10

Reasoning and Representing Viewpoints on the Semantic Web

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1. Introduction

Pertaining to the process of critical thinking is the ability to analyse, assess and discern different points of view that are either explicitly or implicitly expressed in resources. Examples of explicitly represented viewpoints are viewpoints of historical value expressing standpoints or theses which had been recognised as significant for the development of a given area and are based on known theories and assumptions. Explicit representation and comparison of these viewpoints is particularly useful in the learning domain, where different theories and theses may have been advocated based on different and possibly conflicting contextual assumptions with advantages and disadvantages for each. Exposition of the learner to these theories helps to broaden understanding, enables the learner to construct new knowledge and motivates the critical thinking activity of the learner. Implicitly recorded viewpoints appear as manifestations of evaluative assessments or outcomes of higher cognitive processes, like comparison, decision making, choice etc. Resources on the web are underpinned by ontologies which may be considered as particular theories of the world. Although ontologies were originally intended to be shareable conceptualizations of the world, particular ontologies usually represent only partially a domain and do so in a way that addresses the needs of particular users and reflects the experience, perspective and personal judgment of particular experts. In this case, the viewpoints of the domain experts are implicit to the design of domain knowledge. Differences in points of view inherent in different ontologies may give rise to inconsistencies in the representation of domain knowledge and need to be made explicit. Otherwise, differences in domain representation may be explained as differences in the local meaning of concepts used by different resources rather than positions which may be defended by sound arguments rooted in coherent theories, judgements, assumptions, or other contextual factors narrowing the scope of reasoning.

So, what is a viewpoint (or point view)? Intuitively, we understand a viewpoint as the position held about an issue which may be disputed, supported by a coherent set of beliefs, theory, etc. Obviously, the notion of viewpoint may be used in natural language to express different things, e.g. a spatial viewpoint which refers to what an agent can see from a particular spatial point. There is something common with this interpretation of viewpoint and the viewpoint we discuss in this chapter. The commonality is based on the fact that the validity of a particular viewpoint may be verified with reference to: The scope of perception of the agent, the actual point where she stands -this would mean cognitive state, mental state, attitude etc, the ability to place herself relative to the surrounding objects and reflect on her relative position, the ability to place herself outside this setting and compare with other viewpoints. A viewpoint in this chapter is represented as a structure consisting of a set of statements, a distinct formula representing the position or standpoint of the viewpoint, the resource of the assertions, axioms, rules, etc from which a viewpoint derives its position, a set of arguments defending the position, any set of relevant assumptions and the vocabulary used in the viewpoint. As argued in (Panayiotou & Dimitrova, 2007), awareness of a position or viewpoint does not necessarily imply agreement with it. An agent may accept more than one points of view without necessarily supporting a particular one. Also, for the purposes of this chapter we make the assumption, that the beliefs of an agent are consistent, and an agent may believe at most one position about a particular topic of dispute. Further we assume that each resource is consistent.

In (Panayiotou & Bennett, 2009 : © 2009 IEEE), the notion of reason was defined as a propositional modal logic formula. The intention of the definition of reason there, was to represent the situation where the truth of a proposition is sufficient to deduce the truth of another proposition. Also, in (Panayiotou & Bennett, 2008) we addressed the problem of necessary and sufficient conditions for the classification of an object: if an individual of the domain satisfies a set of properties that sufficiently define a class then the individual belongs to that class. Satisfaction of sufficient conditions (properties) may be interpreted as another way of expressing the fact that a formula a reason for deducing a classification. So, reason, can be used to represent this situation too. Propositional logic is not expressive enough to capture the types of discrepancies that can arise in concept definitions and individual classification problems. The alternative would be to use a modal logic approach. First order modal logic approaches need careful consideration with regard to domain assumptions over quantified formulas. For example, the intuitive interpretation of the Barcan formula (Blackburn et al., 2001) requires that it is valid in case where the (possible) worlds' domains are invariant.

An alternative to the modal approach has been a purely syntactic approach. The syntactic approach has attracted much interest and has been used to address the problem of relativized truth. McCarthy (McCarthy, 1994), and Konolige (Konolige, 1983), were among the first who experimented with the syntactic approach. Giunchiglia and Serafini (Giunchiglia & Serafini, 1994) argued that problems encountered by modal logic can be avoided by using Multilanguage logical systems (ML) (Serafini & Giunchiglia, 2000). Moreover, they proved that the theorems of the most common modal logics can be embedded into their corresponding ML systems. ML systems also follow a syntactic approach to relativized truth of formulas resulting from hierarchical models (Serafini & Giunchiglia, 2000; Giunchiglia & Serafini, 1994). The notion of viewpoint is relevant to the notion of context and relativized truth: In order to evaluate a viewpoint it is necessary to evaluate the truth of its formulas with respect to its local vocabulary definition, assumptions and theoretical underpinnings, in the context in which valuation takes place. Context-based reasoning has its roots in reasoning with micro-theories (Guha, 1991). Contexts are local models describing a local view about a domain. Microtheories and local contexts can be reused to provide information and draw inferences in other contexts (Guha, 1991). The same applies to viewpoints. Unlike theories and contexts which are assumed to be complete and use the closed world assumption (CWA) to draw inferences, ontologies underpinning resources on the web are assumed to be incomplete. This raises new challenges with regard to deciding the compatibility of different points view of resources where either assertions or axioms important for checking compatibility are missing from some of them. The rest of the chapter is outlined as follows. Section 2 discusses some basic notions concerning ontology entailment and reasons.

