Dealing with Conflicts between Human Activities: An Argumentation-based Approach

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Abstract

Human-aware Artificial Intelligent systems are goal directed autonomous systems that are capable of interacting, collaborating, and teaming with humans. Two relevant tasks of these systems are recognizing human's desires and intentions and providing a proactive and contextual support. This article tackles the problem of recognizing the activities a human is performing and providing support for avoiding possible conflicts that may arise between activities. Our approach is based on formal argumentation, which is an appropriate technique for dealing with conflicts and inconsistencies in a knowledge base. By considering a set of observations, a model of the world and of the human is constructed in form of hypothetical fragments of activities. These hypothetical fragments will be goal-oriented actions and may be conflicting. We formalize three forms of conflicts, namely terminal conflict, resource conflict, and superfluity. To the best of our knowledge, the two last forms of conflicts have not been considered and formalized in the activity recognition context. We consider extension-based argumentation semantics for dealing with conflict between hypothetical fragments. The result of this selection (called local selection) will be consistent sets of hypothetical fragments that are part of an activity or are part of a set of non-conflicting activities. Besides, by considering degrees of fulfillment of activities a selection (called global selection) of hypothetical fragments is defined. Finally, we apply our proposal to a cooking scenario.

Introduction

In the last years, a part of Artificial Intelligence (AI) researchers have focused their efforts in human-centric applications such as intelligent tutoring systems (read (Akkila et al. 2019) for a survey about this topic) or social robotics (e.g., (Belpaeme et al. 2018)(Leite, Martinho, and Paiva 2013)(Cabibihan et al. 2013)). Thus, as human-AI interaction increases, there is a need for developing human-aware AI systems. The idea behind these systems is to develop approximate models about the goals or capabilities of the human in order to better interact with him/her.

In (Kambhampati 2019), some challenges about human-aware AI systems are discussed. Such challenges include recognizing the human's desires and intentions and providing proactive support. For a better illustration of the problem, let us present the following scenario. This is a cooking scenario where a person (let us call him `Mike`) is preparing the dinner and a supporter robot (let us call it `BOB`) observes the different actions `Mike` performs in order to recognize what dishes `Mike` is preparing (goal recognition). `BOB` employs the observed actions for distinguishing the activities and for support `Mike` by predicting possible conflicts between the actions for preparing the dishes (proactive support). Let us assume that `BOB` recognizes that `Mike` may be cooking chicken stew and vegetarian stuffed potatoes. These activities share some actions like cutting the vegetables, boiling water, or mixing the ingredients. On the other hand, there are other actions that are different, for example, the person needs to chop the chicken for the chicken stew and mash the potatoes for the stuffed potatoes dish. Besides, the amount of the ingredients is limited and `Mike` has to consider it because some of them are used in both recipes.

By considering works in autonomous agents, (Castelfranchi and Paglieri 2007) claim that three forms of incompatibility could emerge between procedural goals[1] in the autonomous agents context, namely terminal, instrumental, and superfluity. In this work, we suggest that these three forms can also be used in the activity recognition and support context since activities can be seen as plans, which are used to identify conflicts between goals (Morveli-Espinoza et al. 2019). These conflicts or incompatibilities determine that two actions are part of different activities Thus, let us present an example of each kind of incompatibility based on our scenario:

- *Terminal incompatibility*: This occurs when two actions are inconsistent. For example, `Mike` has to boil the potatoes without having to cut them for the stuffed potatoes and has to chop the potato for the stew. Since these actions are inconsistent, `BOB` determines that are part of different activities, in this case, of different dishes.
- *Instrumental or resource incompatibility*: It arises because the amount of resources is limited. Suppose that `Mike` has five carrots and both recipes need carrots. In the

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[1] A goal is called procedural when there is a set of plans for achieving it. This differs from declarative ones, which are a description of the state sought (Winikoff et al. 2002).

case of chicken stew, three carrots are necessary whereas for the stuffed potatoes four carrots are necessary. If BOB intuits that the amount of carrots will not be enough for both recipes; that is, there may be a resources conflict; BOB has to warn him about it.

- *Superfluity*: It occurs when two actions lead to the same end. Suppose that Mike used salt for season the stew, later he wants to use a seasoning sauce without tasting the food. In both cases, the goal is to have the stew seasoned; however, if Mike uses both it is likely that the stew will be very salty. We can say that the second action may be superfluous and BOB has to warn Mike about it.

Notice that both instrumental conflict and superfluity are more related with activity support whereas terminal conflict is more related with activity recognition. This is because, instrumental conflict and superfluity can be avoided by the human once he is informed about them.

The treatment of conflict in activity recognition and formal argumentation is not a novelty. In (Nieves, Guerrero, and Lindgren 2013), the authors studied the inconsistency between actions, which can be compared with the terminal incompatibility. However, they did not studied instrumental conflicts and/or superfluity. Besides, they did not tackle the problem of proactive support.

Against this background, the aim of this work is to study and formalize the aforementioned three forms of conflict in the activity recognition and support context. Our proposal is based on argumentation-based reasoning, since it is a suitable approach for reasoning with inconsistent information (Dung 1995). Thus, the research questions that are addressed in this paper are:

1. Can we identify when a form of conflict arises between two actions? If so, how can this identification be done?,
2. How to recognize different activities from conflicting actions?, and
3. How to tackle the problem of activity supporting?

In addressing the first question, we use hypothetical fragments for representing both an action and its context in terms of (i) related observations (about both the human and the environment), (ii) necessary resources, and (iii) the goal that can be achieved by performing such action. Based on the elements of its context, emerging conflicts can be identified.

