

Cognitive Context and Arguments from Ontologies for Learning

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Abstract. The deployment of learning resources on the web by different experts has resulted in the accessibility of multiple viewpoints about the same topics. In this work we assume that learning resources are underpinned by ontologies. Different formalizations of domains may result from different contexts, different use of terminology, incomplete knowledge or conflicting knowledge. We define the notion of *cognitive learning context* which describes the cognitive context of an agent who refers to multiple and possibly inconsistent ontologies to determine the truth of a proposition. In particular we describe the cognitive states of *ambiguity* and *inconsistency* resulting from incomplete and conflicting ontologies respectively. Conflicts between ontologies can be identified through the derivation of conflicting arguments about a particular point of view. Arguments can be used to detect inconsistencies between ontologies. They can also be used in a dialogue between a human learner and a software tutor in order to enable the learner to justify her views and detect inconsistencies between her beliefs and the tutor's own. Two types of arguments are discussed, namely: arguments inferred directly from taxonomic relations between concepts, and arguments about the necessary and jointly sufficient features that define concepts.

Keywords. ontologies, reasoning, formal comparison between ontologies

Introduction

Learning resources are becoming increasingly available on the web. As a result a learner may have access to multiple resources about a single topic. We assume that each learning resource is underpinned by an ontology. Ontologies of the same domain may be represented at various degrees of abstraction and granularity. They may also represent knowledge at different degrees of completeness. Reasons can be traced to different points of view and experience of the experts that derive them. The learner may not be able to determine whether discrepancies in ontologies arise due to incompleteness of knowledge, due to disagreement between ontologies, or due to differences in the perspectives giving rise to different viewpoints. Our long term objective is to develop a computational framework of an agent capable of handling viewpoint discrepancies in the ontologies of learning resources and to enable a learner to engage in a dialogue with the software tutor to clarify differences of her own viewpoints with the viewpoints of learning resources.

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This paper focuses on the formalization of three important aspects of this framework, described below.

Firstly we formalize two cognitive states, namely the cognitive states of ambiguity and inconsistency that enable us to plan the interaction between a human learner and the software agent. In order to address the problem of cognitive ambiguity and confusion of learners, we allow resources with conflicting or different information to be part of the same cognitive context. We assume that the context is related to the goal of the learning activity (referred to as the *focus* of the learning activity) rather than on the compatibility of the resources referred to by the context. As a consequence, the context may involve multiple domains, if multiple domain points of view are relevant to the learning topic. For example, the topic may involve the points of view of multiple domains like psychology, social science and anthropology in order to form a particular position.

Secondly, we propose a proof-theoretic approach to the automatic derivation of arguments from ontologies. To resolve cognitive confusion arising from inconsistencies in ontologies, we suggest the use of reasoning via argumentation. A theorem prover can be used to check consistency of arguments of one ontology with ontologies of other resources when arguments are translated into an appropriate form. It can also be used in human computer interaction to enable the learner and the tutor to clarify their positions about a topic via arguments. The software agent can also verify the validity (soundness) of a learner's argument from its form. We formalize two different types of arguments that are useful in learning. These are syllogistic arguments derived from hierarchical relations in ontologies and arguments about necessary and jointly sufficient features of concepts.

Thirdly, we suggest a set of utterances that enable a learner and a tutor to exchange arguments in a human computer interaction and check the validity of the learner's arguments. In order to facilitate human-computer interaction, utterances between agents are represented internally as dialogue moves. Each move may include an ontological statement of a particular resource and may cause a change on the beliefs (ontologies) of the participants of the dialogue. Also as the focus of the interaction may change during the dialogue, the set of ontologies associated with the cognitive learning context may change as well. In order to capture this dynamic behavior of the system we make the learning context of the participants and the belief stores of the participants of the dialogue situation depended and we formalize changes via the use of situation calculus. Our third objective in this paper is to formalize a set of moves that enable the exchange of arguments inferred from particular ontologies.

The rest of this paper is outlined as follows. Section 1.2 reviews related work on the definition of context and on paraconsistent logics. The notions of cognitive learning context, cognitive ambiguity and cognitive inconsistency are discussed in this section. In section 3 we discuss syllogistic arguments and arguments related to the necessary and jointly sufficient properties of concepts. Section 4 shows an example of an interaction of a learner with the software agent in order to discuss differences in ontologies of underlying resources. Finally section 5 outlines the main issues discussed in this paper and briefly describes future research plans.