2. Background

In (Panayiotou & Bennett, 2009; © 2009 IEEE) we defined a language L_{ARG} of argumentation using propositional logic. L_{ARG} uses the notion of reason to account for sentences of the form 'p is a reason for q', represented as (p↪q) where p and q are propositions. Intuitively, a reason is an instance of a rule A⇒B where all variables in the formula schemata A and B are instantiated and which, in natural language takes the form of an IF … THEN statement. Propositional logic, may be extended to allow for formulas of the form: Q⇒P where Q and P represent propositional formula schemata. The double arrow notation aims to show that a rule in strict sense cannot be described as a material conditional. For example, A⇒B would not make sense if B was always true independently of A. In order to be able to determine how reasons are related, we need to determine the syntax and semantics of the language in which reasons and rules are represented. In Description Logics (DL) inclusion terminological axioms may be considered as rules whose formulas may be expressed in first-order logic. For example, for any two atomic concepts A, and B such that $A \sqsubseteq B$, we may derive the rule $A(x) \Rightarrow B(x)$. It is also important to be able to determine conflicting formulas. For example if DL is used and the axiom $A \sqsubseteq B$ is used in the construction of a reason then its important to be able to deduce that $A \sqsubseteq \neg B$ is a conflicting axiom, and hence a reason based on the latter axiom conflicts with a reason based on the first. The logic developed in (Panayiotou & Bennett, 2009; © 2009 IEEE) to give a semantic account of the notion of reason, like many well known relevance and conditional logics, suffers from some drawbacks. For example it allows for formulas of the form $\alpha \hookrightarrow (\alpha \vee \beta)$. One reason for this result is that ↪ is defined in terms of a modal formula involving necessary material implication within a set of worlds. Thus, within this set of worlds (which are assumed to be normal (Blackburn et al., 2001) and compatible with the actual world of the reasoning agent), every valid propositional logic formula holds, e.g. $\alpha \rightarrow (\alpha \vee \beta)$.
In this chapter we focus on a syntactic axiomatization of reasons using *ALC*. Concept languages, like *ALC* are uniquely identified by its set of concept-forming and role-forming constructors that permit the creation of concept expressions and role expressions (Patel-Schneider, 1990). The syntax and semantics of concept-forming constructors and role-forming constructors are shown in tables 1 and 2. The terminology adopted is identical to (Patel-Schneider, 1990). That is, concept names are denoted with the letters A, B, role names with P and individual names with a, b,... , possibly with subscripts. Concept expressions and role expressions (typically referred to as concepts and roles) are denoted with the letters C, D and Q, R, respectively. The notion of satisfiability is defined on the statements of ontology as usual. An interpretation I is a model of an ontology O = <T, A> if and only if it is both a

model of T and a model of A. An ontology O logically implies a formula α (either an assertion or a T-axiom) if and only if α is true in every model of O. We denote this as: O |= a. A set of statements F satisfies a, denoted as F |= a if and only if whenever O |= F then O |= a. *ALC* is a decidable fragment of first order logic. The language of arguments described above can be extended to cover first order statements in schematic form with two variables. Therefore, we argue that we can determine the association between DL statements and schematic statements with the 'reason for' operator as will be shown below.

CONSTRACTOR NAME	SYNTAX	SEMANTICS
Concept name	A	$A^I \subseteq \Delta^I$
Top	$\top$	Δ^I
bottom	$\bot$	$\varnothing$
conjunction	$C \sqcap D$	$C^I \cap D^I$
disjunction	$C \sqcup D$	$C^I \cup D^I$
negation	$\neg C$	$\Delta^I \setminus C^I$
Universal quantification	$\forall R.C$	$\{d_1 \mid \forall d_2 : (d_1,d_2) \in R^I \rightarrow d_2 \in C^I\}$
Existential quantification	$\exists R.C$	$\{d_1 \mid \exists d_2 : (d_1,d_2) \in R^I \wedge d_2 \in C^I\}$
Number restrictions	$\geq nR$	$\{d_1 \mid \#\{d_2 : (d_1,d_2) \in R^I\} \geq n\}$
	$\leq nR$	$\{d_1 \mid \#\{d_2 : (d_1,d_2) \in R^I\} \leq n\}$
Collection of individuals	$\{a_1,\ldots,a_n\}$	$\{a^I_1,\ldots,a^I_n\}$

Table 1. Syntax and Semantics of concept-forming operators

CONSTRUCTOR NAME	SYNTAX	SEMANTICS
Role name	P	$P^I \subseteq \Delta^I \times \Delta^I$
Role conjunction	$Q \sqcap R$	$Q^I \cap R^I$

2.1 Reasons, in DL Ontologies

Consider an ontology O = <T, A> where T is the set of terminological axioms in O and A the set of assertions in O. Further assume that O comes with a vocabulary $\Sigma = C \cup R \cup I$ and domain D, where C denotes the set of concept names, R the set of role names and I the set of individual names used in the ontology O, respectively. An interpretation function ·I assigns to each name in Σ an individual of the domain, to each concept a subset of the domain and to each role a subset of D×D. A reason is entailed from a (set of) assertions and axioms in the following way:

Definition 2.1

If O = <T, A>, then we say that a reason $\alpha \hookrightarrow \beta$ is valid in O and denote it as O:[$\alpha \hookrightarrow \beta$] if and only if there is a subset of formulas,

1. $T \models \Phi$

2. $A \vDash \alpha$
3. $\Phi \cup \alpha \vDash_{min} \beta$

where $\vDash_{min}$ is interpreted as 'minimally entails'.
We note that although the above definition for reason is different from the one given in (Panayiotou & Bennett, 2009; © 2009 IEEE), it is nonetheless equivalent since in (Panayiotou & Bennett, 2009) 'reason' is defined within an S5 modal logic system.

2.2 Computing the Closure of an Ontology

One way to deduce all relevant information in order to construct reasons is to obtain the closure of $T \cup A$ which is computed as follows.

