Abstract. The evaluation of physical activities in health domains such as Physiotherapy, is performed by using standard assessment tests which use direct observational and time-based procedures to measure physiological processes. In this paper, we introduce an Activity Argument-based Time-framed Framework \( \text{AcArTiF} \) for evaluating physical activities by resembling the kind of assessment reasoning performed by clinicians. In a logic program, we capture sets of observations, goals and actions framed on an activity, and as output of the framework, we obtain sets of atomic hypotheses, so-called timed fragments explaining the performed activity. We propose a set of conditions under which timed fragments and structured arguments in general, are internally consistent. We consider the time scope of goals for evaluating the dynamics of an activity which is used to quantify the time performance.

1 Introduction

In this paper, an approach for evaluating physical activities when the activity structure changes is presented. Our study is framed on the assessment of human activities where the following holds: 1) activities are hierarchical, consisting in sets of goal-based actions and each action consists in sets of observations\(^1\); 2) activities are defined in a period of time; 3) goals have a finite time scope. A graphical representation of the activity structure considered in this paper is presented in Figure 1. Our approach adopts a deductive strategy for the activity evaluation by following methods used in health domain. A deductive reasoning method can be seen as a basic form of medical diagnostic reasoning, forming decisions about observations of the world (in \([3]\) deductive and abductive diagnostic reasoning methods are analyzed). In this context, particularly in Physiotherapy, clinicians use direct observational procedures to measure physiological processes using different assessment protocols (\([4, 5]\) among others). These protocols can

\(^1\) Actions have goals and are executed by the actor at a conscious level, in contrast with observations of operations which do not have a goal of their own and which are executed at the lowest level as automated, unconscious processes. We define this structure as a goal-based activity following Activity Theory \([1, 2]\).
be seen as activities in a controlled environment [6]. We test our approach identifying such protocols with the activities whose performance they are intended to assess.

In this paper, we explore a novel approach for evaluating physical activities by resembling the kind of assessment reasoning performed by clinicians: 1) gathering data through observations; 2) generating current function status hypothesis; 3) deduce an explanatory outcome of explanation; 4) retracting the explanation under new evidence. We propose a general method to evaluate activity performance considering achievement of goals when such accomplishment of goals is framed on a time scope. We present a argumentation-based framework for evaluating structured and dynamic human activities, considering: 1) evaluation as the quantification process of what an individual does during the execution of an activity; 2) structured activity as a hierarchy of goals, actions and operations based on a Social Sciences theory [1, 7, 8]; and 3) a time-framed goals representing the dynamics of human activities in time. In this regard, we aim to solve the following research questions:

- How to model time in a goal-based activity structure?
- How to evaluate structured and dynamic activities?
- How to build time-framed hypotheses regarding dynamic activities?
- In what extent, the activity evaluation method depends on the selection process of hypotheses (argumentation semantics)?

The contributions of this paper are:

- An argument-based framework for evaluating physical activities considering time constrains.
- A characterization of activity atomic explanations considering a time scope.
- A set of consistency conditions for structured arguments.
- A characterization of standard assessment tools as hierarchical activity structures.

The rest of the paper is structured as follows: in Section 2 some background about Logic Programming as well a running example involving a real scenario
using a Physiotherapy assessment test. We present our argument-based framework introducing the atomic units for evaluating activities, the so called timed fragments in Section 3. In Section 4, we present a method for evaluating activities using sets of fragments estimating the time accomplishment of a goal. In Section 5 we compare our approach and results against of the state of art. In the last Section, a summary of our conclusions is presented.

2 Preliminaries

In this section some background about logic programs is introduced as well as a definition of hierarchical activity is introduced. We assume that the reader is familiar with basic terms of Logic Programming and Argumentation Theory\textsuperscript{2}.

2.1 Dynamic hierarchical activities

An activity is the unit of analysis that we consider in this paper. A human activity, particularly a physical activity considers goals, actions and observations of an individual’s world as a structured hierarchy. This notions, firstly introduced in Social Sciences by Leontiev in [7] have a significant correspondence with the Belief Desire Intentions [10] model of an intelligent agent. Our notion of hierarchical activity, shown in Figure 1, can represent different levels of granularity as well as change in the goal composition over time. Figure 1, presents a common scenario for different human activities in which goals are feasible to achieve in a period of time. For instance, in health domain, our hierarchical representation of activities can be used for those defined by the International Classification of Functioning, Disability and Health (ICF)\textsuperscript{3} or more “simple” activities such as rising and sitting down from a chair. Moreover, simple activities can be part of other activity, in this manner, subsets of goals can be seen as sub-activities. Let us consider along the entire paper a running example based on a physical assessment test as an activity, the Short Physical Performance Battery (SPPB) [12] examined as a hierarchical activity. The SPPB evaluates lower-extremity functioning of an individual and it can be described as a 4-goal observation-based activity, as Example 1 illustrates.

