A Heuristic Approach to Explain the Inconsistency in OWL Ontologies

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1 Introduction

Most modern OWL-DL reasoners can only provide lists of unsatisfiable classes without offering any explanation as to why those classes are inconsistent. The process of determining the cause of inconsistent classes, what we refer to as debugging the ontology, is a task that is left for the user. Even expert ontology engineers can find it difficult to work out why a class has been marked as inconsistent. When faced with several inconsistent classes in a moderately large ontology, the task of debugging can become onerous indeed.

In this paper we present a heuristic approach for debugging OWL ontologies, which can be utilised by tools and therefore go some way to automating the debugging process, thereby alleviating the user from this troublesome task. We are are focusing about debugging OWL, however the approach can be applied to general description logics. Since the debugger is based on heuristic, it is not a complete solution. However it do provide the explanation to a majority of inconsistent cases.

The heuristic we used is from the experience of a series of tutorials, workshops and post-graduate modules we have presented over the past five years, teaching people to use OWL-DL and its predecessors effectively. Based on our experience, a set of common made mistakes have been identified. These common have been used as the basic for developing a set of ontology debugging heuristics. These heuristics have been used in an implementation of an ontology debugger for the Protégé-OWL [1] ontology development environment, which with the assistance of a DL-reasoner, can generate descriptions that explain the reasons for inconsistent OWL classes.

The debugger that has been developed treats the DL-reasoner as a ‘black box’. In other words, the debugger does not know the details of any reasoning algorithms that are used by the DL-reasoner. This ‘black box’ approach obviously has many benefits – in particular it is reasoner independent, meaning that the debugger does not need any modification, tuning or parameter setting in order to work with a specific reasoner. This means that the end user is able to select any DIG compliant reasoner that is appropriate for their needs, without worrying about loosing any of the functionality offered by the debugger, or being tied to a specific reasoner implementation. For example, the debugger can still be used in conjunction with a reasoner that offers non-standard reasoning services, or a reasoner that has been optimised to work with a specific style of ontology[1].

2 Debugging process

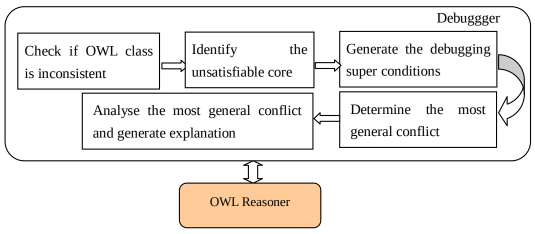

Debuggger
Check if OWL class is inconsistent
Identify the unsatisfiable core
Generate the debugging super conditions
Determine the most general conflict
Analyse the most general conflict and generate explanation
OWL Reasoner

Fig. 1. The debugging process

Figure 1 illustrates the main steps of the debugging process. The user selects an OWL class for debugging, which is checked to ensure it is indeed inconsistent, and that the user is making a valid request to the debugger. The debugger then attempts to identify the *unsatisfiable core* for the input class in order to minimise the search space. The *unsatisfiable core* is the smallest set of local conditions (direct super classes) that leads to the class in question being inconsistent. Having determined the unsatisfiable core, the debugger attempts to generate the *debugging super conditions*, which are the conditions that are implied the conditions in the *unsatisfiable core*. Figure 3 presents the rules that are used in generating the *debugging super conditions*. The debugger then examines the *debugging super conditions* in order to identify the *most general conflicting* class set, which is analysed to produce an explanation as to why the class in question is inconsistent.

There are many different ways in which the axioms in an ontology can to lead an inconsistency. However, in general, we have found that most inconsistencies can be boiled down into a small number of 'error patterns'. In summary the 'error patterns' for class inconsistency may be boiled down to following reasons:

The inconsistence is from some local definition.

1. Having both a class and its complement class as super conditions.
2. Having both universal and existential restrictions that act along the same property, whilst the filler classes are disjoint.
3. Having a super condition that is asserted to be disjoint with owl:Thing.
4. Having a super condition that is an existential restriction that has a filler which is disjoint with the range of the restricted property.

[1] For example, a large ontology which is conceptually simple, or a small ontology which is very complex.

5. Having super conditions of *n* existential restrictions that act along a given property with disjoint fillers, whilst there is a super condition that imposes a maximum cardinality restriction or equality cardinality restriction along the property whose cardinality is less than *n*.
6. Having super conditions containing conflicting cardinality restrictions.

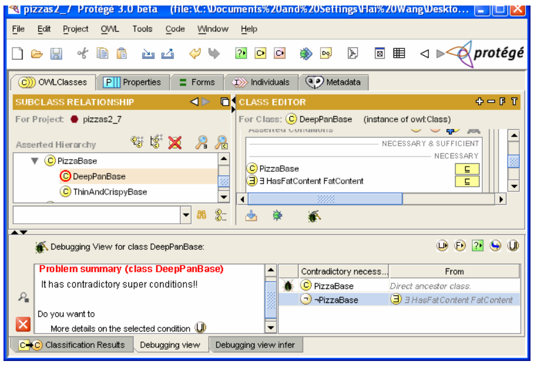
The inconsistence is propagated from other source.