Regarding the second question, hypothetical fragments are small parts of activities, this means that conflicting fragments belong to different activities. So, we will apply formal argumentation techniques for determining consistent sets of hypothetical fragments. Each set denotes an activity or a set of non-conflicting activities. This is called local selection. Besides, we propose a global selection, which aims to determine the degree of fulfillment or non-fulfillment of a given activity. Both types of selections aim to recognize the activities a human is performing.

Regarding the last question, in this work supporting an activity is related with avoiding a conflict. The idea is that during the activity perception, that is when the autonomous agent is constructing the hypothetical fragments, he may identify a possible instrumental conflict or a possible superfluity, which may be avoided. For instance, in the example of superfluity we have that Mike is seasoning the stew twice, which can lead him to have a salty food. For supporting Mike – that is, for avoiding superfluity – BOB has to warn him about it. This support can be successful or not depending on decision of the human and the degree of correctness of the recognition. Thus, we study how the supporting task impacts on the activity recognition.

Section *Background* presents main definitions about formal argumentation. Section *Preliminaries* is devoted to the formal language that will be used throughout the article. Section *Building Blocks* presents the concepts of human activity framework and hypothetical fragment of activity. In Section *Conflicts between Hypothetical Fragments*, we formalize the terminal conflict, instrumental conflict, and superfluity in the context of activity reasoning (that is, activity support and recognition). Section *Local and Global Selection* presents how these two steps of the activity recognition are performed. Section *Activity Supporting Task* discusses how the support occurs and how it impacts on the local selection. In Section *Applying the Proposal to the Cooking Scenario*, we show how the conflicts between hypothetical fragments are identified and how the local selection determines different activities in the scenario. Finally, Section *Conclusions and Future Work* summarizes this article and outlines future research.

Background

In this section, we will recall basic concepts related to the Abstract Argumentation Framework defined by (Dung 1995), including the notion of acceptability and the main semantics.

Definition 1. (Abstract Argumentation Framework) An abstract argumentation framework $\mathcal{AF}$ is a tuple $\mathcal{AF} = \langle \mathtt{ARG}, \mathcal{R} \rangle$ where ARG is a finite set of arguments and $\mathcal{R}$ is a binary relation $\mathcal{R} \subseteq \mathtt{ARG} \times \mathtt{ARG}$ that represents the attack relation between two arguments of ARG, so that $(A, B) \in \mathcal{R}$ denotes that the argument A attacks the argument B or B is attacked by A.

Next, we introduce the concepts of conflict-freeness, defense, admissibility and the four semantics proposed by (Dung 1995).

Definition 2. (Argumentation Semantics) Given an argumentation framework $\mathcal{AF} = \langle \mathtt{ARG}, \mathcal{R} \rangle$ and a set $\mathcal{E} \subseteq \mathtt{ARG}$:

- $\mathcal{E}$ is *conflict-free* if $\forall A, B \in \mathcal{E}$, $(A, B) \notin \mathcal{R}$.
- $\mathcal{E}$ *defends* an argument A iff for each argument $B \in \mathtt{ARG}$, if $(B, A) \in \mathcal{R}$, then there exist an argument $C \in \mathcal{E}$ such that $(C, B) \in \mathcal{R}$.
- $\mathcal{E}$ is *admissible* iff it is conflict-free and defends all its elements.
- A conflict-free $\mathcal{E}$ is a *complete extension* iff we have $\mathcal{E} = \{A | \mathcal{E} \text{ defends } A\}$.
- $\mathcal{E}$ is a *preferred extension* iff it is a maximal (w.r.t set inclusion) complete extension.
- $\mathcal{E}$ is a *grounded extension* iff it is the smallest (w.r.t set inclusion) complete extension.

- $\mathcal{E}$ is a *stable extension* iff $\mathcal{E}$ is conflict-free and $\forall A \in \texttt{ARG}$ and $A \notin \mathcal{E}$, $\exists B \in \mathcal{E}$ such that $(B, A) \in \mathcal{R}$.

Preliminaries

We start by presenting the logical language that will be used. Let $\mathcal{L}$ be a first order logic language used to represent the mental states of the agent, $\vdash$ stands for the inference of classical logic, $\top$ and $\bot$ denote truth and falsum respectively, and $\equiv$ denotes classical equivalence. We use lowercase roman characters to denote atoms and uppercase Greek characters to denote formulae, such that an atomic proposition b is a formula. If b is a formula, then so is $\neg b$. If b and c are formulae, then so are $b \wedge c$, $b \vee c$, and $b \rightarrow c$. Finally, if b is a formula, then so is (b).

From $\mathcal{L}$, we can distinguish the set $\mathcal{RES}$, which denotes the resources of the environment and of the human. $\mathcal{RES}$ is a subset of atoms from the language $\mathcal{L}$. Besides, let $\mathcal{RES}_{qua}$ be an infinite set of ground atoms that denote a given resource along with a given quantity, which is expressed numerically. Then, we have that $\mathcal{RES}_{qua} = \{res\_q(name, value) | res(name) \in \mathcal{RES}, value \in \mathbb{N}\}$. For example, assume that $\mathcal{RES} = \{res(carrot)\}$, where $carrot$ is the name that denotes the resource carrot. We may have $\mathcal{RES}'_{qua} = \{res\_q(carrot, 7), res\_q(potato, 10)\}$ such that $\mathcal{RES}'_{qua} \subset \mathcal{RES}_{qua}$ and the ground atoms $res\_q(carrot, 7)$ and $res\_q(potato, 10)$ denote that 5 units of carrots and 10 units of potatoes are necessary, respectively.