Example 1. The “sit-to-stand” test (S2S) is part of the SPPB as is presented in Table 1. This test is designed to evaluate the balance and leg strength of an individual by testing the ability to rise from a chair. An expert Physiotherapist performs the sit-to-stand test with the help of a sensor-based system capturing observations, evaluating the activity and providing audio indications (sounds) to persuade an individual to execute some actions. The S2S has different steps as follows: a straight-backed chair is placed next to a wall; participant is asked to

\textsuperscript{2} A basic introduction about Logic Programming can be found in [9].

\textsuperscript{3} Examples of self care activities are: oneself, washing and drying oneself, caring for one’s body and body parts, dressing, eating and drinking, and looking after one’s health [11].
Activity structure of the SPPB test.

<table>
<thead>
<tr>
<th>Activity</th>
<th>SPPB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td></td>
</tr>
<tr>
<td>Goal 1</td>
<td>Goal 2</td>
</tr>
<tr>
<td>Side-by-side</td>
<td>Semi-Tandem</td>
</tr>
<tr>
<td>Observations</td>
<td></td>
</tr>
<tr>
<td>Light sway</td>
<td>Light sway</td>
</tr>
<tr>
<td>Moderate sway</td>
<td>Moderate sway</td>
</tr>
<tr>
<td>Vigorous sway</td>
<td>Vigorous sway</td>
</tr>
<tr>
<td>Task on time</td>
<td>Task on time</td>
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<tr>
<td>Task out of time</td>
<td>Task out of time</td>
</tr>
</tbody>
</table>

Table 1. Activity structure of the SPPB test.

fold their arms across their chest and to stand up from the chair one time when an alarm sounds. If successful, participant is asked to stand up and sit down five times as quickly as possible, and is timed from the initial sitting position to the final standing position at the end of the fifth stand. An expert Physiotherapist, evaluates the S2S with a score of 0 those individuals who could not complete the task (the goal) assigned. Those completing the task are assigned scores of 1 to 4, with the fastest times scored 4 [12].

2.2 Underlying logical language

Modelling and capturing the type of human activities considered in this paper, require an underlying logic language able to deal with uncertain and lack of observational evidence (e.g., sensor-based data) as well as inconsistency of the goals (e.g., two contradictory goals to achieve at the same time). All these elements can be captured by logic programs. We use propositional logic as a syntax language which is constituted by propositional symbols: $p_0, p_1, \ldots$; connectives: $\land, \land, \lor, \land, \top$; and auxiliary symbols: ( ), in which $\land, \land$ are 2-place connectives, $\top$ are 1-place connectives and $\top$ is a 0-place connective. The propositional symbols $\top$ 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. The atoms of the form $\neg p_i$ are also called extended atoms in the literature. In this setting, we can capture observations of the activities dealing with data incompleteness coming from, for example, sensors.

An Extended logic program (ELP) [13] uses both strong negation $\neg$ and negation-as-failure not (NAF), representing common-sense knowledge through logic programs. On programs with NAF, the consequence operator: $\leftarrow$ is not monotonic, which means that the evaluation result may change as more information is added to the program. This non-monotonic process in some sense, follows the natural treatment of lack of evidence performed by a therapist in an assessment process. A large number of non-monotonic reasoning approaches have been developed for capturing this kind of common-sense knowledge [14, 15] among others.

In Example 1, the sit-to-stand test as a sub-activity of the SPPB is captured by the program $P$ in Figure 2. We denote $\mathcal{L}_P$ as the set of atoms in
the signature of a program \( P \). In this program, an intuitive reading of a clause such as: \( \text{incorrRise}_g : \text{scp}_i \leftarrow \text{Slow}_\text{Rise}_o \land \text{Fast}_\text{Sit}_o \land \text{incorrBalance}_g : \text{scp}_i \land \text{HAct}_2 \), would be: “given that, there is evidence of a slow rising-up and evidence of a fast sitting-down and a no sound indication is played, then the rising was not performed correctly”. Goal scope is captured by attaching a time scope to the goal, i.e., the period of time when the goal is achievable, e.g., \( \text{incorrRise}_g : \text{scp}_i \) refers to an expectation of the incorrect rising during a time scope: \( \text{scp}_i(i > 0) \). The achievement of a goal is linked to the execution of an action. Different actions may be undertaken to meet the same goal. In Example 1, actions are sound indications played in the starting time scope of every goal. An action such as \( \text{HAct}_2 : \text{Not}_\text{sound}_a \) indicates that not sound was played. We assume that a sound indication enables the achievement of a correct rising goal. The S2S test is evaluated by an expert observing the achievement of three goals over time: correct balance, correct get-up and correct sit-down which accomplish a successful sub-activity. This test is performed 4 times, each attempt is called profile, as is represented in Figure 2.2. In this figure, black lines represent temporal scope of a goal, being the scope expectation finite, e.g., it is expected that from \( t_0 \) to \( t\text{inter}0-1 \) an individual get up from the chair, after that, from \( t\text{inter}0-1 \) to \( t_1 \) it is expected that the person sits down during each profile.