1. Related Work

1.1. Mental Spaces

Notable approaches to modeling cognitive context can be found in the linguistics literature. We note the works of Fauconnier [1] and Dinsmore[2]. Fauconnier [1] advocated the idea of *mental spaces*, which are described as constructs build up in any discourse according to guidelines provided by linguistic expressions. Objects in mental spaces are treated as real objects independently of their status in the actual world. Mental spaces can be built up from many sources and domains. Examples, of sources are: the immediate experience of the agent, what other people say to us, or what other people think, etc. They are created by *Space Builders* which are particular words triggering the creation of a new space. For example, one such space builder is the word *maybe* used to build the *possibility* mental space. A *base mental space* is the mental space in which the discourse takes place. Other important notions introduced in the literature of mental spaces are: the notion of ambiguity arising from multiple connecting paths between partitioned configurations that yield multiple understandings and the requirement of compatibility between mental spaces. Fauconnier's work aimed to address the problems of referential opacity, the projection of presuppositions, the semantic processing of counterfactuals, etc [3].

Dinsmore [2] complemented Fauconnier's theory by focusing on the external structure of mental spaces and attributed semantics to them so that they can be used in representing and reasoning about knowledge. He introduced the notion of knowledge partitioning as the process of distributing knowledge along different spaces according to context. The context of a space is a propositional function, e.g. the context of Mary's space is a function that takes a proposition p and maps it onto the proposition that Mary believes p . Dinsmore, showed that inheritance of information from one space in another is determined by the semantic properties of the respective contexts. Inheritance contexts constitute a form of secondary contexts, the latter being used to provide a mapping from the content of one space to the contents of another [3].

Fauconnier's contribution to modeling mental spaces that correspond to linguistic forms and words is important for representing the context of utterances and for referencing objects in different contexts. However, the focus of his investigation was the mental configurations resulting from english sentences and the construction of meaning during discourse. Instead, we focus on the epistemic state of agents who have access to incomplete resources. Several of the notions used in the representation of knowledge partitions by Dinsmore point to the artificial intelligence perspective of context representation and contextual reasoning [4,5,6,7]. Although they provide a significant insight to the problem of context representation and reasoning, their models do not capture the notions of incompleteness and inconsistency between different resources.

1.2. Local reasoning with multiple epistemic alternatives

The Local Model Semantics [8] provide a foundation for reasoning with contexts which is based on two main principles: the principle of *locality* and the principle of *compatibility*. The first states that reasoning requires only a part of what is potentially available [8]. The principle of compatibility states that there is compatibility among the kinds of reasoning performed in different contexts [8] and associates different contexts with some

meaningful relation of subsets of their local models. Our notion of cognitive context is different from the above as it may include incompatible resources that are related to the reasoning task of the learning activity. However, the principle of locality and the assumption that the available information may be incomplete affect the way learners interpret information and are used to model the cognitive state of the learner.

Several logics addressed the problem of inconsistency in logic theories and knowledge bases. To name but a few, paraconsistent logics, many-valued logics and modal logics have been developed to tackle inconsistency. Among those, notable uses of paraconsistent and possible world semantics to model mental models and epistemic states are the works of [9] and [10]. Fagin and Halpern [9] consider each agent as a *society of minds* rather than a single mind. Inspired by the work of Fagin and Halpern [9], Lokhorst [11] developed a (two-valued) local reasoning model of split-patients as a structure:

$$M = \langle W, w_0, \Psi, S, R, V \rangle \quad (1)$$

where W denotes a set of possible worlds, w_0 the actual world, Ψ a set of minds (each mind behaves independently of the other), S a function $S : W \rightarrow \wp(\Psi)$ (S maps a world to the set of minds in which this world is possible) and R is a function from Ψ into $W \times W$. The above model had some utility in creating our cognitive learning context for the following reason. Suppose that we represent each mind in Ψ above, as a (local) ontology with its own signature. Then S would associate each (separate) ontology with the set of worlds with which this ontology is compatible. This would be useful if the learner was unable to compare information from different ontologies. Hence lack of comparison would mean lack of confusion caused from differences between ontologies. But this differs from the problem we are trying to solve. Therefore the above model cannot be applied as it is to model the cognitive learning context of a learner.

The paraconsistent logic *LEI* is based on the idea of multiple observers having diverging views about a certain state of affairs. It extends classical logic with the formula $p?$ where $p?$ is satisfied whenever p holds in all plausible worlds. Unlike the traditional modal logics approach to modeling necessity and possibility, the *LEI* employs two satisfaction relations: the credulous and the skeptical approach. Martins et al. [10] provided a multiple world semantics to the above idea where each plausible world corresponds to a particular view of the world. The above approach is useful in comparing beliefs derived by the credulous vs. skeptical entailment relation which is different from the focus of this paper. In this paper we assume that each agent combines two levels of reasoning: a local reasoning level which considers each ontology locally and the meta-epistemic level, at which the agent compares inferences drawn locally in each ontology and determines compatibility with other ontologies.

2. Cognitive Context, Incompleteness and Inconsistency

We illustrate the notion of incompleteness and inconsistency in resources via the use of an example. Then we introduce our proposed definitions for the concepts of cognitive context, ambiguity due to incompleteness and inconsistency using the possible world semantics.