Notice that we use the suffix res_q for denoting resources in $\mathcal{RES}_{qua}$ and the suffix res for denoting resources in $\mathcal{RES}$.

Building Blocks

In the introduction section, we said that the idea behind human-aware systems is to construct approximate models about the human. In this section, we will introduce the concept of *human activity framework*, which represent such approximate model. A human activity framework will define all the components for building hypothetical fragments of activities. These hypothetical fragments will define hypotheses that will help the agent to recognize the activities the human is performing. Besides, based on this hypothetical fragments, the agent can provide support to avoid possible conflicts.

In order to model the human, we will follow the structure of the beliefs-desires-intentions (BDI) model (Bratman 1987). The following definition is an extension of the definition presented in (Nieves, Guerrero, and Lindgren 2013). Unlike the definition of Nieves et al., in this work we consider that each action in a human activity work is is associated with a set of resources. This is more natural and will allow us to identify instrumental conflicts between activities. Besides, we consider the contraries concept to define opposite or different actions.

Definition 3. (Human Activity Framework) An human activity framework $ActF$ is a tuple of the form $\langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ in which:

- $\mathcal{T} \subseteq \mathcal{L}$ is a first order logic theory. $\mathcal{T}_A$ denotes the set of atoms that appears in $\mathcal{T}$;
- $\mathcal{H}_A = \{d_1, ..., d_n\}$ denotes the set of hypothetical actions that a human can perform in a world. It holds that $\mathcal{H}_A \subseteq \mathcal{T}_A$;
- $\mathcal{G} = \{g_1, ..., g_n\}$ denotes a set of goals of the human. It holds that $\mathcal{G} \subseteq \mathcal{T}_A$;
- $\mathcal{O} = \{o_1, ..., o_n\}$ denotes a set of observation from a world. It holds that $\mathcal{O} \subseteq \mathcal{T}_A$;
- $Acts \subset 2^{\mathcal{G}}$. $Acts$ denotes a set of activities. We assume that a set of goals defines an activity;
- $\mathcal{RES}_{sum} \subset \mathcal{RES}_{qua}$ is a resource summary, which contains the information about the available amount of every resource of the agent. We assume that $\mathcal{RES}_{sum}$ is normalised so that each resource appears exactly once and that all the resources represented in $\mathcal{RES}$ have their corresponding available amount in $\mathcal{RES}_{sum}$. Let $\rho : \mathcal{RES} \rightarrow \mathbb{N}$ a function that returns the currently available amount of a given resource; thus, $\rho(res(name))$ denotes the availability of resource $res(name)$;
- $\mathcal{C} = \{(x, y) | x, y \in \mathcal{H}_A \text{ and } x \equiv \neg y\}$.

Besides, it holds that $\mathcal{H}_A, \mathcal{G}, \mathcal{O}$, and $\mathcal{RES}_{sum}$ are pairwise disjoint.

Given a human activity framework, one can build small pieces of knowledge which give hypothetical evidence of the achievement of a given goal by considering a set of believes (a set of formulas), a *hypothetical action*, a set of necessary resources, and a set of observations of the world. These small pieces of knowledge will be called *hypothetical fragments of activities*:

Definition 4. (A Hypothetical Fragment of an Activity) Let $ActF = \langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ be a human activity framework. A hypothetical fragment of an activity (henceforth, hypothetical fragment) is represented by $A = \langle \mathcal{S}, \mathcal{O}', RES', a, g \rangle$ such that:

- $\mathcal{S} \subseteq \mathcal{T}$, $\mathcal{O}' \subseteq \mathcal{O}$, $RES' \subseteq \mathcal{RES}_{qua}$, $a \in \mathcal{H}_A$ and $g \in \mathcal{G}$;
- $\mathcal{S} \cup \mathcal{O}' \cup \{a\} \cup RES'$ is consistent;
- $\mathcal{S} \cup \mathcal{O}' \cup \{a\} \cup RES' \vdash g$;
- $\mathcal{S}$, $\mathcal{O}'$, and RES' are minimal w.r.t. set inclusion.

Let us denote by HF_{ActF} the set of hypothetical fragments that we can construct from $ActF$. $\texttt{CONC}(A) = g$ denotes the conclusion of the hypothetical fragment A and $\texttt{SUPP}(A) = \mathcal{S} \cup \mathcal{O}' \cup \{a\} \cup RES'$ denotes the support of A.

Observe that a hypothetical fragment is basically *a goal-oriented action* which takes as input observations of the world. From an intuitive point of view, the construction of hypothetical fragments represents the process of building *hypotheses* about the fulfillment of some possible activities. Since the hypothetical fragments are based on *hypothetical actions*, the hypothetical fragments are *defeasible*. In order to deal with the defeasible information which is present in the hypothetical fragments, we will follow a *defeasible reasoning process* based on *attack relations* between the hypothetical fragments and argumentation semantics. These two elements will be *the core* for the local selection (the first selection) of hypothetical fragments.

Conflicts between Hypothetical Fragments

In this section, we focus on the identification of conflicts or attacks among hypothetical fragments, which will lead to the identification of conflicts among activities. The kind of attack depends on the form of conflict. We have identified one type of attack for each form of conflict. These conflicts between hypothetical fragments are defined over HF_{ActF} and are captured by the binary relation $\mathcal{R}_x \subseteq HF_{ActF} \times HF_{ActF}$ (for $x \in \{t, r, s\}$) where each sub-index denotes the form of conflict. Thus, t denotes the attack for terminal incompatibility, r the attack for instrumental conflict, and s the attack for superfluity. We denote with (A, B) the attack relation between two hypothetical fragments A and B. In other words, if $(A, B) \in \mathcal{R}_x$, it means that the hypothetical fragment A attacks the hypothetical fragment B.

