# A Multipurpose Goal Model for Personalised Digital Coaching

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**Abstract.** Supporting human actors in daily living activities for improving health and wellbeing is a fundamental goal for assistive technology. The personalisation of the support provided by assistive technology in the form of digital coaching requires user models that handle potentially conflicting goals and motives. The aim of this research is to extend a motivational model implemented in an assistive technology, into a multipurpose motivational model for the human actor who is to be supported, which can be translated into a multipurpose goal model for a team of assistive agents. A team of assistive agents is outlined with supplementary goals following the human's different properties. A method for generating multipurpose arguments relating to different motives were developed, and implemented in a human-agent dialogue system. The results are exemplified based on a use case from an earlier pilot user study of the assistive technology. Future work includes user studies to validate the model.

**Keywords:** Personalisation · Motivation · Multiagent systems
Assistive technology · Argumentation · Persuasive technology
Behaviour change

## 1 Introduction

A number of systems for digital coaching have been developed for different purposes, in particular, for the purpose to increase physical exercise (e.g., [9,19,37,43]). They are typically focussed on one purpose, although the nature of humans' motivation and activity is complex [16,25,41]. Little research has been done with the aim to explore situations where multiple purposes, or goals may be relevant, and even less when different goals may be conflicting.

The purpose of the research presented in this paper is to explore multiple motives and driving forces behind human activity, and develop formal models of goals and motives as part of user modelling in order to enrich coaching for


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improving health and well-being. Research questions include how multiple potentially conflicting motives can be handled by a team of digital agents with different responsibilities and different knowledge domains, and how person-tailored multipurpose arguments can be composed to promote health in humans. The motive for why applying the more holistic method to generate arguments to be posed to the user is to target reasons to conduct activity that are *intrinsically* motivated, in terms of Self-Determination Theory (SDT) [41], and thereby more likely to be achieved. This way, motivation for some activities may reinforce other activities, and lead to a more sustainable behaviour change for the purpose to improve health.

The motivation for using multi-agent systems in our work is that this approach allows for modelling the conditions for reasoning and knowledge generation, in spite of ambiguous, uncertain and incomplete domain knowledge and knowledge about the user's situation. The agency of semi-autonomous software agents can be used for mixed-initiative collaborative reasoning and actions, involving also humans [42]. In addition, we anticipate that agent-based human-agent dialogues will facilitate the interaction design of more intuitive and natural dialogues between the user and the system. In particular, earlier studies with older adults (age 70 or older) participating in creating the content of digital coaching applications elicited the diverse range of trust in who or what they perceived being receiving their information [24]. We expect that the problem of transparency and trust in intelligent coaching applications that aim to support the human to change behaviour for improving health, can be addressed through clarifying the purpose of different co-operating software agents and what different sources of knowledge they utilise.

Based on humans' multiple properties and motives, we define a team of digital agents encompassing a range of goals and responsibilities to meet the needs of a human actor, which is presented in Sect. 2. A prototype mobile coaching application that aims to encourage older adults to increase their level of social and physical activity has been developed that includes a user model, which is further developed in this work into a multipurpose motivational model. The mobile application, a baseline assessment application and a dialogue application form the prototype system for personalised digital coaching, briefly introduced in Sect. 3. The proposed multipurpose motivational model is exemplified in Sect. 3.4 with a use case obtained in a user study presented in [23]. Strategies to select supporting arguments, and multipurpose arguments supporting different potentially conflicting motives are exemplified. The multipurpose motivational model is translated into a multipurpose goal model for orchestrating the personalised support by the team of agents with different goals and responsibilities, which is exemplified in Sect. 4. Related work is discussed in Sect. 5, and some conclusions and future work are summarised in Sect. 6.

## 2 Software Agents' Purposes, Roles and Instruments

Different roles of intelligent software agents have been targeted in research literature, e.g., *activity supporter* [2,3,21,22], *social and emotional supporter*

[10,39,54], *learning supporter* [50], *monitor of physical processes and environment* [17,21,35,38,44], *information mediator* [40] and *product promoter* [48]. Moreover, an agent may be assigned more than one role in the implementation of the different agent-based systems. A consequence of the different roles is that their motives may be in conflict, which requires that the agents have strategies to handle conflicting motives and preferences, while optimising the value of the support they provide to the human actor. In this section an analysis is presented of the different roles, which aim at proactively improving humans' health, well-being and activity performance. A summary of the roles and their properties is given in Table 1.

Our categorisation of roles of agents follows partly the functional domains of a human distinguished in the International Classification of Functioning, Disability and Health (ICF)[1], which provides an instrument for distinguishing each agent's domain of knowledge, responsibilities and prioritised goals. Another advantage is that a human actor is familiar with these domains and can relate to their different purposes, which facilitates cooperation. ICF categorises information into the following main categories: *Body Functions* and *Body Structures*, *Activity and Participation*, *Environmental Factors* (physical and social) and *Personal Factors*.

Since activity support is central to digital coaching, a generic *Activity Agent* is defined, along with activity agents targeting specific activity domains *Soc Agent*, *Bio Agent* and *Exercise Agent* (Table 1). The Activity Agent has a composite role, where for instance, the Activity Agent may be dependent on the other agents to provide the optimal support, considering the physical environment and the human actor's mental, physical and social resources. Other agents may be dedicated to focus on a subarea of another agent, such as the *Exercise Agent*, which is primarily focusing muscle strength and balance for reducing the risk for an older adult to fall. Following Activity Theory, *activity* is defined by its objective, and instruments are used for mediating the activity [25]. A *Physical Environment Agent* tracks the physical objects that are used as instruments in human activity in addition to environmental factors that affect activity such as weather and location [7].

To complement ICF, specific knowledge relating to the medical and health domains is included as instrument, utilised by agents with the role of *domain experts*. The medical and health-related qualified knowledge, which the health professionals are expected to possess, is knowledge that the human actor who is utilising the assistive technology is not expected possess, and possibly not yet the novice health professional. This knowledge is typically informally represented in medical guidelines, evidence-based medical sources, and medical terminologies and classifications. Therefore, the *Domain Expert Agent* plays a crucial role in agent-based medical decision-support systems, aiming at assisting and educating the clinician in the diagnostic procedure. Moreover, a team of domain expert agents with different domains of expertise could be useful to define for providing more reliable assessments. An important observation is that the knowledge

[1] http://www.who.int/classifications/icf/en/.