2.1. Example

A learner L comes across a professional training programming course on visual basic. This resource states that *visual Basic is an object-oriented language*. The learner believes that an object-oriented language needs to satisfy the property of encapsulation but she does not know whether visual basic has this property. In addition the online notes of her class instructor show visual basic as an example of a non 'object oriented language' because it does not have the property of inheritance.

The learner in this example makes use of three resources - her own background knowledge about object oriented languages, the instructor's online notes and the professional programming course site. All of them are part of the cognitive context of the learner. Two of these resources, namely the instructor's notes and the professional programming course are inconsistent. Although the learner's background knowledge is not directly inconsistent with the online resources, it is not reinforced by them either. Since both online resources are assumed to be expert resources the learner does not know how to interpret lack of evidence supporting her own knowledge. Do the experts possess partial knowledge about significant concepts of the domain? Should relevant information from both resources be integrated or should one be dropped for another? Since there is no definite answer for all situations and more than one interpretations of the situation are possible, we interpret the epistemic state resulting from this situation as ambiguous. In the following paragraphs of this section we formalize the notions referred to in the above example. In this paper we represent each learning resource via its underlying ontology. So a definition of ontology is relevant.

2.2. Ontology

In this project we use *OWL-DL* as an ontology representation language because it is a decidable fragment of description logic and expressive enough to satisfy our need for the representation of concepts, roles and hierarchies that give rise to the type of arguments formalized in this work. An Ontology in this paper is described as a structure $\langle T, A \rangle$ where T denotes a DL TBox (i.e. a set of terminological) axioms and A denotes a DL ABox (i.e. a set of grounded assertions). Each ontology has its own signature consisting of a disjoint set of relation names, concept names and constant names of individuals. We denote the signature of an OWL ontology O_i by $Sig(O_i) \equiv R \cup C \cup N$, where R denotes the relation names, C the concept names and N the set of individual names. The interpretation I_i of the $Sig(O_i)$ is the structure $\langle D_i, \cdot^{I_i} \rangle$ where D_i is the domain of the ontology and \cdot^{I_i} is the interpretation function such that: $C^{I_i} \subseteq D_i$, $R^{I_i} \subseteq D_i^n$ (in OWL is $D_i \times D_i$).

2.3. Cognitive Learning Context

The model of the local reasoning learning context of a learner L is defined as a structure

$$\Upsilon_{sit} \equiv \langle O, W, \delta, \eta, s \rangle \quad (2)$$

where $O = \{O'_1, \dots, O'_n\}$ and $O'_i \equiv \langle T'_i, A'_i \rangle$ represents the part of each ontology $O_i \equiv \langle T_i, A_i \rangle$ referenced that is relevant to the *focus*, η , of the learning activity, i.e. $T'_i \subseteq T_i$ and $A'_i \subseteq A_i$. Each ontology O_i has a standard interpretation $I_i = \langle \Delta_i, \cdot^{I_i} \rangle$. Let $T =$

$T_1 \cup \dots \cup T_n$ and $A = A_1 \cup \dots \cup A_n$. Let I_i^* be an extension (interpretation) of I_i on $T \cup A$. We define W to be the set of interpretations of $T \cup A$, i.e. $W = \{I_i^*\}_{i=1\dots n}$ and δ to be an accessibility relation associating each $O'_i \in O$ in each situation to a set of possible epistemic alternatives: $\delta : O \rightarrow \wp(W)$. η is a proposition.

Note that there may not be any interpretation satisfying all ontologies. If we assume that ontologies are locally consistent then there is at least one interpretation satisfying each ontology in O . For example, if $A \sqsubseteq B \in T_i$ and $A \sqsubseteq C \in T_j$ but $A \sqsubseteq C \notin T_i$ then there exist two subsets of possible worlds in W , W_1 and W_2 say, such that W_1 supports both $A \sqsubseteq B$ and $A \sqsubseteq C$ and W_2 supports $A \sqsubseteq B$ but not $A \sqsubseteq C$. Also, for each conflicting set of formulae $A \sqsubseteq B \in T_i$ and $A \sqsubseteq \neg B \in T_j$ for $i \neq j$, there is at least one possible world $w \in W$ which assigns true to one formula and false to the other. Using the above definition of the cognitive state of a learner, we are now able to discuss the cognitive states of ambiguity and inconsistency.

2.4. Cognitive Ambiguity due to Incompleteness

Intuitively, a learner reaches a cognitive state of ambiguity whenever she has access to more than one plausible epistemic alternatives and the learner is unable to choose one. The Oxford English Dictionary defines ambiguity as: *wavering of opinion, hesitation, doubt, uncertainty, as to one's course, or, capable of being understood in two or more ways, or, doubtful, questionable, indistinct, obscure, not clearly defined and lastly, admitting more than one interpretation or explanation; of double meaning or several possible meanings* (in [12]). The notion of ambiguity in our case refers to the interpretation of incompleteness of information contained in learning resources by the learner. We assume that a learner becomes aware of the incompleteness of a learning resource when she compares it with her background knowledge or with another resource.

