







Design Principles and Action Reflection for Agent-Based Assistive Technology

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Abstract. This paper is aimed at formalizing the interplay among a person to be assisted, an assistive agent-based software, and a caregiver. We propose general principles for designing the interplay between a person to be assisted and an agent based on formal argumentation theory to characterize the agent's reasoning processes. These principles emerge from a novel perspective to understand assistive technology using the concept of zone of proximal development (ZPD) from social sciences. ZPD can be understood as a measurement of activity development, comparing what a person can perform with or without external help. We characterize a rational agent in four ZPD zones: (I) independent activity execution, agent takes no action; (II) ZPD_H : a person supported by another person, agent takes no action; (III) ZPD_S : a person is supported by an agent; and (IV) ZPD_{H+S} : a person is supported by a caregiver and a software agent at the same time. An algorithm was developed for the agent to reason about the actions to be selected in different situations, based on formal argumentation theory for allowing non-monotonic reasoning. The formal models and algorithm were implemented in a prototype system using augmented reality as interface. Future work includes evaluating the principles and algorithm in actual use situations.

Keywords: Argumentation theory · Rational agents · Assistive technology · Human activity · Activity theory

1 Introduction

Intelligent *assistive technology* (AT) is an umbrella of artificial intelligence-based machinery, that in general, is able to observe and reason about appropriate and tailored support to individuals [24]. An AT may have different aims, as an *assurance system*, *compensation system* or as an *assessment system* [31]. No matter what the *assistive goal* is, the internal machinery of an intelligent AT should

reason about: (1) the client-caregiver interaction¹; and (2) the context where the AT service is provided. Moreover, the AT system should generate consistent services, as *outputs* of the intelligent system. In contrast to AT provision based on artificial intelligence, public AT service provision is regulated by policies, procedures and approaches, being part of different national or regional health care and welfare systems [39].

In the *deductive systems*[26] literature as part of AI, different effort have been developed to provide formal principles of a deductive system (see [2, 7, 12, 16]). In this setting, and inspired by public AT efforts to provide high quality services, we propose in this paper a novel formal set of principles that AT based on AI should follow to warranty consistent AT services. We hypothesize that the internal reasoning process of an AT needs to fulfill general principles of consistency and soundness, aiming at not interfere, contradict or disregard client and/or caregiver actions.

To this end, this paper has a two-fold goals: (1) propose a general decision-making mechanism (algorithm) considering information of a client and a caregiver who supports during activity execution; and (2) introduce general principles of no-contradiction to which any AT reasoning about observations, goals and actions of individuals must comply. We framed those principles in a client-caregiver-agent² interaction in four common AT scenarios, as follows:

- S1. Independent activity execution: a client does not need to be assisted during the execution of an activity, an AT is present but it takes no action.
- S2. Human support: a caregiver assists a client that needs support during an activity execution. An AT is present but it takes no action.
- S3. Agent supporting: a client is supported by an AT. A caregiver is not present during such interaction.
- S4. Joint assistance: a client is supported by a caregiver and an AT.

Formal argumentation theory [3] is used to embed non-monotonic reasoning in an agent, *i.e.*, resembling the kind of assessment reasoning performed by clinicians: (1) gathering data through observations; (2) handling ambiguous and uncertain observation information; (3) generating current function status hypothesis; (4) deduce an explanatory outcome of explanation; and (5) retracting the explanation under new evidence [18]. In this sense, the proposed argumentation-based algorithm (Algorithm 1) takes different decisions depending on the observations, goals and actions in particular scenarios (S1–4).

Scenarios S1–4 are analyzed from an *activity theory* [13, 21] perspective, which investigates these AT contexts as a continuum of support adaptation. We analyze S1–4 as “distances” from what a client can do independently, to the activity potential of that client supported by a caregiver or an AT system. We explore

¹ In this context, *client* is an individual that receives support from a caregiver and/or an intelligent AT system.

² In this paper, an *agent* is an AT machinery based on the concept of software agents that takes decisions about how to support an individual during activity execution see [14].

computational versions of the so-called *zone of proximal development* (ZPD) [38] for each scenario.

We present a basic architecture for an AT system able to identify these assistive scenarios. We implement a prototype of such architecture using a projected *augmented reality* the AT system supports a client displaying personalized information. Our AT system captures information from the client and caregiver using 3D cameras, goals and hypothetical actions are embedded in a program using a multi-agent system platform.

This paper is organized as follows: in Sect. 2 methods and theories utilized as foundation of our proposal are presented. Section 3 introduces an algorithm goal-based reflection as an internal mechanism of an agent. Section 4 introduces a set of general principles that an AT system should fulfill. In Sect. 5, the architecture of an AT system that we developed using projected augmented reality is presented. A discussion with our future paths of this investigation are presented in Sect. 6.

2 Theoretical Background

In this section, some concepts of activity theory [22] and formal argumentation theory [3] are introduced. The former, is used in this paper as a framework to represent knowledge about an activity; the later is used to characterize the internal decision-making process of the intelligent assistive system.

2.1 Activity Theory

In this paper, activity theory is used for two purposes: (1) for knowledge representation, structuring information of clients and caregivers following a hierarchical model; and (2) to understand the potential level of activity achievement of a person.