3 Hypotheses about dynamic activities

In this section, we present our argument-based framework which creates atomic hypothesis about the activity been performed, the so called timed fragments. We present first, the dynamics of a hierarchical activity as follows.

3.1 Dynamics of hierarchical activities

Dynamics in argumentation frameworks deals with variation of the argumentation graph in time. Different approaches have been proposed analyzing the
\[
\begin{align*}
\text{incorrRise}_g : \text{scp}_i & \leftarrow \text{Slow}_\text{Rise}_o \land \text{Fast}_\text{Sit}_o \land \\
\text{incorrBalance}_g : \text{scp}_i & \leftarrow \text{corrBalance}_g : \text{scp}_i \land \text{HAct}_2 \\
\text{corrRise}_g : \text{scp}_j & \leftarrow \text{Fast}_\text{Rise}_o \land \text{Slow}_\text{Sit}_o \land \\
\text{corrBalance}_g : \text{scp}_j & \leftarrow \text{corrBalance}_g : \text{scp}_j \land \text{HAct}_1 \\
\text{corrRise}_g : \text{scp}_j & \leftarrow \text{Fast}_\text{Rise}_o \land \text{Fast}_\text{Sit}_o \land \\
\text{corrBalance}_g : \text{scp}_j & \leftarrow \text{corrBalance}_g : \text{scp}_j \land \text{HAct}_1 \\
\text{incorrRise}_g : \text{scp}_i & \leftarrow \text{Fast}_\text{Rise}_o \land \text{Fast}_\text{Sit}_o \land \\
\text{incorrBalance}_g : \text{scp}_i & \leftarrow \text{corrBalance}_g : \text{scp}_i \land \text{HAct}_2 \\
\text{corrBalance}_g : \text{scp}_i & \leftarrow \text{Little}_\text{Sway}_o \\
\text{corrBalance}_g : \text{scp}_i & \leftarrow \text{not Much}_\text{Sway}_o \\
\text{incorrBalance}_g : \text{scp}_j & \leftarrow \text{Much}_\text{Sway}_o \\
\text{incorrBalance}_g : \text{scp}_j & \leftarrow \text{not Little}_\text{Sway}_o \\
\text{Little}_\text{Sway}_o & \leftarrow \text{not Much}_\text{Sway}_o \\
\text{Much}_\text{Sway}_o & \leftarrow \text{not Little}_\text{Sway}_o \\
\text{Slow}_\text{Rise}_o & \leftarrow \text{not Fast}_\text{Rise}_o \\
\text{Fast}_\text{Rise}_o & \leftarrow \text{not Slow}_\text{Rise}_o \\
\text{Fast}_\text{Sit}_o & \leftarrow \text{not Slow}_\text{Sit}_o \\
\text{Slow}_\text{Sit}_o & \leftarrow \text{not Fast}_\text{Sit}_o \\
\end{align*}
\]

\[
O := \{ \text{Little}_\text{Sway}_o \leftarrow \top, \text{Much}_\text{Sway}_o \leftarrow \top, \\
\text{Slow}_\text{Rise}_o \leftarrow \top, \text{Fast}_\text{Rise}_o \leftarrow \top, \\
\text{Fast}_\text{Sit}_o \leftarrow \top, \text{Slow}_\text{Sit}_o \leftarrow \top, \\
\} \cup \ldots
\]

\[
G := \{ \langle \text{corrRise}_g, \text{scp}_i \rangle, \langle \text{incorrRise}_g, \text{scp}_j \rangle, \\
\langle \text{correctBalance}_g, \text{scp}_i \rangle, \langle \text{incorrectBalance}_g, \text{scp}_j \rangle \}
\]

\[
\text{HAct} := \{ \text{HAct}_1, \text{HAct}_2 \}
\]

Where: \( \text{HAct}_1 : \text{Starting\_sound}_a \) and \( \text{HAct}_2 : \text{Not\_sound}_a \)

**Fig. 2.** Example 1. Partial structure of a logic program capturing the sit-to-stand test of the SPPB for an individual.
availability of arguments during a time period, verifying time conditions of attacks/defense \[16, 17\] and analyzing the graph structure \[18\], among others. In order to manage the dynamics of a physical activity for providing argument-based explanations, we extend an Activity Argumentation Framework \[19\] with time-related attack among semantic fragments by considering a Temporal Argumentation Framework (TAF) \[16\]. In this setting, the extended activity framework can capture dynamics of real-world hierarchical activities such as the SPPB or its sub-activities as the S2S in Figure 2.2.

