# Contextual Argumentation in Ambient Intelligence: Overview and Future Steps

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## I. Introduction

The study of Ambient Intelligence (AmI) environments and pervasive computing systems has introduced new research challenges in the field of Distributed AI. These are mainly caused by the imperfect nature of context and the special characteristics of the entities that operate in such environments. Context may be unknown, ambiguous, imprecise or erroneous, while ambient agents are expected to have different goals, experiences and perceptive capabilities and use distinct vocabularies to describe their context. Due to the highly dynamic and open nature of the environment and the unreliable wireless communications that are restricted by the range of transmitters, ambient agents do not typically know a priori all other entities that are present at a specific time instance nor can they communicate directly with all of them.

Motivated by these challenges, we propose *Contextual Defeasible Logic* (*CDL*) - a fully distributed approach for contextual reasoning. CDL is a nonmonotonic extension of Multi-Context Systems ([1], [2]), in which local context knowledge of agents is encoded in rule theories, and information flow between agents is achieved through mapping rules that associate concepts used by different contexts. To resolve potential conflicts that may arise from the interaction of mutually inconsistent contexts, it uses contextual preference information represented as a total preference ordering over the set of contexts. The basic representation model of CDL and associated algorithms for distributed query evaluation were presented in [3], an argumentation semantics was introduced in [4], and its relevance to the areas of AmI and Social Networks was analyzed in [5] and [6]. Here we present an overview of these results and propose potential future research directions.

## II. Overview of CDL

### A. Representation Model

CDL defines a MCS $C$ as a collection of distributed context theories $C_i$. A context $C_i$ is defined as a tuple $(V_i, R_i, T_i)$, where $V_i$ is the vocabulary used by $C_i$ (a set of positive and negative literals), $R_i$ is a set of rules, and $T_i$ is a strict total preference ordering on $C$ used to express confidence in the knowledge imported from other contexts. $R_i$ consists of two sets of rules: the *local* rules and the *mapping* rules. The body of a local rule is a conjunction of *local* literals (literals that are contained in $V_i$), while its head contains a local literal. There are two types of local rules: (a) strict rules, of the form

$$r_i^l : a_i^1, a_i^2, ...a_i^{n-1} \rightarrow a_i^n$$

which express sound local knowledge and are interpreted in the classical sense: whenever the literals in the body of the rule are strict consequences of the local theory, then so is the conclusion of the rule; and (b) defeasible rules:

$$r_i^d : b_i^1, b_i^2, ...b_i^{n-1} \Rightarrow b_i^n$$

used to express local uncertainty, in the sense that a defeasible rule cannot be applied to support its conclusion if there is adequate contrary evidence.

Mapping rules associate local literals with literals from the vocabularies of other contexts (*foreign literals*). To deal with ambiguities caused by the interaction of mutually inconsistent contexts, mapping rules are also modeled as defeasible rules with heads labeled by local literals:

$$r_i^m : a_i^1, a_j^2, ...a_k^{n-1} \Rightarrow a_i^n$$

### B. Argumentation Semantics

CDL extends the argumentation semantics of Defeasible Logic [7] with the notions of distribution of knowledge, and preference among system contexts. An argument $A$ for a literal $p_i$ in context $C_i$ is defined as a tuple $(C_i, PT_{p_i}, p_i)$, where $PT_{p_i}$ is the proof tree for $p_i$ based on the set of local and mapping rules of $C_i$. There are two types of arguments: (a) *local arguments*, which use local rules only, and (b) *mapping arguments*, which use at least one mapping rule.

The *rank of a literal* $p$ in context $C_i$ (denoted as $R(p, C_i)$) equals 0 if $p \in V_i$. If $p \in V_j \neq V_i$, then $R(p, C_i)$ equals the rank of $C_j$ in $T_i$. The *rank of an argument* $A$ in $C_i$ (denoted as $R(A, C_i)$) equals the maximum between the ranks in $C_i$ of the literals contained in $A$.

An argument $A$ *attacks* a local defeasible or mapping argument $B$ at $p_i$, if $p_i$ is a conclusion of $B$, $\sim p_i$ (negation of $p_i$) is a conclusion of $A$, and the subargument of $B$ with conclusion $p_i$ is not a strict local argument. Furthermore, $A$ *defeats* $B$ at $p_i$, if for the subarguments of $A$, $A'$ with conclusion $\sim p_i$, and of $B$, $B'$ with conclusion $p_i$, it holds that $R(A', C_i) \leq R(B', C_i)$.