Activity theory describes an *activity* as a hierarchical structure composed of *actions*, which are composed of *operations* as is represented in Fig. 1. Actions are directed to goals; goals are conscious, *i.e.*, a human agent is aware of goals to attain. Actions, in their turn, can also be decomposed into lower-level units of activity called *operations*. Operations are routine processes providing an adjustment of an action to the ongoing situation, they are oriented toward the *conditions* under which the agent is trying to attain a goal.

In this paper we use *logic programs* to capture information about an activity, we denote P as a program and \mathcal{L}_P the set of *atoms* which appear in such program. In this regard, an *activity model* (\mathcal{A}) corresponds to information characterizing mental states of an agent framed on a particular activity. \mathcal{A} can be expressed using propositional logic as a syntax language.

Definition 1 (Activity model). *Let P be a logic program capturing the behavior rules of an activity. An activity model \mathcal{A} is a tuple of the form $\langle Ax, Go, Op \rangle$ in which:*

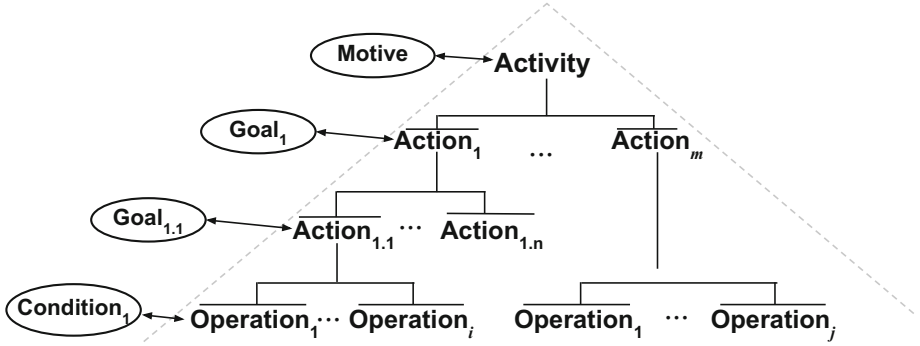


Fig. 1. Hierarchical structure of activity. Activities are composed of actions, which are, in turn, composed of operations. These three levels correspond, respectively, to the motive, goals, and conditions, as indicated by bidirectional arrows. Adapted from [21]

- $Ax = \{ax_1, \dots, ax_j\} (j > 0)$ is a set of atoms such that $Ax \subseteq \mathcal{L}_P$. Ax denotes the set of actions in \mathcal{A} .
- $Go = \{g_1, \dots, g_k\} (k > 0)$ is a set of atoms such that $Go \subseteq \mathcal{L}_P$. Go denotes the set of goals in \mathcal{A} .
- $Op = \{o_1, \dots, o_l\} (l > 0)$ is a set of atoms such that $Op \subseteq \mathcal{L}_P$. Op denotes the set of operations in \mathcal{A} .

In our approach, an activity model \mathcal{A} (Definition 1) may capture information from a client or a caregiver (as in [18]) or/and a software agent-based system (as in [14]). In this paper, we denote \mathcal{A}_c , \mathcal{A}_g and \mathcal{A}_a to represent the activity models of a client a caregiver and an agent respectively. In terms of activity theory, $\mathcal{A} = \langle Ax, Go, Op \rangle$ can be seen as a partial description of a complex activity.

In this paper, activity theory is also used to quantify the potential level of activity achievement aiming to frame the decision-making process of the intelligent assistive system. Vygotsky [38] proposed to measure the level of development not through the level of current performance, but through the difference (“the distance”) between two performance indicators: (1) an indicator of independent problem solving, and (2) an indicator of problem solving in a situation in which the individual is provided with support from other people [21]. This indicator was coined as a *zone of proximal development* (ZPD) and it has been used extensively in social sciences (see [1,9,19,34]) to understand changes of individuals during assisted learning processes.

In order to create a computable version of the concept of zone of proximal development, we use a function dist that compares two variables (*e.g.* observations of an activity) and returns a numerical value $\alpha \in \mathbb{R}$ representing in this case, a ZPD difference. For convenience, we rename scenarios described in Sect. 1 S1–4 as ZPD_i , ZPD_h , ZPD_s and ZPD_{h+s} respectively.

2.2 Formal Argumentation Theory

Generally speaking, a formal argumentation process can be seen as a mechanism consisting of the following steps (see Fig. 2): (1) Constructing *arguments* (in favor/against a “statement”) from a knowledge base; (2) Determining the different *conflicts* among the arguments; (3) Evaluating the *acceptability* of the different arguments; and (4) Concluding, or defining the *justified conclusions*. From artificial intelligence perspective, the important and distinctive characteristics of this process are: (1) their *non-monotonic* behavior, *i.e.*, changing the conclusion when more knowledge is added, and (2) their *traceability*, providing explanations in every step of the reasoning process.