### 3.2 Activity time-framed framework

We extend the activity framework \[19\] considering the time scope of goals and subgoals of an activity. Accordingly, the scope of a goal is given by the tuple: \(\langle g, \text{scope} \rangle\), where scope is a period of time (probably infinite) such that \(\text{scope} \in \mathbb{R}\), e.g., \(\langle g_1, (t_0, t_{\text{inter}_0 - 1}) \rangle\), being \(\text{scope} = (t_0, t_{\text{inter}_0 - 1})\) the start-end period of profile 1 Figure 2.2 and captured by \(P\) in Figure 2. The achievement of a goal is given by the time scope and a corresponding action which is considered timeless or instantaneous. We define the activity time-framed framework (AcTiF) as follows:

**Definition 1 (Activity time-framed framework).** An activity time-framed framework is a tuple of the form \(\langle P, \mathcal{H}, \mathcal{G}, \mathcal{O}, \mathcal{A} \rangle\) in which:

- \(P\) is an extended logic program.
- \(\mathcal{H} = \{h_{a_1}, \ldots, h_{a_n}\}\) is a set of \(n\) atoms such that \(\mathcal{H} \subseteq \mathcal{L}_P\) and represents the set of hypothetical actions that an agent\(^4\) can performed during the scope of a goal.
- \(\mathcal{G} = \{\langle g_1, \text{scope}_{g_1} \rangle, \ldots, \langle g_n, \text{scope}_{g_n} \rangle\}\) is a set of \(n\) atoms such that \(\mathcal{G} \subseteq \mathcal{L}_P\), representing the set of goals framed in a time scope in the activity.
- \(\mathcal{O} = \{o_1, \ldots, o_i\}\) is the set of \(i\) atoms such that \(\mathcal{O} \subseteq \mathcal{L}_P\), representing the set of world observations captured by an agent.
- \(\mathcal{A} \subseteq 2^\mathcal{G}\) denotes the all possible sets of goal-based sub-activities.

The AcTiF framework in Definition 1 lies on four assumptions: 1) a goal has a finite time scope\(^5\); 2) an hypothetical action is directed by a goal; 3) observation atoms define a context where the activity is performed; and 4) any set of goals can define a sub-activity.

We are interested in generate hypothesis regarding the activity performance, providing argument-based explanations w.r.t. an activity, i.e., building argument-like structures support-conclusion as follows:

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\(^4\) We consider a rational agent able to receive percepts from the environment and perform actions. Each such agent implements a function that maps percept sequences to actions and it is one that acts so as to achieve the best outcome \[20\].

\(^5\) We assume here a finite scope of a given goal because an infinite scope would imply a infinite span of the activity prescribing a non-dynamic behavior.
Definition 2 (Semantic fragment of an activity). Let $\text{AcTiF} = (P, \text{Hact}, G, O, \text{Activ})$ be an activity time-framed framework. A semantic fragment of an activity has a form $F = (S, O', a, \{g, \text{scope}\})$ such that:

1. $S \subseteq P$, $O' \subseteq O$, $a \in \text{Hact}$, $g \in G$,
2. $S \cup O' \cup \{a\}$ is consistent,
3. $g \in \text{True}$ during a time: scope, such that $\text{WFS}(S \cup O' \cup \{a\}) = \langle \text{True}, \text{False} \rangle$,
4. $S$ and $O'$ are minimal w.r.t. set inclusion.
5. $a$ and $O'$ are available during the scope of $g$.

Where $\text{WFS}(S)$ is a function inferring the Well-Founded Semantics (WFS) [21] to a set of clauses $S \subseteq P$.

A semantic fragment deals with inconsistent goals and incomplete observations by using a semantic alternative for building arguments [22]. In this sense, our approach fulfills different principles of quality for rule-based argumentation systems [23, 24]. The notion of a semantic fragments holds only during the time scope prescribed by the goal, e.g., during the correct sit-down scope $(t_{\text{inter}}-1, t_1)$ it is not possible to infer anything regarding to a correct get up (see Figure 2.2). The third condition in Definition 2 is based on the relevance property [25] that WFS satisfies. Informally speaking, the relevance property states that it is perfectly reasonable that the truth-value of an atom, with respect to any semantics, only depends on the subprograms formed from the relevant clauses with respect to that specific atom [26]. The last condition in Definition 2, suggests a close relationship between a goal and an hypothetical action under certain conditions described by the observations. In Activity Theory literature, the lowest level of the hierarchy is given by so called operations which differ from action by the level of automatization, over the course of execution actions in an activity can become automatic operations [1]. In our approach operations are captured by observations.

