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On Coordinating Pervasive Persuasive Agents

(Extended Abstract)

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ABSTRACT

There is a growing interest in applying multiagent systems for smart-home environment supporting self-caring elderly. In this paper we investigate situations and conditions for coordination for such kind of system. We specify a high level architecture of it based on the notions of beliefs, desires, and intentions for both individual and group behavior of the agents including the human occupant's. The framework enables flexible coordinations among loosely-coupled heterogeneous agents that converse with the user. This work is conducted towards producing a coordination framework for agents and people in such a kind of smart-home environment as mentioned.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

Keywords

Smart home; Aging in Place; BDI; Coordination

1. INTRODUCTION

Aging in place, referring to the preference to live safely, independently, and comfortably in one's own home regardless of age or ability, has initiated studies worldwide towards the application of smart-home environment. We consider the smart-home to include pervasive computing devices that unobtrusively monitor the occupants to make a comprehensive situation model and, accordingly, provide recommendation and reminder to ensure their well being. It needs to be persuasive or non-coercively trying to change the occupants attitudes or behaviors through interaction or dialog that involves intentionality [1]. In this paper, we provide a theoretical framework for pervasive heterogeneous agents in a smart-home environment that may have persuasive roles. Based on BDI logic [3] formalization similar to $\mathcal{LORA}$ [5], the framework treats the occupants as agents together with the applications that provide care to elderly. Unlike the common views in BDI coordination or teamwork (e.g [2, 4]), an aggregated model of BDI is adopted that relaxes the responsibility of each agent towards acknowledging each other. The BDI modalities are considered as collective properties of groups besides the attitudes of individual agent. Accordingly, we enumerate different types of agents that can be applied and identify situations for coordination. In this way, we can devise coordination framework and protocols for adaptive group of agents that continuously monitor and cooperatively persuade the occupants.

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2. AGENTS AND GROUPS

$\mathcal{A}g$ is the set of agents denoted by numeral $1, 2, ..., n$. The human subjects $\mathcal{A}g^{sub} \subset \mathcal{A}g$ and computational agents $\mathcal{A}g^{comp} \subset \mathcal{A}g$.

2.1 Individual Agent

Based on [5], the agent can be described as $M = \langle T, \mathcal{R}, W, D, Act, Agt, \mathcal{B}, \mathcal{D}, \mathcal{I}, Val\rangle$. T is the set of all time points; $\mathcal{R} \subseteq T \times T$ is a total, backwards-linear branching time over T; W is a set of worlds over T; D is a domain or $D = \langle \mathcal{A}g, \mathcal{G}r, \mathcal{A}c, P\rangle$; $Act : \mathcal{R} \rightarrow \mathcal{A}c$ associates an action with every $\mathcal{R}$; $Agt : \mathcal{A}c \rightarrow \mathcal{A}g$ associates an agent with every action; $\mathcal{B} : \mathcal{A}g \rightarrow \wp(W \times T \times W)$ is a belief accessibility relation; analogously $\mathcal{D}$ and $\mathcal{I}$ are desire accessibility and intention accessibility relations respectively; $Val : P \rightarrow \{0, 1\}$ maps a proposition to its truth value. BEL (belief), DES (desire), and INT (intention) are the attitudes modal operators. There are temporal connectives like $\bigcirc$ (next), $\Diamond$ (eventually), $\Box$ (always), $\mathcal{U}$ (until), and $\mathcal{W}$ (while). Definitions about ability (and inability) are as follows:

$\mathsf{CAN}_i\varphi \hat{=}$ agent i can bring about φ; and $\mathsf{Unable}_i\varphi \hat{=} \neg\mathsf{CAN}_i\varphi$.

2.2 Groups of Agents

$\mathcal{G}r : 2^{\mathcal{A}g}$ is the set of possible grouping. A group $g \in \mathcal{G}r$ is a set of agents or $g \subseteq \mathcal{A}g$. $\mathcal{B}^*_g$ accumulates all accessible worlds and relations from all belief accessible relations of all group members such that $\forall i \in g, \forall w' \in \mathcal{B}^{*w}_t(g), \forall w'' \in \mathcal{B}^w_t(i), w'' \in w'$. Modal operator BEL^* can be defined such that $(\langle M, w, t\rangle \models_{\mathcal{S}} \mathsf{BEL}^*_g\varphi) \Leftrightarrow (\forall w' \in W, w' \in \mathcal{B}^{*w}_t(g) \Rightarrow \langle M, w', t\rangle \models_{\mathcal{S}} \varphi)$.