**Table 1.** The team of agents, their roles, responsibilities and examples of implementations presented in research literature.

| Name | Role | Motives | Responsibilities | Reference |
|---|---|---|---|---|
| Companion Agent | A friend, coach or discussion partner | Guard and monitor the user's interests, prioritised goals | 1. Recognise user's needs, goals, preferences; 2. Respond/act upon user's requests, needs and lack of goal satisfaction | [4,5,47,52] |
| Emo Agent | Monitor emotional health | Optimise positive experience and well-being | 1. Recognise, evaluate emotions, experiences 2. Maximise positive emotions, experiences | [10,36] |
| Activity Agent | Activity supporter | Optimise activity performance | 1. Recognise, evaluate activities, 2. Personalise activity support | [1,2,21,33] |
| Soc Agent | Monitor social environment | Organise the social resources and optimise social experience | 1. Recognise, evaluate social activities 2. Maximise positive social activities | [12] |
| Bio Agent | Monitor physical health | Organise and optimise the body/physiological resources | 1. Recognise, evaluate body signals and actions 2. Personalise support for rest vs. active life, day-night routines, food intake | [21,34,49] |
| Exercise Agent | Personal Trainer | Optimise strength and balance | 1. Recognise, evaluate strength and balance 2. Personalise physical exercise | [2,9,19,43] |
| Physical Environment Agent | Monitor physical environment | Organise and optimise the tools of activity | 1. Monitor the physical space and objects including the user's location 2. Personalise support for tool manipulation | [17,35,44] |
| Domain Expert Agent | Domain Expert | Contribute to reasoning and decision-making | Provide the expert's view on a situation | [46,53] |

utilised by the Domain Expert Agent necessarily needs to be developed and validated by domain experts.

A human actor possesses resources in the following basic domains: physical, cognitive, emotional, social and environmental. Activity requires composite resources we typically call knowledge, problem solving and (motor and process) skills, partly for utilising instruments in an efficient way [26]. These resources are taken into use by the human actor in the conduction of activity and in the case of limited personal resources, a team of agents may compensate for identified limitations. However, another key to activity performance is the person's well-being, motivation, and emotional resources in a particular situation. Therefore, we define also the *Emo Agent* to elicit the particular properties required to managing the emotion and experience-related personal factors of ICF.

Finally, we add to this set of agents the *Companion Agent* that maintains the holistic perspective on the human's situation, preferences, needs and prioritised activities. In addition to these purposes, the Companion Agent may need to act as an *orchestrator* of the other agents' potential proactive behaviour, since the Companion Agent should acknowledge the human actor's current motivational status and optimise the tailored support provided the human actor. The needs and wishes of a human actor are complex and are often conflicting, which is a reason to assign the Companion Agent, this task. Moreover, it acts as the primary mediator of support from all types of agents, for not confusing, or overloading the user with information. This will be illustrated in the following sections.

To summarise, the purposes and the roles of the agents are distinguished in our approach partly by what knowledge they access, and partly, what domain of interest they should govern related to the human's activity and situation.

## 3 A Prototype System for Personalised Digital Coaching

The prototype system HemmaVis was developed with the aim to support older adults in planning physical and social activities, and in evaluating these (Fig. 1) [23]. Older adults include people over the age of 70 and who are at risk of social exclusion and/or falling down. This system consists of three interactive modules: (i) a baseline web application for collecting information to be fed into the initial user model (HemmaVis); (ii) a mobile application that guides in every day activities (mHemmaVis); and (iii) a web-based human-agent dialogue application for elaborating on topics related to health (NejaVis).

The content of the modules, and the structure of the baseline and mobile applications were modelled using ACKTUS, a platform for developing knowledge-based systems [32]. The platform provides a core ontology based on ICF that is used for organising information into a semantic model that distinguishes between types of motives, motivation, activities, body functions and human capabilities.

The mobile application mHemmaVis reminds the user to plan activities, encourages with messages, and the user is given feedback on their performance. The modules HemmaVis and mHemmaVis were evaluated in a formative and qualitative pilot study with four older adults, and different aspects were studied regarding how a supportive application in the form of a personalised persuasive coach could be designed to increase motivation [23]. Based on the user study and the focus groups with young and older adults, the motivational model was further extended in this work. The purpose is to develop a method for aggregating *multipurpose arguments* for the user to increase physical and social activities that are based on the user's motivation to conduct the different activities. The model is also based on theories of human motivation (SDT) [41] and on Activity Theory [25]. The formalisation of the model and implementation is built on argumentation theory [15,51].

The encouraging messages provided by mHemmaVis in the user study were the result of workshops with older adults [24]. They were designed for being generic and suitable for a range of different physical and social activities. They were also primarily designed for giving feedback as a post reflection on a day's activities. In this work, we supplement these messages with motivational person-tailored arguments, primarily aimed at encouraging the person to conduct an activity as planned. Feedback messages of a more argumentative type were created, also using ACKTUS and its ontology.

The human-agent dialogue system NejaVis provides the initial implementation of a Companion Agent that utilises such arguments, and complements the baseline assessment and the mobile application by allowing the human to select a topic to be discussed relating to his/her situation. Conclusions are collaboratively drawn through nested argumentation-based dialogues about a condition and about what to do about the situation. If there are disagreements about what to do, the agent will argue to persuade the human to follow earlier stated priorities. NejaVis uses the baseline information, but will update and extend this information during the dialogues.

In the following subsections we present the baseline assessment that generates the initial user model, and the dialogue application that implements different types of argumentation-based dialogues using tailored multipurpose arguments.