We can exemplify the notion of a semantic fragment considering program $P$ in Example 1 and extending the knowledge base by adding, for instance, sensor-based observations as follows:

Example 2. A lecturer professor is assessed by an therapist using the SPPB sit-to-stand test, registering her movements in a sensor-based application. Data captured by sensors shows the following evidence:

- Strong swaying in the rising task during the profile 1 (Much_Sway in $P$).
- Slow speed in rising up during profiles 1 to 4 (Slow_Rise in $P$).
- There is not evidence regarding a slow speed in sitting down at any profile (not Slow_Sit in $P$).

With the obtained sensor-based facts and the program $P$, we can obtain the following semantic fragments:
$F_1 = \langle \{ \text{incorrRise}_g : \text{profile} \leftarrow \text{Slow Rise} \land \text{Fast Sit} \land \\
\text{incorrBalance}_g : \text{profile} \land \text{HAct} \rangle, \\
\{ \text{Much Sway} : \text{profile} \leftarrow \top, \text{Slow Rise} \leftarrow \top, \text{Fast Sit} \leftarrow \neg \text{Slow Sit} \}, \\
\text{HAct} \rangle \rangle$

$F_2 = \langle \{ \text{incorrBalance}_g : \text{profile} \leftarrow \text{Much Sway} \}, \\
\text{Much Sway} \leftarrow \top \rangle \rangle$

In Example 2, $F_1$ and $F_2$ support the hypothesis that the lecturer had performed an incorrect rise in the sit-to-stand test during profile 1.

A tuple $\langle \text{goal}, \text{scope} \rangle$ imposes time boundaries to the semantic fragment (see point 5 in Definition 2) we can designate a timed fragment as a pair $t-F = \langle F_{\text{goal}}, \text{scope} \rangle$ where $F_{\text{goal}}$ is the semantic fragment prescribed by a given goal during a time scope. The support of a timed fragment can be an assembled substructure of other fragments. In order to define the concept of sub-structure, we introduce some auxiliary functions $\text{Supp}$ and $\text{Concl}$ which return the support, conclusion and scope of a given fragment respectively, e.g., given the fragment $F = (S, O', a, \langle g, \text{scope} \rangle)$ we have $\text{Supp}(F) = \{ S, O' \}$, $\text{Concl}(F) = \{ g \}$ and $\text{Scope}(F) = \text{scope}$.

**Definition 3 (Sub-fragment).** Let $F_1 = (S_1, O_1', a_1, \langle g_1, \text{scope}_{g_1} \rangle)$, $F_2 = (S_2, O_2', a_2, \langle g_2, \text{scope}_{g_2} \rangle)$ be two fragments of an activity. $F_1$ is a sub-fragment of $F_2$ iff $\text{Supp}(F_1) \subseteq \text{Supp}(F_2)$ and $\text{scope}_{g_1} \subseteq \text{scope}_{g_2}$.

The notion of sub-fragment as a structure supporting other fragments allows us provide hypothesis regarding sub-goals in the hierarchical structure of the activity. In Example 2, $F_2$ is a sub-fragment of $F_1$.

### 3.3 Consistency of semantic fragments

In argumentation literature, a set $S \subseteq P$ is consistent iff $\not\exists \psi, \phi \in P$ such that $\psi = \neg \phi$.

Intuitively, we want to prevent sub-fragments containing counterfactual information, i.e., given two sub-fragments of a fragment $F$: $F_1 = (S, O', a, \langle g, \text{scope} \rangle)$ and $F_2 = (S, O'', a, \langle g, \text{scope} \rangle)$, a counter-factual situation occurs when $x \in O'$ and $y \in O''$ and $x$ contradicts or attacks $y$ during the scope of $g$. The semantic approach for building fragments prevents this phenomena by evaluating the fragment support of every sub-fragment, particularly by holding the minimality state of the fragment support (conditions 3 and 4 respectively in Definition 2). We introduce a general internal consistency condition for any argument-based structure such as the semantic fragments:

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\[ \text{Definition 6. Consistent set in [27].} \]
Definition 4 (Internal consistency).

Let \( P \) be an extended logic program, \( AF_P = \langle Arg_P, Attack(Arg_P) \rangle \) be the resulting argumentation framework from \( P \), and let \( Arg = \langle S, concl \rangle \) be an argument with \( S \) being the support and \( concl \) its conclusion. An argument \( Arg \) is internally consistent w.r.t. \( AF_P \) iff: \( \forall a, b \in \text{ Supp}(Arg) \), \( a \) attacks \( b \).

