Towards a Human-Centric Argument-Based Decision-Making Framework

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Abstract

ALI is an Assisted LIving system aimed at supporting individuals in their performance of daily living activities, through positive feedback and encouraging messages. ALI integrates a novel approach to integrating a human behavior theory with an argument-based decision-making framework. This integration allows us to model a decision-making problem from a human activity-centric point of view. An activity tracking and monitoring sub-system is proposed in order to I) determine what activities were performed over a period of time (activity recognition tracking), and II) send personalized notifications suggesting the most suitable activities to perform (decision-making monitoring). The ALI system is exemplified and evaluated from the perspective of two adolescents with needs and goals related to social activities and physical exercise.

1 Introduction

Providing tailored and appropriate guidance or recommendations to individuals with the purpose of improving their performance of daily living activities is a complex task. One of the major challenges is motivating an individual to change their behavior to a healthier lifestyle pattern.

Different methods have been developed for building behavior change and persuasive systems in order to influence another's mental state. However, at some level, it is not possible to control social responses; they are instinctive rather than rational [1]. Moreover, as different authors have highlighted [1–3], psychological cues of persuasion, lie in considering different information sources, such as human-centric (*emotions, preferences, motivations, goals*) and environment context (*time, place, language, visual interface*). How to model and use these different information sources in order to provide sound, persuasive and encouraging messages for improving daily activities, is without doubt a complex task.

First, computational methods are needed for the decision-making problem related to concluding when and how to guide the person in changing attitudes and behavior. The logical soundness for a solution needs to be solved. Second, there have to be decisions made about which persuasive method to be used for delivery and reaching the solution.

Different efforts have been developed in order to answer these two questions, through different *techno-cognitive* approaches [2–6]. Most of these approaches focus on the psychological-oriented persuasive method. In contrast, other approaches [7–9] provide theoretical resources that lack human-centric vision.

Argumentation Theory has roots in philosophy and rhetoric, and is increasingly applied to and developed in fields of research in artificial intelligence [10] Argumentation Theory provides methods and tools for logical reasoning and decision-making in the presence of incomplete and uncertain information. In this setting, Argumentation Theory seems to be a reasonable approach to a scenario for delivering persuasive messages such as the following:

Hey Anna, it's been a while since you took a hike,
maintaining a healthy lifestyle by jogging improves your (1)
self-confidence and it is also fun. Let's run!

Argumentation theory can be used for reasoning about the best moment for the delivery of the message, the goal-based intention and, at the same time, considering rhetorical characteristics of the message.

Against this background, we introduce an *Assisted LIving system* (ALI) to address the complex scenario of providing appropriate guidance and recommendations in the conducting of daily activities, tailored to individuals who may have different needs and desires for support. ALI offers personalized recommendations for daily activities, based on two different sources: 1) user data: her/his context (temporal and spatial) and her/his preferences (needs, motives, activities, goals); and 2) domain expert's information.

The ALI concept is based on a novel integration of an argument-based decision-making framework rooted in the research field of artificial intelligence with the Activity Theoretical framework for understanding human activity, developed mainly within the fields of social science and psychology [11]. This integration allows us to reason and infer sets of sound argument-based explanations of human behavior and select the best guidance action to take, by considering a human-centric point of view. Argumentation theory provides us with sound, common-sense reasoning tools, for building *arguments* (like 1). In contrast to logical proofs, arguments are *defeasible*, that is, the validity of their conclusions can be disputed by other arguments [12].

In this setting, the key purpose of ALI is twofold: I) monitoring activities of an individual and guiding him/her in his/her daily living activities through notifications; and II) tracking his/her activities for a time lapse and, in this way, offering therapists extra assessment data.

We address the following research questions:

- **Q1:** How does information about the context, preferences and personalized suggestions contribute to building arguments?
- **Q2:** How is the human-computer interaction performed through a mobile phone?
- **Q3:** How does the user react to positive and encouraging messages?

We summarize the main technical contributions of this paper as follows:

- An integration between a possibilistic argument-based decision framework and Activity Theory is developed and described. Its purpose is to recognize, argue, justify and provide argumentative explanations for human activities.
- Sets of sound argument-based explanations (*argument extensions* in argumentation literature) are interpreted based on Activity Theory for selecting and formulating messages.
- A real time activity monitoring-recommender sub-system is developed and described, which manages uncertain and incomplete observations of the individual's activity context.
- A modular architecture is described, which is used for recognizing and providing advice on activities to the individuals, supervised by a health-care team.

We exemplify the functionalities of the prototype system ALI from the perspective of a young individual, typical his/her age. Encouraging an individual using positive feedback when an activity is performed and suggesting activities in which the individual takes control over his/her own situation are the two strategies of ALI in order to support behavior change in an individual.

A running example is introduced in the following, with a brief description of the method for capturing user information (personal data and preferences among activities and goals) using the ACKTUS platform and related applications for assessments. The modeling of knowledge by health-care professionals using ACKTUS is described in [13]. ALI retrieves a predefined set of goal-based activities, which an individual has selected and prioritised.

Example 1 (Maintaining physical condition) *Anna is a young adult typical for her age, who has had some difficulties coping with her teenage years. A therapist has reason to meet Anna, and discuss* *her situation. Anna would like to see some changes in her everyday life, which the therapist supports. Generic patterns of behavior, which can be seen as potentially "unhealthy", are identified and focused on, such as Anna's tendency to avoid leaving the house and getting stuck by the computer without much physical exercise.*

In this scenario, Anna and her therapist agreed that maintaining a good physical condition *is the most preferred activity to monitor and track during the period of intervention. From Anna's perspective, maintaining a healthy pattern of physical exercise implies achieving different goals, like regularly accomplishing physical exercise, minimizing inactive behavior such as sitting by the computer and increasing the time spent outside her home. Some observations that would imply the achievement of these goals are detecting that she is jogging or running. Also, for achieving more social contacts and getting out of her home environment, Anna found it desirable to meet her family and friends more often.*

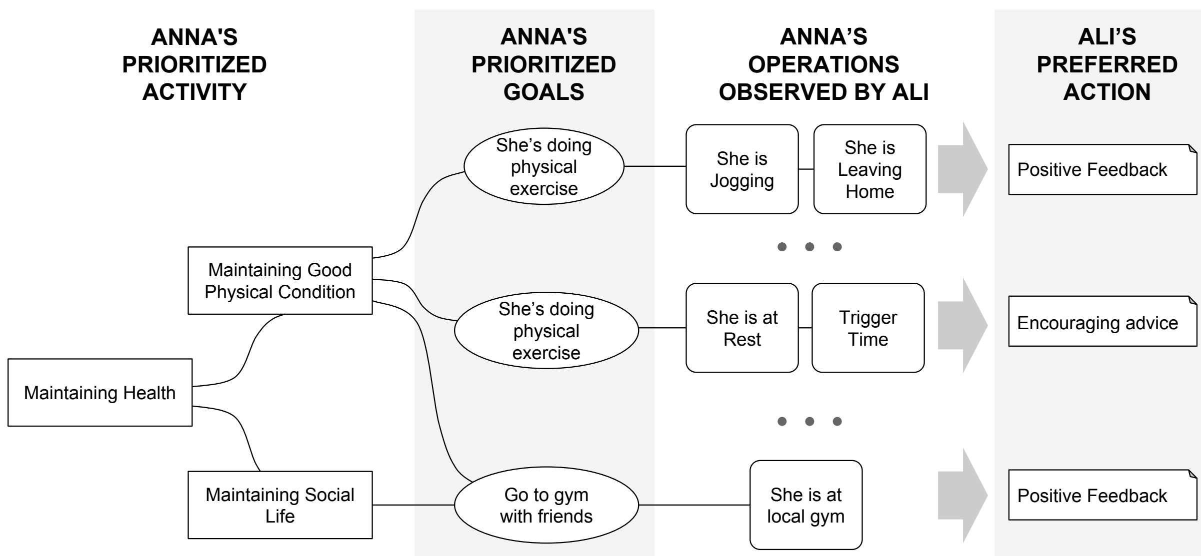

Figure 1. Anna scenario, based on Activity Theory

where each trajectory (rows) represents a possible decision that ALI has to make

A graphical representation of the Anna scenario is introduced in Figure 1, where each row represents a possible decision (a potential trajectory) that ALI has to make. This full scenario is obtained by the therapist using the assessment application I-Help[1], which provides information about the prioritized activities, goals for achieving those activities, a set of observations for inferring that Anna is performing an activity and, finally, a set of preferred actions, which were defined in the initial assessment.

Three main tasks are performed by ALI while it is running as a mobile application: I) monitoring Anna's activities; II) guiding Anna through daily living activities with notifications; and III) tracking Anna's activities for a time lapse, which gives data that can be used to assess patterns and changes of patterns of behavior over time.

The rest of the paper is divided as follows. In Section 2, the integration of Activity Theory and an argumentation framework is depicted and a motivational context is developed. In Section 3, the

[1]I-Help is a Web application and a part of the ACKTUS infrastructure, which presents assessment questions designed by a professional expert. Each assessment question has a predefined set of answer alternatives, which is used to quantify the answer of the user.

prototype architecture of ALI is presented; in Section 4, a pilot study of ALI is introduced; and, in Section 5, conclusions are provided, in addition to future work.

2 An Argumentation-based Possibilistic Decision-Making Framework Integrating Activity Theory

Formal argumentation is concerned primarily with reaching conclusions through logical reasoning, that is, claims based on premises. In the past few years, formal models of argumentation have been steadily gaining importance in artificial intelligence, where they have found a wide range of applications in specifying semantics for logic programs, decision-making, generating natural language text and supporting multi-agent dialogue, among others.

Dung made an important contribution to the research field of argumentation in [14] by showing that argumentation can be "viewed" as Logic Programming (LP). Dung provided a meta-schema of such systems, defining a general architecture for meta-interpreters for argumentation systems.

Extending Dung's approach, we can represent an argumentation system as a "three-step" system, starting with a knowledge base and obtaining argument-based conclusions as output (Figure 2). This chain resembles an inference process, starting with *raw* data and ending with a conclusion or a sound set of conclusions. ALI follows this meta-architecture, providing sound proofs of goal-based human activities, using a possibilistic decision-making framework (Step 1 and Step 2) and a human-centric explanation of an activity (Step 3) using Activity Theory.

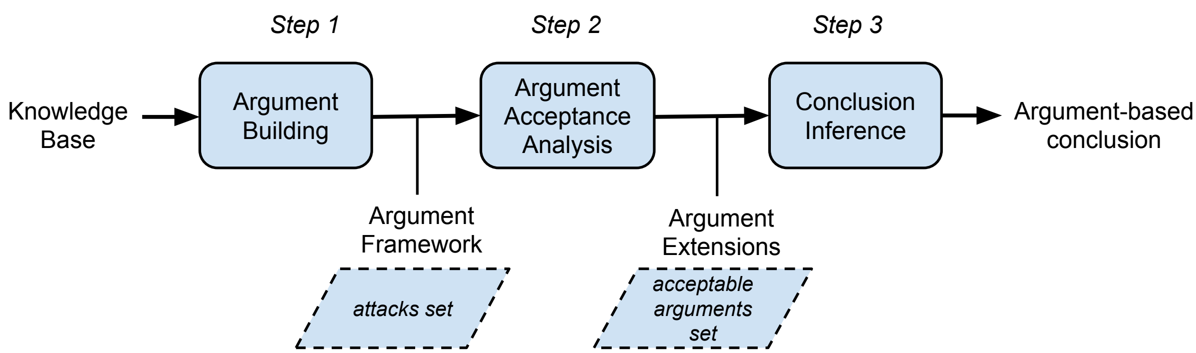

Figure 2. Meta-interpreter for an argumentation system

In this section, we introduce the necessary background in order to analyze the integration of an argumentation-based decision-making framework and Activity Theory. This section is divided into three subsections, following the three steps of the meta-architecture presented in Figure 2.