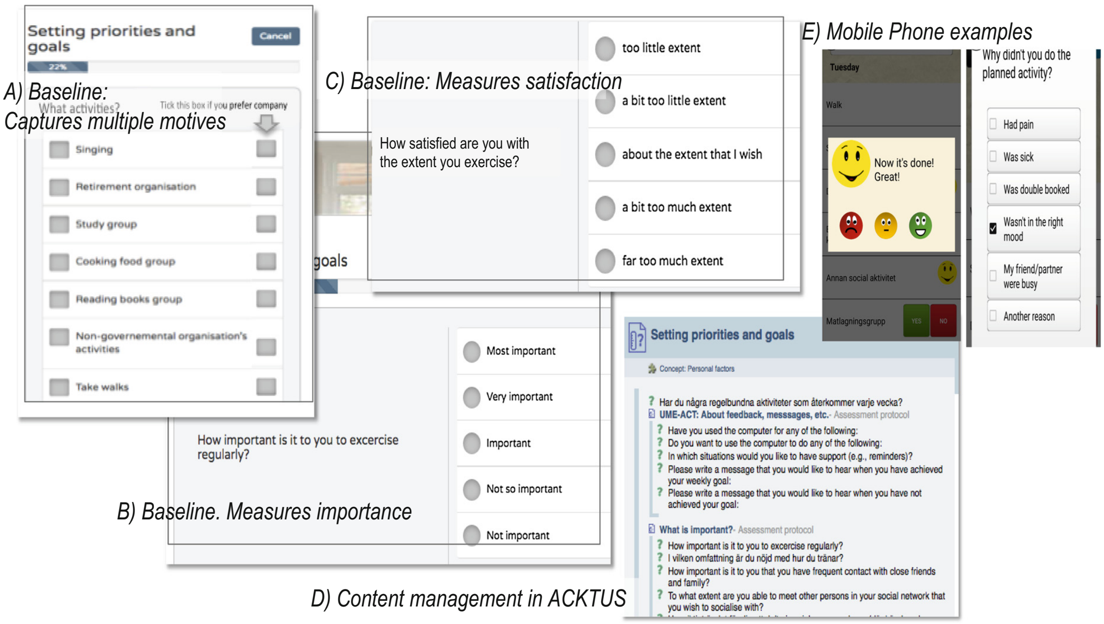


**Fig. 1.** Screenshots from the baseline application, the mobile application and the content management system ACKTUS.

### 3.1 Baseline Assessment for Creating the Motivational Model

At baseline the user provides information about how important different kinds of activities are (Fig. 1). This information forms a base for a motivational model, as an extension to the user model [23,28,29].

The categories of *motives* or *needs* that direct human activity, following the terminology of Activity Theory [25], are based on earlier studies involving a group of older adults [27]. These are the following:

(i) being part of, and maintaining a social network,
(ii) being part of society,
(iii) maintaining physical strength and physical health,
(iv) maintaining mental health,
(v) performing activities of one's choice,
(vi) having fun and being entertained,
(vii) feeling safe and secure.

Notably, Motives (i)–(vi) correspond to the purposes of the different agents, described in Table 1, while Motive (vii) should be a common goal for all agents. Questions about activities relating to these motives are integrated as part of the baseline assessment. The human specifies for each category of activity the following:

1. **Importance:** the degree of importance to the client following a five item scale ranging from *not important* to *most important* (Fig. 1B),
2. **Satisfaction:** to which extent the activity is currently being performed in a satisfactory way. The categories of degrees relate to satisfactory or not satisfactory, here distinguished between *too extensively*, or *too little* (Fig. 1C),
3. **Intervention:** whether or not the client wants to have support from assistive technology to manage the activity, and thereby define a goal relating to this activity.

The user's motivation for different activities is captured by the set of questions posed at baseline where they rank the importance, and their satisfaction with their performance. The levels of importance and satisfaction are translated into a measure of *weight*, which is used in the agent's prioritisation of actions, including selection of argument to pose to the human in a dialogue (see further Sect. 4). This information is aggregated into a generic user model, see example in Table 4. In a specific situation when focusing a certain activity, a multipurpose motivational model is aggregated that relates to the situation, and that includes degrees of importance and different potentially conflicting motives and goals. This is done by applying strategies for inclusion of relevant motives and goals, and ranking these (further described in the Sects. 3.4 and 4).

### 3.2 Agent Model Implemented in the Human-Agent Dialogue System

The agent model includes goals, priorities, responsibilities, role(s) and knowledge, which contributes to a cognitive agent architecture [4] that implements the BDI

(Belief, Desire, Intention) framework [14]. In brief, a set of *Beliefs* represents the agent's knowledge, *Desires* are the agent's goals, and *Intentions* are the agent's plans of action. The belief and desire properties of agents are described in this section, and intentions, or plans, will be briefly introduced in the following section (Sect. 3.3). The agent architecture is implemented in the human-agent dialogue system NejaVis, which functions as a module in the ACKTUS-based HemmaVis architecture, and which illustrates the Companion Agent.

A separate project for modelling the agents was created by using the ACKTUS platform [32] including the ACKTUS core ontology, which is shared between ACKTUS applications. The agent knowledge repository was built using the ACKTUS core ontology and extended to include the different roles and social knowledge relating to the different kinds of human-agent dialogues, which is shared by the different agents. The agent-specific knowledge repository and the domain-specific knowledge bases are represented using the Resource Description Framework (RDF)[2] and Web Ontology Language (OWL)[3], and function as the common vocabulary in the dialogues.

Each instantiated agent stores its specific learnt knowledge in an *actor repository*, along with the dialogue lines. The following is an example of how the companion agent NejaVis presented in this article is defined in the actor repository:

```
<rdf:Description rdf:about="http://www.cs...na/owl-files/
    ACKTUS.owl#nejavis">
 <rdf:type rdf:resource="http://www.w3.org/2000/01/rdf-schema
     #Resource"/>
 <rdf:type rdf:resource="http://www.cs...na/owl-files/ACKTUS.
     owl#companion-agent"/>
 <ACKTUS:has-name>NejaVis</ACKTUS:has-name>
 <ACKTUS:has-role>companion-agent</ACKTUS:has-role>
</rdf:Description>
```

The agent utilises different domain-specific knowledge bases as instruments depending on its role. In the ACKTUS knowledge bases, domain expert knowledge utilised by the Domain Expert Agent is distinguished by its association to the argument scheme *Argument from Expert Opinion* [51], or more specific medical schemes. In argumentation literature the notion of *argument scheme* is applied for providing semi-formal or formal templates and defeasible inference rules for different kinds of dialogues [51]. An argumentation scheme is defined as a generic patterns of reasoning, and is instantiated by computable arguments, e.g., following the Argument Interchange Format (AIF), which is the approach taken in our research [15].

