent creates and asserts a trigger (e.g Agent02 and Agent01), Collaboration Proxy automatically compares the trigger with the other stored triggers in the shared knowledge and obtain the trigger density ϑ of the asserted trigger. The proxy will report the overcrowding status to the last asserting agent (in this case Agent02) including ϑ value and the other conflicting triggers.

Based on the reply from Collaboration Proxy, the agent may re-schedule its trigger to another time when there is no conflict ($\vartheta < \gamma$) and re-assert it to the proxy. The



(i)



(ii)

Figure 8: (i) The heuristic to resolve target conflict by re-scheduling (changing the timing) or changing the content; (ii) The heuristic of recruiting other agents to produce a spark or facilitator trigger for supporting another trigger

above cycle continues until it finds one that the density ϑ is under the limit (γ). This implies that the agent that asserts the trigger must wait for the reply from the collaboration proxy to confirm that there is no overlapping or overcrowding triggers within the requested time slot of the corresponding trigger. If there is an overlap with an existing scheduled trigger, the asserted trigger must be updated

Figure 8(i) illustrates the processes in resolving target conflicts. Similar to overcrowding, the trigger just asserted is checked by the collaboration proxy for its potential conflicts based on its effect attribute. The conflicting status is then returned by the collaboration proxy together with all triggers that are potentially in conflict. The agent can choose either to suspend or to re-schedule the trigger to a time that no other targets are conflicting or to change the target (effect) of the trigger to avoid the conflict. It is also shown that whenever the proxy does not find any conflict, the trigger will be stored automatically in the shared knowledge straight away.

Figure 8(ii) shows the cooperative persuasion heuristic in which one agent observes (as a belief) that the user is less motivated to achieve a persuaded target. The asserted belief initiates the collaboration proxy to broadcast the message to other agents. An agent more capable to create a spark or facilitator for the target can create and assert the supporting trigger to the collaboration proxy. In this case, the decision that one agent can be included in a group that help or support another agent to successfully persuade the user depends on the agent itself. In other words, the cooperative process is conducted in a distributed manner without a centralized controller or authority. Subagdja & Tan (2015) have conducted an experiment to evaluate this basic strategy of cooperation. It is found that some supporting triggers for the same target may still be in conflict with each other reducing the effectiveness of cooperative persuasion. For example, a supporting advice to encourage exercise like "how about playing basketball with your friend" is in conflict with another supporting spark like "playing monopoly can be fun" (Subagdja & Tan, 2015).

To resolve this conflict, an additional check for conflicting contents among the existing supporting triggers is applied. As shown in Figure 8(ii), when agent `Agent02` creates a supporting trigger before commiting to post the spark into Collaboration Proxy, and additional check process to detect conflicts is in place. When no conflict is detected, the supporting trigger can then be posted or otherwise the agent has to refrain from helping the other. Consequently, the posted trigger must be included in the list of supporting triggers so that whenever there is another proposal of trigger in the next time around, the criteria to check for the conflict has been updated. In this case, the extended incremental check for conflict in cooperative triggers serves as an external mechanism to select which agents can help beyond the individual agent decision.

4.4.2. Towards a Generic Framework for Multi-Agent Persuasion

By Collaboration Proxy, the adviser agents depend on each other. Each agent must consider the potential conflicts or interferences with others before deciding to give an advice to the user. Consequently, the general architecture of a persuasive agent in Figure 2 should be updated to handle the interdependency with other agents in producing the advice. Figure 9 shows a modified version of the architecture in Figure 2 to deal with multi-party advice giving and persuasion involving *Collaboration Proxy*. In this case, *Coordination Manager* is included as an additional module that handles the interaction with *Collaboration Proxy*. Triggers produced by *Trigger Generation Process* are checked for their potential conflicts with other triggers scheduled in *Collaboration Proxy*. Triggers become committed to be delivered if their contents and timing are not conflicting with the others as responded by *Collaboration Proxy*.

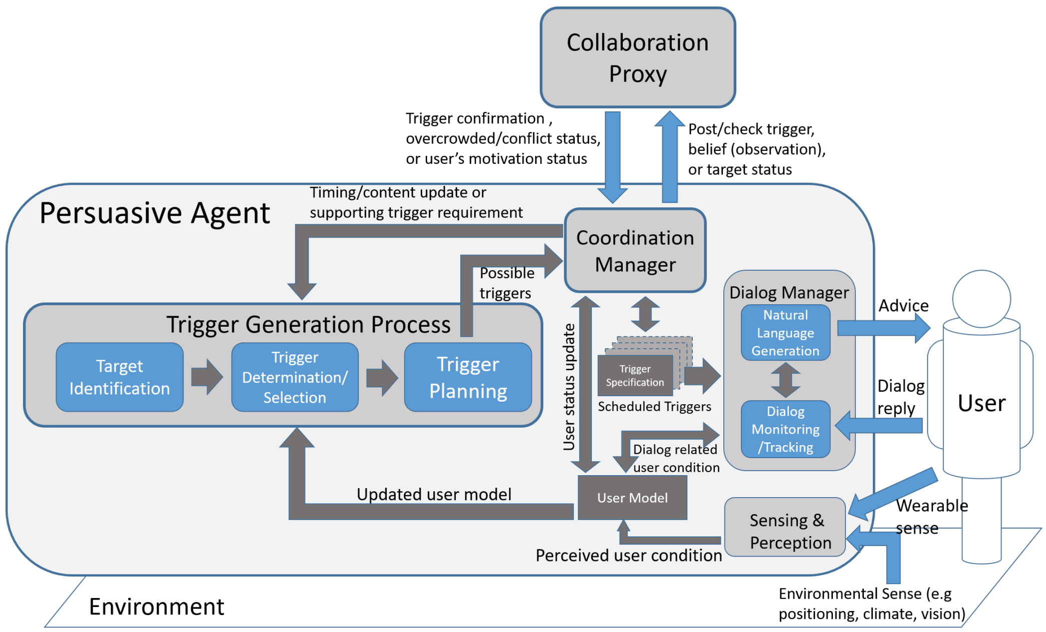


Figure 9: Architecture of Persuasive agent updated for multi-agent settings

If conflicts occur, *Coordination Manager* initiate the update of conflicting triggers in *Trigger Generation Process* in which the search for non-conflicting interval or contents continues. When the agent detects a condition related to the trigger, like a lack of motivation to perform an activity, *Coordination Manager* may also submit a belief based on the updated *User Model* to *Collaboration Proxy* so that other agents may provide some supports.