2.4.1. Definition of Cognitive Ambiguity

Assume a resource R_1 and $\delta(R_1) = W_{R_1} \subseteq W$ i.e. R_1 is compatible with a subset of possible worlds W_{R_1} of W . Then, assume that the agent has access to another resource R_2 which is compatible with $W_{R_2} \subseteq W$. If there exist $w_1, w_2 \in W$ where $w_1 \in W_{R_1}$ and $w_2 \in W_{R_2}$ such that w_1 supports η and w_2 supports $\neg\eta$ then we say that agent A is ambiguous with respect to η and we denote this as: $U_A(\eta)$.

2.4.2. Vocabulary Assumption

The type of ambiguity we address here is the ambiguity that results from incompleteness of knowledge rather than the lexical vocabulary used by each resource. The set of resources relevant to the subject of the learning activity may change in each situation according to the focus of the learning activity. To be able to determine incompleteness and inconsistency between ontologies we need to make some assumptions regarding the vocabularies of the ontologies that form part of the cognitive context. Assume a unified signature Σ which consists of the union of all the signatures $Sig(O'_i)$ (defined as above). To simplify matters, we assume that any two identical non-logical symbols of two resources R_1 and R_2 are considered the same unless there is evidence to the contrary. Further, where we have explicit default mappings between terms we may apply default inference rules to draw conclusions between multiple ontologies as follows:

$$\frac{[R_1 : C(x)] : [R_2 : C(x)] \leftrightarrow [R_1 : C(x)]}{[R_2 : C(x)]} \quad (3)$$

Default rule 3 states that if there is no inference inconsistent to $[R_2 : C(x)] \leftrightarrow [R_1 : C(x)]$ in R_2 then $R_2 : C(x)$ can be asserted in R_2 . A similar default inference rule is used for relations between concepts and names of individuals.

$$\frac{[R_1 : R(x, y)] : [R_2 : R(x, y)] \leftrightarrow [R_1 : R(x, y)]}{[R_2 : R(x, y)]} \quad (4)$$

The biconditional used in the inference rules aims to maintain consistency with mappings of terms between different vocabularies. If the conclusion of the default rule that refers to an assertion about a resource is not inconsistent with the assertions of the resource and is not already in the ontology of the resource, then the resource is incomplete.

As an example, of a case where direct equivalences of assumptions can be used to assert new facts about different resources consider two people (P_1 and P_2 say) viewing a scene from opposite sites then $P_1 : right(P1, x) \leftrightarrow P_2 : left(P2, x)$ for some object x . Further assume that the constrain $P_i : right(P1, x) \rightarrow \neg P_j : left(P2, x)$ where $i \neq j$ and $i, j \in \{1, 2\}$ holds for each person. Then obviously, it is inconsistent to assume that $P_1 : right(P1, x) \leftrightarrow P_2 : right(P2, x)$. Note that the intended meaning of the notions of $P_i : right(P_i, X)$ and $P_i : left(P_i, X)$ for each $i \in \{1, 2\}$ is independent of the situation of P_i . However the actual assignment of terms is dependent on their situation.

2.5. Cognitive Inconsistency (Confusion)

Intuitively, we assume that cognitive inconsistency arises when in the actual world of the learner, information about a topic is conflicting. It is different from cognitive ambiguity in that cognitive ambiguity appears as a consequence of possible epistemic alternatives (not necessarily inconsistent) due to lack of knowledge. We model this by the derivation of refuting arguments relating to the *focus* of the learning activity.

2.5.1. Definition of Inconsistency

Assume a resource R_1 and $\delta(R_1) = W_{R_1} \subseteq W$. Then, assume that either $\delta(R_2) = W_{R_2} \subseteq W$ for some resource R_2 (or that $\delta(BK) = W_{R_{BK}} \subseteq W$ where BK is the background knowledge of the agent). If for any two $w_1, w_2 \in W$ such that $w_1 \in W_{R_1}$ and $w_2 \in W_{R_2}$ (or $w_2 \in W_{R_{BK}}$) we have that w_1 supports η and w_2 supports $\neg\eta$ then we say that agent A is inconsistent with respect to η and we denote this as: $Inc_A(\eta)$.

The use of argumentation to identify and justify claims that may be conflicting each other is not only important for the recognition of the cognitive state of the learner but also for the recognition of differences or inconsistencies in ontologies automatically. In the next section we discuss the formalization of two types of arguments that can be inferred from ontologies, namely syllogistic and arguments about necessary and jointly sufficient features associated to the definition of concepts.