Knowledge that is considered as more generic knowledge is associated in our research to the argumentation scheme *Argument from Position to Know*. This type of knowledge is accessed by the other agents in Table 1. In addition, knowledge that is associated to the argumentation scheme *Argument from Observation* is used by the agents that take in information from wearable sensors e.g., the Bio Agent or sensors in the environment e.g., the Physical Environment Agent.

[2] http://www.w3.org/RDF/.
[3] http://www.w3.org/OWL/.

Consequently, several agents can access the same domain knowledge repository but each is restricted to a sub-set of the knowledge, tailored to its role. Moreover, a particular agent may have access to more than one knowledge repository. NejaVis has in the example presented in this paper access to two particular domain-specific knowledge bases: *ACKTUS-Dementia* [31] and *ACKTUS-Rehab* [30].

### 3.3 Personalised Digital Coaching Through Argument-Based Dialogues

Each of the five types of dialogue implemented in NejaVis has a goal in relation to the topic of a dialogue [6] (Table 2). *Information-seeking* dialogues seek new information that can be base for arguments; *inquiry* dialogues aim to generate new knowledge through conclusions about situations; *deliberation* dialogues aim to generate a plan of action to alter the situation; *persuasive* dialogues aim to change attitudes, in our approach the attitude is represented by the value, or weight a person assigns a motive or condition; and *support* dialogues aim to reinforce the human's capacity (autonomy, relatedness and competence).

**Table 2.** Dialogue types and their characteristics. The topic is drawn from the ACKTUS repositories, using the semantic characteristics of the knowledge nodes.

| Type | Goal | Topic | Valid moves |
|---|---|---|---|
| Information-seeking | Collect information | *concept* | Open, ask, tell, affirm, close |
| Inquiry | Create new knowledge in the form of defeasible facts or defeasible rules | *i-node* (defeasible fact) or *s-node* (defeasible rule) | Open, assert, believe, affirm, close |
| Deliberation | Decide about actions to be taken | *i-node* (defeasible fact) or *s-node* (defeasible rule) | Open, assert, believe, affirm, close |
| Persuasion | Change a priority or belief | *i-node* (defeasible fact) or *s-node* (defeasible rule), in particular their *value* as a part of a *scale* | Open, assert, believe, affirm, remind, close |
| Support | Enhance human agent's ability | *information-node* or *conclusion* | Open, affirm, tell, alert, remind, close |

The *topic* of a dialogue is retrieved from a domain ontology based on the ACKTUS core ontology, which incorporates both the Argument Interchange Format (AIF) [15] and the domain knowledge, structured based on primarily ICF. AIF distinguishes between *i-node*, a kind of information node, which forms statements; and *s-node* (scheme-node), from which arguments are generated.

These two types of nodes are used as topic in inquiry, deliberation and persuasion dialogues, with some differences (Table 2). In our approach an i-node is associated to a *concept* to identify the topic, and to a *value*. The formal distinction made in this approach between the inquiry and deliberation dialogues is that the *claim*, i.e., i-node, is in deliberation dialogues associated to a concept related to the ICF-node *Activity and Participation* in the domain ontology (e.g., *Taking a walk*), while in the inquiry dialogues the concept is a node different from the activity and participation branch of the ontology (e.g., *Pain condition*). Persuasive dialogues can have both kinds, since the focus is the *evaluation of* the phenomenon represented by the concept. This evaluation is represented by its *value* (e.g., status of an activity, or degree of importance of a motive), which is targeted to be changed. This can be to change the status of a planned activity from *not initiated*, to *initiated* (example about taking a walk in Table 6), or the attitude towards managing a pain condition that causes trouble in daily life from *not important* to *very important*.

i-nodes are treated as *statements* in the dialogue, and *literals* in the logic implemented in the dialogue system. Formally, we treat the i-nodes that are associated to a value as predicates of the form $\alpha$. Rules extracted from the s-nodes that build the arguments, are formally defined as follows: $\alpha_1 \wedge \cdots \wedge \alpha_n \rightarrow \alpha_0$ where $\alpha_i$ is a literal. The rules together with defeasible facts (statements) fulfilling premises of the rules are used for building arguments of the form $(G, \alpha)$, where $\alpha$ is the claim and G is the support, or grounds for the claim, consisting of rules and facts. An argument is posed in the dialogue with an *assert* move (see examples in Table 6). In order to build arguments, it is assumed that at least one rule exists in the knowledge base for the agent to fetch during the dialogue, which has the dialogue topic or claim ($\alpha$) as the conclusion. If a question posed by an *ask* move in an information-seeking dialogue gives the required answer to fulfil the premise, this new fact and the rule form the grounds ($G$) for the conclusion $\alpha$ (e.g., Fig. 2).

Attacks by the human on arguments are identified by a disagreeing response given by the human to the question posed by the agent using the *believe* move (example in Fig. 2). This disagreement is typically respected, and the agent's argument is considered defeated. However, if the human disagrees on an advice about what to do about a troublesome condition, the Companion Agent can initiate a persuasive dialogue trying to convince the human to take action, such as contacting the nurse about a pain condition. If the human supports the argument, the argument is considered accepted and validated.

The complete list of dialogue moves is presented in Table 3. Formally, a *dialogue move* for the human or software agent is a tuple $(t, a, m)$ where $t$ is time point of the dialogue move, $a$ is the agent and $m$ is the dialogue move. The *Open* move is the first action carried out to initiate a dialogue, and the *Close* move is used for closing, or stating the end of a dialogue. In our implementation, the human initiates the first dialogue, while the agent initiates all sub-dialogues. Moreover, we limit the type of dialogues to *asymmetric* dialogues, where the human is not providing own claims, only responding to questions. The *Assert*