The architecture in Figure 9 can be regarded as a framework to develop a persuasive agent for a particular purpose with a particular strategy of persuasion. By filling in the specific modules or processes inside the the architecture like *Trigger Selection*, *Trigger Planning*, or *Dialog Manager*, the agent can be built to interact directly with the user while take the other agents' beliefs and advising conditions into consideration through the *Coordination Manager*. Beyond responding to a discrete condition like the acceptance or refusal of the advised target from the user, a new module of *Dialog Manager* can be applied to handle more complex responses from the user or even to

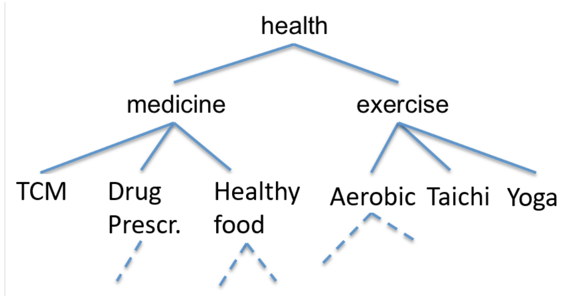


Figure 10: Semantic hierarchical classification of the key terms for interpretation and resolving conflict

initiate a more complex conversation. In that case, a future trigger can be adapted or adjusted according to a more complex valuation derived from the user's responses like the intensity or uncertainty level.

As one of the strategies to resolve conflict, the content modification of the trigger is also not described in detail in this paper. The architecture allows the system developers to implement a specific natural language generation module within *Dialog Manager* for a particular domain. However, in order to conform with another conflicting trigger from a different agent, the adaptation can be based on changing the key terms inside the trigger following a taxonomy or semantic classification of them. For example, if the current key term of a trigger produced by agent A is "aerobic" and is in conflict with another trigger from agent B with the term "Drug prescription", agent A can adapt its content following the global semantic classification like the one shown in Figure 10. In this case, agent A can change its key term into "medicine" as a more general concept than "Drug prescription" and generate advice like "Don't forget to take your medicine" so that it will not confuse the user.

The current design of Collaboration Proxy as described above is limited only to deal with a single user although no particular limit is set for the number of advisers. One potential improvement to this model of multi-agent adviser system is to make the agents serve or accompany multiple users within the same household beyond a single advice recipient. In that case, different agents may also be allocated or assigned to a different user within the same environment or household. Serving multiple users on the one hand may leverage the strategy of persuasion for a user. For example, based on ELM persuasion model, it is possible to generate a persuasion trigger on the peripheral route with social proofing or believed authority strategy based on the actual person or experience gathered from another member in the household (e.g "your brother (or sister) has been routinely doing that exercise every morning", "your spouse will be pleased if you stop smoking"). On the other hand, the social structure in the household can be harnessed so that the functionality of the persuasive system can be extended, for example, to improve the social bonds among family members or relatives through persuasions. Obviously this is possible if the adviser agents are also equipped with domain knowledge about human social relationship.

This potential improvement, however, requires some modification to the collaboration proxy to capture and accomodate the relational or social representation of the household members. The current structure of belief and intention as mentioned above and shown in Table 1 does not include any reference to the identity of the user as the advice recipient. Since, only one user is served, no reference to the user's identity needs to be referred. Consequently, this assumption must be revisited when the system is scaled up to serve multiple users.

5. Case Study and Simulation

5.1. Implementation test-bed

As a proof-of-concept, a custom-built simulation of smart-home environment is developed. The simulation is built in the context of aging-in-place or home-based elderly caregiving domain which includes an artificial occupant residing in the home environment as a virtual user. The virtual user can be programmed to autonomously roam the environment and perform some daily activities. While the user moves around performing routine activities, several agents may advise the user to persuade her towards improvement in the quality of life or well-being. The persuasive agents may reside in different platforms or devices. The agents and the virtual environment interact and communicate through the collaboration proxy. Figure 11 shows the overall view of the architecture. Besides sharing the information, the architecture allows other devices, components, and services to be integrated. For example, Figure 11 shows additional devices and components that can be included requiring that they use the same protocols and rules to interact through collaboration proxy. Other users or parties may also join to participate through the use of an integrated service or application (e.g HealthCare Portal in Figure 11).

Collaboration Proxy is implemented as a web service developed with NodeJS in JavaScript language. Using full-duplex protocols for web connection (WebSocket), an agent can be implemented in a different platform connected to the proxy. Triggers and Beliefs in exchanged and stored in Collaboration Proxy are represented in JSON (Javascript Object Notation) format.

5.2. Study on Perception of Coordinated Multi-Agent Persuasion

A survey is conducted to investigate the effect of multiagent persuasion to the user comprehension and usefulness from humans perspectives. The aim of the user study is to evaluate if the issue of interdependency among the agents in multi-party persuasion can also be perceivable by a human subject and whether the persuasion strategy used in the system is perceived as useful. We compare the cases with and without the coordination heuristics. However, the distractions and coordinated persuasion are associated with *ease-of-use* and *usefulness* as conceptualized in (Davis, 1989). Both concepts have been commonly used in evaluating information system and human-computer interaction. In this case, the objective is to know whether the subjects can