Definition 4 introduces a consistency condition for any structured arguments where an attack between two atoms occurs in the fragment support. This consistency condition complements other approaches to define principles of closure and consistency for argument-based systems [24, 27, 28].

Proposition 1 (Internal consistency of semantic fragments/arguments).

Let \( ActF = \langle P, Hact, G, \mathcal{O}, \text{Acts} \rangle \) an activity argumentation framework and let \( F = \langle S, O', a, (g, \text{scope}) \rangle \) be a hypothetical fragment built using a semantic approach (Definition 2), the following condition holds: \( \exists x, y \in \text{ Supp}(F) \), \( x \) attacks \( y \) during a time scope.

Proof. By contradiction using the condition 3 and 4 of semantic fragment definition.

Proposition 1 introduces a general scheme for internal consistency in argument-based structures which is relevant for the semantic fragments concept. This result can be characterized in terms of only the set of observations \( \mathcal{O} \) given an activity framework \( ActF = \langle P, Hact, G, \mathcal{O}, \text{Acts} \rangle \). In this setting, we can identify the set of consistent observations of the output of an argument system, as follows:

Proposition 2 (Consistent observations). Let \( F = \langle S, O', a, (g, \text{scope}) \rangle \) be a hypothetical fragment internally consistent with two sub-fragments \( F_1 = \langle S_1, O', a_1, (g_1, \text{scope}) \rangle \) and \( F_2 = \langle S_2, O'', a_2, (g_2, \text{scope}) \rangle \), the following condition holds: \( \exists x \in O', y \in O'' \), \( x \) attacks \( y \) during a time scope.

Proof. It follows proof of internal consistency Proposition 1.

Our approach can deal with inconsistencies of fragments by evaluating the support of a fragment before to build it. The WFS evaluation performed in Definition 2, retracts to evaluate that the lecturer in Example 2 has performed an incorrect when inconsistent observations (counter-factual) are in a clause, e.g., \( \text{incorrRise}_g: \text{profile}_1 \leftarrow \text{Slow}_R \text{ise}_o \land \neg \text{Slow}_R \text{ise}_o \land \text{Fast}_S\text{it}_o \land \text{incorrBalance}_g: \text{profile}_1 \land HAct_1 \).
– ∃α ∈ Supp(F_2) such that α ≡ ¬g_1.
– g_2 ≡ ¬g_1
– ∃α ∈ Supp(F_2) and ∃β ∈ Supp(F_1) such that α ≡ ¬β

Definition 5 presents a traditional approach in argumentation theory to infer the “best” explanation. In activity evaluation, survival fragments of an attack relationship are local explanations framed on the strongest fragment scope. The first two conditions of attack between fragments resemble the well-known notions of undercut and rebut [29, 30]. Intuitively, the last condition describes a self-attack between atoms of different sub-fragments. In this circumstance, two atoms α and β in different sub-fragments are attacking each other. In fragment-based activity explanation, this self-attack is prevented by using the semantic construction of fragments, particularly by considering the minimal set condition in Definition 2.

3.5 Activity argument-based time-framed framework

The AcTiF framework defined in Definition 1 frames a basic structure for capturing a hierarchical activity using logic programming. Such framework establishes the foundation for dealing with goal change in an activity considering goals span. In order to infer hypothesis about an AcTiF framework adding a non-monotonic behavior, we consider an activity argument-based time-framed framework by using an availability function which expands the goal span approach to a time availability of the hypotheses as follows:

Definition 6 (Activity argument-based time-framed framework). Let AcTiF = ⟨P, H_{act}, G, O, Activ⟩ be an activity time-framed framework. An activity argument-based time-framed framework AcArTiF is of the form: AcArTiF = ⟨AcTiF, F, Atts, Av⟩, where F is the set of semantic fragments w.r.t. the AcTiF framework; Atts a binary attack relation on F, i.e., Atts ⊆ F × F; and Av is the availability function for timed fragments, defined as Av : Scope(F) → [a, b] with a, b ∈ R specifying start and end availability time points.