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To link arguments through the mapping rules that they contain, we introduce the notion of *argumentation line*. An *argumentation line* $A_L$ for a literal $p_i$ is a sequence of arguments in $Args_C$, constructed in steps as follows:

- In the first step add in $A_L$ one argument for $p_i$.
- In each next step, for each distinct literal $q_j$ labeling a leaf node of the proof trees of the arguments added in the previous step, add one argument with conclusion $q_j$.

The argument for $p_i$ added in the first step is called the *head argument* of $A_L$. If the number of steps required to build $A_L$ is finite, then $A_L$ is a finite argumentation line.

An argument $A$ is *supported* by a set of arguments $S$ if: (a) every proper subargument of $A$ is in $S$; and (b) there is a finite argumentation line $A_L$ with head $A$, such that every argument in $A_L-\{A\}$ is in $S$. A local defeasible or mapping argument $A$ is *undercut* by a set of arguments $S$ if for every argumentation line $A_L$ with head $A$, there is an argument $B$, such that $B$ is supported by $S$, and $B$ defeats a proper subargument of $A$ or an argument in $A_L - \{A\}$.

An argument $A$ is *acceptable* w.r.t a set of arguments $S$ if (a) $A$ is a strict local argument (local argument using strict rules only); or (b) $A$ is supported by $S$ and every argument defeating $A$ is undercut by $S$. Based on the concept of acceptability, we define *justified arguments* and *justified literals*. $J_i^C$ is defined as follows:

- $J_0^C = \emptyset$;
- $J_{i+1}^C = \{A \in Args_C \mid A \text{ is acceptable w.r.t. } J_i^C\}$

The set of *justified arguments* in $C$ is $JArgs^C = \bigcup_{i=1}^{\infty} J_i^C$. A literal $p_i$ is *justified* if it is the conclusion of an argument in $JArgs^C$. That an argument $A$ is justified means that it resists every reasonable refutation. That a literal $p_i$ is justified actually means that it is a logical consequence of $C$.

Finally, we also introduce the notions of *rejected arguments* and *rejected literals* for the characterization of conclusions that are not derived by $C$. An argument $A$ is *rejected* by sets of arguments $S$, $T$ when either it is supported by arguments in $S$, which can be thought of as the set of already rejected arguments, or it defeated or undercut by an argument supported by $T$, which can be thought of as the set of justified arguments. Based on the above definition, we define $R_i^C$ as follows:

- $R_0^C = \emptyset$;
- $R_{i+1}^C = \{A \in Args_C \mid A \text{ is rejected by } R_i^C,\ JArgs^C\}$

The set of *rejected arguments* is $RArgs^C = \bigcup_{i=1}^{\infty} R_i^C$. A literal $p_i$ is *rejected* if there is no argument in $Args^C - RArgs^C$ with conclusion $p_i$. That $p_i$ is rejected means that we are able to prove that it is not a logical consequence of $C$.

## III. Future Steps

The deployment of CDL in application scenarios from AmI and Mobile Social Networks, and its evaluation in real mobile computing environments, such as FORTH's AmI Sandbox, have revealed to us its main limitations, along with potential future extensions, but also broader research directions concerning the application of AI methodologies to challenging problems of the emerging AmI domain.

With respect to CDL, there are two general directions for future research. From a theoretical perspective, we plan to extend our methods to support: (*a*) overlapping vocabularies, which will enable agents to use and reason with common words, such as URIs; (*b*) richer trust models, either in the form of alternative preference models, e.g. partial preference models to handle cases of incomplete preference information or dynamic preferences that agents may even reason about, or in the form of a trust management framework, responsible for computing and providing the agents with the required preference information; and (*c*) distributed access control in the form of a formal framework that will be in line with the privacy principles of AmI proposed in [8]. Among our long-term plans is to study the integration of CDL with other preference-based argumentation systems with the goal of developing an abstract contextual argumentation framework for AmI.

From a practical perspective, we plan to develop more efficient reasoning algorithms, which will enable all devices, even those with limited computing capabilities, to participate equally in the distributed reasoning process. To support cases that some of the involved devices may not always be capable of executing the algorithms and conducting their portion of reasoning tasks, we plan to study semi-centralized reasoning methods that will enable transferring the reasoning responsibilities to more powerful nearby entities. Finally, the deployment of our methods in new scenarios from AmI e.g. from the fields of Ambient Assisted Living or Ambient Assisted Education, will enable us to better investigate the specific requirements and challenges of each field, and study more focused solutions.

Regarding the general relation between AI and AmI, we feel that just like the Web, AmI can serve as an important testbed for AI methods. Some fields of AI, which may provide valuable methods for addressing major challenges of AmI, include activity recognition, reasoning about action, agent coordination, and data and knowledge sharing and replication.

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