Definition 2.1 (Closure of an Ontology)
If O = <T, A>, then we say that the closure of the union of a set of terminological axioms T and assertions A of is computed as follows:

1. CL := { T ∪ A }
2. If (A ⊓ B)(a) ∈ CL then CL := CL ∪ { A(a), B(a) }
3. If {(A ⊔ B)(a) , ¬A(a)} ⊆ CL then CL := CL ∪ { B(a) }; else if ¬B(a) ∈ A then CL := CL ∪ { A(a) }
4. If {A ⊑ B, A(a)} ⊆ CL then CL := CL ∪ { B(a) }
5. If {A ⊑ B , B ⊑ C} ∈ T then CL := CL ∪ { A ⊑ C }
6. If { R(a, b), ∀R.C } ⊆ CL then CL := CL ∪ { C(b) }
7. If {R1 ⊑ R2, (a, b)} ⊆ CL then CL := CL ∪ { R2(a, b) }
8. If Q ⊓ R).C(a) ∈ CL then CL := CL ∪ { R.C(a), Q.C(a)}
9. If { A ⊑ B, R.A(a) } ⊆ CL then CL := CL ∪ { R.B (a)}
10. If { R1⊑ R2 , R1.C(a)} ⊆ CL then CL := CL ∪ { R2.C(a) }
11. If {A⊑ B⊓C} ⊆ CL then CL := CL∪ {A⊑ B, A⊑ C}
12. If { A ⊔ B ⊑ C} ⊆ CL then CL := CL∪ {A⊑ B, A⊑ C}

2.3 Rewriting

Computing the closure of ontology statements is not very efficient, especially for large ontologies. The task becomes even harder when we need to compare the closures of different ontologies. To increase the efficiency of computation we need to extract only those assertions and terminological axioms from an ontology that are relevant to the formula under consideration. Consider the following ontological statements:

Example 2.1
Suppose we have a small ontology about male workers in UK as shown below and we wish to determine whether MALE(John) is relevant to MWUK(John).

1. MWUK = MLE ⊓ WORK.UK
2. MLE = MALE ⊓ EMPLOY EE
3. MWUK(John)

Then, obviously MWUK $\sqsubseteq$ MLE and MLE $\sqsubseteq$ MALE. Therefore, MWUK $\sqsubseteq$ MALE and since MWUK(John) then MALE(John) follows. It turns out that not only MALE(John) is relevant to MWUK(John) but one is the *reason for* the other (i.e. the truth of the first is a sufficient reason to conclude the truth of the second) as will be discussed later. In natural language terms we can say that: MALE(John) because MWUK(John), or, equivalently that MWUK(John) is a reason for MALE(John).

Example 2.2
Suppose we wish to determine what assertions are related to the assertion A(a) in the small ontology below. The letters A, B, C, D below denote generic concepts.

1. $A \sqsubseteq (B \sqcup C)$
2. $\neg B(a)$
3. D(a)

In the above example, it should be possible to identify the relevance between A(a) and ¬B(a) and C(a). The problem with subsumption relation is monotony: If we assume that $A \sqsubseteq B$ then we may deduce that $A \sqsubseteq B \sqcup C$ although concept C may not be related to concept A. Item 1 above, implies that either $A \sqcap B \neq \emptyset$, or, $A \sqsubseteq B$ or $A \sqsubseteq C$. Thus, if B and C are disjoint (i.e. $B^I \cap C^I = \emptyset$) then $A \sqsubseteq (B \sqcup C)$ is superfluous to one of $(A \sqsubseteq B)$ or $(A \sqsubseteq C)$, i.e. $A \sqsubseteq (B \sqcup C)$ is 'too general'. Similarly if we have two axioms: $(A \sqcap B \sqcap C) \sqsubseteq D$ and $(A \sqcap B) \sqsubseteq D$ then the former axiom is 'unnecessarily restricted'.

Definition 2.2 (Minimal Subsumption)
Assume we have an axiom of the form: $\Phi \sqsubseteq \Lambda$. Then, we say that Φ is subsumed minimally by Λ if and only if the following conditions hold:

1. If $\Lambda = \Lambda 1 \sqcup \cdots \sqcup \Lambda n$ and $n \geqq 2$ then Φ is subsumed minimally if and only if $\Phi \not\sqsubseteq [\Lambda \setminus \Lambda j]$ for any $j \in \{ 1 \ldots n \}$.
2. If $\Lambda = \Lambda 1 \sqcap \cdots \sqcap \Lambda n$ and $n \geqq 2$ then Φ is subsumed minimally if and only if $\Phi \not\sqsubseteq \Lambda \sqcap \Psi$ for any Ψ.

Definition 2.3 We say that an axiom is *too generous* if it is subsumed by a non-minimal disjunction.

Definition 2.4 We say that an axiom is *too restricted* if it is subsumed by a minimal conjunction.

When an axiom is neither too generous nor too restricted, then it can be used to create reasons which are valid within an ontology. For example, although $C \sqsubseteq D \sqcup E$ is not inconsistent with $C \sqsubseteq D \sqcup E \sqcup F$ and both can be true, only the first one would be used to determine E: $C \sqcap \neg B \sqsubseteq C$. Since different ontologies may be expressed at different levels of granularity, reasons giving rise to arguments may conflict; thus, reasoning with 'reasons' gives rise to defeasible reasoning. In order to facilitate the matching of statements within an ontology we devised a rewriting mapping that transforms axioms as described below. After this transformation function is applied, all the upper lever conjunctions of the formula will have been eliminated.

Definition 2.5 (Rewriting function - τ)
To ease the task of searching statements relevant to reasons the following rewriting rules are applied on the definitional and terminological axioms of the ontology being considered:

1. Each terminological axiom of the form $A \sqsubseteq B \sqcup C$ where A, B, C denote simple concepts, is translated into $A \sqcap \neg B \sqsubseteq C$.
2. Each terminological axiom of the form $\Phi \sqsubseteq C \sqcup D$ where Φ is not a simple concept is re-written so that Φ has a ⊔ at the top level (the equivalent of disjunctive normal form) i.e. Φ has the form $\Phi = A1 \sqcup A2 \sqcup \cdots \sqcup An$
3. Each axiom of the form $\Phi 1 \sqcup \cdots \sqcup \Phi n \sqsubseteq \Lambda 1 \sqcap \cdots \sqcap \Lambda n$ is translated into a set of axioms: $\Phi i \sqsubseteq \Lambda j$ for all $j \in \{ 1 \ldots k \}$ and $i \in \{ 1 \ldots n \}$.
4. Each axiom of the form: $\Phi \sqsubseteq \Lambda$ where Λ is not a simple concept is re-written so that Λ has a ⊓ at the top level, i.e. into a form equivalent to conjunctive normal form in first-order logic.
5. Definitional axioms of the form: $\Phi = \Lambda 1 \sqcap \cdots \sqcap \Lambda n$ are rewritten into the following two axioms:
   a. $\Phi \sqsubseteq \Lambda 1 \sqcap \cdots \sqcap \Lambda n$
   b. $\Lambda 1 \sqcap \cdots \sqcap \Lambda n \sqsubseteq \Phi$

The above definition is particularly useful since as I argued in the propositional case (Panayiotou & Bennett, 2009 : © 2009 IEEE): $(\alpha \vee \beta) \hookrightarrow \gamma$ if and only if $(\alpha \hookrightarrow \gamma)$ and $(\beta \hookrightarrow \gamma)$, where α, β, and γ denote formula schemata. Intuitively, this rule aims to establish that a disjunction of formulas can only give rise to another formula if both disjuncts are sufficient reasons on their own to cause γ (i.e. the consequent). Implicit to this rule is the assumption that there can be more than one propositions constituting a sufficient reason for a claim.