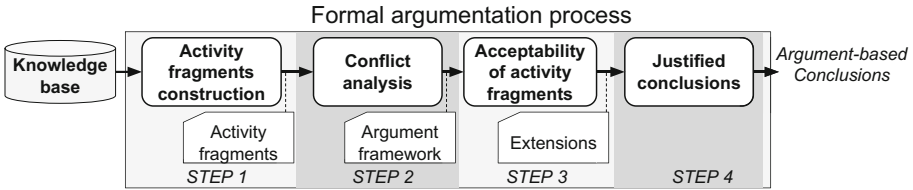


Fig. 2. Inference of an argument-based conclusion using a formal argumentation process

We define the concept of an *activity framework* which frames the necessary knowledge that an agent needs to take a decision.

Definition 2 (Activity framework). *An activity framework $ActF$ is a tuple of the form $\langle P, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, \mathcal{A} \rangle$ in which:*

- P is a logic program. \mathcal{L}_P denotes the set of atoms which appear in P .
- $\mathcal{H}_A = \{h_1, \dots, h_i\}$ is a set of atoms such that $\mathcal{H}_A \subseteq \mathcal{L}_P$. \mathcal{H}_A denotes the set of hypothetical actions which an agent can perform in a world.
- $\mathcal{G} = \{g_1, \dots, g_j\}$ is a set of atoms such that $\mathcal{G} \subseteq \mathcal{L}_P$. \mathcal{G} denotes a set of goals of an agent.
- $\mathcal{O} = \{o_1, \dots, o_k\}$ is a set of atoms such that $\mathcal{O} \subseteq \mathcal{L}_P$. \mathcal{O} denotes a set of world observations of an agent.
- \mathcal{A} is an activity model of the form: $\langle Ax, Go, Op \rangle$, following Definition 1.

$ActF$ according to Definition 2 defines the space of knowledge of an assistive agent. In this space, an argument-based process (see Fig. 2) can be performed to obtain sets of explainable structures *support-conclusion* for what is the best assistive action to take. These structures can be seen as *fragments* of an activity [18] (see Fig. 3) and can be generated as follows:

Definition 3 (Hypothetical fragments). *Let $ActF = \langle P, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, \mathcal{A} \rangle$ be an activity framework. A hypothetical fragment of an activity is of the form $HF = \langle S, \mathcal{O}', h, g \rangle$ such that:*

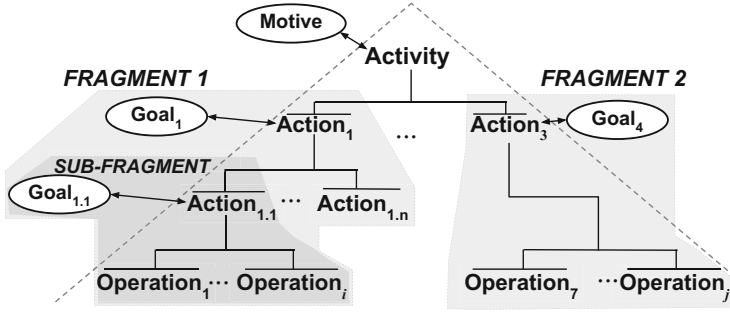


Fig. 3. Fragments and sub-fragments of an hierarchical activity

- $S \subseteq P$, $O' \subseteq \mathcal{O}$, $h \in \mathcal{H}_A$, $g \in \mathcal{G}$;
- $S \cup O' \cup \{h\}$ is consistent;
- $g \neq \perp$; and
- S and O' are minimal w.r.t. set inclusion.

Let us introduce a function $\text{Supp}(HF)$ which retrieves the set $\{S, O', h\}$ of a given fragment, which can be seen as the *support* for concluding a goal g . Next step in the argumentation-based process is find different types of contradictions among such fragments (Definition 3): (1) when two fragments have conclusive evidence about opposed achievement of goals; and (2) when a fragment contradicts the support evidence of another. These two types of relationships among fragments resembles the well-known notions of *undercut* and *rebut* in argumentation theory [4, 32].

Definition 4 (Contradictory relationships among fragments). Let $ActF = \langle P, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts \rangle$ be an activity framework. Let $HF_1 = \langle S_1, O'_1, a_1, g_1 \rangle$, $HF_2 = \langle S_2, O'_2, a_2, g_2 \rangle$ be two fragments such that $HF_1, HF_2 \in \mathcal{HF}$. HF_1 attacks HF_2 if one of the following conditions hold: (1) $g_2 = \neg g_1$; and (2) $g_2 \subseteq \text{Supp}(HF_1) = \perp$ or $g_1 \subseteq \text{Supp}(HF_2) = \perp$.

An *argumentation framework* is a pair $\langle Args, att \rangle$ in which $Args$ is a finite set of arguments and $att \subseteq Args \times Args$. In [17] an argumentation-based activity framework for reasoning about activities was proposed. We reuse this concept for in our paper, as follows:

Definition 5 (Activity argumentation framework). Let $ActF$ be an activity framework of the form $\langle P, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts \rangle$; let \mathcal{HF} be the set of fragments w.r.t. $ActF$ and $Att_{\mathcal{HF}}$ or simply Att the set of all the attacks among \mathcal{HF} . An activity argumentation framework AAF with respect to $ActF$ is of the form: $AAF = \langle ActF, \mathcal{HF}, Att \rangle$.