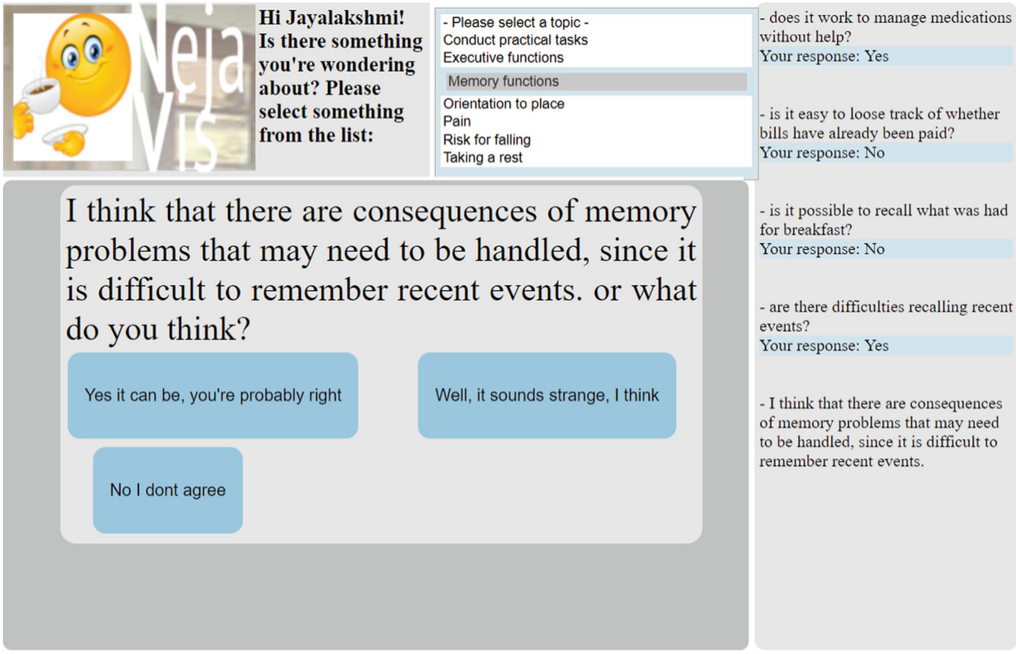


**Fig. 2.** Screenshot from the human-agent dialogue system (NejaVis). The topic of dialogue selected by the user is "Memory functions". The agent initiates an inquiry dialogue on the topic and after a few nested information-seeking dialogue moves, the agent poses its first argument and a *believe* move. The human can then agree or disagree to this argument as response. If the human agrees, the next step would be to initiate a deliberation dialogue to decide what to do about the situation. The dialogue line is visible on the right side.

move is used for making a claim about some topic, and it is supported by the set of grounds on which the claim is being based. The claim is a defeasible fact. The *Believe* move is a particular question posed together with an assert move for investigating if the other agent agrees upon the claim, stated in the assert move. The response is given by a tell move and can be to agree, disagree or being uncertain in our implementation (Fig. 2). In the dialogues between agents exemplified in Sect. 4, the types of moves are limited to *open*, *close* and *assert*.

A *dialogue line* is the sequence of moves conducted by the agents and their time points (e.g., [11]). The Companion Agent stores dialogue lines in its repository in order to continue at a later occasion when a dialogue may have been paused. Such sequence is visible in the examples presented in Fig. 2 and Table 6. The following is an excerpt from the actor repository, stored by companion agent during the running example shown in Fig. 2:

```
<rdf:Description rdf:about="http://www.cs...na/owl-files/
    ACKTUS.owl#event25-06-2017_13:19:00">
 <rdf:type rdf:resource="http://www.w3.org/2000/01/rdf-schema
     #Resource"/>
 <rdf:type rdf:resource="http://www.cs...na/owl-files/ACKTUS.
     owl#event_1430412506833"/>
 <ACKTUS:has-date>25-06-2017</ACKTUS:has-date>
```

```
 <ACKTUS:has-start-time>13:19:00</ACKTUS:has-start-time>
 <ACKTUS:has-dialogueType>infoseeking dialogue</ACKTUS:has-
    dialogueType>
 <ACKTUS:has-dialogueTopic>Concept1299070752573</ACKTUS:has-
    dialogueTopic>
 <ACKTUS:has-evidence>does it work to manage medications
    without help?---Yes</ACKTUS:has-evidence>
.
.
.
</rdf:Description>
```


**The Agent's Planning During a Dialogue:** The Companion Agent implemented in NejaVis retrieves the set of information that relates to the topic selected by the human, and creates a plan based on the human's preference order of the topics. At each step in a dialogue when receiving new information from the human, the agent analyses the information, decides whether to continue the current dialogue, pause it for opening a new sub-dialogue, or close the dialogue to possibly start a new dialogue. After this, the agent either abandons the current plan to make a new plan, or adjusts the current plan.

The content of the plan is different depending on the type of dialogue. In the case of information-seeking dialogues, the plan contains a set of questions

**Table 3.** Valid actions, i.e., moves and their formats. All moves contain the time identifier $t_n$, and the identification of the agent $a_i$, which performs the move.

| Move | Form | Comment |
|---|---|---|
| Open | $(t_n, a_i, open(d_o, \alpha_m))$ | $d_o$ is the dialogue type, $\alpha_m$ is the topic of a dialogue |
| Close | $(t_n, a_i, close(d_o, \alpha_m))$ | $\alpha_m$ is the topic of a dialogue |
| Ask | $(t_n, a_i, ask(CQ))$ | $CQ$ is a structured question |
| Affirm | $(t_n, a_i, affirm(\alpha_m))$ | $\alpha_m$ is an expression reinforcing the previous statement |
| Tell | $(t_n, a_i, tell(\alpha_m))$ | $\alpha_m$ is the message, typically an advice or information |
| Remind | $(t_n, a_i, remind((\alpha_m, G), a_j))$ | $\alpha_m$ is the reminder, $G$ is the set of reasons for the reminder, and $a_j$ is the agent targeted for the reminder |
| Alert | $(t_n, a_i, alert((\alpha_m, G), a_j, t_l))$ | $t_l$ is the timeout for the action |
| Assert | $(t_n, a_i, assert(\alpha_m, G, (\beta, g_m)))$ | $\alpha_m$ is the claim, $G$ is the set of grounds for the claim, $\beta$ is the weight related to the motive $g_m$ |
| Believe | $(t_n, a_i, believe(\alpha_m, CQ))$ | $\alpha_m$ is the claim or message and CQ is a structured question |

(outcome is answers); in inquiry dialogues the plan contains either a set of defeasible rules or facts (outcome is arguments or new knowledge); in the case of a deliberation dialogue the plan contains a set of potential actions to be decided upon (outcome is actions agreed upon); and in the persuasion dialogues the plan contains a set of statements and arguments related to the dialogue goal, which may be used in a persuasive argumentation dialogue (outcome is a change of priority or belief).