3. Syllogistic Arguments and Ontological Taxonomic Relations.

An Ontology may include one or more hierarchies of concepts that can be used to infer categorical statements.

3.1. Concept hierarchy

A *concept hierarchy* is a structure $\mathcal{H} = \langle C_{\mathcal{H}}, R_{\mathcal{H}} \rangle$ where $C_{\mathcal{H}}$ is a set of concepts, st. $C_{\mathcal{H}} \subseteq C$ of the ontology O , and $R_{\mathcal{H}} = \{Disjoint, SubclassOf, Union, Intersects\}$ and every concept in $C_{\mathcal{H}}$ is associated with another concept via a relation in $R_{\mathcal{H}}$. OWL-DL provides for all of relations in $R_{\mathcal{H}}$ and therefore a hierarchy can be represented in it. We are interested in those interpretations of a hierarchy that satisfy all the taxonomic relations within the hierarchy. A model, $\mathcal{M}_{\mathcal{H}}$ of \mathcal{H} is an interpretation I of \mathcal{H} where all the taxonomic relations in $R_{\mathcal{H}}$ are satisfied. Obviously, $\mathcal{M}_{\mathcal{H}}$ is a sub-model of \mathcal{M} and therefore any entailment of $\mathcal{M}_{\mathcal{H}}$ is an entailment of \mathcal{M} .

3.2. Categorical statements

Generalized statements the form: *Every X is a Y* or *Every X has the property of Y* can be inferred from taxonomic hierarchies and can be combined to form *sylogistic arguments*. These statements are referred to as *categorical statements*. A syllogism [13] is a particular type of argument that has two premises and a single conclusion and all statements in it are categorical propositions.

3.2.1. Individuals

In ontologies, a distinction is made between individuals and classes. In the consequent we argue that the set equations that can be used to represent ontological primitives can be translated to propositional logic formulae that can be used to test validity of arguments. To simplify computation and to prove whether an individual belongs to a class (or a refutation that an individual belongs to a class) we represent individuals as singular sets consisting of that individual only. In this way we treat individuals as classes during inference. An ontology may include one or more hierarchies of concepts that can be used to infer syllogisms.

3.2.2. Syllogisms

Syllogisms form a particular type of arguments that are constructed from generalized statements (categorical statements). There are four basic categorical statements which can be combined to produce 64 patterns of Syllogistic Arguments. These are shown below together with the corresponding ontological primitives:

Categorical Statement	Ontological Primitive
Every S is a P	SubclassOf(S, P)
No S is a P	SubclassOf(S, ComplementOf(P))
Some S is a P	Intersects(S, P)
Some S is not P	Intersects(S, ComplementOf(P))

However, only 27 of them are valid syllogisms. This suggests the need to check the validity of syllogisms constructed from ontologies and exchanged during interaction with the learner.

3.3. Necessary and Sufficiency Conditions Arguments.

The classical view of the representation of concepts states that the features representing a concept are *singly necessary* and *jointly sufficient* to define a concept. In line with the above view we propose the following definitions for the *necessary* and *jointly sufficient* features representing a concept.

3.3.1. Necessary Features for the Representation of a Concept

Intuitively, a feature ϕ is *singly necessary* for the definition of C if and only if existence of C implies existence of ϕ . Assume a feature ϕ . We define a set Φ consisting of all individuals of the domain which have property ϕ (e.g. via the `onProperty` restriction in OWL-DL). Then, ϕ is a necessary property for the representation of concept C if and only if $C^I \subseteq \Phi$. An example of a refutation to the assumption that ϕ is a necessary feature for C is the derivation of an individual that belongs to C and to a class disjoint with Φ .

3.3.2. Jointly Sufficient Features for the Representation of a Concept

Let $\{\Phi_1, \dots, \Phi_n\}$ represent the set of concepts corresponding to features ϕ_1, \dots, ϕ_n respectively. Then ϕ_1, \dots, ϕ_n are jointly sufficient for the representation of concept C if and only if $\{\Phi_1 \cap \dots \cap \Phi_n\} \subseteq C^I$. An example of a refutation (i.e. an attacking argument) to the above assumption would be the existence of an individual that has these properties but does not belong to C . Conflicting arguments about these notions can be used to differentiate concept definitions between different ontologies.