Dung [11], introduced a set of *patterns of selection* of arguments called *argumentation semantics (SEM)*³. SEM is a formal method to identify conflict

³ Let $SEM()$ be a function returning a set of extensions, given an argumentation framework such as an AAF.

outcomes from argumentation frameworks, such as an activity argumentation framework.

Definition 6. Let $AAF = \langle ActF, \mathcal{HF}, Att \rangle$ be an activity argumentation framework AAF with respect to $ActF = \langle P, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts \rangle$. An admissible set of fragments $S \subseteq \mathcal{HF}$ is *stable extension* if and only if S attacks each argument which does not belong to S . *preferred extension* if and only if S is a maximal (w.r.t. inclusion) admissible set of AAF . *complete extension* if and only if each argument, which is acceptable with respect to S , belongs to S . *grounded extension* if and only if it is a minimal (w.r.t. inclusion) complete extension. *ideal extension* if and only if it is contained in every preferred set of AAF .

The sets of arguments suggested by SEM are called *extensions*. We can denote $SEM(AAF) = \{Ext_1, \dots, Ext_k\}$ as the set of k extensions generated by SEM w.r.t. an activity argumentation framework AAF . In this setting, from the perspective of an intelligent agent what it is expected to have is: (1) no contradictory or conflicting sets of fragments sets explaining what is happening in the ongoing activity, and (2) fragments sets defending/supporting a hypothesis about the activity from other fragments. These two notions defines two main concepts in Dung's argumentation semantics: acceptable and admissible arguments.

Definition 7. (1) An fragment $HF_A \in \mathcal{HF}$ is *acceptable* w.r.t. a set S of fragments iff for each fragment $HF_B \in \mathcal{HF}$: if HF_B attacks HF_A , then HF_B is attacked by S . (2) *conflict-free set of fragments* S in an activity is *admissible* iff each fragment in S is acceptable w.r.t. S .

Using these notions of fragment admissibility, different argumentation semantics can draw given an activity argumentation framework:

Definition 8. Let $AAF = \langle ActF, \mathcal{HF}, Att \rangle$ be an activity argumentation framework following Definition 5. An admissible set of fragments $S \subseteq \mathcal{HF}$ is: (1) *stable* if and only if S attacks each fragment which does not belong to S ; (2) *preferred* if and only if S is a maximal (w.r.t. inclusion) admissible set of AAF ; (3) *complete* if and only if each fragment, which is acceptable with respect to S , belongs to S ; and (4) the *grounded extension* of AAF if and only if S is the minimal (w.r.t. inclusion) complete extension of AAF .

Conclusions of an argument-based reasoning about an activity may be obtained using a *skeptical* perspective, *i.e.*, accepting only irrefutable conclusions as follows:

Definition 9 (Justified conclusions). Let P be an extended logic program, $AF_P = \langle Arg_P, At(Arg_P) \rangle$ be the resulting argumentation framework from P and SEM_{Arg} be an argumentation semantics. If $SEM_{Arg}(AF_P) = \{E_1, \dots, E_n\}$ ($n \geq 1$), then $Concs(E_i) = \{Conc(A) \mid A \in E_i\}$ ($1 \leq i \leq n$). $Output = \bigcap_{i=1 \dots n} Concs(E_i)$.

Where E_i are sets of fragments called *extensions*. The set of all the extensions generated by $SEM_{Arg}(AF_P)$ are denoted as \mathcal{E} .

3 Reflection on Decisions About Human Activity

Reflection, as an internal mechanism of a rational agent to (re)consider the best decision alternative (inferring strategies), has been an important line of research in AI particularly in practical reasoning (see [20,37]). In this paper, we do not consider an agent with *pro-attitudes* as in Bratman model [6], we propose a *control loop* algorithm (as in [33,36]) to design the action selection and its reflection based on an activity model.

Algorithm 1. Goal-based action reflection

```

input :  $\mathcal{E}$  sets of extensions
output:  $h \in \mathcal{H}_A$ 

1  $H \leftarrow \emptyset$  // list of agent's decisions
2  $Go \leftarrow \emptyset$  // list of human's goals
3  $Ref \leftarrow \emptyset$  // list of human's reference goals
4  $numExt = |\mathcal{E}|$  // number of extensions
5  $numArg = |E_i|, E_i \in \mathcal{E}$  // number of hypoth. decisions per extension
6  $\alpha \leftarrow 0$  // numeric value of a distance ( $0 \leq \alpha \leq 4$ )
7  $decisionLat < \alpha, h > =$  // lattice of decisions

8 for  $i \leftarrow 0$  to  $numExt$  do
9   for  $j \leftarrow 0$  to  $numArg$  do
10     $h \leftarrow Act(hf_j)$ 
11     $\mathcal{O} \leftarrow Obs(hf_j)$ 
12     $\alpha \leftarrow dist(\mathcal{O}_{Go}, Ref_{Go})$  // distance function considering
    observations and a reference value w.r.t. person goals  $Go$ 
13     $decisionLat \leftarrow (\alpha, h)_{hf_j}$  // decision tuple is a ZPD metric for
    the current activity fragment
14   end
15 end
16 return  $max(\alpha, h)$ 

```

Given a set of hypothetical fragments suggested by an argumentation process, our algorithm selects an agent's action that maximize humans' goals. This mechanism is summarized in Algorithm 1.