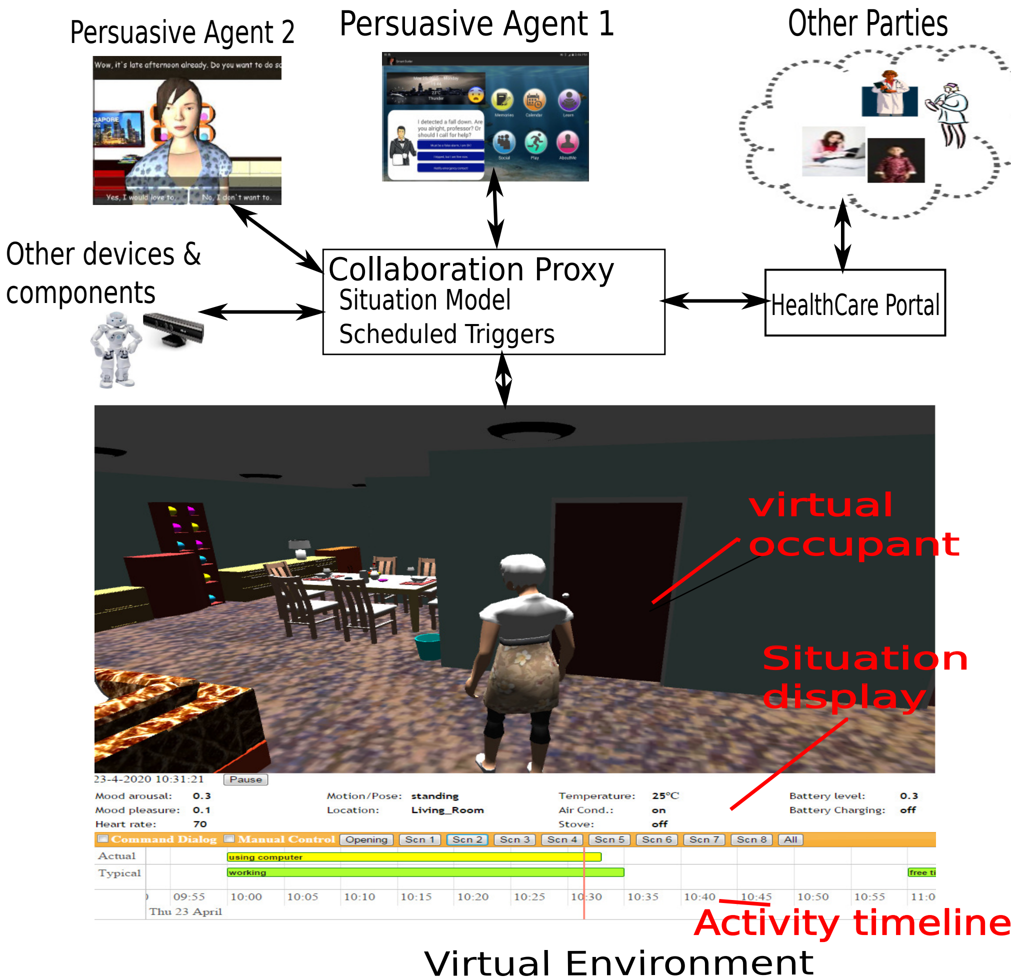


Figure 11: Architecture of Multi-agent Smarthome system for Ageing-in-Place with GUI of the simulation

recognize the difference between coordinated and uncoordinated persuasions. The main conjecture is that the subjects feel that the coordinated model can positively provides greater *ease-of-use* and *usefulness* compared with the uncoordinated one.

The study is conducted not to evaluate the performance of the framework nor the accuracy of the proposed strategies but instead to investigate the significance of the coordination approach from humans' point of view.

5.2.1. Procedure

Subjects were recruited mostly from a university in an asian country. Altogether, 30 subjects participated in this study. After a short tutorial, the subjects were asked to watch different scenarios of multi-party recommendation with and without coordinated persuasion. The subjects then give scores for each scenario according to their perceived *usefulness* and *ease-of-use* as conceptualized in (Davis, 1989). Note that the subjects are not informed about the underlying coordination process in the scenario. They provide the score mainly based on their perception on *ease-of-use* and *usefulness* without the introduction to terms related to coordination like "distraction", "conflict", "incoherent", and so on. In this case, it can be expected that some participants may have opposite views regarding which scenario and configuration are better in regard to the *usefulness* and *ease-of-use* criteria.

Figure 13 shows the virtual environment used for the subjects to watch the scenarios of multi-agent persuasion corresponding to the ones in Figure 12. The scenarios used the same setting as the domain that an elderly occupant living in a smart-home environment performs daily tasks while several persuasive agents are giving advices to improve well-being. The setting is also described in the tutorial prior to the scenarios presentation. In Figure 13, the advice from an agent is shown in a pop-up dialog windows with a picture indicating the identity of the agent (name and picture) and the text of the message as the content of the advice. The text message is accompanied with a voice or speech sound as if the agent talk directly to the occupant. Although the presentation of the texts and the agents' voices are synchronized, the timing considered in the evaluation is based only on the voice presentation.

During the tutorial session, every participant is presented with the scenarios in the same order, that is the uncoordinated scenario first followed by the coordinated one. However, after the introduction, the participant can replay and review both scenarios in any order to compare and differentiate them. Consequently, it can be assumed that each participant has the equal chance to be exposed to both scenarios.

Each scenario consists of two different configurations. One with the proposed coordination approach and the other without coordination. Both scenarios begin with the occupant sitting in the couch in the living room watching TV. It is assumed that she has been sitting down for a long time. After a moment, it starts with an agent showing up to advise her. Specifically, the scenarios are as follows:

- **Scenario I** is when different agents provide different advices with independent contents from each other. As shown in Figure 12(i-ii), the contents of advices as follows "you should move around", "you must call your granddaugther..", and "let's change the TV channel" are independent from each other. This scenario is presented in two different configurations:

1. Configuration 1: Uncoordinated advices in which all advices are presented within a narrow time window (Figure 12(i)). Although they are presented in a sequence and can still be comprehensible since there are corresponding subtitles shown in the pop-up dialog box of the agent, the duration between advices is about one second or less and some small parts in the end of the voice may overlap with the start of another. All advices are given when the occupant is still sitting in the couch.
2. Configuration 2: Coordinated advices in which each advice is presented clearly in a certain order according to their relevant context and time slot(Figure 12(ii)). In this case, each advice is shown only at the beginning of its corresponding performance of the target activity. For example, at first, the occupant stands up and walks to the kitchen after the first advice is presented. The next advice is then given after she goes back to the living room from the kitchen and so on.

- **Scenario II** is when different advices from different agents are supporting to a main trigger advice. For example, as shown in Figure 12(iii-iv), the contents of advices as follows "gentle exercise is more than enough", "exercise hard!", and "exercise is good for the brain", are the motivational cues to support the main trigger advice "you should exercise". The configurations in this scenario are as follows.

  1. Configuration 1: Supporting but overcrowding advices in which all cues are presented in a narrow time window and some of the contents are actually conflicting (e.g "gentle exercise is more than enough" and "exercise hard" in Figure 12(iii)).
  2. Configuration 2: Coordinated advices in which each advice is presented with a bit longer in-between duration (around two seconds) and the contents are regulated to the other advices (e.g "gentle exercise is more than enough" and "exercise regularly" in Figure 12(iii)).

Configuration 1 in Scenario I can be associated with a conflict situation ("you should move around" with "let's change the TV channel") since the intended effect of one advice may confuse the user from the other. It can also be associated with overcrowding (distraction) since they are both presented within a relatively short duration with very brief overlap between the end of the former advice and the start of the later. On the other hand, configuration 2 scenario II demonstrates the coordinated persuasion.