Terminal Conflict

In this conflict, beliefs, actions, and goals are taken into account. Thus, a hypothetical fragment A attacks a hypothetical fragment B when (i) a belief of A is inconsistent with the goal of B, (ii) the action of A is inconsistent with the action of B, and (iii) the goal of A is inconsistent with the goal of B. Formally:

Definition 5. (Terminal attack - $\mathcal{R}_t$) Let $ActF$ be a human activity framework and $A, B \in HF_{ActF}$ such that $A = \langle \mathcal{S}_A, \mathcal{O}'_A, RES'_A a_A, g_A \rangle$, $B = \langle \mathcal{S}_B, \mathcal{O}'_B, RES'_B, a_B, g_B \rangle$. $(A, B) \in \mathcal{R}_t$ if one of the following conditions hold:

(i) $\exists x \in \mathcal{S}_B$ such that $x \equiv \neg g_A$

(ii) $a_B \equiv \neg a_A$

(iii) $g_B \equiv \neg g_A$

It was demonstrated in (Morveli-Espinoza et al. 2019), that $\mathcal{R}_t$ is symmetric. Therefore, if $(A, B) \in \mathcal{R}_t$, then $(B, A) \in \mathcal{R}_t$.

Resources Conflict

Two hypothetical fragments are incompatible due to resources because there are no enough resources for performing the activities to which both fragments belong. In order to deal with resource conflict, we first define a resource consumption inference that works exclusively for reasoning about resources. This inference considers the availability of a given resource and the amount of it that is necessary. Recall that function ρ –introduced in Definition 3– returns the available amount of a given resource; however, the necessary amount has to be obtained from the two fragments whose resource incompatibility is being evaluated. The following steps are carried out in order to obtain this value.

1. First of all, we put together all the same necessary resources of the two fragments in a formula (let us call it $\Phi_{res(name)}$). This means that there is a different $\Phi_{res(name)}$ for each different resource that both fragments need. Thus, the formula $\Phi_{res(name)}$ is a conjunction of atoms that represent a resource and the necessary amount of it. Hence, we have that $\Phi_{res(name)} = \bigwedge res\_q(name, value)$ where $res\_q(name, value) \in \mathcal{RES}_{qua}$. For example, a fragment A needs 3 units of carrot and fragment B needs 4 units of carrot; hence, $\Phi_{res(bat)} = res\_q(carrot, 3) \wedge res\_q(carrot, 4)$.
2. The second step is related to the signature of $\Phi_{res(name)}$. Let us denote the signature of $\Phi_{res(name)}$ by $\mathcal{L}_{\Phi_{res(name)}}$. Continuing with the example, $\mathcal{L}_{\Phi_{res(bat)}} = \{res\_q(carrot, 3), res\_q(carrot, 4)\}$.
3. Finally, we can sum up the necessary amount of a given resource: $\pi(\mathcal{L}_{\Phi_{res(name)}}) = \sum_{[res\_q(name,value) \in \mathcal{L}_{\Phi_{res(name)}}]} value$. Finalizing the example, we have that $\pi(\mathcal{L}_{\Phi_{res(bat)}}) = 7$.

Once we have the available amount and the necessary amount of a given resource, we can define the resource-consumption inference. This type of inference resembles other consumption inferences introduced by other consumption and production resources logics like (Bulling and Farwer 2010).

Definition 6. (Resource-consumption inference - $\vdash_r$) Let $\mathcal{RES}_{sum}$ be the set of available resources and $\Phi_{res(name)}$ be a conjunction of atoms such that $\mathcal{L}_{\Phi_{res(name)}} \subset \mathcal{RES}_{qua}$. $\mathcal{RES}_{sum}$ satisfies a formula $\Phi_{res(name)}$ (denoted by $\mathcal{RES}_{sum} \vdash_r \Phi_{res(name)}$) when $\rho(res(name)) \geq \pi(\mathcal{L}_{\Phi_{res(name)}})$.

The following notation will be used for defining the resource attack. $\mathtt{REC}(A)$ denotes the set of resources necessary for a fragment A:

$$\mathtt{REC}(A) = \bigcup_{pp \in \mathtt{SUPPORT}(A)} \mathtt{BODY}(pp) \cap \mathcal{RES}_{qua}$$

Based on previous definitions, we can now present the definition of instrumental or resource attack.

Definition 7. (Resource attack - $\mathcal{R}_r$) Let $A, B \in HF_{ActF}$ be two hypothetical fragments, $\mathtt{REC}(A)$ be the set of resources necessary for fragment A, and $\mathtt{REC}(B)$ be the set of resources necessary for fragment B. We say that $(A, B) \in \mathcal{R}_r$ occurs when:

- $\exists res(name) \in \mathcal{RES}$ such that $\exists res\_q(name, value) \in \mathtt{REC}(A)$ and $\exists res\_q(name, value)' \in \mathtt{REC}(B)$,
- $\Phi_{res(name)} = \bigwedge_{[res\_q(name,value) \in \mathtt{REC}(A), res\_q(name,value)' \in \mathtt{REC}(B)]} res\_q(name, value) \wedge res\_q(name, value)'$,
- $\mathcal{RES}_{sum} \nvdash_r \Phi_{res(name)}$, this means that $\Phi_{res(name)}$ is resource-inconsistent.