2.1 Argument Building

The Anna scenario introduced in Example 1 presents a decision-making process, which deals with uncertainty. ALI has to make argument-based decisions based on Anna's preferred goals by obtaining sets of possible worlds (or interpretations) of her context. Different approaches based on argumentation theory have been developed dealing with the different forms of information for justifying/explaining rational decisions. Works based on Logical Argumentation, formalizing argument-based decision-making under uncertainty [15, 16] and Possibilistic Logic [17–19].

In fact, in common life scenarios, descriptions of uncertain observations such as "I think that . . . ", "chances are . . . ", or like "it seems like . . . " (in argument 1) usually appeal to our experience or our common sense. A possibilistic logic framework based on possibility theory can be used to model these pieces of knowledge, which are pervaded with uncertainty (like Anna scenario). Such framework is also useful when representing preferences expressed as sets of prioritized goals [20]. Consequently, and due to the technological requirements that Ambient Assisted Living systems represent, we argue that a possibilistic logic framework is suitable for representing the exemplified scenario.

In the logic programming literature, different logic programming semantics exist, which capture possibilistic logic programs in order to infer information from a given possibilistic logic program [21, 22]. Given that ALI is expected to support processes like decision-making and recommendations in real time, *computational complexity of time* is an important issue. In this setting, the Possibilistic Well-Founded Semantics (P_WFS), which is computable in polynomial time, seems to be a suitable semantics for supporting a real-time inference process in the ALI architecture [22]. Moreover, there is an implementation of the possibilistic well-founded semantics for possibilistic logic programs [23].

We describe the main concepts of a Possibilistic Argument-based Decision Framework[2] (PADF) in order to capture Anna's scenario. The formal qualities of PADF were introduced in [19]. A PADF is a tuple $\langle P, \mathcal{D}, \mathcal{G} \rangle$ in which:

1. A knowledge base which is defined by a possibilistic normal logic program P;
2. A set of decisions $\mathcal{D}$ and
3. A set of goals $\mathcal{G}$

where $\mathcal{D}$ and $\mathcal{G}$ are subsets of the signature of the possibilistic normal logic program P. Before showing how PADF captures Anna's scenario, let us introduce the underlying language for describing a possibilistic normal logic program.

2.1.1 Syntaxis: Logic programs

The language of a propositional logic has an alphabet consisting of

(i) proposition symbols: $\bot, \top, p_0, p_1, ...$

(ii) connectives : $\vee, \wedge, \leftarrow, \neg,$ *not*

(iii) auxiliary symbols : (,).

where $\vee, \wedge, \leftarrow$ are 2-place connectives, $\neg$, *not* are 1-place connectives and $\bot$, $\top$ are 0-place connectives. The proposition symbols, $\bot$, and the propositional symbols of the form $\neg p_i$ ($i \geq 0$) stand for the indecomposable propositions, which we call *atoms*, or *atomic propositions*. Atoms negated by $\neg$ will be called *extended atoms*. We will use the concept of atoms without paying attention to whether it is an extended atom or not. The negation sign $\neg$ is regarded as the so called *strong negation* by the Answer Set Programming (ASP) literature and the negation *not* as the *negation as failure* [24]. A literal is an atom, a (called positive literal), or the negation of an atom *not* a (called negative literal). Given a set of atoms $\{a_1, ..., a_n\}$, we write *not* $\{a_1, ..., a_n\}$ to denote the set of literals $\{not\ a_1, ..., not\ a_n\}$.

An extended normal clause, C, is denoted as:

$$a \leftarrow a_1, \ldots, a_j, not\ a_{j+1}, \ldots, not\ a_n$$

where $j + n \geq 0$, a is an atom and each a_i is an atom. When $j + n = 0$, the clause is an abbreviation of $a \leftarrow \top$ such that $\top$ is the proposition symbol that always evaluates to true.

[2]In A a definition of the Possibilistic Argument-based Decision Framework is introduced

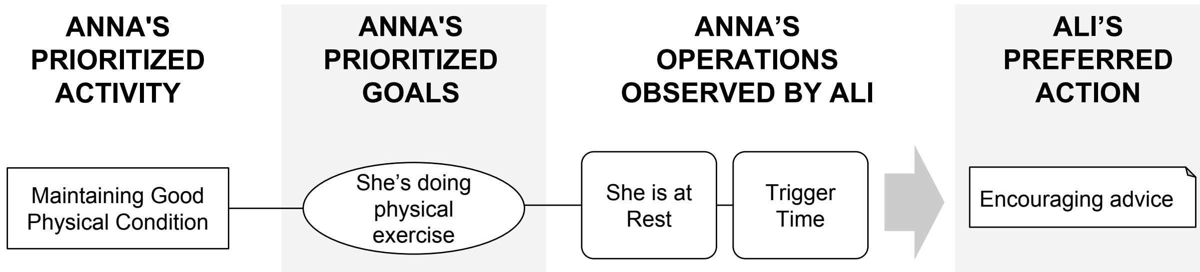

Figure 3. Sub-scenario for giving Anna encouraging advice

An extended normal program P is a finite set of extended normal clauses. When $n = 0$, the clause is called *extended definite clause. An extended definite logic program* is a finite set of extended definite clauses. By $\mathcal{L}_P$, we denote the set of atoms in the language of P. Let $Prog_{\mathcal{L}}$ be the set of all normal programs with atoms from $\mathcal{L}$. We will manage the strong negation ($\neg$) in our logic programs as done in ASP [25]. Basically, each atom of the form $\neg a$ is replaced by a new atom symbol a' which does not appear in the language of the program.

Sometimes we denote an extended normal clause C by $a \leftarrow \mathcal{B}^+,\ not\ \mathcal{B}^-$, where $\mathcal{B}^+$ contains all the positive body literals and $\mathcal{B}^-$ contains all the negative body literals. A *possibilistic atom* is a pair $p = (a, q) \in \mathcal{A} \times Q$, where $\mathcal{A}$ is a finite set of atoms and $(Q, \leq)$ is a lattice. We apply the projection $*$ over p as follows: $p^* = a$. Given a set of possibilistic atoms S, we define the generalization of $*$ over S as follows: $S^* = \{p^* | p \in S\}$. Given a lattice $(Q, \leq)$ and $S \subseteq Q$, $LUB(S)$ denotes the least upper bound of S and $GLB(S)$ denotes the greatest lower bound of S.

We define the syntax of a valid extended possibilistic normal logic program as follows: Let $(Q, \leq)$ be a lattice. A extended possibilistic normal clause r is of the form:

$$r := (\alpha : a \leftarrow \mathcal{B}^+,\ not\ \mathcal{B}^-)$$

where $\alpha \in Q$. The projection $*$ over the possibilistic clause r is: $r^* = a \leftarrow \mathcal{B}^+,\ not\ \mathcal{B}^-$. $n(r) = \alpha$ is a necessity degree representing the certainty level of the information described by r.

An extended possibilistic normal logic program P is a tuple of the form $\langle (Q, \leq), N \rangle$, where $(Q, \leq)$ is a lattice and N is a finite set of extended possibilistic normal clauses. The generalization of the projection $*$ over P is as follows: $P^* = \{r^* | r \in N\}$. Notice that P^* is an extended logic normal program. When P^* is an extended definite program, P is called an extended possibilistic definite logic program.

In order to illustrate how the PADF captures the Anna scenario, let us consider an extension of Example 1, as follows:

Example 2 (Monitoring Anna's physical activity patterns) *Anna agrees with therapists to use ALI to monitor her physical activity patterns. ALI is set up on her mobile phone. In this setting, ALI obtains a register of her location and locomotion activities over a period of time. More details about how location and locomotion observations are obtained is described in Section 3.*

Following the Anna scenario, and following its representation in Figure 1, we obtain an alternative sub-scenario, for example, encouraging Anna to do exercise, as described in Figure 3.

In Figure 3, a sub-scenario where ALI observes that Anna *is at rest* ($She'\ s\_at\_rest_o$) during a defined time ($Trigger\_timeout_o$) is presented, which triggers the action of sending an encouraging notification, which is displayed on her mobile. We can capture this sub-scenario with a possibilistic normal logic program, integrating each block in Figure 3 in a clause. In this setting, each clause represents a *decision* that must be made (*preferred action*), given a set of *observations* of the world (goal-related observations), in order to fulfill a *goal*. *Goals, observations* and *decisions* are identified with sub-indices *g; o; d* respectively, as follows:

$$1 : She's\_Exercising_g \leftarrow She's\_at\_rest_o,\ Trigger\_timeout_o,\\ Encourage\_notification_d$$

Since the information obtained from the mobile sensors is pervaded by vagueness, each piece of knowledge will be attached to *a degree of confidence*, which expresses the uncertainty degree of each rule from a possibilistic point of view (Greek letters whose numerical value belongs to (0,1]). The Anna scenario captured by a possibilistic decision-making framework $PADF_{Anna} = \langle P, \mathcal{G}, \mathcal{D} \rangle$ is introduced in Table 1.

In Table 1, the set of 18 rules of P represents the dependence interaction between observations. The goal $1 - \rho$: *not* $She's\_Exercising_g$ defines the possibility of not performing the action that fulfills the goal; in other words, it has the contrary aim for *sleep*. This "negative" *goal* has an uncertainty degree which is $1 - \rho$ (the complement).

By using a PADF framework, *arguments* can be built, which capture the feasibility of reaching a goal by performing an action (or making a decision), given a set of certain observations of the world [19]. Hence, given this framework $PADF = \langle P, \mathcal{G}, \mathcal{D} \rangle$, and given a function $P\_WFS(S)$ which returns the possibilistic well-founded model[3] of a given possibilistic logic program *S*, we find that an argument A is defined by:

$$A = \langle S, d, (g, \alpha) \rangle \tag{2}$$

where:

1. $(g, \alpha) \in T$ and $g \in \mathcal{G}$ such that $P\_WFS(S \cup \{1 : d \leftarrow \top.\}) = \langle T, F \rangle$, being *T, F* set of possibilistic atoms from which we can infer conclusions.

2. $S \subseteq P$ such that S is a minimal set ($\subseteq$) among the subsets of P *satisfying 1.*

The argument definition (2) is illustrated by using the sub-scenario introduced in Figure 3. In this case, S represents all the clauses which will achieve the goal g, given a decision d taken by ALI, and α represents the preference for that specific goal. In this setting, an argument will have an *informal* reading as follows:

S	*There's no evidence that* ***She's driving*** *so, there's a possibility* λ *that* ***She's running*** *If* ***She's running*** *and* ***ALI sends a message with positive feedback*** *Then, it's possible that* ***She does exercise***
d	***ALI sends a message with positive feedback***
(g, α)	*She prefers* ***Do exercise***

In order to illustrate the process of argument construction, 44 arguments were obtained from $PADF_{Anna}$. In Table 2 a subset of the arguments in the Anna scenario is presented.