2.4 Relevance Relation

Statements related to each other have some properties that enable us to locate them more easily. For example, if an assertion is related to another assertion then it is also related to its negation. Thus, when two ontologies are compared, it is not only important to be able to recognize agreements but also disagreements between them. With hindsight on axioms of relevance theory, relevance between formulas is represented as a relation $\mathfrak{R}$, satisfying the following properties:

1. **(R1)** $\mathfrak{R}(A,A)$
2. **(R2)** $\mathfrak{R}(A, \neg A)$
3. **(R3)** $\mathfrak{R}(A, B)$ if and only if $\mathfrak{R}(B, A)$
4. **(R4)** $\mathfrak{R}(A, B)$, $\mathfrak{R}(B, C)$ implies $\mathfrak{R}(A, C)$.
5. **(R5)** $\mathfrak{R}(A, D \wedge E)$ if and only if $\mathfrak{R}(A, D)$ and $\mathfrak{R}(A, E)$

where A, B, D, E are formula schemata.

Proposition 2.1

Let O = < T, A> and f : T $\mapsto$ T' which translates O into O' according to the rewriting rules stated above. Then, $O \vDash \varphi$ if and only if $O' \vDash \varphi$.

The proof is easy since rewriting preserves satisfiability between the original and the rewritten axioms. Proposition 2.1 refers to ontologies that do not include too generous or too restricted axioms. If this were not the case then reasons entailed by the original ontology might not have been entailed from the translated ontology. Notably, definition 2.1 defines reason as part of an inclusion or subsumption entailment. This is not necessarily the case. Reasons may be defined in different logical languages differently. The main point made here is that inclusion or definitional axioms that can be translated to rules, can give rise to reasons. For example, if we assume that $Ax \Rightarrow Bx$ denotes a rule then when its variables are substituted by names of individuals of the domain, it gives rise to reasons. Next, we show how to deduce reasons from ontological axioms and assertions. After the definition of τ (please refer to definition 2.5), it is possible to select from the knowledge base those axioms and assertions that give rise to reasons.

In order to draw inference using formulas that include 'reasons', we need to define a new inference relation that uses first order formulas and 'reasons' to derive new inferences. We define the *cumulative* inference relation $\vdash_R$, which is a supraclassical non-monotonic inference relation which draws inferences using 'reason' formulas. Studying the meta-theoretic properties of inference (with the term metatheoretic meaning drawing inferences or studying the properties of the inference relation of a language) was originally done by (Szabo, 1969) for the sequent calculus inference relation. Later results for the non-monotonic inference relations were obtained by Gabbay (Gabbay, 1984), by Makinson (Makinson, 1989), by Kraus (Krause et al., 1990) and others. A *cumulative* inference relation is an inference relation satisfying the principles of: *Inclusion*, *Cut* and *Cautious Monotony*. Obviously, the first two properties are satisfied by the classical inference relation as well. The definition of a cumulative inference relation as defined in (Brewka et al., 1997) is given below:

Definition 2.6 (Cumulative Inference Relation) (Brewka et al., 1997)

An Inference relation, $|\!\sim$ is cumulative if and only if it satisfies the following properties:

1. Supraclassicality: $\dfrac{X \vdash \alpha}{X \,|\!\sim \alpha}$
2. Inclusion: $X, \alpha \,|\!\sim \alpha$
3. Cut: $\dfrac{X \,|\!\sim \alpha \quad X, \alpha \,|\!\sim y}{X \,|\!\sim y}$
4. Cautious Monotony: $\dfrac{X \,|\!\sim \alpha \quad X \,|\!\sim y}{X, \alpha \,|\!\sim y}$ instead of monotony: ($X \,|\!\sim \alpha$ implies $X, y \,|\!\sim \alpha$)

The fact that $\vdash_R$ is a cumulative relation follows from the properties of $\hookrightarrow$ and the definition of well formed formulas of the language used to represent reasons. We define this language to be $\mathcal{L}_R$, which is a metatheoretic logical language, including rules for deriving 'reason' expressions from other languages, like DL. $\mathcal{L}_R$ includes rules for deriving reason schemata from DL ontologies and may be extended to include reason schemata from other languages. In addition it includes a set of properties about the 'reason for' operator. Both rule schemata for deriving reasons and properties of $\hookrightarrow$ are discussed below.

Definition 2.7 (Rules for deriving reason schemata applicable to DL ontologies)

Assume an ontology O. Further assume that the inference relations $\vdash_S$ and $\vdash_R$ correspond to subsumption inference in DL and reason inference in $\mathcal{L}_R$ we have the following rules for deriving reasons from O.

1. $\underline{O \vdash_S A \sqsubseteq B}$
   $O \vdash_R A(x) \hookrightarrow B(x)$
2. $\underline{O \vdash_S A \sqsubseteq \forall R.C}$
   $O \vdash_R (A(x) \wedge R(x,y)) \hookrightarrow B(y)$
3. $\underline{O \vdash_S R1 \sqsubseteq R2}$
   $O \vdash_R R1(x,y) \hookrightarrow R2(x,y)$
4. $\underline{O \vdash_S A \sqcup B \sqsubseteq C}$
   $O \vdash_R (A(x) \vee B(x)) \hookrightarrow C(x)$

Properties of $\hookrightarrow$ are discussed below:

1. $(A(x) \hookrightarrow B(x)) \wedge (B(x) \hookrightarrow C(x)) \rightarrow (A(x) \hookrightarrow C(x))$ ($\hookrightarrow$ transitivity)
2. If $\vdash_C A(x) \rightarrow B(x)$ then $\vdash_R \neg (A(x) \hookrightarrow B(x))$

Also we have the following two rules about reasons, which we refer to as (R1) and (R2), respectively.