Let us emphasize that an AcArTiF includes different dynamics aspects about an activity being performed, for instance, the availability function in Definition 6 expresses time change in the goals, as well as a non-monotonic behavior prescribed by the set of attacking/defending hypotheses (fragments). These time characteristics of an AcArTiF have been already mentioned but formally not defined in Social Sciences [1, 7]. The availability function in Definition 6 was firstly introduced in [16] and it is used in this paper for establishing the conditions of fragment admissibility and acceptability according to Dung [31]. In order to select coherent points of view from a set of conflicting semantic fragments, Dung in [31] introduced a set of patterns of selection of arguments-based structures. Argumentation semantics is a formal method to identify conflict outcomes for any argumentation framework, which can be seen as a graph of interrelated semantic fragments. These sets of fragments prescribed by an argumentation
semantics, e.g., \( SEM = \{ Ext_1, \ldots, Ext_k \} \), are called sets of extensions. In this setting, sets of extensions represent “the best” explanation for the current situation of an individual in an activity. Each extension \( Ext_k \) defines unambiguous explanations of the world, this is an abstraction of an extension in terms of the achieved goals or the referenced observations in an activity.

Let us redefine the well-known concepts of conflict-free, admissible and acceptable sets by considering timed fragments, as follows.

**Definition 7 (Conflict-free timed fragments).** A set \( S \) of timed fragments is said to be conflict-free in an AcArTiF framework, if there are no timed fragments \((F_{goal_1}, scope_1), (F_{goal_2}, scope_2) \in S\) such that \((F_{goal_1}, F_{goal_2}) \in Atts\) and \( scope_1 \cap scope_2 \neq \emptyset \).

Conflict-free timed fragments describe sets of hypotheses which provide not contradictory explanations or counter-factual observations.

In Example 2, an expert therapist evaluates physical responses of a lecturer, intuitively an hypothesis \( F_1 \) regarding an activity is acceptable if the therapist can defend \( F_1 \) (from within her/his world of knowledge) against all attacks on such hypothesis. Furthermore, it is reasonable to assume that the therapist accepts a hypothesis only if it is acceptable within a time scope. Let us define an acceptability notion of a time-based hypothesis w.r.t. a set of hypotheses as follows:

**Definition 8 (Acceptable timed fragments w.r.t. \( S \)).** Let \( AcArTiF = (AcTiF, t-F, Atts, Av) \) be an activity argument-based time-framed framework; let \( S \) be a set of timed fragments pairs \( t-F = (F_{goal}, scope) \). An acceptable time scope for a timed fragment \( t-F_1 \) w.r.t. \( S \) is denoted by:

\[
T_{t-F_1|S} = \bigcap_{t-F_2 \in \{X | (X, t-F_1) \in Atts\}} (\text{Scope}(t-F_1) \setminus \text{Scope}(t-F_2)) \cup T_{t-F_2|X}^{t-F_1|S}
\]

where \( T_{t-F_2|X}^{t-F_1|S} \) is the scope of the timed fragment \( t-F_1 \) when is defended of its attacker \( t-F_2 \) by the set \( S \). The intersection of all time intervals in which the fragment \( t-F_1 \) is defended from each of its attackers by the set \( S \), is the time interval where \( t-F_1 \) is available and is acceptable w.r.t. \( S \).

The acceptability as is introduced Definition 8 is based on the scope of timed fragments, when two conflicting hypotheses about an activity exist at the same time. By considering Definition 8 a conflict-free set of timed fragments \( S \) can be named as admissible if and only if each fragment in \( S \) is acceptable w.r.t. \( S \).

Based on the acceptability, conflict-freeness and admissibility notions we can define different selection patterns of semantic fragment-based hypothesis to evaluate the accomplishment of goals within an activity and performance by adopting a time perspective. Since an AcArTiF framework could generate several coherent hypothesis regarding an activity, one can take the maximum admissible sets in order to get maximum coherent point of views. This idea is captured by the concept of preferred extension as follows:

**Definition 9 (Preferred extension).** A preferred extension of an argumentation framework \( AF \) is a maximal (w.r.t. set inclusion) admissible set of \( AF \).
4 Evaluation of physical activities based on a fragment selection

In this section, a method for evaluating activities using sets of fragments is proposed. This method is based on the acceptability definition introduced in [32], estimating the time accomplishment of a goal by considering an overall perspective of the activity.

4.1 Time performance of an activity

The AcArTiF framework can provide consistent explanations regarding an activity, sanctioned for different time-based semantics derived from our definition of acceptability and conflict-free sets. We are now interested in the evaluation of activities sets, i.e., we want to analyze the accumulative evaluation of a more complex activity using AcArTiF. In health diagnosis scenarios, an expert is focused on other qualitative aspects of activity performance such as the efficiency with which an individual carries out an assessment tool [33], e.g., the time and quality evaluation of 10 meters walking in the SPPB test among others.

Definition 10 (Goal polarity). Let $\text{AcTiF} = \langle P, \mathcal{H}_{\text{act}}, (\mathcal{G}, \text{scope}), O, \text{Activ} \rangle$ be a framework. We designate $\mathcal{G}^+ \subseteq \mathcal{G}$ as the set of goals that can contribute to the achievement of an activity $\text{Activ}$, and $\mathcal{G}^- \subseteq \mathcal{G}$ the set of goals with an inverse result for the achievement of $\text{Activ}$.