Once the arguments are constructed, we compare the strengths of those arguments. In this setting, one can identify two types of disagreement between arguments, which are usually called *undercut* and *rebut* in argumentation literature [26]. In order to define these relationships between arguments, let $A = \langle S_A, d_A, g_A \rangle$, $B = \langle S_B, d_B, g_B \rangle$ be two arguments, with $P\_WFS(S_A \cup \{1\colon d_A \leftarrow \top.\}) = \langle T_A, F_A \rangle$ and
$P\_WFS(S_B \cup \{1\colon d_B \leftarrow \top.\}) = \langle T_B, F_B \rangle$. We say that an argument A attacks B if one of the following conditions holds:

[3]The *well-founded model* is a three-valued model. In A.1.1 a definition of a well-founded model is introduced

$$
P := \left\{
\begin{array}{c}
1 : She's\_Exercising_g \leftarrow She's\_running_o,\ Positive\_feedback_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_running_o,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_at\_rest_o,\ Trigger\_timeout_o,\ Encourage\_notification_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_at\_rest_o,\ Trigger\_timeout_o,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_driving_o,\ Trigger\_timeout_o,\ Encourage\_notification_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_driving_o,\ Trigger\_timeout_o,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_inHome_o,\ Trigger\_timeout_o,\ Encourage\_notification_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_inHome_o,\ Trigger\_timeout_o,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_visitingRegion_o,\ Positive\_feedback_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_visitingRegion_o,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_running,\ Positive\_feedback_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_running,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_walking,\ Positive\_feedback_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_walking,\ No\_notification\_Sent_d \\
1 : She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_driving,\ Encourage\_notification_d \\
1 : \neg She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_driving,\ No\_notification\_Sent_d \\
\\
\iota : She's\_running_o \leftarrow not\ She's\_at\_rest_o \\
\kappa : She's\_at\_rest_o \leftarrow not\ She's\_running_o \\
\lambda : She's\_running_o \leftarrow not\ She's\_driving_o \\
\mu : She's\_driving_o \leftarrow not\ She's\_running_o \\
\epsilon : She's\_walking_o \leftarrow not\ She's\_running_o \\
\varepsilon : She's\_running_o \leftarrow not\ She's\_walking_o \\
\nu : She's\_running_o \leftarrow not\ She's\_at\_rest_o \\
\xi : She's\_at\_rest_o \leftarrow not\ She's\_running_o \\
\zeta : She's\_driving_o \leftarrow not\ She's\_at\_rest_o \\
\eta : She's\_at\_rest_o \leftarrow not\ She's\_driving_o \\
\alpha : She's\_walking_o \leftarrow not\ She's\_at\_rest_o \\
\beta : She's\_at\_rest_o \leftarrow not\ She's\_walking_o \\
\gamma : She's\_walking_o \leftarrow not\ She's\_driving_o \\
\delta : She's\_driving_o \leftarrow not\ She's\_walking_o \\
\theta : She's\_inHome_o \leftarrow not\ She's\_leavingHome_o \\
\vartheta : She's\_leavingHome_o \leftarrow not\ She's\_inHome_o \\
\pi : She's\_inHome_o \leftarrow not\ She's\_visitingRegion_o \\
\varpi : She's\_visitingRegion_o \leftarrow not\ She's\_inHome_o
\end{array}
\right\}
$$

$$\mathcal{G} := \big\{(\rho : She's\_Exercising_g),\ (1-\rho : not\ She's\_Exercising_g)\big\}$$

$$\mathcal{D} := \big\{Positive\_feedback_d, Encourage\_notification_d, No\_notification\_Sent_d\big\}$$

Table 1. Possibilistic decision-making framework $PADF_{Anna} = \langle P, \mathcal{G}, \mathcal{D}\rangle$

$A_2 = \langle\{1 : She's\_Exercising_g \leftarrow She's\_running_o,\ Positive\_feedback_d$ $\lambda : She's\_running_o \leftarrow not\ She's\_driving_o\},$ $Positive\_feedback_d,$ $(She's\_Exercising_g, \lambda)\rangle$
$A_{23} = \langle\{1 : She's\_Exercising_g \leftarrow She's\_visitingRegion_o,\ Positive\_feedback_d$ $\varpi : She's\_visitingRegion_o \leftarrow not\ She's\_inHome_o\},$ $Positive\_feedback_d,$ $(She's\_Exercising_g, \varpi)\rangle$
$A_9 = \langle\{1 : She's\_Exercising_g \leftarrow She's\_at\_rest_o,\ Encourage\_notification_d$ $\eta : She's\_at\_rest_o \leftarrow not\ She's\_driving_o\},$ $Encourage\_notification_d,$ $(She's\_Exercising_g, \eta)\rangle$
$A_{29} = \langle\{1 : She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_running_o,\ Positive\_feedback_d$ $\vartheta : She's\_leavingHome_o \leftarrow not\ She's\_inHome_o,$ $\lambda : She's\_running_o \leftarrow not\ She's\_driving_o\},$ $Positive\_feedback_d,$ $(She's\_Exercising_g, min\{\lambda, \vartheta\})\rangle$
$A_7 = \langle\{1 : She's\_Exercising_g \leftarrow She's\_at\_rest_o,\ Trigger\_timeout_o,\ Encourage\_notification_d$ $\beta : She's\_at\_rest_o \leftarrow not\ She's\_walking_o\},$ $Encourage\_notification_d,$ $(She's\_Exercising_g, \beta)\rangle$
$A_{35} = \langle\{1 : She's\_Exercising_g \leftarrow She's\_leavingHome_o,\ She's\_walking_o,\ Positive\_feedback_d$ $\vartheta : She's\_leavingHome_o \leftarrow not\ She's\_inHome_o,$ $\gamma : She's\_walking_o \leftarrow not\ She's\_driving_o\},$ $Positive\_feedback_d,$ $(She's\_Exercising_g, min\{\vartheta, \gamma\})\rangle$

Table 2. Arguments set of an Extension in the Anna Scenario

1. *Rebut*: $a \in T_A$ and $\neg a \in T_B$.

2. *Undercut*: $a \in T_A$ and $a \in F_B$.

In other words, we can say that *rebut* is an attack, which contradicts a conclusion of an argument, and an *undercut* is an attack, which invalidates an assumption of an argument [19].

The attack relationships among the set of arguments obtained from the possibilistic decision-making framework (Table **??**) were identified using the WizArg tool [27]. The attack relationships are presented in Figure 4, where each argument is represented by a node and each attack relation is represented by an edge.

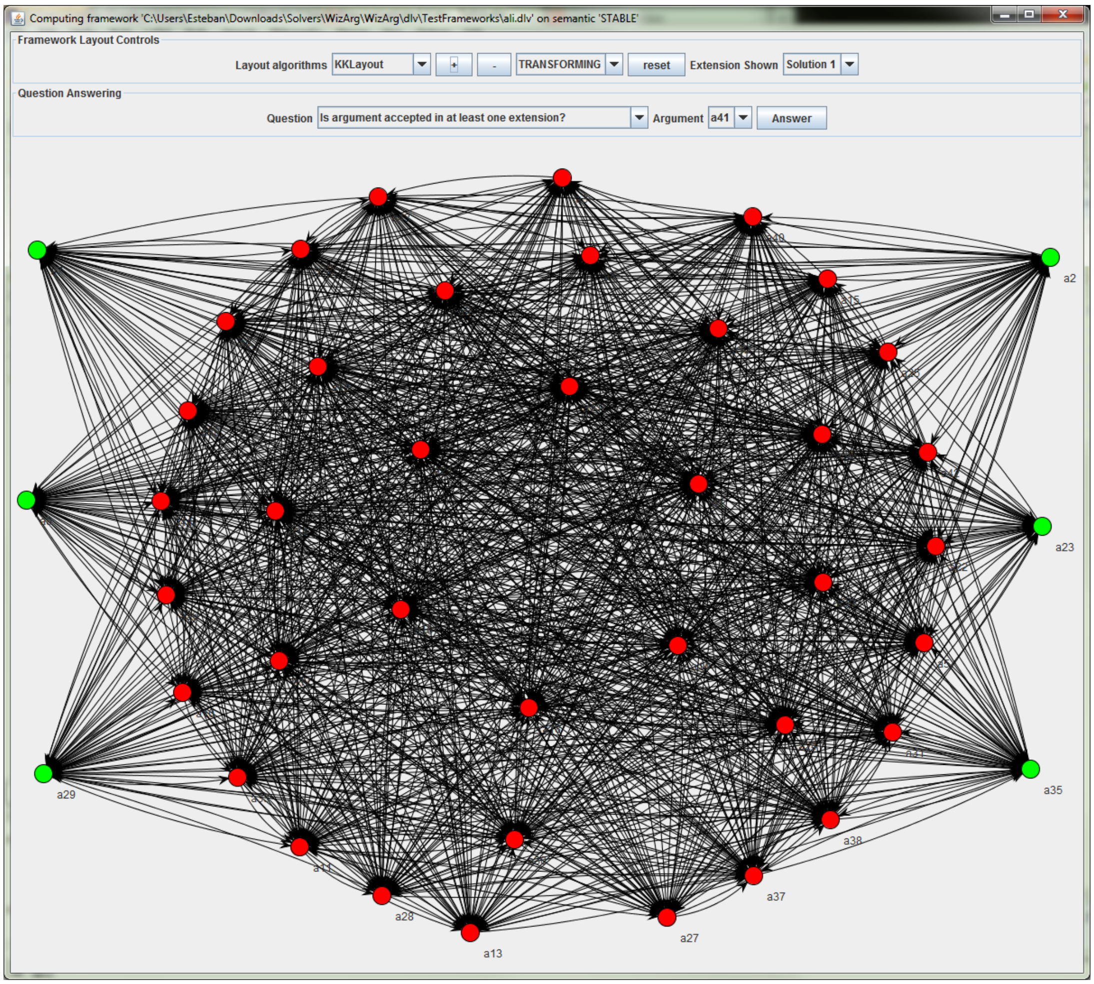

Figure 4. Argument attack relationships

2.2 Argument Acceptance Analysis

Dung [14] defined the so called *Argumentation Framework (AF)*, which is of the form $AF = \langle A,\ attacks \rangle$, where (A) is a set of arguments and $(attacks \subseteq A \times A)$ is the set of their attack relationships.

Given an AF, one can look for subsets of arguments, which suggest coherent points of views from the disagreements among the arguments. The selection pattern of arguments is usually supported by the so called *argumentation semantics* in argumentation theory. In argumentation literature, one can find different argumentation semantics; however, the semantics introduced by Dung in [14] are the most accepted.