(Morveli-Espinoza et al. 2019) demonstrated that $\mathcal{R}_r$ is symmetric. Therefore, if $(A, B) \in \mathcal{R}_r$, then $(B, A) \in \mathcal{R}_r$.

Superfluous Conflict

Superfluity can be defined in terms of the superfluous attack. In this attack, the conclusions of hypothetical fragments are evaluated. Thus, a hypothetical fragment A attacks another hypothetical fragment B when they have the same conclusion.

Definition 8. (Superfluous attack - $\mathcal{R}_s$) Let $ActF$ be an activity framework and $A, B \in HF_{ActF}$ such that $A = \langle \mathcal{S}_A, \mathcal{O}'_A, RES'_A a_A, g_A \rangle$, $B = \langle \mathcal{S}_B, \mathcal{O}'_B, RES'_B, a_B, g_B \rangle$. $(A, B) \in \mathcal{R}_t$ when $\texttt{CONC}(A) = \texttt{CONC}(B)$ and $\texttt{SUPP}(A) \neq \texttt{SUPP}(B)$.

As in previous attacks, (Morveli-Espinoza et al. 2019) demonstrated that $\mathcal{R}_s$ is symmetric. Therefore, if $(A, B) \in \mathcal{R}_s$, then $(B, A) \in \mathcal{R}_s$.

Local and Global Selection

Local Selection and *Global Selection* are the two proposed steps for activity recognition. In this section, we study these two types of selections.

Local Selection

So far, we have defined hypothetical fragments, which can be seen as *arguments* and a set of conflicts, which determine an attack relation between hypothetical fragments. Therefore, we can use argumentation semantics for selecting sets of hypothetical fragments. The idea is that each set is related to an activity or a set of consistent activities, that is, activities that can be performed together.

The aim of the local selection is to deal with the defeasible information which is presented in the hypothetical fragments. Hence, we will follow *an argumentation reasoning approach* for selecting consistent sets of hypothetical fragments, which could suggest potential fulfillment of activities.

Next, we present an argumentation framework for each kind of conflict (i.e., terminal, resource, and superfluity) and a general argumentation framework that involves all the of arguments and attacks of the three kinds of conflict.

Definition 9. (Activity Argumentation framework (AAF)) Let HF_{ActF} be the set of hypothetical fragments that can be built from a human activity framework $ActF$. An AAF can be defined as follows:

- A x-AAF is a pair $\mathcal{AAF}_x = \langle HF^x_{ActF}, \mathcal{R}_x \rangle$ (for $x \in \{t, r, s\}$) where $HF^x_{ActF} \subseteq HF_{ActF}$ and $\mathcal{R}_x$ is the binary relation in HF^x_{ActF}.
- A general g-AAF is a pair $\mathcal{AAF}_g = \langle HF_{ActF}, \mathcal{R}_g \rangle$, where $\mathcal{R}_g = \mathcal{R}_t \cup \mathcal{R}_r \cup \mathcal{R}_s$.

Notice that it may occur that there exist the three kinds of attacks between two hypothetical fragments. In this case, we consider multiple attacks as a unique general attack.

An argumentation semantics $\texttt{SEM}$ is then applied to the AAF in order to infer consistent sets of hypothetical fragments. In this sense, an argumentation semantics $\texttt{SEM}$ will define the local selection (*initial selection*) of hypothetical fragments.

Global Selection

Selecting hypothetical fragments by considering argumentation semantics is only one of the steps of activity recognition. An argumentation semantics can only suggest *multiple competing* sets of hypothetical fragments which could suggest the fulfillment of some activities. Therefore, we require *a global selection* of hypothetical fragments. By global selection, we mean a selection able to suggest:

- degrees of both fulfillment and non-fulfillment of activities, and
- evidence for believing about the fulfillment of activities.

Given that a hypothetical fragment is always associated with a goal, a set of hypothetical fragments can be regarded as a set of goals. To this end, let us define the following notation: Given a set of hypothetical fragments $\mathcal{E}$, $\mathcal{E}^{\mathcal{G}}$ is defined as follows: $\mathcal{E}^{\mathcal{G}} = \{g | \langle \mathcal{S}, \mathcal{O}', RES', a, g \rangle \in \mathcal{E}\}$.

Considering that a set of hypothetical fragments can be regarded as a set of goals, the status of an activity is defined as follows:

Definition 10. (Status of Activities) Let $ActF = \langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ be a human activity framework, $\mathcal{AAF} = \langle HF^x_{ActF} . \mathcal{R}_x \rangle$ (for $x \in \{t, r, s\}$) be an AAF with respect to $ActF$ and $\texttt{SEM}$ be an argumentation semantics. An activity $Act \in Acts$ is:

- *achieved* iff $Act \subseteq \mathcal{E}^{\mathcal{G}}$ for all $\mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$.
- *partially-achieved* iff $\exists \mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$ such that $Act \subseteq \mathcal{E}^{\mathcal{G}}$ and $\exists \mathcal{E}' \in \texttt{SEM}(\mathcal{AAF})$ such that $act \nsubseteq \mathcal{E}'^{\mathcal{G}}$
- *null-achieved* iff for all $\mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$, $Act \nsubseteq \mathcal{E}^{\mathcal{G}}$

It is important to observe that an extension $\mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$ represents hypothetical fragments that argue why a particular activity is fulfilled. Considering the number of goals of each activity, we can define different degrees of achievement *w.r.t.* each activity. Indeed, we can define a degree of achievement and a degree of non-achievement.