Each participant answers the same set of questions. The question is in the form of a statement that the user must answer with Likert scale choices (Strongly disagree,

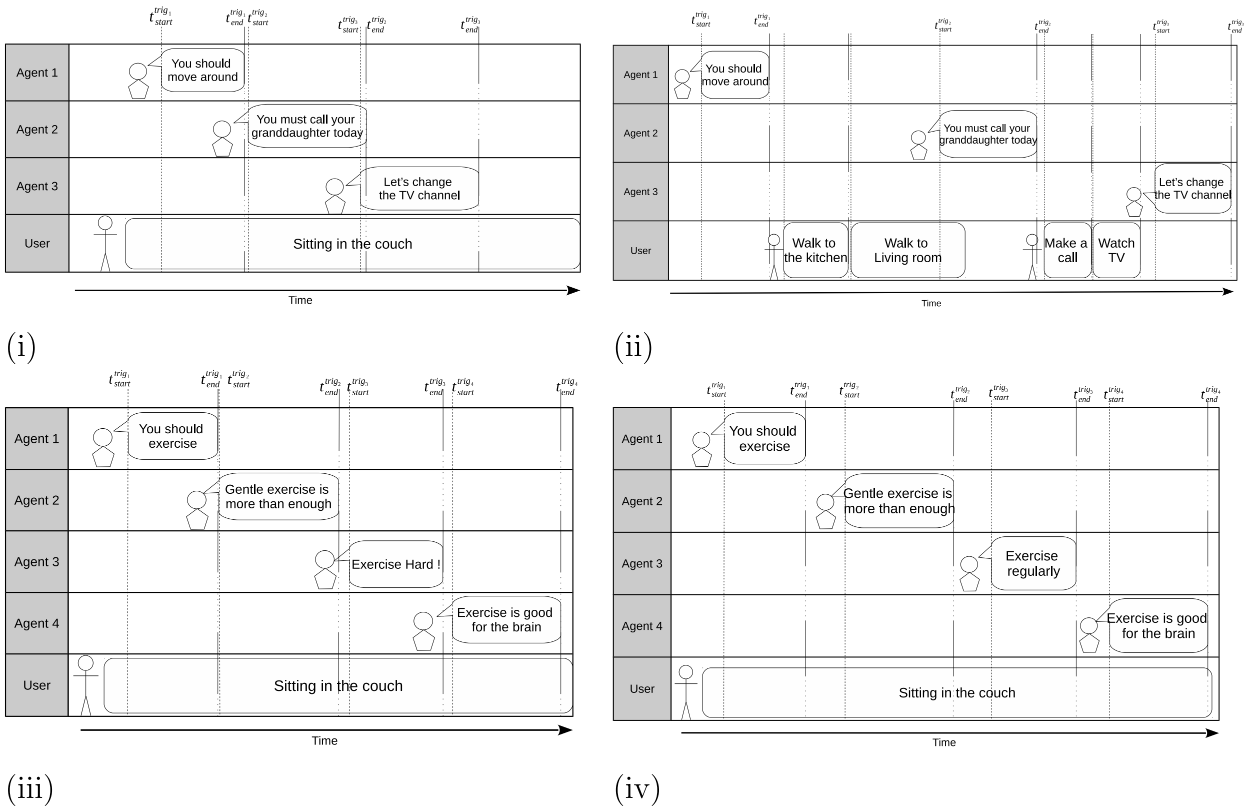


Figure 12: (i) Scenario I - independent advices uncoordinated; (ii) Scenario I - independent advices coordinated; (iii) Scenario II - motivating advices uncoordinated; (iv) Scenario II - motivating advices coordinated

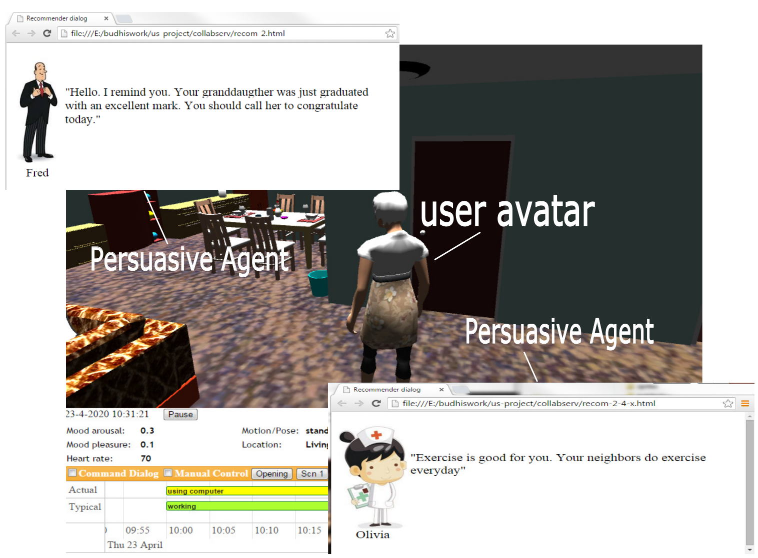


Figure 13: Screen capture of the simulation of multiple persuasive agents for aging in place presented to the respondents.

Table 2: Set of question in the user study

Item	Configuration Aspect	Measurement
Q1	Usefulness	All the advisers reduce unproductive activities
Q2		All the advisers improve the quality of daily activities
Q3		All the advisers are useful in daily activities
Q4	Ease of use	All the advices provided are clear and easy to understand
Q5		All the advices given are confusing
Q6		Understanding every advice given requires a lot of mental effort
Q7		The many advices provided make daily activities more complicated

Table 3: Factor analysis results of each scenario and configuration

Constructs	Scenario 1					
	Configuration 1			Configuration 2		
	mean	SD	CI (at a confidence level of 95%)	mean	SD	CI (at a confidence level 95%)
Usefulness	4.73	1.32	4.26-5.21	5.82	0.75	5.55-6.09
Ease of Use	3.6	1.22	3.16-4.04	5.08	0.73	4.81-5.34

Constructs	Scenario 2					
	Configuration 1			Configuration 2		
	mean	SD	CI (at a confidence level of 95%)	mean	SD	CI (at a confidence level 95%)
Usefulness	4.23	1.17	3.81-4.65	5.18	1.06	4.80-5.56
Ease of Use	4.24	0.98	3.89-4.59	4.84	0.68	4.60-5.08

SD: Standard Deviation; CI: Confidence Interval

Disagree, Somewhat disagree, Neutral, Somewhat agree, Agree, and Strongly agree). Table 2 shows the list of question used for each scenario. Questions from item Q1 to Q3 are related to the aspect of usefulness of the multiple advices. Questions from Q4 to Q7 related to the ease-of-use or level of comprehensible.

5.2.2. Results

The results based on the constructs given in the questionnaire are shown in Table 3. It is shown that the mean score in Scenario I for Configuration 1 is lower than the score for Configuration 2 in both aspects of Usefulness (4.73 in Configuration 1 and 5.82 in Configuration 2) and Ease-of-Use (3.6 in Configuration 1 and 5.08 in Configuration 2). The same thing occurs in Scenario II that the score for Configuration 2 is higher than Configuration 1 in both Usefulness (4.23 in Configuration 1 and 5.18 in Configuration 2) and Ease-of-Use (4.24 in Configuration 1 and 4.84 in Configuration 2).

A quick glimpse significantly indicates that most respondents prefer coordinated advices than the non-coordinated ones. It is shown that the distraction caused by overcrowded advices is viewed to influence the ability of conducting daily activities (Usefulness) compared to those advised in a coordinated fashion. Similarly, conflicting advices (contents) are less preferred than the coherent ones. Moreover, the coordinated persuasion is perceived to be more comprehensible (Ease-of-Use) than the uncoordinated one.