A basic argumentation semantics SEM_{Arg} of a possibilistic argumentation decision-making framework $PADF$ is a function from $PADF$ to $2^{2^{\mathcal{AF}}}$, where $SEM(AF) = \{E_1, \ldots, E_n\}$ such that $E_i \subseteq A$ $(1 \leq i \leq n)$. Usually, each E_i is called an *extension* of the argumentation framework AF representing a set of *acceptable* arguments. Dung semantics represent different selection patterns for acceptable arguments, which in the Anna scenario, represent sets of logical and sound arguments explaining or justifying the possibility of achieving a goal, given a set of observations of whether an action is taken.

In order to compute Dung's argumentation semantics in ALI, we use the $WizArg$ tool in the ALI architecture. By using the possibilistic argumentation framework $PADF_{Anna}$ and the *stable semantics* [14], we obtained the following sets:

$$\begin{aligned} SEM_{stable}(PADF) = \{&\{A_2, A_{23}, A_9, A_{29}, A_7, A_{35}\}, \{A_4, A_{26}, A_6, A_{10}, A_{16}, A_{22}\}, \\ &\{A_{24}, A_7, A_3, A_{20}, A_{13}\}, \{A_{30}, A_{18}, A_{25}, A_{37}, A_4, A_{44}\}, \\ &\{A_{28}, A_{13}, A_{23}, A_3, A_{39}, A_7\}, \{A_{40}, A_8, A_{23}, A_7, A_{33}, A_{14}\}, \\ &\{A_4, A_{25}, A_{42}, A_{10}, A_{31}, A_{16}, A_6\}, \{A_{20}, A_{17}, A_{16}, A_{18}\}, \\ &\{A_{32}, A_{38}, A_5, A_{12}, A_{25}, A_4\}\} \end{aligned}$$

In the Anna scenario, these nine extensions represent sets of justified and conflict-free arguments, which will be used in integrating assessment information obtained by the therapist.

We are interested in representing extensions and their arguments in terms of goals, which in our scenario are already defined by Anna and her therapist. As a consequence, let us consider that given an argumentation framework $PADF$, a set of argument extensions E induced by an argumentation semantics defined by $E \in SEM(PADF)$, we have that: $E := \{A_1, A_2, ...A_m\}$ in which each argument $A_i (1 \leq i \leq n)$ is of the form $\langle S_i, d_i, (g_i, \alpha_i)\rangle$. Hence $\varepsilon(E)$ will be defined in terms of its goal sets (g_i, α_i) as follows:

$$\varepsilon(E) := \{(g_1, \alpha) \mid \langle S, d, (g,\ \alpha)\rangle\ \in E\} \tag{3}$$

Observe that $\varepsilon(E)$ is basically projecting the goals of each argument into a set of possibilistic atoms. Given a set of possibilistic atoms $\varepsilon(E) := \{(a_1, \alpha_1),\ \ldots, (a_n, \alpha_n)\}$, $\varepsilon(E)^*$ is $\{a_1, \ldots, a_n\}$. Observe that $\varepsilon(E)^*$ is removing the possibilistic values of $\varepsilon(E)$.

An intuitive reading for Equation 3 in the Anna scenario, is the possibility to represent justified and conflict-free arguments (extensions) *w.r.t.* the goals of those arguments. These notations will be used in the next section where an interpretation of the extension sets using Activity Theory in the context of the Anna scenario is introduced.

2.3 Conclusion Inference

Activity Theory is an approach in social sciences that aims to understand individual human beings in their *natural everyday life circumstances*, through an analysis of the structure and processes of their activities. The concept of *activity* is therefore the most fundamental concept in Activity Theory [11].

The central idea for the interpretation of extensions using Activity Theory, is to maintain a human-centric perspective of the decision-making process in the argumentation selection.

Given the goal-centered analysis of human activities following Activity Theory, and the context presented in Example 1 and 2, we define a human *activity Act* as a finite set of goals g:

$$Act = \{g_1, ..., g_n\} \tag{4}$$

This representation of an activity (4) is consistent with the idea of an extension of a PADF (3), both of them w.r.t. goals to be achieved. The representation of an activity, in terms of goals, allows us to integrate a decision-making framework directly into a hierarchy of activities (Figure 5), following the distinctions described in Activity Theory. In this setting, we can define the set of all the activities that an individual can perform as follows:

Definition 1 *Let $\mathcal{G}$ be a finite set of goals $g_1, ..., g_n$. $\mathcal{A}$ denotes all the possible activities in terms of goals, that can be performed with $\mathcal{G}$, being $\mathcal{A} = 2^{\mathcal{G}}$.*

Definition 1 describes $\mathcal{A}$ as a set of all the activities in terms goals, on other words $\mathcal{A}$ represents the set:

$$\mathcal{A} = \{\mathcal{G}_1, \ldots, \mathcal{G}_m\} \tag{5}$$

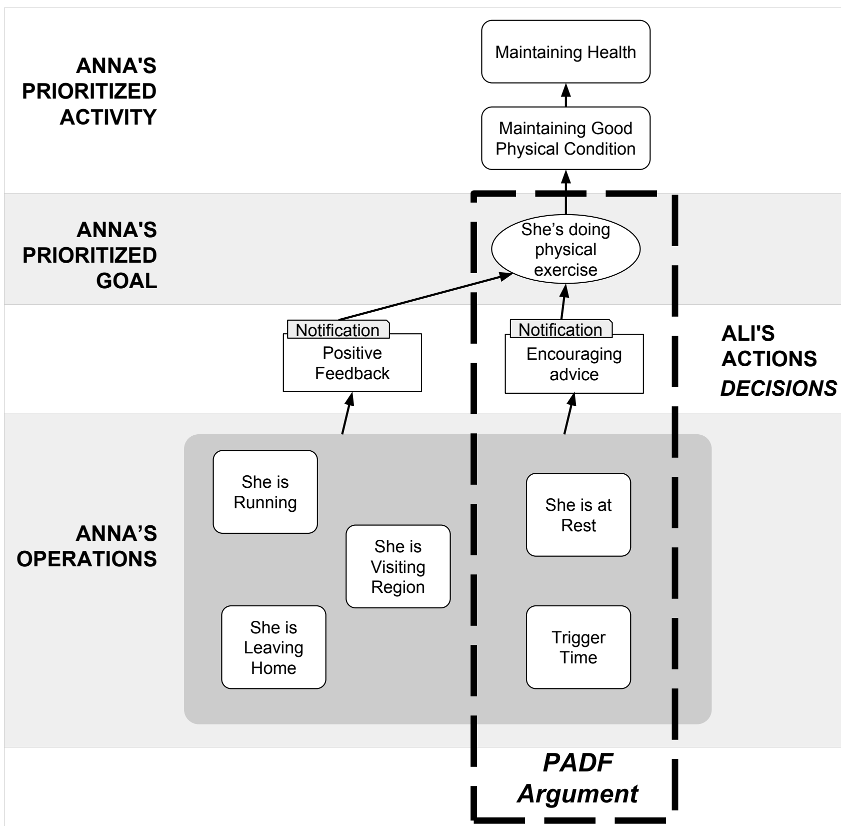

Figure 5. Elements of an activity hierarchy integrated with a Possibilistic Argument-based Decision making Framework

As discussed in Section 1, ALI is intended to be a complementary tool for a health-care team, providing extra information for assessment and monitoring individuals. In this setting, part of the importance of ALI lies in the method of presenting such notifications with positive feedback or encouraging messages. So far, we have been presenting a logical, sound method for decision-making, which is the "reasoner" component, and which provides a set of argument-based alternative explanations (PADF extensions), solving in a logical, sound manner the question of "when" to guide a person in changing her mental state and beginning an activity.

In the remainder of this section, we introduce two main contributions of ALI, which solve the second research question regarding "how" to provide persuasive notifications. The first contribution is a quantification of the activity performance using an integration of Activity Theory and PADF, and the second is a method for building persuasive messages using a *possibilistic goal-based activity scheme.*

2.3.1 Activity Completion

With the previously introduced goal-oriented integration, let us define the concept *completion* of an activity. *Activity completion* is performed by a goal-oriented analysis of extension sets, verifying if an extension contains all, some or no goals of a given activity. The concept of completion is important for quantifying the possibility to perform and complete an activity. The quantifiers used are *complete, partial, indifferent*. In terms of Example 1 and 2, the *completion* quantifies the activity performed by Anna, describing if she performed the recommended activity or not in a time lapse. This is a central contribution to this paper: the concept of tracking a human activity based on the *status of an activity* w.r.t. completion.

Definition 2 *(Status of activities) Let us consider an argumentation framework $PADF$, which has an extension $E \in SEM(PADF)$, where SEM is an argumentation semantics, which induces a set of goals defined by $\varepsilon(E)^*$. Let be $Act \in \mathcal{A}$, the status of an activity is given by:*

- *Complete: iff $Act \subseteq \varepsilon(E)^*$ for all $E \in SEM(PADF)$.*
- *Partial: iff $\exists\ E \in SEM(PADF)$ such that $Act \subseteq \varepsilon(E)^*$ and $\exists\ E^{'} \in SEM(PADF)$ such that $Act \nsubseteq \exists\ \varepsilon(E)^*$.*
- *Indifferent: iff for all $E \in SEM(PADF)$, $Act \nsubseteq \varepsilon(E)^*$*

In order to exemplify Definition 2, let us consider the extensions obtained by arguments in Example 2 and the scenario in Figure 1. Anna's therapist analyzes her activities based on the observations collected by ALI through the mobile and the recommendations, which were presented to her. The therapist notices that there are goals, which were achieved, and there are others for which ALI does not have information. For instance, there are no observations that the action *Walk* was performed.

On the other hand, ALI performs the recommendation in real time using the weight of each argument in the set of extensions. The weight is defined by the goal preferences (defined in our scenario by Anna and therapists) and by the degree of confidence of each rule (possibilistic degree). In ALI, this degree is attached to the *fidelity* of the embedded sensor in the mobile phone. In the ALI prototype implementation, a high accuracy level was pre-defined for accelerometer measures (Anna's movements) and a low one for sound measures (snoring or breathing sounds), and this data depends on the implementation.

In order to exemplify the selection of rules, let us consider Example 2, one of the set of the nine extensions, which is presented in Table 2 and the scenario depicted in Figure 1, in which ALI detects that Anna is running (argument A_2). Given that Anna prefers doing exercise to not doing it, ($She's\_Exercising_g > not\ She's\_Exercising_g$), the argument A_2 is selected and all the arguments generated containing a negative goal are discarded. In this scenario, the set of activities and goals is very limited, but, in spite of this, the complexity of the interactions between arguments (attacks) is high. The number of solutions for the decision-making process must be reduced, which is done by selecting those extensions with preferred goals and preferred activities. Consequently, the process of selecting preferred goals and activities follows a human-centric perspective, using the integration with Activity Theory.