Algorithm 1 prioritizes the activity model of a client over an agent and, at the same time, it computes a distance between activity variables. In lines 8–15 of Algorithm 1, such distance is calculated (line 12) over sets of hypothetical fragments. This distance calculation is based on computing a similarity function between the current achievement of human goals in the activity model *w.r.t.* a set of goal reference (Ref_{Go} line 12). The $dist$ function in line 12 follows the notion of ZPD, by measuring in every computation the distance between the current development of a person and a reference, which can be given by a caregiver. This approach for comparing current activity execution with a reference has been used in previous approaches [17, 18].

The importance of Algorithm 1 lies on the mechanism for associating a human activity quantification with the internal action decision of an agent. The Algorithm output depends entirely on previous extensions computation. Propositions 1 and 2 present two special cases of agent’s behavior when Algorithm 1 is used⁴. One is the possibility to have a conclusion with no action, and the second expresses an inconclusive behavior given that stable semantics may return \emptyset as output.

Proposition 1. *An agent calculating the goal-based action reflection Algorithm 1 using a skeptic semantics, grounded or ideal, may result in a conclusive empty decision.*⁵

Proposition 2. *An agent calculating the goal-based action reflection Algorithm 1 using the credulous semantics: stable, may result in an inconclusive decision.*⁶

3.1 Support in Relation to the Zone of Proximal Development Using Formal Argumentation

In this section, based on the common-sense reasoning of activities using argumentation theory, we propose a theory to calculate the following four scenarios in assistive agent-based technology:

I. ZPD_i independent activity execution. This scenario describes an *observer agent* which takes the decision to do nothing to support a person. More formally, the type of fragments (Definition 3) generated by the agents are of the form $HF = \langle S, O', h^*, g \rangle$ such that $h^* \in \mathcal{H}_A = \{\emptyset, do_Nothing\}$. In this setting, all the extensions generated by $SEM(AF_P) = \mathcal{E}$ during a period of time will create an activity structure. In other words, the cumulative effect of generating fragments, re-construct an activity in a bottom-up manner. Moreover, Algorithm 1 returns only values of α , *i.e.* the current value of a qualifier when the agent does not take any supportive action. This context defines the baseline of activity execution independence of a person.

II. ZPD_h activities supported by another person. Similarly to previous scenario, the role of the software agent is to be an observer. However, built fragments have the form $HF = \langle S, O^*, h^*, g \rangle$ such that $h^* \in \mathcal{H}_A = \{\emptyset, do_Nothing\}$ and $O^* = O' \cup O''$, where O^* is the set of joint observations from the agent’s perspective about the individual supported (O') and the supporter O'' . We have that $O' \subseteq O''$, and $O', O'' \neq \emptyset$. In this scenario, O'' is considered a reference set of observations (Ref lines 3 and 12 in Algorithm 1). Algorithm 1 will return a value of α which measures to what extent an individual follows the guide provided by another person.

⁴ Due to lack of space, the full proofs of these propositions are omitted.

⁵ Proof sketch: output of grounded and ideal may include $\{\emptyset\}$. See [10].

⁶ Proof sketch: output of stable semantics may include \emptyset . See [10].

When multiple extensions are collected during the period of time that the individual is supported, then a different set of activities than individual activity execution may be re-generated in a bottom-up manner.

III. ZPD_s activities supported by an agent. In this scenario, an *assistive agent* takes a decision oriented to uphold human interests, priorities and ability to conduct an activity. This is a straightforward scenario where $h \in \mathcal{H}_A \neq \{\emptyset, do_Nothing\}$.

IV. ZPD_{h+s} caregiver and agent supporting cooperatively. In this scenario, the main challenge for the agent perspective is to detect: (1) actions that an assistant person executes, and (2) observations of both, the person assisted and the person who attends. This is similar to ZPD_H but with fragments built from $\mathcal{H}_A \neq \{\emptyset, do_Nothing\}$. In this case, the level of ZPD_{H+S} is given by Algorithm 1, and the set of extensions \mathcal{E} with *aligned* goals between agent and the caregiver.

4 Principles for Providing Consistent Assistive Services

In this section, we propose a set of general principles that AT based on deductive systems should follow to warranty consistency in their outputs.

4.1 Activity-Oriented Principles

Based on previous detailed analysis of different ZPD scenarios, we propose in the following a set of principles that need to be fulfilled to provide assistive services.

Proposition 3. *Let \mathcal{A}^* be the set of all the possible activity models; let $R \subseteq \mathcal{A}_j$ a set of fragments from an activity model; let $h_j \in \mathcal{H}_a$ and $g_j \in \mathcal{G}_a$ be an agents' action and goal; and let $E_k \subseteq \mathcal{E}$ be an extension of hypothetical fragments. The following holds:*

$$\nexists \langle R, h, g \rangle \text{ in } E_k \notin \mathcal{A}^*$$

Proposition 3 establishes that there is no hypothetical fragment that can be built that does not belong to the set of all the activity models. This proposition defines a principle of *closure*, i.e. that an AT system should not generate outputs (e.g. AT services) that are not contained in the main set of activities.