### 3.4 Multipurpose Motivational Arguments

Motivational arguments for conducting a particular activity can be augmented with different weights, based on how the user rated the importance and satisfaction of the underlying motive. In the multipurpose motivational model these different arguments are used for aggregating strength for conducting a particular activity, by using the strength of arguments promoting other motives. For space reasons, we omit the potential counter-arguments *against* conducting a particular activity, e.g., $Arg_{2a}$ in Table 5. However, in future work, these need also to be weighted, included and evaluated in the dialogues with the human, since these also affect the human's decision-making.

The generation of arguments relating to specific domains is the task of the agent that is responsible for managing activities that aim to fulfil the particular motive and related knowledge (Tables 4 and 5): the Emo Agent for Motive $g_1$; the Soc Agent for the second motive $g_2$ and the Bio Agent and Exercise Agent for Motive $g_3$ and its sub-goals. The Activity Agent monitors the generic every day activities that fulfil the last motive $g_4$. The Companion Agent coordinates the generation of multipurpose arguments.

**Table 4.** The generic user model for a particular person that is translated into a multipurpose motivational model for a particular activity, such as taking a walk.

| $g_i$ | Motive | Goal Rank | Importance: 0–4 | Satisfaction | Motivation |
|---|---|---|---|---|---|
| $g_1$ | Have fun, feel good | 1 | 4: Most important | 4: Too little | intrinsic |
| $g_2$ | Maintain social network | 1 | 4: Most important | 4: Too little | intrinsic |
| $g_3$ | Maintain physical capacity and health | 3 | 2: Not that important | 3: Bit too little | extrinsic |
| $g_{3a}$ | Minimise pain | 2 | 3: Important | 4: Too little | intrinsic |
| $g_4$ | Managing "musts", e.g., personal economy | 3 | 2: Not that important | 3: Bit too little | extrinsic |

Multipurpose arguments are formed (examples in Table 5) that use person-specific information about the different activities (Table 4). The strength of arguments is generated based on the user's rated importance and satisfaction levels corresponding to the Goal Rank in Table 4. Optimal weight of an argument is 1. The average weight is calculated in the following examples of combining arguments into multipurpose arguments. The weight together with broad goal

**Table 5.** Argument examples applied to the situation to decide whether to take a walk. An argument's weight $\beta$ is based on Goal Rank in Table 4, and 1 is the optimal weight.

| $Arg_i$ | Argument components | Motive $g_j$ | $\beta$ |
|---|---|---|---|
| $Arg_1$ | $G_1$: *Taking walks maintains physical capability, you value maintaining physical capability as important*, therefore, $\alpha_0$: *take the walk* | $g_3$: Maintain physical capacity and health | 3 |
| $Arg_{2a}$ | $G_2a$: *It is painful to walk, therefore, not* $\alpha_0$*: Do not take the walk* | $g_{3a}$: Minimise pain | 2 |
| $Arg_{2b}$ | $G_2$: *Walking reduces pain after the walk is done, you value minimising pain as very important*, therefore, $\alpha_0$: *take the walk* | $g_{3a}$: Minimise pain | 2 |
| $Arg_3$ | $G_3$: *Taking walks maintains physical capability, you value maintaining physical capability as important, Walking reduces pain after the walk is done, you value minimising pain as very important*, therefore, $\alpha_0$: *take the walk.* ($Arg_1$, $Arg_{2b}$) | $g_3$: Maintain physical capacity and health; $g_{3a}$: Minimise pain | 2.5 |
| $Arg_4$ | $G_4$: *Be physically active because this is the norm, you value managing "musts" as important*, therefore, $\alpha_0$: *take the walk* | $g_4$: Managing "musts" | 3 |
| $Arg_5$ | $G_5$: *Conducting activity with friends increases joy, you value having fun and feeling good as most important*, therefore, $\alpha_1$: *contact a friend to join the activity* | $g_1$: Have fun and feel good | 1 |
| $Arg_6$ | $G_6$: *Conducting activity together with others maintains social network, you value maintaining social network as most important*, therefore, $\alpha_1$: *contact a friend to join the activity* | $g_2$: Maintain social network | 1 |
| $Arg_7$ | $G_7$: *Conducting activity with friends increases joy, you value having fun and feeling good as most important, Conducting activity together with others maintains social network, you value maintaining social network as most important*, therefore, $\alpha_1$: *contact a friend to join the activity* | $g_1$: Have fun and feel good; $g_2$: Maintain social network | 1 |
| $Arg_8$ | $G_8$: *Conducting activity with friends increases joy, you value having fun and feeling good as most important, Conducting activity together with others maintains social network, you value maintaining social network as most important, Walking reduces pain after the walk is done, you value minimising pain as very important*, therefore, $\alpha_{0,1}$: *contact a friend to join the activity and take the walk.* ($Arg_5$, $Arg_6$, $Arg_{2b}$) | $g_1$: Have fun and feel good; $g_2$: Maintain social network; $g_{3a}$: Minimise pain | 1.3 |

satisfaction are used for evaluating arguments and to find the best argument in a persuasive dialogue with the human.

The following are three potential strategies for building arguments (Strategies 1–3 in Table 6):

1. Combine different arguments that are specifically targeting the motive that is ranked as most relevant in relation to the activity in focus,
2. Combine different arguments that are directly targeting the activity in focus regardless motive, or
3. Merge motives and generate multi-purpose arguments that are directly or indirectly targeting the activity in focus.

If the first strategy is applied in our example of taking a walk, the Companion Agent involves only the Bio Agent and Exercise Agent in the orchestration of generating optimal response. In the third approach, the Companion Agent needs to involve also the Emo Agent and Soc Agent, to be able to aggregate the multipurpose arguments that meet the human's highest ranked motives. In the following section this example is extended to involve a team of agents orchestrated by the Companion Agent.

## 4 Orchestrating a Team of Agents with Different Goals

In this section we outline how the Companion Agent translates the multipurpose motivational model for the human actor in a certain situation into a *multipurpose goal model* for the agent team when orchestrating the team of agents for the purpose to optimise the support to the human.