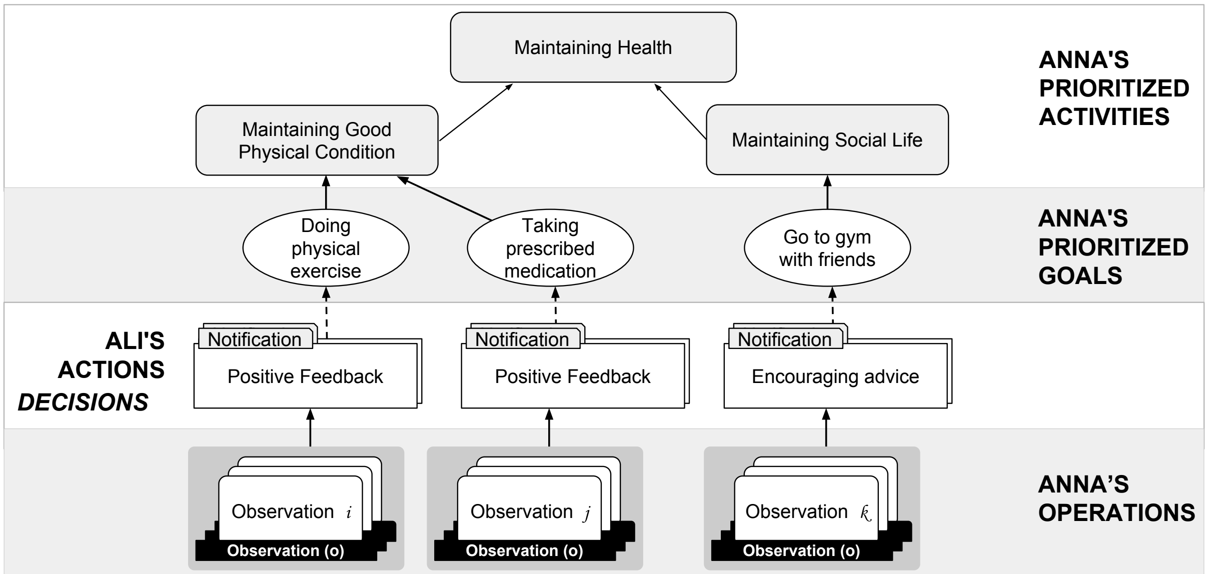

Figure 6. Anna scenario 2, activity with multiple goals.

2.3.2 Persuasive Notifications using a Goal-based Activity Schema

In order to build argument-based messages, we define an *activity-goal scheme*. In argumentation literature, *schemes* are stereotypical patterns of human reasoning, and there are a considerable number of scheme definitions [28, 29]. By using the Activity Theory-PADF integration, a pseudo-natural language monologue is generated, which integrates the main activity, the goal and the type of decision/action given a selected argument. For the Anna Scenario, there are two decision alternatives: send a positive feedback or send an encouraging message. Our approach associates a decision/action with a type of scheme for delivering a specific kind of message. This approach agrees with the notion of *schemes* for argumentation reasoning [29, 30], and also with *rhetorical structure theory*, a well-known approach to building coherent dialogues in rhetorical literature [31, 32]. In this setting, the *intention* of the message (encouraging, justification, persuasion, etc.) directs the structure of the message, where the location of relevant parts of the text (*units* in rhetorical literature), like the goal and context information are not the same for all the schemes.

Anna initially defined a set of messages which she would like to receive as messages (in Swedish). Given that the intention of ALI's messages is to produce positive feedback, which is perceived as encouraging by Anna, her messages include the goal and the activity (part of the argument) to emphasize the intention. Let us call $\mathcal{M} = \{mesg_E, mesg_P\}$ a set of text messages pre-defined, in this case, by Anna. Each message has a specific intention, either encouraging: $mesg_E$ or positive feedback: $mesg_P$. In rhetorical theory, the articulation between units in a text highlights important parts producing the desired intention. We follow a canonical order for rhetorical units introduced in [32], where important unit interactions *nucleus* contain the main content of the text, and other units: *satellites* produce a contextual stress. The canonical order for encouraging ("enablement" in [32]) text follows the form: *nucleus before satellite* and, for positive feedback, the form: *satellite before nucleus*. We introduce the definition of these two activity-goal schemes as follows:

Definition 3 *Given an activity Act defined as a set of goals: $Act = \{g_1, \ldots, g_n\}$, and following the structure of an argument (2): $Arg = \langle S, \mathcal{D}, (g, \alpha) \rangle$ and given that $mesg_E$ is an encouraging message, then* *an encouraging activity-goal scheme will be defined by:* $\langle Act, g, mesg_E \rangle$.

In Definition 3, the interaction between the activity and the goal produces the nucleus of the sentence and Anna's message will be the satellite. Let us consider the following example:

Example 3 *Let us consider the Anna scenario and the Activity Theory-PADF integration represented in Figure 5, with*
$Act = \{$Maintaining good physical condition$\}$,
$g = \{$Doing physical exercise$\}$ *and*
$mesg_E = \{$"Kom igen, ut och spring din latmask!"$(Swedish)$/
"Come out and run lazy!"$(aprox.English)\}$

The activity-goal scheme can be re-written as follows:

$$\langle \text{In order to } \underline{Act}, \text{you might consider } \underline{g}.\ So,\ \underline{mesg_E} \rangle \tag{6}$$

and a grounded *scheme would be a text:*
"In order to <u>*maintain good physical condition*</u>*, you might consider* <u>*doing physical exercise*</u>*. So,* <u>*come out and run, lazy!*</u>*"*

Definition 4 *Given an activity Act defined as a set of goals:* $Act = \{g_1, \ldots, g_n\}$*, and following the structure of an argument (2):* $Arg = \langle S, \mathcal{D}, (g, \alpha) \rangle$ *and* $mesg_P$ *is an encouraging message. A positive feedback activity-goal scheme will be defined by:* $\langle mesg_P, Act,\ g \rangle$.

In Anna's scenario, we consider satellite units with compliment common messages like: "Mycket bra jobbat!"(Swedish)/"Very good job!", and, integrating these satellites to the activity-goal nucleus, we have the schema:

$$\langle \underline{mesg_P}. \text{ You are doing well for } \underline{Act},\ \underline{g} \rangle \tag{7}$$

An example considering $mesg_P = \{$Mycket bra jobbat!!$(Swedish)$/Very good job!$\}$ *would be:*

<u>*Very good job!*</u>*. You are doing well for* <u>*maintaining good physical condition*</u>*,* <u>*doing physical exercise*</u>*.*

Please notice that the structure of the introduced schemes in Definition 3 and Definition 4 are different. The order of $mesg_E$ and $mesg_P$ follows the idea of *nucleus* and *satellite* components in rhetorical theory [32].

The process for message delivering in the ALI implementation is linked to the observations, following an argument-based analysis. Given the Anna scenario, location (in and out of area) and timing triggers (staying for a given time in a specific place: e.g. home) activate this process. Figure 7 shows a typical notification in the form of an encouraging message,

3 ALI Prototype System

We introduce in this section the ALI system architecture. The two main modules of ALI are described (Figure 8): (1) the ALI mobile application; (2) the ALI centralized modules. Some of the relevant functionalities of ACKTUS are introduced in this section (module number 3 in Figure 8). The ALI application was introduced to therapists as an initial step for validating the approach and testing each functionality.

Figure 7. An example of an encouraging notification sent to Anna's mobile, which is running the ALI application.

3.1 ALI Mobile Application

ALI was implemented as a dual service, running as a data collector and, at the same time, delivering notifications in the mobile module.

3.1.1 Data Sensing and Notification Delivery (on{X} service)

The detection task is accomplished by using a mobile application implemented with *on{X}* technology (*https://www.onx.ms*), sending the information collected from sensors in real time to the server via RestWS [33].

on{X} lets us obtain a wide set of mobile sensor features such as location, mode of transport, light sensors, position of the mobile phone (different than location) and the feature called *regions* (*https://www.onx.ms/#apiPage/regions*), which allows for the inference of whether a person is going in or out of a defined place, such as a home environment, as in the Anna scenario. The coordinates of Anna's home location were obtained in the meeting with the therapist.

Visual and vibrating notifications (Figure 7) were also implemented using *on{X}*.

3.1.2 Data Sensing (*funf* service)

A Java background service was part of the ALI, collecting data of location and accelerometer-gyroscope data. This raw data is encrypted and sent to a Web repository (Dropbox, *https://www.dropbox.com/*). This Java service was implemented using an open sensing framework called *funf* (*http://www.funf.org/*).

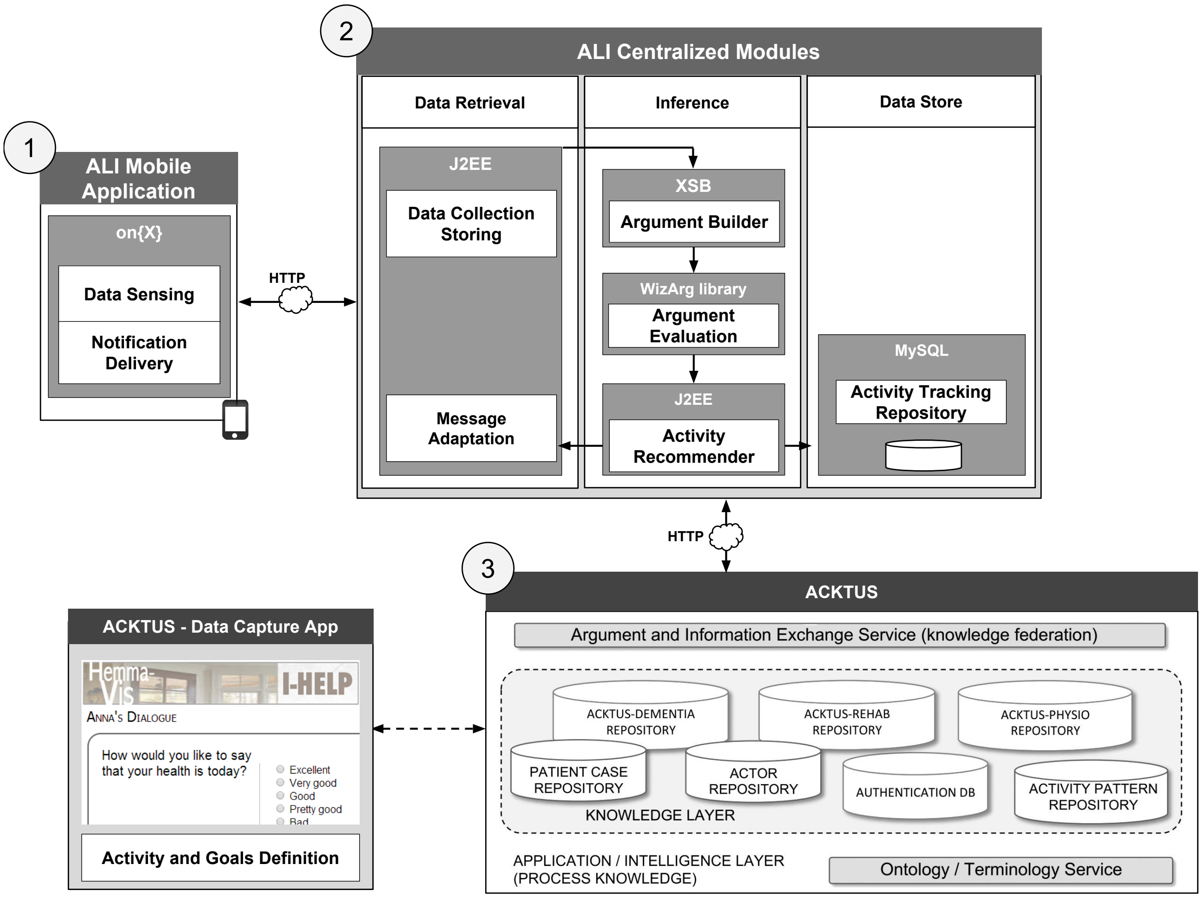

Figure 8. ALI System Architecture

The main idea of this background service was to have a backup or contingency solution, in order to come up with eventual and uncertain complications with the ALI mobile or ALI central modules.