Proposition 4. *Let \mathcal{A}^* be the set of all the possible activity models; and let $\mathcal{A} \langle Ax, Go, Op \rangle$ be an activity model with $\mathcal{A} \subseteq \mathcal{A}^*$. The following holds: \nexists any $ax \in Ax$, $g \in Go$ or $o \in Op \notin \mathcal{A}^*$.*

Proposition 4 seems straightforward but it establishes that only those activities framed on an activity model can be seen as actions, goals or operations. Out of an activity, individually, those elements have not influence in the decision-making of an argument-based assistive system. Proposition 4 has a social science background, activity theory defines an activity by its motive, and activity necessarily builds on the hierarchy of actions and operations, roughly saying that

there not exists any action, goal or operation out of an activity. These elements of an activity can not be considered separately or independently [21]. In this sense, Proposition 4 establishes the same principle, defining with Proposition 3 basic conditions of activity knowledge closure.

Postulate 1. Let \mathcal{O}_{Go} be a set of observations about human goals (Go) and actions (Ax) framed on an activity, captured by an agent using an activity model A . Let \mathcal{G} and \mathcal{H}_A be agent's goals and its hypothetical actions. In order to provide non-conflicting assistance two properties have to be fulfilled:

- PROP1: $\mathcal{O}_{Go} \cap \mathcal{G} \neq \emptyset$
- PROP2: $\mathcal{O}_{Ax} \cap \mathcal{H}_A \neq \emptyset$.

Postulate 1 can be seen as a *self-evident* rule that any intelligent assistive system should follow. PROP1 and PROP2 provides coherence among human-agents actions and goals. This two properties may define a first attempt to establish consistency principles of agent-based assistance. This is a future work in our research.

5 Implementation

The scenario selected for implementing a demonstrator for the formal results describes the situation where an older adult performs the the activity to *distribute medication* into a *medicine cabinet*. This activity is supported by an

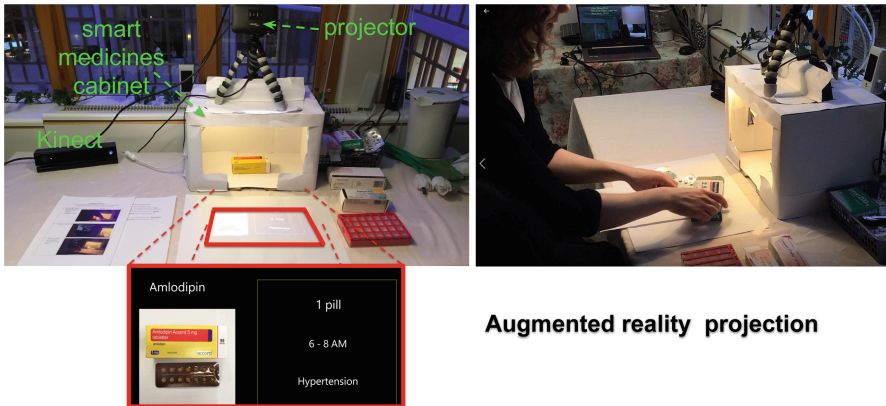


Fig. 4. Smart medicines cabinet using argument-based reasoning and an augmented reality projection. (I) Gesture recognition using three Kinect cameras, one for client body capture, another for assistant personal gesture recognition, last one (Kinect sensor 2) on the top of the cabinet to recognize text from medicines boxes; (II) Google API for text recognition; (III) argument-based reasoning; (IV) goal-based action reflection to consider human side; (V) database containing doses and timing of pill intake.

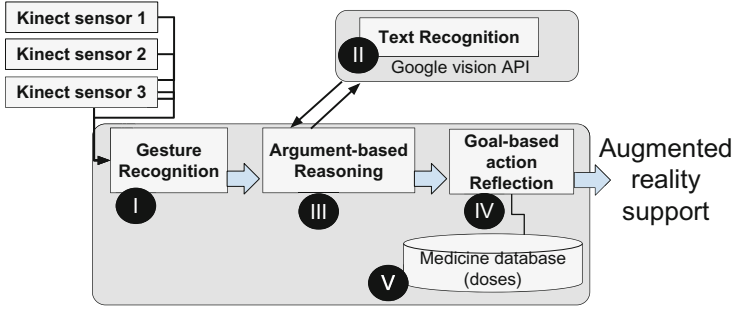


Fig. 5. Text

intelligent system and technology for augmented reality that is used for mediating the information provided by the system (see Fig. 4).

The prototype architecture consists of five main parts (see Fig. 5): (1) gestures recognition: obtaining observations from individuals using Kinect cameras; (2) text recognition using another Kinect camera with Google API text recognition (<https://cloud.google.com/vision>); (3) argument-based reasoning: the main agent-based mechanism of common sense reasoning; (4) goal-based action reflection generating an augmented reality feedback: a module to generate support indications as projections in the smart environment; and (5) a database of medicine doses to obtain appropriate messages.

We use three 3D cameras to capture: (1) observations of an individual that needs help in a physical activity; (2) observations of the smart environment, including a supporting person; and (3) information of the handle gestures of medicine manipulation. A central computer was connected to the cameras, processing the information in real-time analyzing gestures of individuals as observations for the agent. The agent platform (JaCaMo) was used to build the agent. An argumentation process was used using an argumentation library previously developed (see [16]). An agent updates/triggers its plan every time that a pre-defined gesture of the 3D camera is identified. Those pre-defined gestures were defined and trained based on data from three older adults and two medical experts.