Table 4: F-Test Results

Constructs	Scenario 1		Scenario 2	
	Configuration 1 & 2		Configuration 1 & 2	
	F-value	p-value	**F**-value	p-value
Usefulness	**14.97**	**0.0002**	**31.24**	**6.42E-07**
Ease of Use	**10.34**	**0.002**	7.41	0.008

Table 5: Comments from the Subjects

No.	Category	Percentage	Summary
1	Effectiveness of Persuasion	22.2%	Scenario 2 Category 2 is the least effective
2	Technique of presentation	44.4%	Personalized message and multimedia can improve persuasion
3	Scenario Differences	11.1%	No difference in Scenario 2
4	User impression	22.2%	More pressure in scenario 1 and gentler in scenario 2

5.2.3. Analysis and Discussion

A one-way analysis of variance (ANOVA) is conducted to analyze the results. Specifically, the F-test is used to evaluate the hypothesis of whether there are significant differences among the statistic data means for those constructs. As shown in Table 4, with small p-values in both scenarios, it is strongly indicated that participants can recognize the significance of coordinated persuasion in the context of daily living. Interestingly, although for the usefulness factors the results are significant as indicated by high F and low p-value, it is not so in the factor of ease-of-use particularly for Scenario II (F=7.41 and p=0.008).

The higher p-value in Scenario II might be due to the high similarity in the presentation of advices in configuration 1 and configuration 2. The contents of the messages in both configurations are similar. Although the advices in Configuration 1 are meant to be overcrowded, most participants may still be able to understand the contents of the messages clearly for Scenario II. Some participants may miss the distinction that makes the conflict in Configuration 1 ("exercise hard!"). It is possible that although many understand the usefulness (coordinated persuasion), they do not recognize the difficulty (conflict). The higher p-value indicates that differentiating the distraction from non distracting message is less significant. This contrast with the other aspect of the results that showed significant differences. So, although most of the participants agree that the coordinated setting are useful and more pleasant, the results in regard to noticing that some advices are more distracting than the other are still mixed.

This condition is supported by few opinions related to Scenario II from the participants taken from post interview after the collection of the questionnaire data. The comments are categorized and summarized in Table 5.

About 11.1% of the comments suggest that no difference can be found in Scenario II or in other words the advices are indistinguishable. 44.4% of participants feel that advices given in Scenario II are too gentle compared to those in Scenario I which are difficult to comprehend without coordination. It is mentioned also (about 22.2% of the comments) that scenario 2 with strategies in Category 2 is not effective to persuade the user. This may indicate that distraction in the form of conflict may still be hard to notice although the coordination can significantly be recognized. However, the results from the post interview are still less conclusive than the quantitative one above. Further interview to the 22.2% participants reveals that the less effectiveness of persuasion is mainly due to the particular opinions about the use of commanding or dominating words used in persuasion like "you should do . . . " which is considered as counterproductive for persuading the user. It is believed by the corresponding participants that the particular advice can be improved by replacing the second person pronoun with another strategy of command. However, this issue of choosing the right words for persuasion is outside the scope of the study and considered to be irrelevant to the aspect being evaluated in this experiment.

Despite the small insignificance in distinguishing distraction related to the aspect of ease-of-use, the overall results from the user study still indicate that, from a human perspective, coordinating advices in terms of conflict resolution and cooperative advices can be recognized and perceived to improve the effectiveness of persuasion.

5.3. Smart-home simulation

Besides the survey, we apply the multi-agent adviser system to the smart-home simulation that includes an artificial occupant as a virtual user. With the agents and the coordination heuristics in place, the persuasions are exemplified using four persuasive agents that advise the user to do or change activities to improve well-being. Each agent tackles one aspect of well-being. Four aspects used in this simulation are: physical (phs), cognitive (cog), emotion (emo), and social (social).

The level of well-being can be obtained based on each aspect taken by each corresponding agent. For instance, the level of well-being for the ith aspect can be measured by $Q_i(t) = Q_i(t-1) + \sum_j^N \delta_{ij}(t).W_j$, 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. $W_j \in [-1, 1]$ and $Q_i \in \mathbb{R}$. Table 6 presents the activities and some of the key indicators with their associated weigths for the corresponding aspect. A single indicator may contribute positively or negatively to its aspect valuation. The indicators are used to score the user (occupant) daily activities.

In the simulation, the user is modeled as a virtual agent occupying the virtual smart home. As a virtual occupant, the user conducts the activities as listed in Table 6 iteratively for every single (virtual) day following the time period as shown in the table. The activities taken by the virtual occupant follow a particular order with some branches or possible paths in the sequence for variability. However, the key indicators for every aspect can be chosen differently by the occupant in each time cycle (10 virtual minutes), hence different scores.

The virtual occupant selects the activity to perform, as shown in Table 6, according to the current simulation time. For example, starting from 6.00, "waking up" activity will be selected to perform. Similarly, from 12.00 to 14.00 it will select

Table 6: Examples of key indicators and the corresponding weights in aspects of well-being

Activity	key indicator	physical	cognitive	emotion	social	**time period**
waking up	stretching	+0.001	0	+0.00001	0	06.00 – 08.00
	exercise	+0.05	+0.001	0	0	
	watching TV	0	-0.0005	-0.0005	-0.00001	
	stay on bed (sleep)	-0.0001	0	0	0	
taking a bath	cleaning up	+0.001	+0.001	+0.001	+0.001	08.00 – 08.30
	skip cleaning	-0.005	-0.005	-0.005	-0.005	08.30 – 09.00
breakfast	toast bread and eggs	+0.0001	0	0	0	08.30 – 09.00
	american breakfast	-0.000001	0	0	0	09.00 – 10.00
	porridge	+0.0001	0	0	0	10.00 – 11.00
	fruits	+0.005	0	0	0	
	sweets	-0.00001	0	0	0	
	coconut rice	0.00001	-0.0001	0	0	
	skip breakfast	-0.05	-0.05	-0.05	-0.05	
lunch/dinner	salad	+0.01	+0.0001	0	0	12.00 – 14.00 (lunch)
	fruits	+0.05	+0.0001	0	0	18.00 – 20.00 (dinner)
	fish	+0.001	+0.001	0	0	
	steak	+0.0001	0	0	0	
	junk food	-0.00001	0	0	0	
	drink only	-0.001	-0.001	-0.0001	-0.0001	
	skip lunch/dinner	-0.05	-0.05	-0.001	-0.001	
spare time	aerobic	+0.005	+0.0001	0	0	09.00 – 10.00 (morning)
	treadmill	+0.005	+0.0001	0	0	10.00 – 11.00 (morning)
	practicing (e.g play music, study)	+0.00001	+0.0001	+0.0001	0	11.00 – 12.00 (morning)
	hobby/crafting	0	+0.0001	+0.0001	0	14.00 – 15.00 (afternoon)
	snacking (meal)	-0.00001	0	0	0	15.00 – 17.00 (afternoon)
	watching TV	-0.00001	0	0	0	17.00 – 18.00 (afternoon)
	reading	0	+0.0003	+0.00001	0	20.00 – 21.00 (evening)
	playing games	0	+0.0001	+0.00001	0	21.00 – 22.00 (evening)
	social media	0	0	0	+0.0001	
	chatting with relatives	0	0	+0.00001	+0.001	
	doing nothing	-0.0001	-0.0001	-0.0001	-0.0001	
	sleep	0	0	0	-0.0001	
sleeping	sleep	+0.001	+0.001	+0.001	0	14.00 – 15.00
	napping	-0.0001	-0.0001	-0.0001	0	15.00 – 17.00
						17.00 – 18.00
						20.00 – 21.00
						21.00 – 22.00
						22.00 – 06.00 (next day)