The collected raw data was used for obtaining detailed data about the individual's location, which was correlated with timestamp data from the on{X} service. An example of this correlation is presented in Figure 9, using a GPS visualizer (*http://www.gpsvisualizer.com/*) for conducting data analysis. In Figure 9 (top image), the visualization of the location of the person is shown and, at the same time, the time and type of the delivered notification. In the same figure (bottom image), the detailed location of the tracking measure and the feature of each measure (timestamp in the *bubble* callout) are shown.

3.2 ALI Centralized Modules

The ALI Centralized Modules contain inference and recommendation modules. These are briefly described as follows.

3.2.1 Data Collection Storing

Data sent from mobile phone via *HTTP* (Hypertext Transfer Protocol) is collected and transformed to Answer Set Programs [34] in the class of normal programs, which is the admitted language for inference mod-

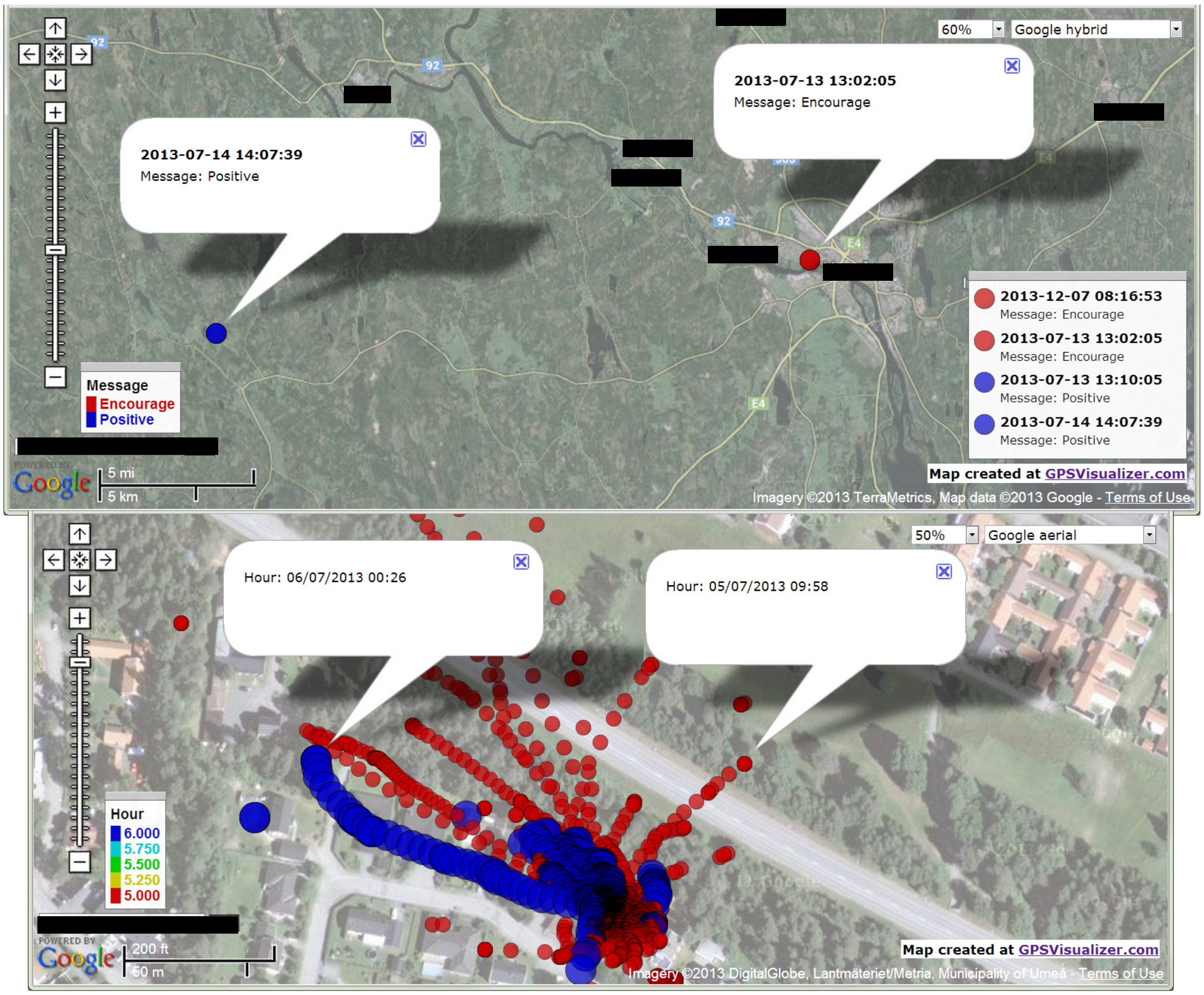

Figure 9. Location and locomotion data is plotted in two test environments.

ules in ALI. This module is built on Java and deployed in a GlassFish server (*https://glassfish.java.net/*). This module also collects all the data from a user and stores it in a MySQL database.

3.2.2 Argument Builder

The XSB system [35] is used for building arguments. The argument Builder module captures the rules from the Data Collection Module, and, using XSB framework, rules are evaluated in the form of dependency graphs. These are evaluated following the Well-Founded Semantics through a full SLG resolution with tabling (see further details in [35]). The Argument Builder module is implemented in Java and linked to XSB using InterProlog [36] as a middleware.

3.2.3 Argument Evaluation

An extension-based argumentation semantics solver library is used for argument evaluation. *WizArg* [27] obtains sets of argument extensions. The *stable semantics* option is used in WizArg. However, it is also possible to choose between *CF2, stable* and *grounded semantics*.

3.2.4 Activity Recommender sub-module

This module obtains the best decision from the arguments and prepares a persuasive notification with the purpose of convincing the individual to perform the action.

3.2.5 Message Adaptation

This module obtains the recommendation and transforms it into an HTTP message to be visualized by the phone. This module sends the notification via Web Rest services.

ALI records all the *executed* arguments (selected arguments to which recommendations were sent) into a MySQL database. ALI quantifies the completion of an activity by analyzing the records and comparing them with the argument extensions. In this way, the tracking analysis is performed. The therapist can access all the tracking information. The access to this module is restricted to only the health-care team via ACKTUS.

3.3 ACKTUS

The ACKTUS platform (Activity-Centered Modeling of Knowledge and Interaction Tailored to Users) was developed for enabling health professionals model domain knowledge to be used in knowledge-based applications, and design the interaction content and flow for supporting different types of activities (e.g., diagnosis, risk assessment, support for conducting Activities of Daily Living (ADL)) [13]. ACKTUS contains a number of knowledge-bases, assessment applications and dedicated user interfaces for different knowledge domains (8). In this work, ACKTUS is used for the following purposes: 1) as an instrument for assessing a user's health status, preferred activities, preferences and goals, through the ACKTUS application *I-Help*; 2) as an instrument for the users participating in the pilot user study to create their own motivational messages, which they would like to receive; and 3) for storing arguments and notifications generated by ALI (i.e., events) in the actor repository together with other person-specific information. All ACKTUS applications share a common core ontology, which is a representation of knowledge at the levels of *activity* and *actions*, in terms of the complexity hierarchy model of human activity provided by Activity Theory. Consequently, ALI supplements this model by providing interpretations of observed *operations*, which can be combined with representations of knowledge defined by the ACKTUS core ontology and fused into a more rich understanding of a human activity and behavior.

4 Pilot Study

A pilot evaluation study based on the Anna scenario was conducted. The study addresses the research questions defined in the introduction; 1) how does information about the context, preferences and personalized suggestions contribute to building arguments?; 2) how is the human-computer interaction performed through a mobile phone?; and 3) how does the user react to positive and encouraging messages? These questions are partially answered, based on the analyses of data obtained by ALI and ACKTUS I-Help and through interviews with the test subjects. The study was formative, aiming to provide results which can be fed into the ongoing development of ALI. The evaluation study focused on the analysis of location and locomotion features obtained from the mobile phone of an individual and building arguments supported by knowledge obtained from the ACKTUS repositories.

Whether or not the behavior of an individual actually changes when personalized suggestions are received through the ALI system is a subject for future work.

4.1 Methods, Participants and Procedure

In this paper, we focus on the decreasing well-being among young individuals between the ages of 18 and 24 years old. We applied the Anna scenario and contrasted our Anna scenario with the scenario of Thea, who was comparably active. The subjects who volunteered to participate in our study were not necessarily suffering from any of these conditions, but could identify with one of the scenarios and were asked to play the role of the persona. The test subjects were informed about the purpose of the study and gave informed consent.

The two female adolescents we call Anna and Thea were first interviewed by a therapist who made an initial assessment, in which priorities and goals were identified. The initial assessment was performed using the ACKTUS application I-Help, through which data was captured and stored in an actor repository. A dedicated assessment protocol for the purpose was used called *Assessment of Goals and Priorities*. This information about the two test subjects was retrieved by ALI and functioned as the source for person-specific information such as preferred goals and prioritized activities. Anna and Thea prioritized physical activity as the main activity to be supported, in order to achieve a healthy and regular activity pattern over day and night.

Anna and Thea were also asked to formulate personalized recommendations, or arguments, which they preferred to be given, and under what conditions they should be presented, which were added to their actor repositories. This was in accordance with the purpose of the messages in ALI, in which positive and encouraging feedback messages follow an approach to coping with depression and anxiety, using an introspective natural dialogue (creating messages to oneself), which has been shown to be an important determinant of physical activity in youth [37, 38]. In this manner, the personalized view represents a trusted source for recommendations, since listening to or reading recommendations from another source or person requires confidence and trust.

The two subjects agreed to carry a smart-phone over a period of one week. They agreed to carry the phone throughout all activities and were explained what kind of data would be collected. Over the evaluation period, the two subjects were asked to try to maintain the phone switched on both day and night.

4.2 Results

The results are divided into results related to the argument building process and the generation of tailored messages and the interaction between the users and the ALI application.

4.2.1 Building argument-based explanations on different human-centric information sources

The outcomes of the assessment performed by therapists are described in natural language and follow the topics that the individual have created arguments about. Consequently, there are two main sources of human-centric arguments (the individual as a baseline view and the therapist, based on their expertise and knowledge of the client), which are supplemented with the current opinions that the individual holds in a particular situation in which an argumentative dialogue is performed. These opinions may not necessarily be the opinions that the individual holds as a baseline set of opinions. In our pilot study, we applied only the arguments formulated by the individual.

One example of an encouraging message is presented in Figure 7. The message is presented when Argument 7 (See Table 2) is triggered. This notification was suggested by Anna, talking to herself in order to "move" and do any kind of outdoor activity, because she had stayed at home more than two days, which was included as a trigger time observation in Figure 5.