Definition 11. Let $ActF = \langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ be a human activity framework, $\mathcal{AAF} = \langle HF^x_{ActF}, \mathcal{R}_x \rangle$ be an AAF with respect to $ActF$, $\texttt{SEM}$ be an argumentation semantics, and $Act_1 \in Acts$ such that $Act_2 \subseteq Act_1$:

- Act_1 is (i/n)-achieved if Act_2 is achieved w.r.t $\texttt{SEM}(\mathcal{AAF})$, $i = |Act_2|$ and $n = |Act_1|$.
- Act_1 is $(1 - i/n)$-null-achieved if Act_2 is achieved w.r.t. $\texttt{SEM}(\mathcal{AAF})$, $i = |Act_2|$ and $n = |Act_1|$.
- Act_1 is (i/n)-hard-null-achieved if for all $\mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$, $Act_2 \cap \mathcal{E}^{\mathcal{G}} = \emptyset$, $i = |Act_2|$ and $n = |Act_1|$.

Considering *the number of extensions* that make a given activity partially-achieved, one can define a preference relations between partially-achieved activities.

Definition 12. Let $ActF = \langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ be a human activity framework, $\mathcal{AAF} = \langle HF^x_{ActF}, \mathcal{R}_x \rangle$ be an AAF with respect to $ActF$, $\texttt{SEM}$ be an argumentation semantics, and $Act_1, Act_2 \in Acts$ such that Act_1, Act_2 are partially-achieved activities. The preference relation $\succeq_n$ between partially-achieved activities is defined as: $Act_2 \succeq_n Act_1$ if and only if $|\mathcal{E}(Act_2, \texttt{SEM}(\mathcal{AAF}))| \geq |\mathcal{E}(Act_1, \texttt{SEM}(\mathcal{AAF}))$, where $\mathcal{E}(Act, \texttt{SEM}(\mathcal{AAF})) = \{\mathcal{E} | \mathcal{E} \in \texttt{SEM}(\mathcal{AAF})$ and $Act \subseteq \mathcal{E}\}$.

Activity Supporting Task

During the process of activity recognition, an autonomous agent constructs hypothetical fragments. In any point of the process, he can identify possible emerging conflicts (instrumental or superfluous). In order to help the human to get success in his/her activities, the agent has to warn him/her about it. After the warning, the following situations may occur:

1. The human confirms the conflict and resolves it. In this case, the conflict is not taken into account anymore and it is not considered in the local selection.
2. The human confirms the conflict; however, he/she does not resolve it. In this case, the conflict is considered in the local selection and impacts on the final result of the activity recognition.
3. The human denies the conflict. In this case, the conflict is not considered in the local selection and the agent has to check his hypothesis about the performed activities.

With resolving, we mean:

- When an instrumental conflict emerges, the human can use another resource or redistribute the amount of necessary resource. In this case, both (quasi-conflicting) hypothetical fragments are constructed; however, their resource elements change.
- When superfluity emerges, the human does not perform the superfluous action. In this case, the second hypothetical fragment is not constructed anymore.

Applying the Proposal to the Cooking Scenario

In this section, we apply our proposal to the scenario presented in the introduction section. Indeed, this is a large scenario and we only take into account the necessary elements for illustrating the conflicts and the local and global selections.

First let us present the theory $\mathcal{T}$ and the set of atoms $\mathcal{T}_A$ that are part of the human activity framework $ActF_{cook}$:
$a_1 = chop(potatoes)$, $a_2 = boil(potatoes)$,
$a_3 = cut(chicken)$, $a_4 = season\_with(salt)$,
$a_5 = season\_with(sauce)$, $a_6 = cut(carrots, coins)$,
$a_7 = grate(carrots)$,
$a_8 = mix(carrots, cheddar, bacon)$,
$g_1 = have(dinner)$, $g_2 = cook(chicken\_stew)$,
$g_3 = cook(stuffed\_potatoes)$,
$g_4 = have(chopped, potatoes)$,
$g_5 = have(boiled, potatoes)$,
$g_6 = have(chopped, chicken)$,
$g_7 = season(stew)$, $g_8 = have(cut, carrots)$,
$g_9 = have(grated, carrots)$, $g_{10} = prepare(filling)$,
$o_1 = in\_kitchen(mike)$, $o_2 = heat(oven)$,
$o_3 = on(stove)$, $o_4 = has(mike, knife)$,
$o_5 = has(mike, grater)$,
$res_1 = res(potato, 20)$, $res_2 = res(chicken, 1)$,
$res_3 = res(carrot, 5)$, $res_4 = res(garlic, 4)$,
$res_5 = res(bacon, 5)$, $res_6 = res(cheddar, 1)$,
$res_7 = res(salt, 20)$, $res_8 = res(sauce, 10)$,
$rq_1 = res_q(potato, 3)$,$rq_2 = res_q(potato, 5)$,
$rq_3 = res_q(chicken, 0.5)$, $rq_4 = res_q(salt, 0.1)$,
$rq_5 = res_q(sauce, 1)$, $rq_6 = res_q(carrot, 3)$,
$rq_7 = res_q(carrot, 4)$, $rq_8 = res_q(cheddar, 1)$,
$rq_9 = res_q(bacon, 2)$,
$r_1 = o_1 \wedge rq_1 \wedge a_1 \rightarrow g_4$
$r_2 = o_1 \wedge o_2 \wedge rq_2 \wedge a_2 \rightarrow g_5$
$r_3 = o_1 \wedge o_4 \wedge rq_3 \wedge a_3 \rightarrow g_6$
$r_4 = o_1 \wedge rq_4 \wedge a_4 \rightarrow g_7$
$r_5 = o_1 \wedge rq_5 \wedge a_5 \rightarrow g_7$
$r_6 = o_1 \wedge o_4 \wedge rq_6 \wedge a_6 \rightarrow g_8$
$r_7 = o_1 \wedge o_5 \wedge rq_7 \wedge a_7 \rightarrow g_9$
$r_8 = o_1 \wedge rq_7 \wedge rq_8 \wedge rq_9 \wedge a_8 \rightarrow g_{10}$
$r_9 = o_1 \wedge o_5 \wedge rq_{10} \wedge a_7 \rightarrow g_9$