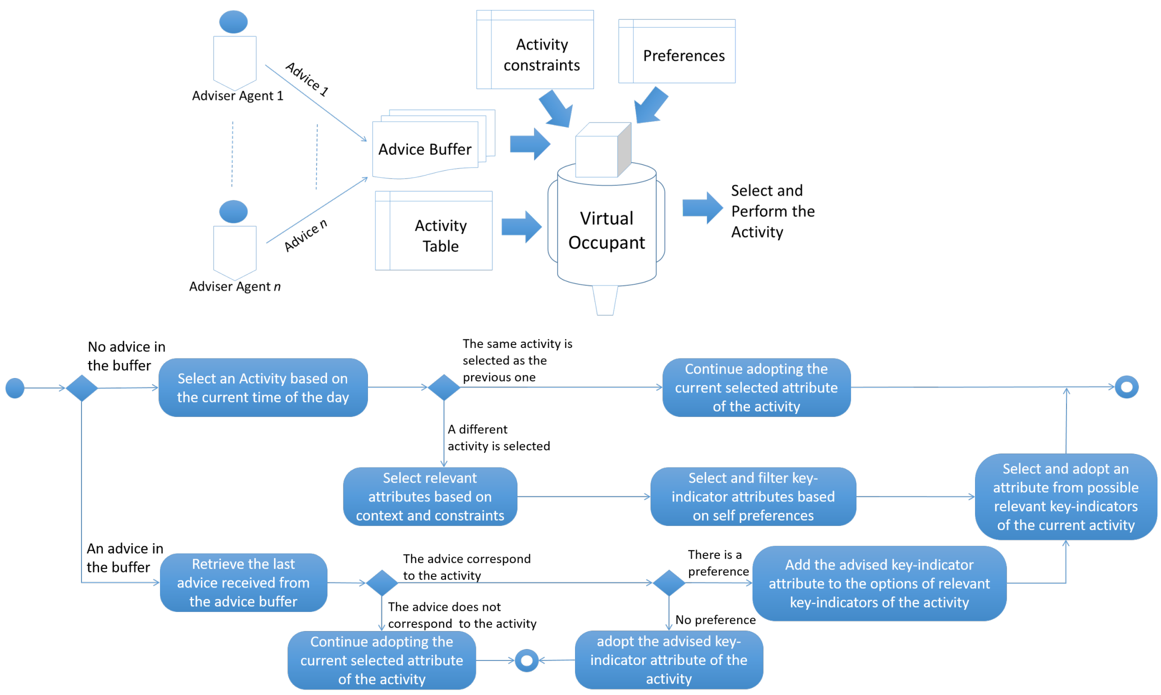


Figure 14: Architecture and algorithm of the virtual occupant in the simulation of smart-home environment

"lunch" activity. In the running simulation, the activities in Table 6 are selected in a consecutive order according to each corresponding time. At a particular time period, there can be different options of activity that the occupant can choose so that different trajectory of activities can be taken from one day to another. For example, "waking up", "taking a bath", "breakfast", "spare time", "lunch", "spare time", "dinner", "spare time", and "sleeping" may be selected consecutively in a single day. However, a sequence of "waking up", "taking a bath", "breakfast", "spare time", "lunch", "sleeping", "dinner", "spare time", "sleeping" may also be chosen following the possible time periods of activity in Table 6. Consequently, different sequences may be selected and performed when the simulation is run for several days. Although the selection of activity by the virtual occupant is based on pre-determined periods of time, the key-indicator attribute of the activity as shown in Table 6 is selected based on different criteria and preferences by the user which can also be influenced by the advices from the adviser agents.

Figure 14 shows the architecture and the algorithm of the virtual occupant. The top part of the figure shows the architecture in general in which the virtual occupant maintains a memory buffer to hold the incoming messages received from different adviser agents at one time. The adviser agents run concurrently and send the advice asynchronously to the occupant so that the it may receive the messages in a random order. In this simulation, the buffer is configured to be minimal that only one message is held at one time. A new incoming advice will replace the pre-existing one in the buffer. This is to simulate the user's limited memory to handle multiple advices. Based on the preset activity, the occupant has to choose a specific key-indicator attribute for the particular activity following the activity table (as in Table 6). The available options of attribute also depend on the predefined constraints of particular key-indicator given the previous attributes selected. For example, if the occupant has chosen "sleep" too many times in a single day, that key attribute will not be included in the options to select in the next round. Similarly, if too many exercises (e.g treadmill) have been taken, the particular choice will not be available in the next round of the same activity, for instance, because the occupant is considered already feeling tired or fatigue. The virtual occupant may also have some preferences towards particular key-indicator attributes for a particular activity. It may tend to adopt a particular attribute although it has been advised to perform another one in the same activity.

The bottom part of Figure 14 shows the flow of the process of the virtual occupant in selecting the key-indicator attribute of an activity. If there is no change of activity or still in the same activity period, the same key attribute will still be continually adopted and performed. When the activity changes, the corresponding attributes of key-indicators of the activity as in Table 6 are selected or added according to certain rules of activity constraints and the context of activities that have been performed. In this simulation, the following rules of constraints are used to add the realism.

- If the "treadmill" or "exercise" has been performed for six hours in a day (within the range of 06.00 to 24.00 hours), another option of "treadmill" or "exercise" will not be considered for selection in that day.
- If "sleep" has been adopted for eight hours in a day, another option of "sleep" will not be selected in that day (unless it is a part of a continuous selection of the same activity).
- If "sleep" has only been adopted for less than six hours in a day at the end of the day (at 24.00 midnight), the "sleep" attribute will be prioritized for selection in the next round until the minimum limit of six hours is exceeded whenever the relevant activity with the corresponding key-indicator is selected.