(R1) $[A(x) \hookrightarrow B(x)]\,[y\backslash x] \equiv A(y) \hookrightarrow B(y)$ if and only if $x^I = y^I \in A^I$

(R2) $O \vdash_R (A(x) \vee B(x)) \hookrightarrow C(x)$ if and only if $O \vdash_R A(x) \hookrightarrow C(x)$ and $O \vdash_R B(x) \hookrightarrow C(x)$.

Note that item 4 above is particularly important since after the translation function τ is applied on the ontology, the resulting formulas are in disjunctive form.

Definition2.7 (Conflicts between reasons)

Two reasons $\Gamma 1 \hookrightarrow \alpha$ and $\Gamma 2 \hookrightarrow \beta$ conflict if and only if:

1. $\Gamma 1 \wedge \Gamma 2 \nvdash_R \bot$ and $\alpha \wedge \beta \vdash_R \bot$
2. $\Gamma 1 \wedge \Gamma 2 \vdash_R \bot$ and $\alpha \wedge \beta \nvdash_R \bot$

It is important to mention that $\vdash_R$ is a supraclassical inference relation, which means that it includes classical inferences.

Proposition 2.2
Let O = <T, A>. Then O is inconsistent only if there are conflicting reasons r1 and r2 such that O $\vdash_R$ r1 and O $\vdash_R$ r2.

The proof follows easily by referring to definition 2.7 above and considering each formula type by induction. Note the 'only if' site.

Example 2.3
Let O = <A, T > and { D(a) } = A and {A ⊑ C, D ⊑ ¬C} ⊆T . Then O $\vdash_R$ A(x) ↪ C(x) and O $\vdash_R$ D(x) ↪ ¬C(x).

2.4 Arguments

In this section we discuss the notion of argument and its relevance to reason. Argumentation is a popular field of study in AI and has been researched extensively by many researchers. Among the most important contributions can be traced in the works of Parsons (Parsons et al., 1998), Jennings (Jennings et al., 2001), and Wooldridge (Wooldridge, 2002) and in the area of multi-agent reasoning, Walton (Walton, 2006) and Toulmin (Toulmin, 2005) in the area of philosophy, etc. These approaches provided us with a solid theoretical background in what is now legitimately referred to as the area of argumentation. Apart from very few approaches, the vast majority of work on argumentation focuses on the relationships between arguments and the argument's semantic status (in particular whether it is acceptable or not) and not so much on the internal structure of arguments themselves. Besnard and Hunter (Besnard & Hunter, 2008), are among the exceptions since their work elaborates on the structure of deductive arguments. Below we give our definition of an ontology argument.

Definition 2.8 (Ontology Argument) An ontological argument is a structure < Γ, ∏, C > where:
- C is a claim,
- Γ is a set of assertions or instantiated reason schemata { γ1,...,γn }
- ∏ = { R1,... Rk } is a set of rules (including axioms),
- ∃γk, γm ∈ Γ such that ∃Ri ∈ ∏ and Ri(γk, γn, γi) where i ∈ { 1,…,k }.

We now elaborate on the structure of arguments. In the previous section we presented reasons as grounded instances of rules where the antecedent was the reason for the consequent. In terms of ontologies, grounded instances of rules can take the form of instantiated terminological axioms. For example, (A⊑ B)(a) implies that A(a) ↪ B(a) holds in logic R. The claim of an argument may represent a derived assertion or a derived axiom.

If Σ is a set of statements in an ontology O, then, obviously if Σ $\vdash_S$ α where α is an assertion, $\vdash_S$ denotes the subsumption inference relation and Σ is minimal, then Σ ↪ α. Further, Σ ∧ (Σ ↪ α) $\vdash_R$ α. So, in logic R, we assume an inference rule similar to modus ponens in classical logic which we shall call RMP (from Reason Modus Ponens) and which takes the form:

$$\frac{A(x) \wedge (A(x) \hookrightarrow B(x))}{B(x)}$$

and may be expressed as the relation: RMP(A(a), A(a) $\hookrightarrow$ B(a), B(a)).
Following the above definition of argument we have that < { A(a) }, { MPR }, B(a) > is an argument. The rules included in argumentation logic do not have to be the inference rules of classical logic and reason logic R, alone. Argumentation permits itself a wide range of rule schemata that can be used to derive claims. For example, Walton defines a number of argumentation schemes for arguments (Walton, 2006). One such scheme is the argumentation scheme for appeal to expert opinion, which says that: (i) if source E is an expert in subject domain D containing proposition A and (ii) E asserts that proposition A (in domain D) is true (false), then A may plausibly be taken to be true (Walton, 2006). A rule can be anyone of these schemes.

2.4 Conflicts between Arguments

Assume two ontologies O1 and O2 and α = < Γ1, Π1, C1 > and β = < Γ 2, Π2, C2 > entailed from O1 and O2, respectively. Then α conflicts with β if:

1. The claims of the arguments, i.e. C1 and C2 are inconsistent,
2. The claim of one argument is inconsistent with the premises of the other argument. For example, $A(d) \hookrightarrow B(d) \in \Gamma 1$ and $\{A(d), \neg B(d)\} \subseteq \Gamma 2$.

Proposition 2.3
Suppose that both arguments α and β are entailed from ontology O. Argument α conflicts with argument if β and only if the ontology is inconsistent.

3. Viewpoints

In this section we discuss a structural definition of viewpoint. Let us first discuss the characteristics of viewpoints.

3.1 Characteristics of Viewpoints

A viewpoint consists of a set of reasons or arguments, a set of labeled beliefs describing the underlying ontological theory used in the construction of arguments, mapping rules that map concepts and relations between terminologies from different ontologies used in the viewpoint, a formula representing the position expressed by the viewpoint, the set of resources that are used in the construction of beliefs and arguments and any other contextual beliefs used in the construction of arguments/reasons. Thus, a viewpoint is defined as follows:

Definition 3.1 (Structural definition of a Viewpoint)
A viewpoint is defined as a structure V = < Φ, p, A, R, υ > where

1. Φ is a set of formulas which we assume to be consistent and relevant.
2. p is the formula representing the position of the viewpoint - assume for the time being that the position refers to an ontological assertion.