The agents' communication process to coordinate activities is based on the agent model presented in Sect. 3.2 that includes their shared *vocabulary* in the form of a formal ontology, and a set of *strategies*, or *heuristics* that the agents agree upon. The strategies regard how to collaboratively find the best action

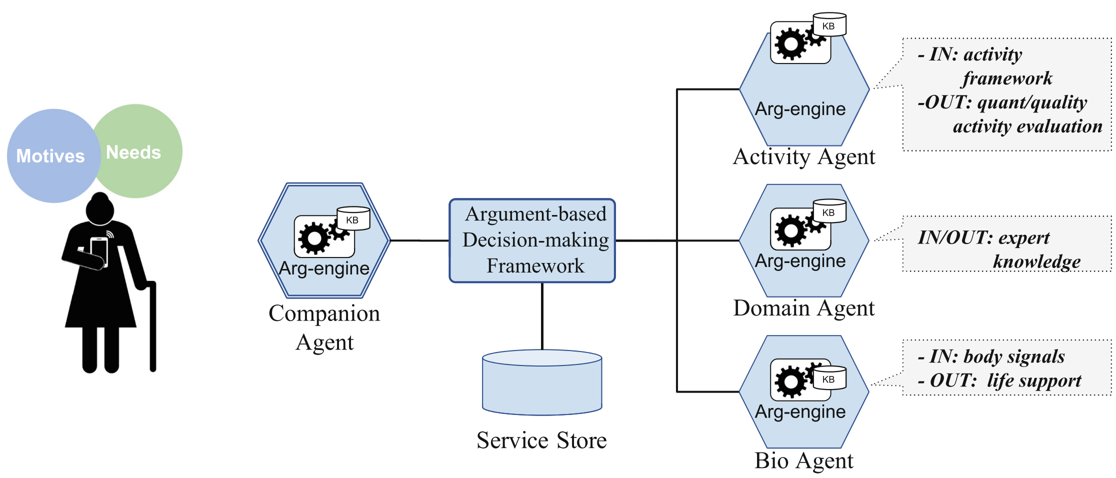


**Fig. 3.** Multiple agents being orchestrated by a Companion Agent.

to make in a given situation to provide support to the person. These strategies form a decision-making framework based on argumentation (Argument-based decision-making framework module in Fig. 3). In this paper, we extend the notion of deliberative argumentation dialogues introduced in [35] to centralise the decision-making process into the Companion Agent by updating goal priorities of a *commitment store* $CS$ and by adding a *service store* $SS$ with the selected best actions following a different ranking based on current situation. In the agent's topology shown in Fig. 3, we assume a broadcasting operation of the communications using a publish-subscribe communication pattern.

Along the entire dialogue-based communication, every agent updates their commitment stores. In this setting, the process for updating services in the $SS$ is performed by the Companion Agent by re-ranking potential services according to user preferences through aggregating multipurpose arguments.

The Companion Agent (CA) initiates a deliberation dialogue (dd) with relevant agents based on the status of a planned activity item part of the plan of action that was agreed upon between the human and the Companion Agent, and that has not been initiated at a particular pre-defined time point: ⟨*Taking a walk, Today, Not initiated*⟩, associated to the motive *Maintain physical capacity and health* defined in our ontology. The dialogue follows the structure introduced in Sect. 3.3, but limits the types of moves to *open*, *assert* and *close*. The outcome of a dialogue that follows the first strategy introduced in Sect. 3.4, to focus only on information relevant to the motive directly associated to the activity, would unfold as the first 1–4 moves in Table 6 and end with a conclusion based on the weights of the two relevant arguments $Arg_1$ and $Arg_2$, which would be $Arg_3$ in Table 6.

**Table 6.** Example of an orchestrated dialogue where the Moves 1–4 follows Strategy 1, Move 5 is added if applying Strategy 2, and Moves 5–9 are added if Strategy 3 is applied.

| $t_i$ | Agent | Argument | Move | $SS$ |
|---|---|---|---|---|
| 1 | CA | $\alpha_0$: *Taking a walk*, $value_0$: *Not initiated* | $(t_1, a_1, open(dd_1, (\alpha_0, value_0)))$ | |
| 2 | ExA | $Arg_1$ | $(t_2, a_2, assert(G_1, \alpha_0, (3, g_3))$ | |
| 3 | BA | $Arg_2$ | $(t_3, a_3, assert(G_2, \alpha_0, (2, g_{3a}))$ | |
| 4 | CA | $Arg_3$ | $(t_8, a_1, assert(G_3, \alpha_0, (2.5, g_3))$ | $Arg_3$ |
| 5 | AA | $Arg_4$ | $(t_5, a_4, assert(G_4, \alpha_0, (3, g_4))$ | $Arg_3$ |
| 6 | EmA | $Arg_5$ | $(t_6, a_5, assert(G_5, \alpha_1, (1, g_1))$ | |
| 7 | SA | $Arg_6$ | $(t_7, a_6, assert(G_6, \alpha_1, (1, g_2))$ | |
| 8 | CA | $Arg_7$ | $(t_8, a_1, assert(G_7, \alpha_1, (1, g_{1,2}))$ | |
| 9 | CA | $Arg_8$ | $(t_9, a_1, assert(G_8, \alpha_{0,1}, (1.3, g_{1-3}))$ | $Arg_8$, $Arg_3$ |
| 10–14 | ALL | close | $(t_6, a_{1-5}, close(dd_1, (\alpha_0, value_0)))$ | |

If the second strategy would be applied where the activity is in focus, then also Move 5 that targets taking a walk would be considered. However, the outcome would remain the same in our example. If the third strategy presented in Sect. 3.4 would be applied, the Companion agent would engage additional agents that contribute with arguments targeting activity at a more general level. Then the dialogue may continue with the moves 6–9 in the example in Table 6.

Consequently, the Companion Agent can aggregate multipurpose arguments using different decision-making strategies. To maximise the weight of an argument, the average needs to be as low as possible. The support for the decision to pose the recommendation to take the walk would be strongest if the argument only contains the reminder about the pain issue (weight = 2). If all grounds are applied that target the activity in focus ($G_1$, $G_2$, $G_4$), the weight would be 2.67 and may actually have the opposite effect on the human, i.e., decrease motivation.

If instead the strategy is to maximise the weight, then only the arguments provided by the Emo Agent and the Soc Agent would be posed to the human (weight = 1). This may shift the focus of the human from the pain condition, and the semi-motivation for exercise in general, towards something valued as significantly more important to the person. However, then the agent will loose the activity in focus as topic, and the effect may be that the person conducts a completely different activity.