6 Discussion and Conclusions

Our main contribution in this paper is a formal understanding of the interplay among an assistive agent-based software, a person to be assisted and a caregiver.

Argumentation-based systems, have become influential in artificial intelligence particularly in multi-agent systems design (see [8] for a systematic review). Argumentation theory can be seen as a process to provide *common-sense* to the decision-making process of a deductive system. Common-sense reasoning about an activity implies a non-monotonic process in which the output may

change, when more knowledge is added. In the context of this paper, the contrary of a non-monotonic behavior is, for example a *stubborn system*, providing support when an individual does not need it and even under direct negative response from a user. In this paper we argue that non-monotonic reasoning may be used as main mechanism for decision-making of intelligent assistive systems. In fact, in ambient-assistive literature few authors have explore this approach (see [18, 25, 27, 28, 30]).

We propose an algorithm to integrate client’s information (the activity model Definition 1) into the final decision-making process of an agent. This mechanism captured in Algorithm 1, resembles a process of “reflection” which in humans is a re-consideration of actions and goals given some parameters. Our reflection mechanism can be seen as an “action-filtering” process with the human-in-the-loop⁷. We also analyze different outputs of Algorithm 1 considering two groups of argumentation semantics (Propositions 1 and 2).

We propose different properties that software agents should follow if their goals are linked to human goals. We highlight the relevance of Postulate 1 which is understood as a primary rule for an intelligent assistive system. The relevance and impact of these properties not only covers agents based on formal argumentation theory, but other approaches, such as those based on the Belief Desire Intention model [5].

Our proposed principles are a starting point for evaluating assistive technology systems. This is a first step to establish general properties that such system should follow. We are aware that several principles can be added and we are aiming to continue this research line as future work.

We are also interested in the analysis of activity dynamics extending our formal results. In activity theory, the hierarchical structure is dynamic, there are transformations among internal levels of the hierarchy triggered by the demands and prerequisites in the environment [23]. We aim to investigate transformations in the activity, for example when the ZPD “increases”, *i.e.* a person can achieve more activities with help of a caregiver or an assistive technology system, the activity hierarchy changes. From computational point of view, such change implies a modification at the information structure level, which may define scenarios where consistency can not be assured. In this sense, part of the future work will be focused on analyzing activity dynamics, but leveraged by the current “static” research of activities *e.g.* in [15, 17, 18, 29].

References

1. Aljaafreh, A.L., Lantolf, J.P.: Negative feedback as regulation and second language learning in the zone of proximal development. *Mod. Lang. J.* **78**(4), 465–483 (1994)
2. Amgoud, L.: Postulates for logic-based argumentation systems. *Int. J. Approx. Reason.* **55**(9), 2028–2048 (2014)
3. Bench-Capon, T., Dunne, P.E.: Argumentation in artificial intelligence. *Artif. Intell.* **171**(10), 619–641 (2007). <http://www.sciencedirect.com/science/article/pii/S0004370207000793>

⁷ A concept to integrate human information in *cyber-physical systems* [35].

4. Besnard, P., Hunter, A.: A logic-based theory of deductive arguments. *Artif. Intell.* **128**(1–2), 203–235 (2001)
5. Bratman, M.: *Intention, Plans, and Practical Reason*. Harvard University Press, Cambridge (1987)
6. Bratman, M.E., Israel, D.J., Pollack, M.E.: Plans and resource-bounded practical reasoning. *Comput. Intell.* **4**(3), 349–355 (1988)
7. Caminada, M., Amgoud, L.: On the evaluation of argumentation formalisms. *Artif. Intell.* **171**, 286–310 (2007)
8. Carrera, Á., Iglesias, C.A.: A systematic review of argumentation techniques for multi-agent systems research. *Artif. Intell. Rev.* **44**(4), 509–535 (2015)
9. Chaiklin, S.: The zone of proximal development in vygotsky’s analysis of learning and instruction. *Vygotsky’s educational theory in cultural context* **1**, 39–64 (2003)
10. Dix, J.: A classification theory of semantics of normal logic programs: II. Weak properties. *Fundam. Inform.* **22**(3), 257–288 (1995)
11. Dung, P.M.: On the acceptability of arguments and its fundamental role in non-monotonic reasoning, logic programming and n-person games. *Artif. Intell.* **77**(2), 321–357 (1995)
12. Dung, P.M., Thang, P.M.: Closure and consistency in logic-associated argumentation. *J. Artif. Intell. Res.* **49**, 79–109 (2014)
13. Engeström, Y.: *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research*, vol. 53. Orienta-Konsultit Oy, Helsinki (2015). <https://doi.org/10.1017/CBO9781107415324.004>
14. Guerrero, E., Lindgren, H.: Practical reasoning about complex activities. In: Demazeau, Y., Davidsson, P., Bajo, J., Vale, Z. (eds.) *PAAMS 2017. LNCS (LNAI)*, vol. 10349, pp. 82–94. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-59930-4_7
15. Guerrero, E., Nieves, J.C., Lindgren, H.: ALI: an assisted living system for persons with mild cognitive impairment. In: *2013 IEEE 26th International Symposium on Computer-Based Medical Systems (CBMS)*, pp. 526–527. IEEE (2013)
16. Guerrero, E., Nieves, J.C., Lindgren, H.: Semantic-based construction of arguments: an answer set programming approach. *Int. J. Approx. Reason.* **64**, 54–74 (2015)
17. Guerrero, E., Nieves, J.C., Sandlund, M., Lindgren, H.: Activity qualifiers in an argumentation framework as instruments for agents when evaluating human activity. In: Demazeau, Y., Ito, T., Bajo, J., Escalona, M.J. (eds.) *PAAMS 2016. LNCS (LNAI)*, vol. 9662, pp. 133–144. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-39324-7_12
18. Guerrero, E., Nieves, J.C., Sandlund, M., Lindgren, H.: Activity qualifiers using an argument-based construction. *Knowl. Inf. Syst.* **54**(3), 633–658 (2018)
19. Hedegaard, M.: The zone of proximal development as basis for instruction. In: *An Introduction to Vygotsky*, pp. 183–207. Routledge, Abingdon (2002)
20. Horvitz, E.J., Cooper, G.F., Heckerman, D.E.: Reflection and action under scarce resources: theoretical principles and empirical study. In: *IJCAI*, pp. 1121–1127 (1989)
21. Kaptelinin, V., Nardi, B.A.: *Acting with Technology: Activity Theory and Interaction Design*. Acting with Technology. MIT Press, Cambridge (2006)
22. Leontyev, A.N.: *Activity and Consciousness*. Personality, Moscow (1974)
23. Lindgren, H.: Activity-theoretical model as a tool for clinical decision-support development. In: *15th International Conference on Knowledge Engineering and Knowledge Management, Poster and Demo Proceedings in EKAW*, vol. 215, pp. 23–25 (2006)