3. R is the union of a set of rules and reasons.
4. A is a set of arguments supporting position p.
5. υ is an interpretation, assigning to each constant used in the viewpoint an individual of a domain D, to each concept a subset of a domain and to each role a subset of the Cartesian product of the domain D x D.

Each viewpoint uses a vocabulary, denoted as L_V consisting of concept names, individual names and role names from possibly more than one ontology. Below we define the notion of inconsistency between different viewpoints.

Definition 3.2 (Viewpoint inconsistency)

A viewpoint Vi = < Φi, pi, Ai, Ri, υi > is inconsistent with a viewpoint Vj = < Φj, pj, Ai, Rj, υj > if and only if anyone of the following situations hold:

1. There exists rk ∈ Ri and rm ∈ Rj such that rk conflicts with rm.
2. There exists ψ ∈ Φi which is inconsistent with χ ∈ Φj.
3. There is an argument α in Ai and an argument β in Aj such that α and β conflict.

We also say that a viewpoint *attacks* another viewpoint if the former position supports a position which is conflicting to the latter.

Definition 3.3 (Viewpoint attack)

A viewpoint Vi = < Φ_i, p_i, A_i, R_i, υ_i > attacks a viewpoint V_j = < Φ_j, p_j, A_j, R_j, υ_j > if and only if $p_i \vdash \neg p_j$.

Intuitively a viewpoint is *plausible* if it can survive the attacks of other viewpoints. We have the following definition of a plausible viewpoint:

Definition 3.4 (Plausible Viewpoint)

A plausible viewpoint is a viewpoint V = < Φ, p, A, R, υ > where:

1. The reasons supporting a conflicting viewpoint do not *defeat* any reason r ∈ R.
2. The set R is *admissible*.
3. The set A is *admissible*.
4. Any other relevant belief in the viewpoint that underpins the context in which beliefs, arguments or reasons are evaluated *is* compatible with the actual context in which the viewpoint is evaluated. (e.g. domains overlap, vocabulary compatibility or mapping, constraints in the context in which the argument is valid, etc).

The notion of admissibility used in the definition of a plausible viewpoint above is defined below and is based on the notion of acceptability as defined by Dung in (Dung, 1995) with slight verbal adaptation to fit the current context:

Definition 3.5 (Acceptability of arguments) (Dung, 1995)

An argument A is acceptable with respect to a set S of arguments if and only if for each argument B that can be raised: if B attacks A the B is attacked by an argument in S (we say simply say that A is attacked by S).

Definition 3.6 (Acceptability of reasons, rules and arguments)
In this chapter, an argument, rule, or reason A is acceptable with respect to a set of arguments, reasons or rules S if for each argument, reason or rule that follows from the knowledge base of the software agent, if A conflicts with B then S conflicts with B, in the sense of definition 3.5 above.

Definition 3.6 (Admissibility of arguments) (Dung, 1995)
A conflict-free set of arguments S (i.e. one that does not contain arguments A and B such that A attacks B) is admissible if and only if each argument in S is acceptable with respect to S.

The above definition can be extended to cover reasons and rules as in definition 3.6 above.

3.2 Viewpoints created from multiple ontologies

In order to represent viewpoints from multiple ontologies, we first need to define a language for representing reasons, arguments and viewpoints from different ontologies. Let us call this language, $\mathcal{L}_{MV}$, The vocabulary of $\mathcal{L}_{MV}$, henceforth referred to as V($\mathcal{L}_{MV}$), consists of:

1. A set of labels, λ = { λ1,… λn }, where each label refers to a resource,
2. Reason expressions,
3. Rule expressions,
4. The predicate *Trust*,
5. A partial order relation $\prec$ on resources,
6. The relations *contradicts*,
7. Argument expressions,
8. The inference relation $|\sim$

where each label is a type of unique resource identifier, reason expressions are formulas of the form $\alpha \hookrightarrow \beta$ where α and β are formula schemata, rule expressions are domain rules of the form $\alpha \Rightarrow \beta$ used to denote natural language statements of the form 'IF α THEN β', the predicate *Trust* shows whether the reasoning agent trusts a resource, $\prec$ is a partial order on resources (preference relation); the relations *contradicts* shows whether viewpoints contradict to each other or attack each other respectively, and the inference relation $|\sim$ enables reasoning over formulas of $\mathcal{L}_V$. Further, we assume that if $\alpha \vdash_R \beta$ then $\alpha \; |\sim \beta$. An expression of the form: λ_i:φ means φ holds in the ontology which is uniquely identified by the label λ_i.
A viewpoint may be derived from the statements of a single resource or from the combined statements of multiple resources. Let us first represent entailment for a single resource. Semantic entailment may be defined as follows: Assume resource R1 is underpinned by an ontology O = < T, A > with an interpretation I = < D, I > where D represents the domain of the ontology. Then T ∪ A models φ, denoted as $T \cup A \models \varphi$, if and only if φ is true whenever T∪A is true. We say that any set of statements $S \subseteq (T \cup A)$ models ϕ if and only if whenever O models S it also models φ. We denote this as: $S \models \varphi$. Then, we may derive 'reasons' as in definition 2.6 from τ(O) = O'.

Definition 3.5 (DOAF)

Let I be a finite non-empty set of indices {1,…, n}. Further assume that {…,Oi,…}, i ∈ I, is a set of ontologies with at least overlapping domains Δ_i where i∈ I, respectively. Then a distributed ontology argumentation system DOAF is a tuple < {…,λi,…}, {…,Ti,…}, {…,Ai,…}, IR, DR > where

1. λi is the label of the ith ontology, Oi.
2. Ti is the set of terminological axioms of Oi
3. Ai is the set of assertions of Oi
4. IR is the set of inference rules and bridge axioms (Ghidini et al., 2007) employed by DOAF.
5. DR is the set of default rules for reasoning with concepts in different ontologies of the same or overlapping domain.