The virtual occupant may also have its own preferences towards particular attributes of the activity. The occupant's preferences in the simulation are defined based on the particular aspect of well-being (physical, cognitive, emotion, or social) under consideration. During the start of activity selection, one aspect to consider is selected randomly from all the four options. One particular key-indicator is then selected according to the preferences. In that case, 9 different configurations of preferences are applied and compared in this simulation as follows:

- 1 occupant configuration with no particular preference on any aspect of well-being. Every key-indicator of an activity has an equal chance to be selected.

- 4 occupants, each prefers the maximum increase (positive) or improvement on a different corresponding physical, cognitive, emotion, or social aspect of well-being.
- 4 occupants, each prefers the least value or negative improvement on a different corresponding physical, cognitive, emotion, or social aspect of well-being.

The process shown in Figure 14 indicates that the occupant configuration with no preference will follow the advice whenever it is available in the buffer. In this case, the virtual user is fully obedient but with a very limited memory. The occupant will make up the choice on the next cycle based on whatever advice received from an agent. However, the latest message received may replace the previous one hence a target conflict. On the other hand, with a preference in place, there is 1 out of 4 chance in the activity that the occupant does not follow the advice even though the advice buffer is not empty. Instead, it may pursue the activity according to its own preference which can be negative or sub-optimal.

Each persuasive agent monitors the key-indicator selected for its corresponding aspect by the occupant for every decision or activity cycle. In the simulation, the agents will only start to provide the advice on the second day since they take the time to observe the occupant's behavior in the first day. The activity cycle is triggered for every 10 (virtual) minutes. When a non-optimal action (with a negative key indicator) is selected by the occupant causing a decline in the score, the agent initiates a trigger to recommend a change towards the optimal one. If a non-optimal decision is still made by the user after the advice, a target conflict is considered to occur.

5.3.1. Result

Different well-being scores can be obtained from the running simulation for different configurations of the occupants and persuasive agents. The dynamic of conflicts and persuasions can be exemplified and compared given that the scores are averaged over 30 independent runs in different agents configurations conducted in 14 consecutive (virtual) days. From the total of nine different configurations of the occupant as mentioned above, the scores are grouped into three categories: the score of one occupant with no (or equal) preferences towards particular activity attributes; the average of scores from every occupant in the group that tends towards the positive weighting of physical, cognitive, emotion, or social aspect; the average of scores from every occupant in the group that tends towards the negative weighting of the corresponding aspect as above.

The top part of Figure 15 shows the scores gained for each day (taken at the end time of the day at 24.00 midnight) by the occupants when no advice is given. The score is then reset to 0.5 for the next day. In an idealistic situation, the occupant will always select an attribute that provide the optimal weights. This is shown as dashed line at the top of the chart that scores mostly around 3. In the worst case scenario, on the other hand, the occupant always select the ones with the least weight values. The

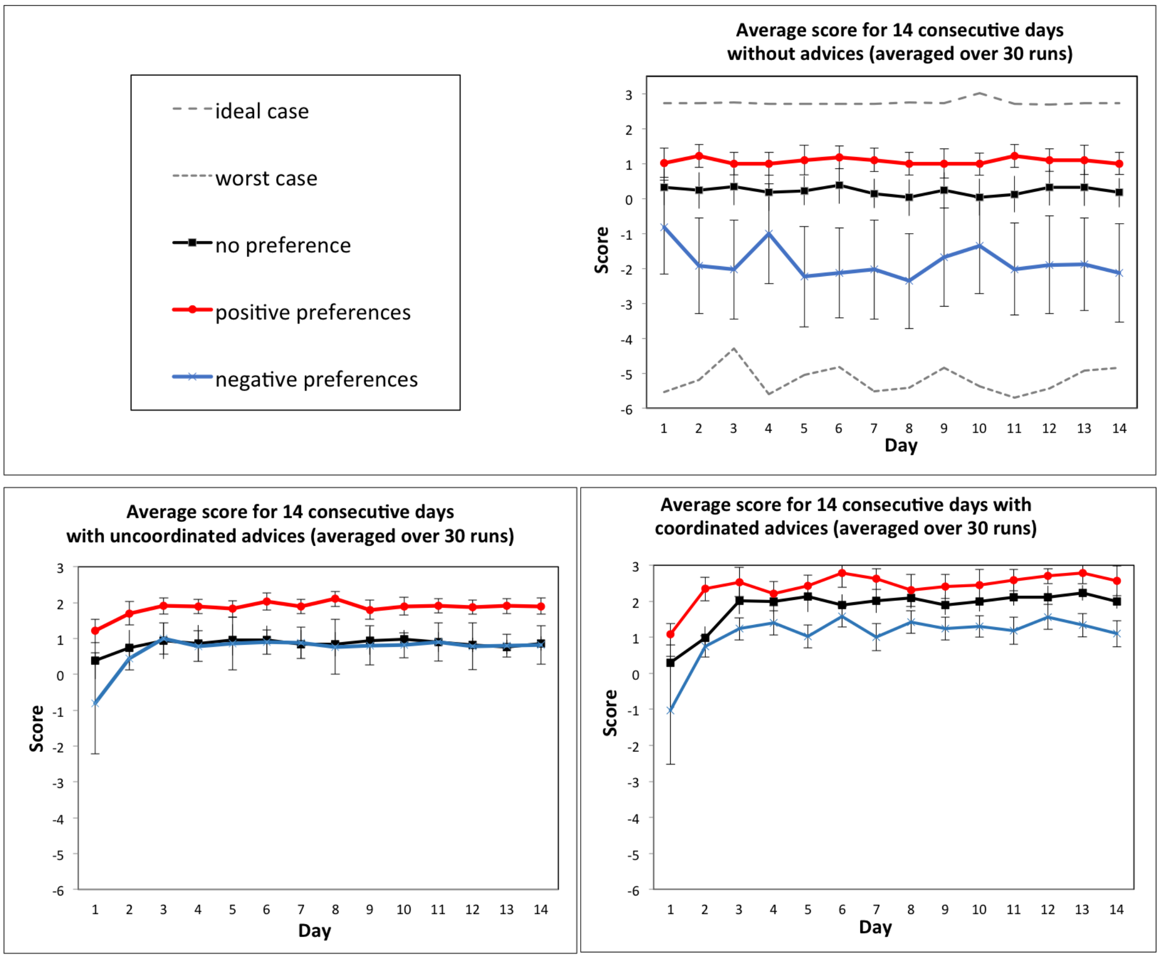


Figure 15: Average well-being scores of different configurations of virtual occupants in 14 consecutive days when no advices are given, advices are given but uncoordinated, and with the coordinated model of multiple advices giving.

least scores in the chart fluctuate around -4 to -6. The constraint rules that exclude some options of key attribute from consideration contribute to the fluctuation as the process may oscillate between the lack of selection to the surplus of adoption of a particular key attribute (e.g "sleep").