4.2.2 Interaction between ALI and the study subjects

Interviews were conducted in order to investigate the positive and negative aspects of using a mobile phone to receive notifications, as perceived by the two test users. Thea pointed out that one of the disadvantages was that she frequently forgot to bring along the charger for the mobile phone, which was one of the causes for only obtaining data on two days of activity. Anna, on the other hand, had no problems with forgetting the charger, since she was at home most of the time. She also highlighted that she was receiving some notifications regarding going and doing exercise, but she was sick, and ALI continued sending notifications. Anna suggested that she was interested in establishing a direct dialogue with the system in order to state that she was unable to do the exercise and had a good argument for not complying with the suggestions.

The question of whether the individual changed her behavior or not as a consequence of using ALI was not a subject of this pilot study. However, the following was observed, which creates a base for future studies. Given the data log, when Anna received an encouraging message, she left her home, and ALI detected that she was out of town. It was confirmed later that she was visiting relatives, which was considered as complying with the Ali notifications. However, taking into account the location analysis and the number of notifications sent, we can infer that Anna and Thea were not attending to all the recommendations immediately.

A different kind of information was obtained using the GPS Visualizer. The plotted images were shown to Anna, who responded with interest and curiosity and wanted to see exactly where she had been walking in a forest nearby. Her interest in the potential feedback in the form of a map of her routes offered suggestions for a future improved version of ALI. The top map of Figure 9, shows when and what type of notification was sent and shows Anna's position before and after. The bottom map shows the different locations where Thea was located in her home.

5 Discussion and Related Work

In this article the assisted living system ALI is presented, which is being developed for supporting individuals in improving their performance of daily living activities, through positive feedback and encouraging messages. Methods for recognizing and justifying human activities are presented, which lead to providing pro-active support tailored to an individual's preferences and goals in different situations. The contributions of this work are discussed in the following sections.

5.1 Integrating a possibilistic argument-based decision-making framework and Activity Theory

An integration of components of Activity Theory into a formal framework was performed in order to recognize, justify and provide argumentative explanations for human activities. The integration of an argument-based decision-making framework with a human behavior framework allowed including into the focus of analysis the user's goals and what drives, or motivates the user to conduct activity. By considering the three main steps of a meta-interpreter depicted in Figure 2, a logical sound set of arguments (Step 1) is obtained, which explains the detected activity performed by the individual. In order to obtain these arguments a Possibilistic Well-Founded Semantics (P_WFS) [22] was applied. In order to obtain a sound set of *acceptable arguments* (Step 2), a Possibilistic Argument-based Decision Framework (PADF) [19] was used, combined with Activity Theory [11] in order to obtain a human-centric argument-based output: an appropriate, persuasive and sound message (Step 3).

In argumentation literature, there are some psychological-oriented approaches, which also strive for a human-centric perspective, such as [2,3,5]. By contrast, other approaches such as [6–9] focus on providing sound and consistent argument-based explanations regardless a human-centric perspective. In this setting, the main general contribution of our approach is the combining of focus to goal-based activities of an individual, which enables a human-centric perspective that includes driving forces for conducting activity. This is particularly important when applications are aimed at supporting behavior change, as in our case, changing behavior towards a more healthy pattern of behavior.

In argumentation literature, Abstract Argumentation Frameworks (AAFs) ([14, 39], among others) provide a theoretical basis for exploring issues of defeasible reasoning. The ALI approach follows the line of AAFs introduced in [14]. However, it is closer to approaches in which the knowledge is coded in the structure of arguments and argumentation semantics is used to determine the acceptability of arguments.

Dung in his seminal work [14] made one of the major contributions to the argumentation field by showing that logic programming can be shown as a form of argumentation, and at the same time, argumentation itself can be viewed' as logic programming with *negation as failure*. In this setting, the underlying formalisms for knowledge representation are of particular importance. In other words, the underlying language for capturing a knowledge base is crucial for representing information. Different "non-monotonic" logics have been proposed for capturing commonsense knowledge [40–43]. A knowledge base like the one used in the Anna scenario, is captured by a possibilistic version of an Extended Logic Program (ELP) [44]. Representing incomplete information as well as exceptions, it allows for the description of scenarios with uncertain information, like the sensor-based information obtained from a mobile phone. Other approaches also define incomplete information and exceptions [45–47]. However, an ELP seems to fit perfectly for the purpose of defining decision-making scenarios with uncertain data. In this setting, the possibilistic decision-making framework used in the ALI approach has a main desirable property, in comparison with the approaches described in [48,49], which is that it can deal with reasoning that is at the same time non-monotonic and uncertain. This main characteristic makes the PADF the optimal approach for developing real implementations. PADF is based on the Well-Founded Semantics (WFS) [50], which applies a skeptical reasoning approach, and is defined for all general logic programs [50]. In contrast to WFS, the stable model semantics [44] do not always generate a model. In other words, WFS allows for a model for a given knowledge base to always be obtained (sometimes coinciding with the empty model).

5.1.1 Using Activity Theory for argument interpretation

By considering a psychology framework for the interpretation of a sound set of acceptable arguments, a human-centric perspective is developed, obtaining as a contribution a quantification of the human activity performance and the possibility of planning analysis as a future work. Activity Theory is a more complex framework for human behavior analysis, involving not only the hierarchy *activities-actions-operations*, but also defining human *needs*, which are the ultimate cause behind human activities [51].

Consequently, the integration of Activity Theory into a formal decision-making process, offers two different paths for future work. First, a further deepened human-centric analysis can be integrated. Argument-based explanations can be obtained for conscious and unconscious causes for human activities, which makes it possible to analyze the different aspects of human activity, both the hierarchical characteristics (activities-goals-operations), and motives and needs. It was suggested by Karowski and coworkers that *press* can be included in the Activity-theoretical model of activity [52]. Figure 10 shows how *press* as external stimuli creates a desire to obtain or avoid something.

Second, the goal-centered analysis of human activities introduced in Equation 4, where an activity is based on human-centric goals: $Act = \{g_1, ..., g_n\}$ resembles a *plan*. An integration between PADF and Activity Theory enables the quantification of the performance of activities. Moreover, new plans can be formulated in order to perform similar, or the same activity in a different manner.

5.2 Generating persuasive messages by using *activity-goal scheme*

In literature, there is an important amount of persuasive and guiding systems. Persuasive approaches have different perspectives depending on the underlying reasoning approach and the *philosophical* model

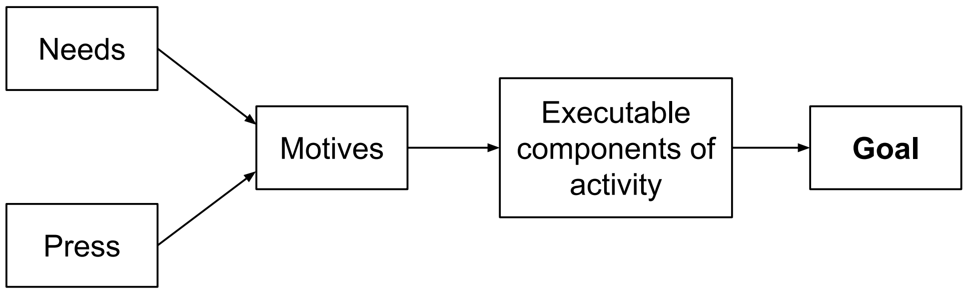

Figure 10. Relationship between press and the activity-theoretical concepts needs, motives, and goals [52].

adopted. In multi-agent system approaches, the interaction between agents is sometimes governed by the *belief-desire-intention* (BDI) model, which has become possibly the best known and best studied model of practical reasoning agents [53]. Different approaches have proposed persuasive systems following the BDI model [2,6]. In argumentation literature, there are a vast amount of approaches based on *rhetorical* models like *informal argumentation* [2] or *practical reasoning* [4,6], where the reasoning patterns are mostly based on philosophical orientation, rather than on logical and sound inferences. Since the ALI approach is based on the integration of Activity Theory and a possibilistic decision-making framework, it is possible to provide sound and logical decisions at the same time as a human-centric analysis to choose the best method to deliver the *answer*. In this process, the ambition is closer to an argumentative dialogue such as a human would perform.

Our approach has some similarities with the work introduced in [3,4,54], where *values* (in terms of social values) and *emotional states* are considered. In [3], the BDI model is extended with emotions, feelings and goals that a person pursues, similar to [2], using the hierarchical classification of values in [54]. These approaches introduce a reasoning process based on schemes; however, the importance of the sound and consistency of the proofs is disregarded.

The generation of persuasive messages in ALI, based on the *activity-goal scheme* (Subsection 2.3.2), is similar to scheme-based reasoning [29,30,55]. The *persuasive message* generated by ALI has a different point of view than the *persuasion dialogues* in argumentation literature ([4,29,56]). In [29], such differences are established, where persuasion is intended to persuade another individual to accept some contested proposition that s/he did not previously believe. In our approach, the *persuadee*, in principle, agrees with and believes in the persuasion method used, which uses her own words and follows the idea of self-motivation.

An *argument scheme* is a structure of inference representing common types of arguments used in everyday discourse. A scheme has *critical questions* attached, which evaluate the *correctness* of a given argument in a particular context. Our strategy for building a persuasive discourse in the Anna scenario was to generate a pseudo-natural language dialogue (the notification) based on the contextual and sound reasoning process integrating person-specific information.

The *activity-goal scheme* introduced for persuasion follows a more dialectical integration of supports-conclusion arguments, since it is closer to the graph-oriented representation of a persuasion reasoning in [3], and, at the same time, moves away from the persuasion schemes in [4,29,56], where persuasion is intended to persuade another individual to accept some argued proposition that s/he did not previously believe. In this setting, our approach in the Anna scenario of integrating the type of messages that she prefers for encouraging herself produced positive results in our pilot study. The built messages, following the proposed schemes 6 and 7, seem to follow a natural sense in both Swedish and English. This is an aspect to take into consideration, since ALI is intended for being a multi-linguistic tool for multi-cultural environment. Considering this, some of the approaches in [2,5,57] are impossible to implement in other cultural contexts without profound changes in the reasoning model, because they are mostly based on the dialectical and specific context of the English natural language.

5.3 A modular architecture for recognizing human activity in a non-intrusive manner

The approach presented in this work fulfills three major requirements; 1) a non-intrusive human recognition alternative; 2) dealing with uncertain and incomplete information from sensors with no data training; and 3) the activity recommendation should be supported and monitored by a health-care team. The prototype was oriented towards modularize the sensors in order to being able to integrate other from the Ambient Assisted Living systems in future.

This work differs from simpler approaches for human activity recognition such as those described in [58–60]. There is a significant difference in this implementation compared to approaches, which use sensors placed on different parts of the body of a person in an Ambient Assisted Living environment [61, 62]. This is sometimes not feasible due to practical reasons. Uncertain and incomplete data from sensors were also analyzed in Ambient Assisted Living contexts (e.g., [58] and [62]). This approach uses a different alternative, where more than one possible scenario (set of argument extensions) is inferred in real time based on an argumentation semantics.

5.4 A formative pilot evaluation study

In order to test different parts of ALI architecture, a pilot study was conducted. Regarding the building process of natural arguments, the architecture obtains from the individual their preferences and feedback and encouraging messages. The information is used for building human-centric arguments, which are implemented in an introspective natural dialogue between a human agent and the system agent.