Without Activity Supporting Task

Let us assume that no supporting activity task is carried out. This means that the human is not warned about the conflict and it impacts on the activity recognition. Thus, we have that $ActF_{cook} = \langle \mathcal{T}, \mathcal{H}_A, \mathcal{G}, \mathcal{O}, Acts, \mathcal{RES}_{sum}, \mathcal{C} \rangle$ be the human activity framework where:
$\mathcal{H}_A = \{a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8\}$
$\mathcal{G} = \{g_1, g_2, g_3, g_4, g_5, g_6, g_7, g_8, g_9, g_{10}\}$
$\mathcal{O} = \{o_1, o_2, o_3, o_4, o_5\}$
$Acts = \{Act_{stew}, Act_{stuff}\}$ where $Act_{stew} = \{g_1, g_4, g_6, g_7, g_8\}$ and $Act_{stuff} = \{g_2, g_5, g_9, g_{10}\}$
$\mathcal{RES}_{sum} = \{r_1, r_2, r_3, r_4, r_5, r_6, r_7, r_8\}$
$\mathcal{C} = \{(a_1, a_2), (a_6, a_7)\}$

Table 1 shows the hypothetical fragments that can be constructed from $ActF_{cook}$.

ID	$\mathcal{S}$	$\mathcal{O}'$	RES'	a	g
A	$\{r_1\}$	$\{o_1\}$	$\{rq_1\}$	a_1	g_4
B	$\{r_2\}$	$\{o_1, o_2\}$	$\{rq_2\}$	a_2	g_5
C	$\{r_3\}$	$\{o_1, o_4\}$	$\{rq_3\}$	a_3	g_6
D	$\{r_4\}$	$\{o_1\}$	$\{rq_4\}$	a_4	g_7
E	$\{r_5\}$	$\{o_1\}$	$\{rq_5\}$	a_5	g_7
F	$\{r_6\}$	$\{o_1, o_4\}$	$\{rq_6\}$	a_6	g_8
G	$\{r_7\}$	$\{o_1, o_5\}$	$\{rq_7\}$	a_7	g_9
H	$\{r_8\}$	$\{o_1\}$	$\{rq_7, rq_8, rq_9\}$	a_8	g_{10}
I	$\{r_9\}$	$\{o_1, o_5\}$	$\{rq_{10}\}$	a_7	g_9

Table 1: Hypothetical Fragments from $ActF_{cook}$.

We have that $HF_{ActF} = \{A, B, C, D, E, F, G, H\}$. Let us identify the emerging conflicts:

- $(A, B), (B, A), (F, G), (G, F) \in \mathcal{R}_t$ because actions a_1 and a_2 and a_6 and a_7 are inconsistent.
- $(F, G), (G, F) \in \mathcal{R}_r$ because there is no enough carrots for both hypothetical fragments.
- $(D, E), (E, D) \in \mathcal{R}_s$ because $\texttt{CONC}(D) = \texttt{CONC}(E)$ but $\texttt{SUPP}(D) \neq \texttt{SUPP}(E)$.

So, we can define now the AAF: $\mathcal{AAF}_{cook} = \langle HF_{ActF}, \mathcal{R}_t \cup \mathcal{R}_r \cup \mathcal{R}_s \rangle$.

The first step of activity recognition is local selection. Let us now apply a preferred semantics in order to obtain consistent sets of hypothetical fragments. The result are eight

preferred extensions. Next, we present the extensions and their respective set of goals:
$\mathcal{E}_1 = \{A, C, D, F, H\}$,$\mathcal{E}_1^{\mathcal{G}} = \{g_4, g_6, g_7, g_8, g_{10}\}$
$\mathcal{E}_2 = \{B, C, E, G, H\}$, $\mathcal{E}_2^{\mathcal{G}} = \{g_5, g_6, g_7, g_9, g_{10}\}$
$\mathcal{E}_3 = \{A, C, E, G, H\}$, $\mathcal{E}_3^{\mathcal{G}} = \{g_4, g_6, g_7, g_9, g_{10}\}$
$\mathcal{E}_4 = \{B, C, D, G, H\}$, $\mathcal{E}_4^{\mathcal{G}} = \{g_5, g_6, g_7, g_9, g_{10}\}$
$\mathcal{E}_5 = \{A, C, D, G, H\}$, $\mathcal{E}_5^{\mathcal{G}} = \{g_4, g_6, g_7, g_9, g_{10}\}$
$\mathcal{E}_6 = \{B, C, D, F, H\}$, $\mathcal{E}_6^{\mathcal{G}} = \{g_5, g_6, g_7, g_8, g_{10}\}$
$\mathcal{E}_7 = \{B, C, E, F, H\}$, $\mathcal{E}_7^{\mathcal{G}} = \{g_5, g_6, g_7, g_8, g_{10}\}$
$\mathcal{E}_8 = \{A, C, E, F, H\}$, $\mathcal{E}_8^{\mathcal{G}} = \{g_4, g_6, g_7, g_8, g_{10}\}$