Without any preference, the occupant selects a corresponding attribute of the activity with an equal chance. The scores obtained stay around 0.5 when there is no influence from the adviser agents. With the positive tendency towards an attribute with the maximum weight for a particular aspect, the occupant gains a higher score on each day though still lesser than the ideal one. Similarly, with negative tendency towards the lowest attribute of a certain aspect, the occupant gets negative scores every day. It is also shown that the negative scores fluctuate a lot as the constraint rules are often triggered.

The bottom left of Figure 15 shows that the advices given by the agents can improve the scores. All occupants with every configuration gain more scores although the provision of the advices are not coordinated. Without any preference, the occupant gains slightly higher scores when the advice is provided. Those with preferences also gain some improvements including the ones with the negative tendencies. The bottom right 15 shows that with the coordinated advice giving technique, more improvement can still be obtained. With the positive tendency towards an attribute, the idealistic level of well-being score can even almost be reached. The improvements in the other configurations can also be clearly observed.

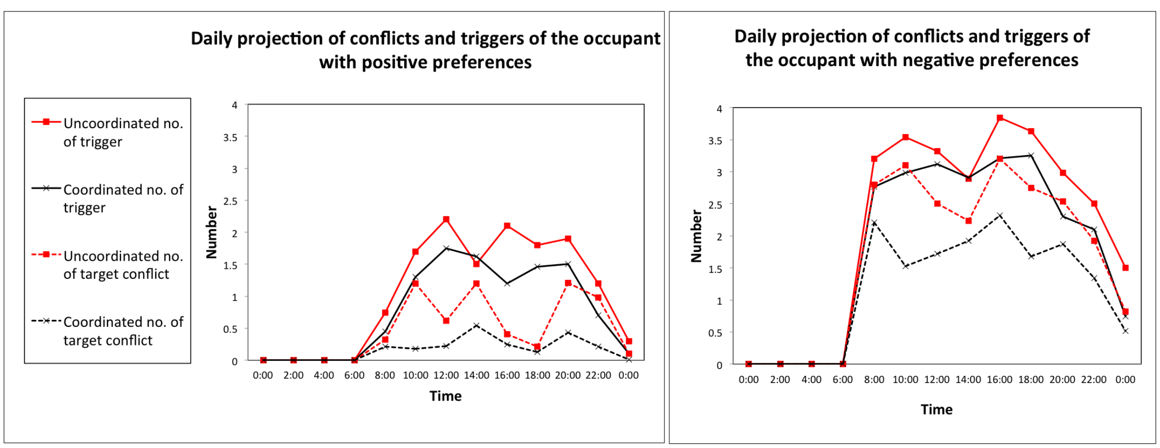


Figure 16: Average number of triggers and conflicts in a day over 24 hours.

Figure 16 shows the number of triggers produced by the agents averaged over time in a single day for every two hours. Samples from the seventh day in the running simulation is picked representing the single day to reveal. At the beginning of the day, triggers are started to be given at 06.00 which is the waking up time of the occupant. In this case, only configurations of the occupant with positive and negative tendencies towards an attribute are shown. The number of triggers and conflicts are counted based on the number of their occurrences since the previous two hours (except those in the previous day).

The left-hand side of Figure 16 indicates that even though the score is improved by the advices without coordination, many conflicts still occur. Note that a conflict is considered to occur whenever the occupant selects a key-indicator for the activity with a smaller value than expected after a corresponding advice is given by an adviser agent. A deeper analysis to the simulation outcome when no coordination is applied has indicated that many triggers from different agents are provided at the same time slot (a window of 10 minutes of the occupant's decision cycle) so that the virtual user may miss some important trigger that potentially contribute to a greater score (Subagdja & Tan, 2015).

On the other hand, the protocol to handle overcrowding in the coordinated model can reduce the number of conflicts. In Figure 16, it is shown that, with the coordination, the number of conflicts are significantly reduced. Dealing with the conflict implies more reductions on the number of triggers at one time and eventually improves the score. However, the chart also shows that the target conflicts may also be due to the negative preferences of the occupant. The right-hand side of Figure 16 shows that many conflicts still occur since it is likely that the key attribute suggested by the adviser agent is the opposite of the user preference hence non-optimal attribute will be chosen instead. On the other hand, with a positive preference, it is more likely that the occupant's choice aligns with the agent's advice since both inherently are made towards the optimal score.

In any case, the simulation has demonstrated how reduction of conflicts and the density of triggers may contribute to the overall score improvement. Coordinating the provision of advices in this way can improve the performance of activities.

6. Conclusion and Future Work

We have presented our model of coordination for multi-agent persuasion in which multiple agents provide different advices together to a user as the message recipient. The benefits of multiple advices for persuasion by different agents have been identified as allowing different strategies of persuasion to be employed and enhancing conversational engagement to make the persuasion more effective. On the other hand, putting multiple agents to persuade the user may also distract the user from pursuing the appropriate, significant, and/or useful advice. We have characterized two different kinds of distraction. The first one is conflicting advices in which the recipient believes that the target of one advice may cancel out the target effect of another. The second type of distraction is the overcrowding messages produced by different agents that reduce the ability of the recipient to comprehend all the important messages provided. Based on the characteristics of the interpendencies among persuasive agents when they are working together in the same domain, it has been proposed as well that the way to resolve them include sharing information and knowledge so that they are aware of each other beliefs and plans.

As parts of the coordination model, a set of meta-heuristics based on the sharing information and knowledge framework is made to tackle the interdependency among the agents. It has been exemplified and evaluated to show that the sharing heuristics can reduce distractions, conflicts, and leverage the user daily performance in a simulation. We have conducted a survey study showing that people can also recognize the benefits of multiple advices by different agents. It is agreeable as well that distractions by incoherent messages or conflicts require a coordination mechanism to overcome the unwanted effects.

Besides the promising aspects of the model with the coordination strategies for any applications or services that interacts both with human and other systems, this work still deserves more study. In the future, the other features of inconsistency resolution and full-featured cooperation strategy should be included in the framework to be evaluated in the experiment. More variations on the occupant behavior including capabilities of learning or memorizing what have been recommended can be incorporated to find the strategy that is suitable when the human participant can be subjected to adaptation. In this case, the agents may need to take the user responses into consideration in order to adapt the advice given in the future. Another potential of development is to scale-up the multi-agent adviser system to handle multiple users within the same household in a general smart-home setting. In any case, more tests involving real human subjects in a realistic settings that involve real tasks and user motivations should be conducted to give more insight on the effectiveness of this framework.

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