3.4. Bennett's theory

Bennett [14] proved that set equations can be translated to propositional logic formulae that can be tested for their validity with a Gentzen theorem prover. Although his theory was intended primarily for reasoning with mereological relations it is applicable in our case for reasoning with the type of arguments described above. This is because the mereological relations being represented using this theory closely resemble the set-theoretic semantics attributed to the ontological primitives describing associations between concepts in ontologies. Bennett [14] proves that the mereological equations with set theoretic semantics can be translated to equivalent universal equations which can in turn be converted to propositional logic formulae that can be validated with a simple Gentzen theorem prover. Based on Bennett's *classical entailment correspondence theorem* we were able via a small adaptation to derive a *taxonomic entailment correspondence theorem* which is very similar to the theorem described above but concerns hierarchical relations. This is stated below:

3.4.1. Taxonomic entailment correspondence theorem

$$M_H \models \phi \text{ if and only if } M_{C^+} \models \tau = \mathcal{U} \quad (5)$$

where \mathcal{U} is the universe of discourse. Unintended models of the theory are excluded by the use of (entailment) constraints. It therefore follows that satisfaction of these constraints forms a refutation against the association of concepts being modeled. To avoid technical details which are beyond the scope of this paper, it suffices to say that since each

categorical statement in a syllogistic argument can be translated to propositional form, then the validity of the syllogistic argument can be tested against a propositional theorem prover.

3.5. Conflicts between arguments

Intuitively, a set of arguments consists of a minimal set of premises (here categorical statements) used in the derivation of a claim. In this paper we focus on strict arguments that are inferred via the classical entailment relation. Two arguments conflict with each other (attack) if either (i) the claim of one argument is inconsistent with the claim of the other argument (i.e. *rebutal* [15]) or (ii) the claim of one argument is inconsistent with one of the other premises of the other argument (i.e. *undercutting* [15]) or (iii) one argument's premises are inconsistent with the other argument's premises. Since a syllogism is defined entirely in terms of categorical expressions then two syllogistic arguments conflict each other if any expression in one argument is inconsistent with an expression in the other argument.

4. Human Computer Interaction Using Arguments

In this section we extend the example given in section 1.2 to include an interaction between a human learner and a software agent to clarify differences in ontologies.

4.1. Extended Example

Scenario as above but extended to show the situation where a learner initiates a dialogue with the agent to discuss the differences in conceptualizations (in this paper we make the simplifying assumption that ontologies are used to represent conceptualizations). The software agent uses the ontology of the resource to provide tutoring support to the learners. The dialogue proceeds as follows:

- (1) **L:** Let us Discuss the statement in Resource: URI_1 : *Visual Basic is an Object Oriented Language?*
- (2) **A:** Does the resource provide a justification why *Visual Basic is an Object Oriented Language?*
- (3) **L:** The resource URI_1 states that *visual basic is an object oriented language because visual basic contains Objects.*

In line (1) above the learner is confused about the truth of a statement. The focus of the dialogue is 'visual basic is an object oriented language'. The agent responds to the request of the learner to discuss this statement by trying to find out whether the resource provides a justification (i.e. whether the statement is a claim of an argument) or whether the statement is an assertion. To find out whether the learner agrees with the viewpoint of the resource, the software agent *A* explores the viewpoint of the learner. The interaction continues with:

- (4) **A:** So do you agree that *visual basic includes objects?*
- (5) **L:** Yes..I agree that *visual basic includes objects*
- (6) **A:** Do you agree that a *programming language is object oriented language* because it *contains objects?*
- (7) **L:** I disagree with this.
- (8) **A:** OK, do you agree that *contains objects is a necessary property of object oriented language?*
- (9) **L:** Yes.

During lines (4) – (9) the agent collects information about the learner. The learner may disagree with the argument given by the resource in the following ways: (i) either disagrees that 'visual basic contains objects' or (ii) disagrees that the property 'contains

objects' is necessary to infer that visual basic is object oriented language, or (iii) disagrees that 'contains objects' is sufficient to infer that visual basic is object an oriented language. In lines (4) – (5) the agent determines whether the learner believes that visual basic has property 'contains objects'. In lines (6) – (7) the agent determines whether the learner believes that 'contains objects' is a necessary and sufficient property of 'object oriented language' (i.e. whether it defines the concept object oriented language). In lines (8) – (9) the agent determines whether the learner believes that property contains objects is necessary for the concept object oriented language. After this interaction the agent knows that although the learner believes that 'contains objects' is a necessary property of 'object oriented language', it is not sufficient to define the concept of 'object oriented language'.

(10) **A:** What other property is a necessary property of object oriented language?

(11) **L:** Encapsulation is a necessary property of Object oriented language.

(12) **A:** So, you think that *IF a programming language contains objects AND has the property of encapsulation then it is an object oriented language?*

(13) **L:** Yes, that's it!

(14) **A:** Therefore, you think that *IF visual basic has the property of encapsulation THEN visual basic is an object oriented Language*

(15) **L:** Yes.

During the lines (10) – (15) the agent is able to obtain the learner's definition of object oriented language and is able to explain her confusion. In this case, confusion arises due to inconsistency between the knowledge of the resource and the learner. Such confusion can arise due to directly conflicting arguments.