A set of default rules and inference rules is in DOAF are shown below. A substantial amount of work has been done by Giunchiglia (Giunchiglia & Serafini,), Serafini and Giunchiglia (Serafini & Giunchiglia, 2000), Ghidini (Ghidini et al., 2007) on the proof theory of multi-language systems, hierarchical contexts, distributed ontologies, and mappings between ontologies. Our work on the construction of inference rules and natural deduction from assumptions and axioms from different ontologies is very much influenced by this work. However, although a distributed ontology argumentation framework takes into account known mappings between concepts of different ontologies, in case where explicit mappings are not available we employ default rule (D1) shown below. In addition the rule (↪ Ei) is used to draw inferences

$$\textbf{(D1)}\ \frac{i{:}A,\ j{:}(A \hookrightarrow B) \mid i{:}A \leftrightarrow j{:}A}{[i+j]{:}A} \qquad \textbf{(}\hookrightarrow \textbf{Ei)}\ \frac{i{:}A \quad i{:}(A \hookrightarrow B)}{i{:}B}$$

where A, B and C are formula schemata. Note that i:(A ↪ B) is equivalent to (i:A ↪ i:B)

$$\textbf{(M1)}\ \frac{i{:}C \sqsubseteq j{:}D}{i{:}C(x) \hookrightarrow j{:}D(x)}$$

where C and D are concepts in ontologies uniquely identified by labels i and j respectively and i:C(x) and j:D(x) are the unary predicates corresponding to these concepts.

In addition, the local context of a reasoning agent is defined as follows:

Definition 3.6 (CSWA)

The (reasoning) context of a semantic web agent, CSWA consists of:

1. A topic, T, under consideration,
2. A set of reasoning rules: R,
3. A set of local judgments J,
4. Inferences from DOAF.

5. A Local vocabulary with mappings from its local vocabulary to the vocabulary of the ontologies.

Notably, local judgements, reasoning rules and inferences from DOAF need to be relevant to a particular topic at each instance.

We may consider the above logic as a hierarchical logic (Serafini & Giunchiglia, 2000), capable of using formulas from other logics or theories to infer arguments and viewpoints.

4. Application Issues and Potentialities

Up to now we've taken a rather abstract view of the notion of viewpoints without mentioning how this notion could be applied in practice to benefit applications. My work on viewpoint representation and reasoning aimed to be applied in the identification of discrepancies of viewpoints in the learning domain. For example, in trying to model the initial concepts involved in the introduction section of a programming language course on the web, it became obvious that viewpoints could play a role in constructing an orderly investigation of different ideas, scientific events and theories that led the field to its current state. Viewpoint representation and reasoning can be used constructively to motivate learners to engage in a critical thinking activity in order to choose or compare landmark achievements and historical results that led to the outbreak of the current level of technology in the programming domain. Traditionally, reference to different theses developed within particular scientific areas which were supported by theories, had been mainly recorded as subjects of historical significance and learning. However, comparing and contrasting the applicability of theses within different contexts, and engaging into a reasoning about their relevance, order of appearance, problems they tackle, can lead to the creation of (possibly conflicting) viewpoints that provide scientific insight. For example, the learners may be asked to decide which programming languages should be used to solve a particular problem. In this way they are motivated to justify their own point of view.

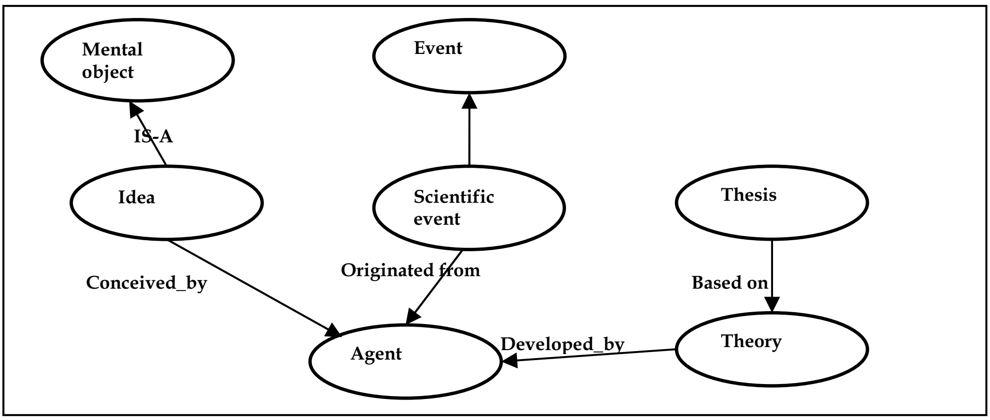

Fig. 1. An example of a small ontology that can be useful in clarifying concepts relevant to viewpoints.

The small ontology above is aimed to discuss the utility of a proper ontological approach to the definition of concepts associated to viewpoints for the purpose of reasoning. Of course the granularity at which the ontology will be represented is important and influences the representation of subtle differences in notions which are used similarly in natural language, as well as the range of inferences that can be drawn from them. Concepts such as *thesis*, *theory*, *idea*, and *mental object* are linked together: a theory had been initiated by an idea induced by a particular agent. The outcome of a theory is a thesis supported by scientific evidence, postulates, assumptions, justifications, and judgments. A *judgment* is the outcome of an evaluation, which is a higher level cognitive process. A *position* is supported by arguments driven from a theory or judgment(s). Unlike a thesis, a position is typically associated to the set of beliefs and attitudes (such as intentions and desires) of an agent. An agent is typically positioned about a topic if she is aware that it is a debatable issue. Each one of the above concepts is linked to the derivation and representation of viewpoints and their support via argumentation.