The second step is the global selection. Regarding the status of activities, both Act_{stew} and Act_{stuff} are null-achieved because none of the preferred extensions contains the set of goals necessary for achieving the activities. However, there are degrees of fulfillment for both activities. Thus, we have:

- Act_{stew} is $2/5$-achieved w.r.t to $\mathcal{E}_2$ and $\mathcal{E}_4$
- Act_{stew} is $3/5$-achieved w.r.t to $\mathcal{E}_3, \mathcal{E}_5, \mathcal{E}_6$, and $\mathcal{E}_7$
- Act_{stew} is $4/5$-achieved w.r.t to $\mathcal{E}_1$ and $\mathcal{E}_8$
- Act_{stuff} is $1/4$-achieved w.r.t to $\mathcal{E}_1$ and $\mathcal{E}_8$
- Act_{stuff} is $2/4$-achieved w.r.t to $\mathcal{E}_3, \mathcal{E}_5$ and $\mathcal{E}_6$
- Act_{stuff} is $3/4$-achieved w.r.t to $\mathcal{E}_2, \mathcal{E}_4$ and $\mathcal{E}_7$

With Activity Supporting Task

Now, let us assume that `BOB` warns `Mike` about the instrumental conflict and the superfluity. let us also assume that `Mike` confirms the conflicts and resolves them.

In the case of the instrumental conflict, `Mike` decides to use just two carrots for the stuffed potatoes, so a new resource quantity atom is created $rq_{10} = res_q(carrot, 2)$. This means that we have now the hypothetical fragment $I = \langle \{r_9\}, \{o_1, o_5\}, \{rq_{10}\}, a_7, g_9 \rangle$.

In the case of the superfluity, `Mike` confirms the conflict and decides not to use the seasoning sauce. This means that the hypothetical fragment E is no longer constructed.

We have now that $HF'_{ActF} = \{A, B, C, D, F, G, H\}$. Let us identify the emerging conflicts:

- $(A, B), (B, A), (F, G), (G, F) \in \mathcal{R}_t$ because actions a_1 and a_2 and a_6 and a_7 are inconsistent.

In this case, we only have the terminal conflict. So, we can define now the AAF: $\mathcal{AAF}'_{cook} = \langle HF'_{ActF}, \mathcal{R}_t \rangle$.

Let us now apply a preferred semantics in order to obtain consistent sets of hypothetical fragments for the local selection. The result are four preferred extensions. Next, we present the extensions and their respective set of goals:
$\mathcal{E}_9 = \{A, C, D, F, H\}$, $\mathcal{E}_9^{\mathcal{G}} = \{g_4, g_6, g_7, g_8, g_{10}\}$
$\mathcal{E}_{10} = \{B, C, D, F, H\}$, $\mathcal{E}_{10}^{\mathcal{G}} = \{g_5, g_6, g_7, g_8, g_{10}\}$
$\mathcal{E}_{11} = \{B, C, D, G, H\}$, $\mathcal{E}_{11}^{\mathcal{G}} = \{g_5, g_6, g_7, g_9, g_{10}\}$
$\mathcal{E}_{12} = \{A, C, D, G, H\}$, $\mathcal{E}_{12}^{\mathcal{G}} = \{g_4, g_6, g_7, g_9, g_{10}\}$

Regarding the global selection, both Act_{stew} and Act_{stuff} are null-achieved because none of the preferred extensions contains the set of goals necessary for achieving the activities. However, there are degrees of fulfillment for both activities. Thus, we have:

- Act_{stew} is $2/5$-achieved w.r.t to $\mathcal{E}_{11}$
- Act_{stew} is $3/5$-achieved w.r.t to $\mathcal{E}_{10}$ and $\mathcal{E}_{12}$
- Act_{stew} is $4/5$-achieved w.r.t to $\mathcal{E}_9$
- Act_{stuff} is $1/4$-achieved w.r.t to $\mathcal{E}_9$
- Act_{stuff} is $2/4$-achieved w.r.t to $\mathcal{E}_{10}$ and $\mathcal{E}_{12}$
- Act_{stuff} is $3/4$-achieved w.r.t to $\mathcal{E}_{11}$

Conclusions and Future Work

In this paper we have presented a bottom-up approach to human activity recognition and support. This approach takes as starting point activity theory which argues for goal-oriented actions which are motivated by needs. In our approach the general problem of activity recognition and support is captured by the so called activity frameworks which have as input a predefined set of activities in terms of sets of goals.

In order to recognize activities, we build hypothetical fragments from a given human activity framework. We defined three types of attacks between hypothetical fragments in order to deal with the defeasible information which is present in the hypothetical. Regarding the attacks, it is a novelty the formalization of resource attacks and superfluity in the context of activity reasoning.

The selection of hypothetical fragments is based on two selections: a local selection and a global selection. Both the local selection and global selection are not easy processes since we will must look for coherent sets of fragments of activities.

We have shown that by considering argumentation semantics for the local selection, we can define different degrees of fulfilment and non-fulfilment of activities at global selection level.

Besides, we have studied how the activity support is carried out and how it impacts on the local selection.

As part of our future work, we consider an implementation of our approach in order to validate the suggested approach with real scenarios. We also want to further study the integration of activity support and recognition considering the suggested conflicts.

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