4.2. Dialogue Moves

Interaction between the learner and the tutor is enabled via a set of statement openers and templates which provide the structure of communication and constrain the scope of interaction. The parts that the user is required to complete represent ontological statements which correspond to OWL-DL statements. Utterances are parsed internally as *moves*. A dialogue move is a tuple of the form:

$$DM(id, Speaker, Move, \phi) \quad (6)$$

where *id* is the identifier of the move, *Speaker* is the utterer, *Move* is a performative verb representing the locution being uttered, and ϕ is an ontology statement.

4.3. Situation Calculus Approach to Formalizing Moves

A situation calculus [16,17,18] approach to modeling moves and changes in the commitment stores of the participants of the dialog, is followed. A similar approach is advocated by Brewka in [19]. Each move in our framework is formalized in terms of its effect on the beliefs of the participants and advances the existing situation to the next situation. Below we illustrate the formalization of a set of effect rules from moves performed by the learner. It is important to note that both the learner and the tutor are allowed to disagree and challenge each other's opinion. A complete list of the effect rules is beyond the scope of this paper.

4.3.1. The learner initiates the discussion

$commit(learner, \{*\phi\}, do(DM(id, learner, iDiscuss, \phi), s_0))$ where $*\phi = \neg Bel\phi \wedge \neg Bel\neg(\phi)$.

i.e. the learner commits to not knowing whether ϕ after it initiates the discussion.

$commit(learner, \{*\phi, R_i:\phi\}, do(DM(id, learner, iDiscuss, R_i:\phi), s_0))$

i.e. the learner commits that $R_i:\phi$ after it initiates the discussion for $R_i:\phi$.

4.3.2. The learner clarifies a statement asked to clarify by the tutor

$commit(learner, R_i:\psi, do(DM(id, learner, iClarify, R_i:\phi \textbf{ because } \psi), do(a, s)) \leftarrow a = do(DM(id, tutor, qClarify, \phi) \wedge commit(learner, R_i:\phi, s))$.

i.e. the learner is committed that $R_i:\psi$ is the justification (in our case sufficient condition) provided for $R_i:\phi$.

4.3.3. The learner justifies a statement challenged or questioned to clarify by the tutor

$commit(learner, \phi \textbf{ because } \psi, do(DM(id, learner, iJustify, \textbf{ because } \psi), do(a, s))) \leftarrow commit(learner, \phi, s) \wedge (a = DM(id, tutor, qClarify, \phi) \vee (a = DM(id, tutor, qChallenge, \phi)))$.

i.e. the learner provides a justification (sufficiency condition) for believing ϕ .

4.3.4. Either of the agents disagrees a statement

$commit(S, \neg\phi, do(DM(id, S, iDisagree, \phi), do(a, s))) \leftarrow commit(\dot{S}, \phi, s) \vee a = DM(id, \dot{S}, qInquire_1, \phi)$.

i.e. agent S disagrees that ϕ if the other participant, \dot{S} have already committed to ϕ A

full list of moves with their corresponding natural language expression is provided in the table below.

5. Conclusion and Future Work

In this paper we introduced the notion of cognitive learning context that refers to multiple and possibly inconsistent ontologies. Differences in ontologies can be identified via arguments that can be inferred from relevant subsets of terminological axioms and assertions of ontologies referred to by the cognitive context. We show that syllogistic arguments follow naturally from ontological primitives and we represent arguments about the necessary and jointly sufficient properties of concepts. We also illustrated via the use of an example a dialogue where the learner interacts with the software tutor in order to clarify differences in ontologies via the use of justifications provided in support of claims made either by the learner or the learning resources accessible to the learner. Issues like alignment of vocabularies of different ontologies are addressed via default inference rules. In the near future we plan to elaborate on the formalization of arguments and define precisely the associations between arguments and their relevance to different situations. Additionally we plan to work on dialogue management taking into consideration the cognitive state of the learner in each situation.