Linked to the recognition of viewpoints are also higher level cognitive processes, such as comparison, choice, etc, which are part of the critical thinking activity. Critical thinking is a higher level cognitive process (Wang et al., 2006) evoking, among others, the sub-processes of comparison and choice among alternatives via the process of argumentation, externalization of personal beliefs, and reflection. For example, a qualitative assessment stating that one programming language is better than another for a particular scenario can be interpreted as a 'reason for' a choice. The same applies when different theories are compared. The notion of theory is a multifaceted one. However, in all types of theories one expects to find a coherent (not self conflicting) set of principles, judgments and assumptions. Under this general definition of a theory, it follows that theories are prone to comparisons of theories of judgments, assumptions, principles, etc. A *judgment* is described in (ref. wikipedia) as a statement which is usually the evaluation of alternatives. According to the same resource, 'the existence of corroborating evidence for a judgment is necessary; it must corroborate and be corroborated by a system of statements which are accepted as true' (ref. wikipedia); Further, 'the corroborating evidence for a judgment must out-weight any contradicting evidence', as stated in (ref. wikipedia). From this definition of judgment, it follows that it is an output of a higher level cognitive process (evaluation) (Wang et al., 2008) rather than a simple assertion and that it is supported by some sort of factual evidence. The cognitive process of evaluation is part of comparison, another higher level cognitive process. So, the relationship between a comparison and a judgment seem to be that judgment is the outcome of comparison.

The notions of: judjement, position, thesis, reason, justification, and standpoint are closely associated and are related to the recognition and construction of viewpoints. The diagram below is not intended to provide a precise or even 'correct' model of the concepts mentioned above, at this stage. A thorough discussion of these concepts and their associations is a subject of a further philosophical exploration and my future research[1] which is beyond the scope of this chapter. Rather, it presents a possible model of the association of these concepts that can be used in the derivation of viewpoints. A possible model of some of the associations of these concepts (for illustration purposes) is shown below.

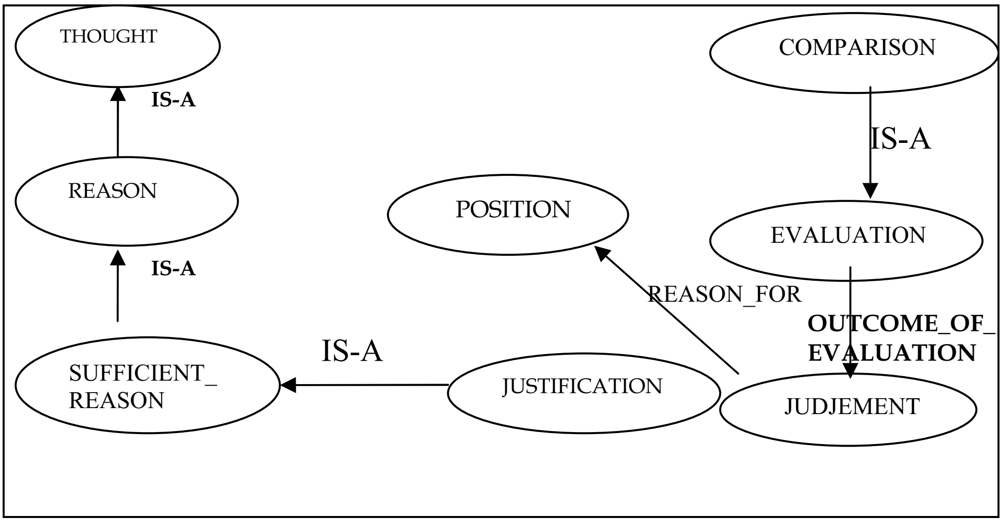

Fig. 2. An initial design of ontological associations between concepts relevant to the identification of viewpoints

Sufficiency conditions, causality and the classification problem. A *reason* is an explanatory or justificatory factor (wikipedia). In the context of explanation, the word ″(a) reason″ can be a synonym for ″(a) cause″ (wikipedia). In this paragraph we focus on sufficiency conditions which can be used as reasons for claims.

Although a domain representation explicitly in terms of viewpoints may be inflexible, the design of the domain representation can facilitate the extraction of viewpoints implicit in other tasks. Another example worth considering is the definition of concepts and the classification problem. An individual belongs to a particular class if it satisfies a particular set of properties. Differences or inconsistencises in the definition of concepts may be recognised via a comparison between the set of properties that sufficiently define concepts. If the definition of objects identifies sufficient and necessary concepts the task of raising refutals to claims of particular individuals' classifications (i.e. misclassifications) becomes easier. So, in order to reason with viewpoints, it is necessary to design systems so as to facilitate viewpoint representation, extraction and reasoning. This involves thinking about the design of systems at several levels: domain representation, upper ontology linking critical thinking tasks to reasons (meta-level), interactive level, and reasoning level.

5. Conclusion and Future Work

This chapter was concerned mainly with the representation of viewpoints from learning resources which are

represented as ontologies. We focused on the representation of domain knowledge via DLs and considered how reasons and arguments can be derived from these logics. The logic may be equally applicable to theories, or other languages provided that for each particular language we establish the set of rules which translate formulas to reasons or to domain rules where the latter is meant to represent statements of the form 'if...then...'. Although the content of each individual resource was assumed to be consistent, different resources may be inconsistent with each other. The software agent should be able to combine information from compatible resources in order to construct viewpoints. It should also be able to extract viewpoints from individual resources. Although in this chapter, reasons were derived from axioms of ontologies, this does not have to be the case. The reason schemata should be equally applicable to any relation expressing the fact that one (set of) premise(s) is a sufficient reason to deduce another. In the application issue section we outlined areas in the learning domain that could benefit from the use of viewpoints. It has been argued that apart from the merits of an explicit representation of viewpoints, viewpoints can also be extracted from other cognitive activities. It has also been stated that in order to make a better use of the notion of viewpoint, the relevant concepts of judgement, opinion, thesis, etc, which relate to the identification of implicitly stated viewpoints, need to be clarified and the domain ontology need to take into consideration these concepts. The same applies in case where differences in viewpoints exist about the definition of concepts: if the representation of concepts refers to its necessary and sufficient conditions then differences in viewpoints can be traced. Future research will help clarify further these issues. This chapter gave an initial account of certain concepts that relate to the derivation of viewpoints. For example, the notions of judgement, theory, idea, thesis, etc were not thoroughly discussed[1]. Viewpoints were also defined at an abstract level. Future work will focus on establishing a firm theory related to the notions that can be used to produce viewpoints as well as the viewpoints themselves.

[1] Research on this issue is not part of my PhD research at the University Of Leeds.

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