The evaluation study, where location sensors from the mobile phones were used, showed the following advantages: 1) ALI is a non-intrusive solution; 2) young users are familiar with mobile phones, and 3) the approach is a low cost alternative. The identified obstacles to use mobile phones for the purpose were: 1) inaccuracy of location sensors (Figure 9 shows the inaccuracy of Anna's location when she was in her home), 2) real time data transmission failed when the user was outside of the mobile Internet service coverage area, and 3) battery limitations.

In order to improve the argumentative dialogue between the user and the system (i.e., interaction), future work includes the implementation of a functionality in the next version of the prototype where the user can provide a response in natural language to the arguments provided by the system. In the pilot study, only the arguments formulated by the individual were applied. In future work, there will be three agents involved in the dialogues: 1) ALI as an agent, mediating the user's baseline view including the arguments created by the user; 2) the therapist as an agent, mediating the domain professional's view, and 3) the human agent, contributing with her current opinion about her situation at the moment of a dialogue.

6 Conclusions

This paper presents ALI, which is a persuasive-tracking system using a novel approach to argument-based reasoning. This approach combines formal argumentation systems and informal models of human activity. This facilitates the tailoring of advices to the human actor, taking into consideration the human's motives, goals and prioritized actions. The contributions of this work are the following:

- A non-intrusive approach to tracking and monitoring individual activities, assisted by health professionals.

- An argument-based framework for decision-making, framed on a theory for describing human activities.
- A recommender system architecture, inferring the best decisions for advising goal-based activities.

To summarize, different perspectives were used in this interdisciplinary work for the purpose of recognizing, inferring and recommending human activities. Future work includes improving the human-ALI dialogue, methods for handling changes of preferences and verifying the validity of arguments with respect to time. User studies will be conducted, which will involve more subjects and a longer test period. Allowing the use over a longer period of time will provide insight into how the application affects the user's decision-making and activity performance.

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A A Possibilistic Argument-based Decision Framework

Originally introduced in [22].

A.1 Background

A.1.1 Well-Founded Semantics

In this section, we present a definition of the well-founded semantics in terms of rewriting systems. We start presenting a definition of a 3-valued logic semantics.

Definition 5 (*SEM*) *[63]*
For normal logic program P, we define $\mathrm{HEAD}(P) = \{a|\ a \leftarrow \mathcal{B}^+,\ not\ \mathcal{B}^- \ \in P\}$ *— the set of all head-atoms of P. We also define* $\mathrm{SEM}(P) = \langle P^{true}, P^{false}\rangle$*, where* $P^{true} := \{p|\ p \leftarrow \top \in P\}$ *and* $P^{false} := \{p|\ p \in \mathcal{L}_P \backslash \mathrm{HEAD}(P)\}$. $\mathrm{SEM}(P)$ *is also called model of P.*

In order to present a characterization of the well-funded semantics in terms of rewriting systems, we define some basic transformation rules for normal logic programs.

Definition 6 (Basic Transformation Rules) *[63]*
A transformation rule is a binary relation on $Prog_{\mathcal{L}}$. The following transformation rules are called basic. *Let a program $P \in Prog_{\mathcal{L}}$ be given.*

RED$^+$: *This transformation can be applied to P, if there is an atom a which does not occur in* HEAD*(P).* ***RED$^+$*** *transforms P to the program where all occurrences of not a are removed.*

RED$^-$: *This transformation can be applied to P, if there is a rule $a \leftarrow \top \in P$.* ***RED$^-$*** *transforms P to the program where all clauses that contain not a in their bodies are deleted.*

Success: *Suppose that P includes a fact $a \leftarrow \top$ and a clause $q \leftarrow body$ such that $a \in body$. Then we replace the clause $q \leftarrow body$ by $q \leftarrow body \setminus \{a\}$.*

Failure: *Suppose that P contains a clause $q \leftarrow body$ such that $a \in body$ and $a \notin HEAD(P)$. Then we erase the given clause.*

Loop: *We say that P_2 results from P_1 by* Loop_A *if, by definition, there is a set A of atoms such that:*

1. *for each rule $a \leftarrow body \in P_1$, if $a \in A$, then $body \cap A \neq \emptyset$,*
2. *$P_2 := \{a \leftarrow body \in P_1 | body \cap A = \emptyset\}$,*
3. *$P_1 \neq P_2$.*

Let CS_0 be the rewriting system such that contains the transformation rules: RED^+, RED^-, $Success$, $Failure$, and $Loop$. We denote the uniquely determined normal form of a program P with respect to the system CS_0 by $norm_{CS_0}(P)$. Every system CS_0 induces a semantics SEM_{CS_0} as follows: $SEM_{CS_0}(P) := SEM(norm_{CS_0}(P))$.

In order to illustrate the basic transformation rules, let us consider the following example.

Example 4 *Let P be the following normal program:*

$$d(b) \leftarrow \; not\; d(a). \qquad d(c) \leftarrow \; not\; d(b). \qquad d(c) \leftarrow d(a).$$

Now, let us apply CS_0 to P. Since $d(a) \notin HEAD(P)$*, then, we can apply* $\boldsymbol{RED}^+$ *to P. Thus we get:*

$$d(b) \leftarrow \top. \qquad d(c) \leftarrow \; not\; d(b). \qquad d(c) \leftarrow d(a).$$

Notice that now we can apply $\boldsymbol{RED}^-$ *to the new program, thus we get:* $d(b) \leftarrow \top. \quad d(c) \leftarrow d(a).$ *Finally, we can apply* ***Failure*** *to the new program, thus we get:* $d(b) \leftarrow \top$*. This last program is called the* normal form *of P* w.r.t. *CS_0, because none of the transformation rules from CS_0 can be applied.*

WFS was introduced in [64] and was characterized in terms of rewriting systems in [65]. This characterization is defined as follows:

Lemma A.1 *[65] CS_0 is a confluent rewriting system. It induces a 3-valued semantics that it is the Well-founded Semantics.*

A.1.2 Extended Possibilistic Normal Programs

In order to define the class of extended possiblistic normal programs, it is necessary to define a single reduction of an extended possibilistic normal logic program *w.r.t.* a set of atoms. This reduction is defined as follows:

Definition 7 *Let* P *be an extended possibilistic logic program and* S *be a set of atoms. We define $R(P, S)$ as the extended possibilistic logic program obtained from P by deleting:*

1. *all the formulae of the form not a in the bodies of the possibilistic clauses such that $a \in S$, and*

2. *each possibilistic clause that has a formula of the form not a in its body.*

Observe that $R(P, S)$ does not have negative literals. This means that $R(P, S)$ is an extended possibilistic definite logic program.

Definition 8 *(Possibilistic Well-Founded Semantics) Let $P = \langle (Q, \leq),\; N \rangle$ be an extended possibilistic normal logic program, S_1 be a set of possibilistic atoms, S_2 be a set of atoms such that $\langle S_1^*, S_2 \rangle$ is the well-founded model of P^*. $\langle S_1, Q_{\top_Q}(S_2) \rangle$ is the possibilistic well-founded model of P if and only if $S_1 = \Pi Cn(R(P, S_2))$. Where $\Pi Cn(P)$ is a fix-point operator. By $P\_WFS(P)$, we denote the possibilistic well-founded model of P.*

A.2 Possibilistic Argumentation-based Decision Framework

Generally speaking, a possibilistic decision-making problem follows a structure of cognitive states, namely beliefs, desires and intentions. In fact, the beliefs that an agent has about the world are captured by a possibilistic knowledge base, while intentions and goals of the given agent are expressed in terms of a set of decisions and a set of prioritized goals. Therefore, we can define:

Definition 9 *A possibilistic decision-making framework is a tuple $\langle P, \mathcal{D}, \mathcal{G} \rangle$ in which:*

1. *P is a possibilistic normal logic program.*

2. *$\mathcal{D} = \{d_1, \ldots, d_n\}$ is a set of decision atoms such that $\mathcal{D} \subseteq \mathcal{L}_{P^*}, \mathcal{D}^*$ denotes the set of all possible decisions.*

3. $\mathcal{G} = \{(g_1, \beta_1), \ldots, (g_m, \beta_m)\}$ *is a set of possibilistic atoms such that* $\mathcal{G}^* \subseteq \mathcal{L}_P^*, \mathcal{G}^*$ *denotes the set of all possible goals and* $\beta_j (1 \leq j \leq n)$ *represents the priory of the goal* g_j.

4. $\mathcal{D}^* \cap \mathcal{G}^* = \emptyset$.

The possibilistic decision-making framework of Definition 9 is based on a possibilistic theory with negation as failure. Indeed, the user is able to express assumptions by means of negation as failure. Since the possibilistic decision-making framework is based on a possibilistic default theory, a possibilistic default reasoning inference for building arguments is required. Consider the possibilistic version of the well-founded semantics (Definition 8).

Definition 10 *Let* $F = \langle P, \mathcal{D}, \mathcal{G} \rangle$ *be a possibilistic decision-making framework. An argument on a decision* $d \in \mathcal{D}$ *is a tuple* $A = \langle S, d, (g, \alpha) \rangle$ *such that:*

1. $(g, \alpha) \in T$ and $g \in \mathcal{G}$ such that $P\_WFS(S \cup \{1 : d \leftarrow \top.\}) = \langle T, F \rangle$, being T, F set of possibilistic atoms from which we can infer conclusions.

2. $S \subseteq P$ such that S is a minimal set ($\subseteq$) among the subsets of P *satisfying 1.*

Once we have identified the set of arguments of our possibilistic default theory, the relationships between these arguments need to be identified.

Three elements make an argumentation system a framework for defeasible argumentation: the first is the notion of a *conflict* between arguments (also called '*attack*' and '*counter argument*') [26]. Two types of conflicts are established in [66] and defined w.r.t to P_WFS in Definition 3.3 [19]: let $A = \langle S_A, d_A, g_A \rangle$, $B = \langle S_B, d_B, g_B \rangle$ be two arguments, with $P\_WFS(S_A \cup \{1 : d_A \leftarrow \top.\}) = \langle T_A, F_A \rangle$ and $P\_WFS(S_B \cup \{1 : d_B \leftarrow \top.\}) = \langle T_B, F_B \rangle$. We say that an argument A attacks B if one of the following conditions holds:

1. *Rebut*: $a \in T_A$ and $\neg a \in T_B$.

2. *Undercut*: $a \in T_A$ and $a \in F_B$.

By having a set of arguments and their relationships, a possibilistic decision-making framework can be instantiated into a possibilistic argumentation decision-making framework. Since any pair of arguments can be compared according to different criteria (such as the certainty level of the goal reached by the given argument), a possibilistic argumentation decision-making framework is provided with a partial order relation. Hence, given a set of arguments $\mathcal{A}_F, \preceq_{\mathcal{A}_F}$ denotes a partial order in $\mathcal{A}_F$.

Definition 11 *A possibilistic argumentation decision-making framework is a tuple* $PF = \langle F, \mathcal{A}_F, Att, \preceq_{\mathcal{A}_F} \rangle$, *where* F *is a possibilistic decision-making framework, and* Att *denotes the binary relations of attacks in* $\preceq_{\mathcal{A}_F}$, i.e. $Att \subseteq mathcal A_F \times mathcal A_F$.

Essentially, a possibilistic argumentation decision-making framework is an extension of a possibilistic decision-making framework.