Based on this analysis, the shared decision-making strategy in our approach is therefore based on that the Companion Agent follows the procedure presented in List 1, and that the other agents agree on the procedure and evaluation criteria.

Finally, as results of the orchestration process, the Companion Agent has a holistic perspective on the individual's current situation, and a ranked set of situated actions that the agent can take on behalf of the team of agents part of the multiagent system. These actions and their new ranking are stored in $SS$ ($Arg_8$, $Arg_3$). Since $Arg_5$-$Arg_7$ are not targeting the activity in focus, these are not options stored in $SS$. However, by considering them as part of the deliberation dialogue, they have contributed with persuasive content to the activity in focus. Consequently, four of the five agents (CA, BiA, EmA, SoA) have contributed to selecting the best action for persuading the person to conduct the particular planned activity. In our example, the actions are persuasive arguments to motivate the human to follow though with her/his plan of actions to improve her/his health.

The Companion Agent's next step would be to select a time point suitable to remind the person about the planned activity and initiate a composite dialogue consisting of the reminder, motivating messages to support the activity initiation, and persuasion using the top ranked argument among the arguments generated by the team of agents. In case the human decides anyway to not initiate the activity as planned, an information-seeking dialogue can be initiated to investigate the reasons (could be change of attitudes, increased pain, etc.), and a deliberation dialogue to make a new plan can be conducted.

**Orchestration steps (List 1):** The Companion Agent's steps to orchestrate a deliberation dialogue to decide the agent's optimal next move in a persuasive dialogue with a human.

1 CA identifies the *Activity in focus* that has not been initiated as planned.
2 CA identifies the Motive behind the *Activity in focus*.
3 CA identifies the agents responsible for the *Motive*.
4 CA initiates a deliberation dialogue using an opening move: $\langle CA, open\ (d, \langle \alpha_0, (\beta, g)\rangle)\rangle$.
5 Agents make moves targeting both *Motive* and *Activity in Focus*: $\langle a_i, assert\ (\langle G, \alpha_j, (\beta, g)\rangle)\rangle$
6 CA merges motives and generates multi-purpose arguments targeting both *Motive* and *Activity in focus*.
7 CA evaluates the arguments based on Motive, selects the best argument and stores this in $SS$.
8 Additional agents contribute with arguments targeting the *Activity in focus* regardless motive: $\langle a_i, assert\ (\langle G, \alpha_j, (\beta, g)\rangle)\rangle$.
9 CA merges motives and generates multi-purpose arguments targeting the Activity in focus.
10 CA evaluates the arguments based on the *Activity in focus*, selects the best argument and stores this in $SS$ if not stored before.
11 Additional agents contribute with arguments targeting any motive and activity at a more general level: $\langle a_i, assert\ (\langle G, \alpha_j, (\beta, g)\rangle)\rangle$.
12 CA merges motives and generates multi-purpose arguments targeting activity at a more general level.
13 CA evaluates the arguments based on the Activity in focus in combination with the most high-ranked Motives above a threshold, and stores this in $SS$ if not stored before.
14 All agents make a close move to end the dialogue: $\langle a_{i-n}, close, (d, \langle \alpha_0, (\beta, g)\rangle)\rangle$.

## 5 Related Work

The coordination of teams of agents with different roles has been explored in decision making in medical contexts, e.g. regarding organ viability [46], and in ambient assisted living (AAL) (e.g. [17]). In the example of organ transplantation, the task follows treatment protocols defined for the domain to reach an optimal medical decision, and is as such constrained by the relevant medical knowledge. A moderator agent has the role of making the final decision, in case of conflicting opinions among the agents. It is not clear whether this agent is a physician, in order to assign the responsibility of the medical decision to a human. In the AAL project [17], the task to be conducted has also been primarily defined from the care provider organizations perspective, that is, to deliver certain care services, without taking a holistic perspective on the human actor's motives and goals into consideration. When addressing person-adaptive systems that aim to promote changes in behavior towards more healthy living, the holistic and situated perspective on human activity similar to what therapists aim for, is instrumental [37,41]. Along the theme to support professionals in the health domain, a multi-agent system for primarily supporting occupational therapists is presented, which includes a method to also involve the patient [13]. However, to our knowledge, there is no system that handles the complexity and uncertainty of human reasoning using agents with multiple and potentially conflicting roles, all with the purpose to adhere to the human's intentions.

Several generic platforms and methodologies for creating multi-agent systems have been developed [8,20,45]. Some of these approaches simply support the creation and interaction of agents such as JADE [8]. However, for our requirements, to develop a multi-agent system with the human as one of the actors, in the healthcare domain, key concepts such as norms, knowledge base and agent roles, are significant. The initial version of the Tropos methodology [20] was focused on supporting the agent development life cycle; however, it does not support the concept of norms. In an enhanced version of Tropos by Telang [45], commitments represent contracts between actors however, they do not establish limits on their behaviours. In addition, it is to be noted that social relationship contracts are only partially supported. Similarly, JADE allows the execution of agents in mobile devices but requires using specific libraries that are only available for certain platforms such as Android or J2ME (Java 2 Micro Edition). In addition, it lacks the support for the development of virtual organization with norms etc. Other approaches to MAS such as PANGEA [13,55] can be used for our purposes since they permit the creation of virtual organizations with key concepts such as norms and roles. However, for the purpose of prototyping, we focus on the agents modeling and development based on Java with communication based on the exchange of JSON messages between the human and software agent. Their utilization of the ACKTUS knowledge bases are also instrumental in our approach.

## 6 Conclusions and Future Work

A multipurpose motivational model that captures potentially conflicting motives for social and physical activity is presented. This model is used by a Companion Agent that transforms the information into a multipurpose goal model for orchestrating a team of agents with different goals and responsibilities. The agent team provides personalized support in the form of encouraging arguments tailored to the human actor's situation and motivation.

The results include also further development of the prototype application for personalized coaching. Questions were added that are posed to the user at baseline for capturing the aspects illuminated in the user studies, and feedback messages were added suitable for multipurpose arguments, following what the participants in the studies expressed.

Ongoing work includes the formalisation of the multipurpose motivational model and the agent team's goals, and implementation based on methods for formal argumentation such as answer set programming for handling the uncertainty and strengths in multipurpose arguments.

The results will be evaluated in studies with a group of older adults using the coaching application during a longer period of time.

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