Speech Act	Natural Language Expression
With inform (super)type:	
The discuss move	
$DM(id, l, iDiscuss^*, ist(URL, \phi))$	Let us discuss statement ϕ in URL .
The clarify move	
$DM(id, l, iClarify, ist(URL, \{\psi, \psi \Rightarrow \phi\}))$	The resource with $URI = URL$ states that ϕ holds because ψ holds
The justify moves	
$DM(id, l, iJustify, \phi)$	Because ϕ .
$DM(id, t, iJustify\phi)$	$(\psi$ holds) Because ϕ .
$DM(id, l, iJustify, \psi)$	Because ψ and $\psi \Rightarrow \phi$.
The agree moves	
$DM(id, l, iAgree, \phi)$	Yes, I agree that ϕ .
$DM(id, t, iAgree, \phi)$	Yes, I agree that ϕ .
The disagree moves	
$DM(id, l, iDisagree, \phi)$	I disagree that ϕ .
$DM(id, t, iDisagree, \phi)$	I disagree that ϕ .
$DM(id, l, iDisagree, _)$	I disagree with the previous statement.
$DM(id, t, iDisagree, _)$	I disagree with this statement.
$DM(id, l, iDisagree, \psi)$	I disagree because ψ .
$DM(id, l, iDisagree, \psi \Rightarrow \phi)$	I disagree because ψ implies ϕ .
The claim moves	
$DM(id, l, iClaim, \phi)$	I think that ϕ .
$DM(id, l, iClaim, \psi \Rightarrow \phi)$	I think that if ψ then ϕ .
The concede moves	
$DM(id, S, iConcede, \phi)$	Yes, I think that ϕ .
With Question (super)type:	
The clarify move	
$DM(id, l, qClarify, ?\psi : ist(URI, \psi \Rightarrow \phi))$	What is the explanation given in resource with $Resource_{uri} = URI$ for ϕ ?
The inquire moves	
$DM(id, t, qInquire_1, \phi)$	Do you think that ϕ ?
$DM(id, t, qInquire_1, \psi \Rightarrow \phi)$	Do you think that if ψ then ϕ ?
$\langle id, t, qInquire, \phi \rangle$	What is ϕ ?
The challenge moves	
$DM(id, t, qChallenge, \phi)$	Why do you think that ϕ ?
$DM(id, t, qChallenge, \psi \Rightarrow \phi)$	Why do you think that ψ implies ϕ ? (Here we assume that ψ is given as a reason, the rule of which is not clear)

Table 1. l stands for the learner, t stands for the tutor, ϕ is a statement in the domain language, URL is the uri of the external resource and $ist(URL, \phi)$ means that ϕ is true in resource with $URI = URL$.

References

- [1] Fauconnier, G.: Mental Spaces. A Bradford Book, The MIT Press Cambridge, Massachusetts, London, England (1985)
- [2] Dinsmore, J.: Mental spaces from a functional perspective. Cognitive Science (1987) 1–21

- [3] Giunchiglia, F., Paolo Bouquet: Introduction to contextual reasoning, an artificial intelligence perspective. Technical report, D.I.S.A-University of Trento (2000)
- [4] Guha, R.: Varieties of context. CONTEXT 2003, pages 164–167 (2003)
- [5] Bouquet, P., Giunchiglia, F., van Harmelen, F.: Contextualizing ontologies. Dit-04-013, Department of Information and Communication Technology, University of Trento (2004)
- [6] Bouquet, P., Serafini, L., Zanobini, S.: Peer-to-peer semantic coordination. Technical report, Istituto Trentino di Cultura (2004)
- [7] McCarthy, J.: Notes on formalizing contexts. In Kehler, T., Rosenschein, S., eds.: Proceedings of the Fifth National Conference on Artificial Intelligence, Los Altos, California, Morgan Kaufmann (1986) 555–560
- [8] Ghidini, C., Giunchiglia, F.: Local models semantics, or contextual reasoning = locality + compatibility. Artificial Intelligence **127** (2001) 221–259
- [9] Fagin, R., Halpern, J.: Awareness and limited reasoning. Artificial Intelligence **34** (1988) 39–76
- [10] Martins, A. T., Pequeno, M., Pequeno, T.: A multiple worlds semantics for a paraconsistent nonmonotonic logic. In Carnielli, W., Coniglio, M., eds.: Lecture notes in pure and applied mathematics, paraconsistency: the logical way to the inconsistent. Volume 228. (2002) 187–209
- [11] Lokhorst, G.J.C.: Counting the minds of split-brain patients. Logique and Analyse (1996) 315–324
- [12] Dalmau, M.: Ambiguity as a conceptual framework for design. (Technical report)
- [13] Walton, D.: Fundamentals of Critical Argumentation. Cambridge University Press (2006)
- [14] Bennett, B.: Logical Representations for Automated Reasoning about Spatial Relationships. PhD thesis, School of Computer Studies, The University of Leeds (1997)
- [15] Dung, P.: On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. Artificial Intelligence **77** (1995) 321–357
- [16] Levesque, H., Pirri, F., Reiter, R.: Foundations for the situation calculus. European Transactions on AI (**reference paper**) (1998)
- [17] Reiter, R.: The frame problem in the situation calculus: A simple solution (sometimes) and a completeness result for goal regression. In: Artificial Intelligence and Mathematical Theory of Computation: Papers in Honor of John McCarthy. Academic Press (1991)
- [18] Reiter, R.: Knowledge in action: Logical foundations for describing and implementing dynamical systems. book draft (1999)
- [19] Brewka, G.: Dynamic argument systems: A formal model of argumentation processes based on situation calculus. Journal of Logic and Computation **11**(2) (2001) 257–282