24. Lindgren, H., Baskar, J., Guerrero, E., Nieves, J.C., Nilsson, I., Yan, C.: Computer-supported assessment for tailoring assistive technology. In: Proceedings of the 6th International Conference on Digital Health Conference, pp. 1–10. ACM (2016)
25. Marçais, J., Spanoudakis, N., Moraitis, P.: Using argumentation for ambient assisted living. In: Iliadis, L., Maglogiannis, I., Papadopoulos, H. (eds.) AIAI/EANN -2011. IAICT, vol. 364, pp. 410–419. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-23960-1_48
26. Maslov, S.: Theory of Deductive Systems and Its Applications. MIT Press Series in the Foundations of Computing. MIT Press, Cambridge (1987)
27. Muñoz, A., Augusto, J.C., Villa, A., Botía, J.A.: Design and evaluation of an ambient assisted living system based on an argumentative multi-agent system. *Pers. Ubiquitous Comput.* **15**(4), 377–387 (2011)
28. Muñoz, A., Serrano, E., Villa, A., Valdés, M., Botía, J.A.: An approach for representing sensor data to validate alerts in ambient assisted living. *Sensors* **12**(5), 6282–6306 (2012)
29. Nieves, J.C., Guerrero, E., Lindgren, H.: Reasoning about human activities: an argumentative approach. In: 12th Scandinavian Conference on Artificial Intelligence (SCAI 2013) (2013)
30. Oguego, C.L., Augusto, J.C., Muñoz, A., Springett, M.: Using argumentation to manage users' preferences. *Future Gener. Comput. Syst.* **81**, 235–243 (2018)
31. Pollack, M.E.: Intelligent technology for an aging population: the use of AI to assist elders with cognitive impairment. *AI Mag.* **26**(2), 9 (2005)
32. Pollock, J.L.: Defeasible reasoning. *Cogn. Sci.* **11**(4), 481–518 (1987). https://doi.org/10.1207/s15516709cog1104_4, http://doi.wiley.com/10.1207/s15516709cog1104_4
33. Rao, A.S., Georgeff, M.P., et al.: BDI agents: from theory to practice. In: ICMAS, vol. 95, pp. 312–319 (1995)
34. Salomon, G., Globerson, T., Guterman, E.: The computer as a zone of proximal development: internalizing reading-related metacognitions from a reading partner. *J. Educ. Psychol.* **81**(4), 620 (1989)
35. Schirner, G., Erdogmus, D., Chowdhury, K., Padir, T.: The future of human-in-the-loop cyber-physical systems. *Computer* **46**(1), 36–45 (2013)
36. Schut, M., Wooldridge, M.: Principles of intention reconsideration. In: Proceedings of the Fifth International Conference on Autonomous Agents, pp. 340–347. ACM (2001)
37. Schut, M., Wooldridge, M., Parsons, S.: The theory and practice of intention reconsideration. *J. Exp. Theor. Artif. Intell.* **16**(4), 261–293 (2004)
38. Vygotsky, L.S.: *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press, Boston (1980)
39. de Witte, L., Steel, E., Gupta, S., Ramos, V.D., Roentgen, U.: Assistive technology provision: towards an international framework for assuring availability and accessibility of affordable high-quality assistive technology. In: *Disability and Rehabilitation: Assistive Technology*, pp. 1–6 (2018)