Theorem 1 : $\models_{\mathcal{S}} \mathsf{BEL}^*_g\varphi \Leftrightarrow (\exists i \in g, \mathsf{BEL}_i\varphi$, and $\forall j \in g, \neg\mathsf{BEL}_j\neg\varphi)$. A group g aggregately believes that φ is the case iff a member of g believes φ is the case and every member of g does not believe that $\neg\varphi$.

Other aggregated version of modalities like $\mathcal{D}^*$ and $\mathcal{I}^*$, and modal operators DES^*_i and INT^*_g are defined analogously. Ability of group can also be defined such that $\mathsf{CAN}^*_g\varphi \hat{=} \exists i \in g, \mathsf{CAN}_i\varphi$. There are conditions relevant to coordination that can be defined using the above mental notions as follows.

Inconsistency: $\mathsf{Inconsistent}_g \varphi \doteq \exists i, j \in g, \mathsf{BEL}_i \varphi \wedge \mathsf{BEL}_j \neg\varphi$, or the aggregate beliefs of group g about φ is inconsistent iff one agent in the group believes that φ holds but another one in the group believes otherwise.

Conflict: $\mathsf{WeakConflict}_g \varphi \doteq (\exists i, j \in g, \mathsf{INT}_i \Diamond\varphi \wedge \mathsf{INT}_j \Diamond\psi \wedge \mathsf{BEL}^*_g \mathsf{E}(\psi \Rightarrow \neg\varphi))$, or group g is in (weak) conflict when one member's intention may have a side effect that may cancel out the other. $\mathsf{StrongConflict}_g \varphi \doteq \exists i, j \in g, \mathsf{INT}_i \Diamond\varphi \wedge \mathsf{INT}_j \Diamond\neg\varphi \wedge \mathsf{BEL}^*_g \mathsf{E}((\Diamond\neg\mathsf{DES}_i \Diamond\varphi) \vee (\Diamond\neg\mathsf{DES}_j \Diamond\neg\varphi))$, or group g is in (strong) conflict when two of its members have contradictory intentions to achieve. On the other hand, $\mathsf{HardConflict}_g \varphi \doteq \exists i, j \in g, \mathsf{INT}_i \Diamond\varphi \wedge \mathsf{INT}_j \Diamond\Box\neg\varphi$, is a (hard) conflict for group g if two of its members have contradictory intentions to achieve and at least one of the agents has the goal that the achieved condition persists.

Cooperation: $\mathsf{PotHelp}^*_g \varphi \doteq \exists i, j \in g, \mathsf{DES}_i \Diamond\varphi \wedge \mathsf{Unable}_i \varphi \wedge \mathsf{CAN}_j \varphi$, or group g is in potential helping condition to achieve φ if there is a member in g that has a goal to achieve φ but unable to realize it individually, but another member in g can achieve it. $\mathsf{Cooperative}_i \varphi \doteq$ for $i \in g, (\mathsf{PotHelp}^*_g \varphi \wedge \mathsf{CAN}_i \varphi \wedge \mathsf{INT}^*_g(\mathsf{INT}_i \Diamond\varphi)) \Rightarrow \mathsf{INT}_i \Diamond\varphi$ or agent i of group g is cooperative regarding goal φ if i is willing to achieve φ when another agent in g wants it but unable to do so and the group g wants i to achieve it. $\mathsf{PotCoop}^*_g \varphi \doteq \forall k \in g, \exists i \in g, \mathsf{DES}^*_g \Diamond\varphi \wedge \mathsf{Unable}_k \varphi \wedge \mathsf{BEL}^*_g(\psi \Rightarrow (\mathsf{CAN}^*_g \varphi)) \wedge \mathsf{CAN}_i \psi \wedge \mathsf{Cooperative}_i \psi$, or group g is in potential for cooperation if g (aggregately) wants φ and no member of the group can achieve it, but one member has the ability to bring about another thing (ψ) which enables the ability of the group to achieve φ.