Definition 10 establishes a preference in the set of goals regarding a given activity. An example of a $\mathcal{G}^+$ set can be $g_1, g_2$ and $g_3$ in Figure 2.2, w.r.t. a set $\mathcal{G}^- = \{g_4 : \text{Incorrectget-up}, g_5 : \text{Incorrectsit-down}, g_6 : \text{Incorrectbalance}\}$.

We can calculate efficiency $\text{ActivEff}_g$ on the achievement of a goal $g$ by considering expected scope of a goal w.r.t. an acceptable set of fragments, as follows:

$$\text{ActivEff}_g = \frac{\sum_{g \in \mathcal{G}^+} T_{g|S}}{\text{expected scope}_g} \quad (1)$$

Equation 1 represents a comparison between the time which is explained by using timed fragments and the expected scope of a goal. In this equation, we use the time for the acceptable sets which we consider that can be used as a highest time boundary. We can also obtain time information from a goal in the set $\mathcal{G}^-$ being this a degree of inability to perform a given activity.

5 Discussion and conclusions

Physical activity evaluation is performed by therapist using structured methods called assessment tests. We capture in a logic program such test as a hierarchical
structure based on Activity Theory. Extended logic programs (ELP) [13] capture incomplete information as well as exceptions, e.g., sensor-based data, using strong negation and negation-as-failure (NAF). ELP is not the only approach for capturing defaults and partial information, other approaches [34, 14, 35] capture incomplete information and exceptions as well. We select ELP as knowledge representation language given its semantic expressiveness and the existence of efficient tools for computing ELP semantics. Two major semantics for ELP have been defined: 1) answer set semantics [13], an extension of Stable model semantics; and 2) a version of the Well-Founded Semantics (WFS) [21]. In the definition of our semantic fragment, we evaluate semantically the support of our hypothetical fragment by considering a WFS function (point 3 in Definition 2). The same semantic evaluation can be performed by using a function calculating the Stable model of the fragment support. In our approach, this correspondence between WFS and Stable is obtained given that every fragment has a stratified logic program as support (see [22]).

An assessment test such as the SPPB, can be used as example for showing the capacity of ELP for capturing and representing uncertainty in the observations, but it cannot show inconsistent or conflict in the program given that SPPB as well as other tests ([4, 36, 5] among others) are structured hierarchically and the set of goals is limited. From the theoretical point of view, the SPPB does not show a complex structure of the argumentation framework prescribed, i.e., there are no cycles among attacks, but most of the real world assessment tests for evaluating physical conditions have similar hierarchical structure to the SPPB.

Our approach rests on an argumentation-based process in order to: 1) generate hypothesis about the assessment test/activity; 2) deal with uncertainty of word observations, e.g., sensor data; and 3) obtain sets of time-framed hypothesis explaining the current state of the activity. This reasoning process is non-monotonic which resembles the kind of deductive analysis that a therapist or clinician performs in the assessment of activities. The activity argument-based time-framed framework AcArTiF is based on timed fragments. It is worthy to mention two assumptions under which this atomic units lie: 1) an hypothetical action is executed during a period of time defined by a linked goal; and 2) a goal has time scope. The first assumption is based on Argumentation Theory and formalized in [19]. The second assumption was mentioned in terms of the activity as a future work in [1] and formalized for a Timed Argumentation Framework in [16]. We integrate those ideas from social sciences and argumentation theory in the AcArTiF framework. The time analysis presented in [16] and recently in [32] was incorporated to our framework given the “elegant simplicity”\(^8\) for tackling the dynamics of an argument system. Our AcArTiF framework is the first step for analyzing the complex dynamics of a real world activities beyond of the assessment tests. As a future work, we want to analyze in more detail the first assumption of our framework, given the time complex interlink between a goal and action.

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\(^8\) Simplicity in terms of the readability and absence of unnecessary complexities in the analysis of time in argumentation-based systems.
In this work we define a method for capturing, testing and evaluating structured assessment tools. We consider an assessment tool as a hierarchical structure where the information for guiding a therapeutic intervention is based on goals and observations. In order to quantify such hierarchical activities, we propose to compare the explained scope time and the expected scope time. We use the time for the acceptable sets which we consider as a time boundary. In this regard, a comparison between different Dung’s semantics must to be performed in order to support such time hypothesis, this will be also part of our future work as well as using real scenario information to confirm/disprove that hypothesis.

We conducted a pilot study in order to exemplify our approach using the SPPB test. Results of such a pilot study and the aforementioned future work will be part of an extended version of this paper.

References