3. COORDINATION

We view coordination process as the process of detecting a relevant condition or situation as described above and all the agents involved may take particular actions to resolve it. As a pervasive monitoring system, the smart-home may consist of different types of agents as follows: (1) *Sensory non-adaptive* agents continually classify data and assert beliefs in a standard way. (2) *Sensory cooperative* agents can carry out new tasks or adjust its parameters besides the originally prescribed ones based on the conditions of the others. (3) *Fusing and coordinating* agents collect information from the others, identify inconsistent conditions, and initiate the resolution. For example, if there is a belief inconsistency $\mathsf{BEL}_x(\mathsf{Inconsistent}_g \varphi \wedge \mathsf{BEL}_i \varphi \wedge \mathsf{BEL}_j \neg\varphi)$ and $\mathsf{BEL}_x(\mathsf{Cooperative}_i(\mathsf{INT}_i(\Diamond\mathsf{BEL}^*_g \varphi)) \wedge \mathsf{Cooperative}_j(\mathsf{INT}_j(\Diamond\mathsf{BEL}^*_g \neg\varphi))$, a group intention can be setup such that $\mathsf{INT}^*_g((\mathsf{INT}_i(\Diamond\mathsf{BEL}^*_g \varphi))$ and $\mathsf{INT}^*_g((\mathsf{INT}_j(\Diamond\mathsf{BEL}^*_g \neg\varphi))$ so that the two sides will defend themselves against each other arguments to settle the inconsistency. On the other hand, conflict conditions occur in persuasive agents with two types of coordination strategy.

Dialog Turn. Given a special action halt_i to halt agent i to realize φ, ϕ_j as a conversation task with j, each agent should conform with $(\mathsf{INT}_i \phi_j \wedge \mathtt{InConversation}_j) \Rightarrow (\mathsf{INT}_i (\mathsf{Happens}(\mathsf{halt}_i \phi \mathcal{U} \neg\mathtt{InConversation}_j))$ where $i \in \mathcal{A}g^{comp}$.

Persuasive Conflict Resolution. A conflict can be resolved by introducing actions for dropping or abandoning one's desire or intention as follows. $\mathtt{drop\_int}_i(\varphi) \doteq \mathsf{INT}_i \varphi \wedge \mathsf{INT}_i \mathsf{Happens}(\mathtt{drop\_int}_i(\varphi)) \Rightarrow \bigcirc\neg\mathsf{INT}_i \varphi$ to drop i's intention of φ, and $\mathtt{drop\_des}_i(\varphi) \doteq \mathsf{DES}_i \varphi \wedge \mathsf{INT}_i \mathsf{Happens}(\mathtt{drop\_des}_i(\varphi)) \Rightarrow \bigcirc\neg\mathsf{DES}_i \varphi$ to drop i's desire of φ. In $\mathsf{WeakConflict}$, the agent with the goal that has the side effect to cancel the other goal should drop its intention, or $\mathsf{WeakConflict}_g \varphi \wedge \mathsf{INT}_j \Diamond\psi \wedge \mathsf{BEL}^*_g \mathsf{E}(\psi \Rightarrow \neg\varphi)) \Rightarrow \mathsf{INT}_j \mathsf{Happens}(\mathtt{drop\_int}(\psi))$. In the $\mathsf{StrongConflict}$ case, it is also possible to suspend one intention using previously defined halt action until there is no longer conflicting situation. In the $\mathsf{HardConflict}$ case it is more difficult to determine which agent should concede or abandon its goal.

4. TOWARDS THE FRAMEWORK

The theoretical model above shows that the coordination process may be handled by one or more members which makes groups of agents flexible and fluid. The model is made as the basis for multiagent coordination framework for aging-in-place smart-home system. The framework should comprise interaction protocols for agents that cover how and what to communicate between agents and with the human occupant. In any case, the main tenet in the framework is that if several agents want to work together, they need to share or infer each other mental states. Not every agent needs to know it all, but at least one member is aware about everybody else.

5. CONCLUSION

A logical model of coordination for pervasive heterogeneous agents that have persuasive tasks to intervene people attitudes or behaviors has been presented. The model is based on BDI logic to characterize agents and participants in the system with mental attitudes of belief, desire, and intention. A novel approach is applied to characterize the mental attitudes of a group of agents by aggregating all attitudes of the members in the group. With this aggregation model, the group or team can be viewed as an entity with its own mental attitudes which can also be reflected back to its member. Different types of conflict, inconsistency, and potential for cooperation are identified in this model. Some approaches for resolutions have been suggested to let the agents as members of the group to cooperate to resolve the conflict whenever they have the suitable capacity to cooperate. In this paper it is also suggested that the coordination process can be considered as the process of maintaining consistent views within the group while resolving conflicts as they occur.

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