1. Having a super condition that is an existential restriction that has an inconsistent filler.
2. Having a super condition that is a hasValue restriction that has an individual that is asserted to be a member of an inconsistent class.

The debugger determines which of the above cases led to an inconsistency, and then uses provenance information that describes how the debugging super conditions were generated in order to determine the 'root' cause of the inconsistency.

Inconsistencies have 'mechanisms' of propagating throughout an ontology. For example, any concept that is inconsistent and is used in an existential restriction, causes that existential restriction to be inconsistent. This in turn causes the named class that the existential is a super class of to become inconsistent, which causes all subclasses of that named class to become inconsistent. These propagation mechanism can cause a single inconsistency in a densely interconnected ontology to make large swathes of the ontology inconsistent. The process of tracking down the root cause of such inconsistencies then becomes incredibly time consuming and frustrating. The debugger therefore has the functionality to trace an ontology subsumption hierarchy and existential graph in order to discover the root causes of unsatisfiable classes.

Figure 2 shows the debugging tool.



For Project: pizzas2_7

For Class: DeepPanBase (instance of owl:Class)

PizzaBase
- DeepPanBase
- ThinAndCrispyBase

PizzaBase ⊑
∃ HasFatContent FatContent ⊑

Debugging View for class DeepPanBase:

Problem summary (class DeepPanBase)
It has contradictory super conditions!!

Do you want to
More details on the selected condition

Contradictory necess...	From
PizzaBase	Direct ancestor class.
¬PizzaBase	∃ HasFatContent FatContent

Fig. 2. Debugging DeepPanBase class

References

1. Alan Rector Holger Knublauch, Mark Musen. Editing description logic ontologies with the protege-owl plugin. In *International Workshop on Description Logics - DL2004*, 2004.

Rule 1: Named class rule

(a) **IF** $C_1 \in DSC(C) \wedge C_1 \sqsubseteq C_2$, where C_1 is a named OWL class
THEN $C_2 \in DSC(C)$

(b) **IF** $C_1 \in DSC(C)$ and $Disj(C_1, C_2)$, where C_1 and C_2 are named OWL classes
THEN $\neg C_2 \in DSC(C)$

Rule 2: Complement class rule

(a) **IF** $\neg C_1 \in DSC(C)$, where C_1 is a named OWL class
THEN IF $C_2 \sqsubseteq C_1$, **THEN** $\neg C_2 \in DSC(C)$
IF $C_1 \equiv C_2$, **THEN** $\neg C_2 \in DSC(C)$

(b) **IF** $\neg C_1 \in DSC(C)$, where C_1 is an anonymous OWL class
THEN $NORM(C_1) \in DSC(C)$

Rule 3: Domain/Range rule

(a) **IF** $\exists S.C_1 \in DSC(C) \ \vee \ \geq \ n\, S \in DSC(C) \ \vee \ = \ n\, S \in DSC(C)$, where $n > 0$, and $DOM(S) = C_2$
THEN $C_2 \in DSC(C)$

(b) **IF** $\exists S.C_1 \in DSC(C) \vee \geq \ n\, S \in DSC(C) \vee = \ n\, S \in DSC(C)$, and where $n > 0$, $INV(S) = S_1$ and $RAN(S_1) = C_2$
THEN $C_2 \in DSC(C)$

(c) **IF** $\exists S.C_1 \in DSC(C) \ \vee \ \geq \ n\, S \in DSC(C) \ \vee \ = \ n\, S \in DSC(C)$, where $n > 0$, and $RAN(S) = C_2$
THEN $\forall S.C_2 \in DSC(C)$

Rule 4: Functional/Inverse functional property

(a) **IF** $\exists S.C_1 \in DSC(C)$ or $\geq \ n\, S \in DSC(C)$ or $= \ n\, S \in DSC(C)$, where $n > 0$ and $S\ is\ functional$
THEN $\leq \ 1\, S \in DSC(C)$

(b) **IF** $\exists S.C_1 \in DSC(C)$ or $\geq \ n\, S \in DSC(C)$ or $= \ n\, S \in DSC(C)$, where $n > 0$ and $INV(S) = S_1$, $S_1\ is\ inverse\ functional$
THEN $\leq \ 1\, S \in DSC(C)$

Rule 5: Inverse Rule
IF $\exists S.C_1 \in DSC(C)$ and $INV(S) = S_1$,
and $C_2 \sqsupseteq C_1$ and $C_2 \sqsubseteq \forall S_1 C_3$
THEN $C_3 \in DSC(C)$

Rule 6: Symmetric Rule
IF $\exists S.C_1 \in DSC(C)$ and S is a symmetric property,
and $C_2 \sqsupseteq C_1$ and $C_2 \sqsubseteq \forall S C_3$
THEN $C_3 \in DSC(C)$

Rule 7: Transitive Rule
IF $\forall S.C_1 \in DSC(C)$ and S is a transitive property,
THEN $\forall S\, \forall S.C_1 \in DSC(C)$

Rule 8: Intersection Rule
IF $C \wedge C_1 \in DSC(C)$,
THEN $C \in DSC(C)$ and $C_1 \in DSC(C)$

Rule 9: Subproperty Rule

(a) **IF** $\forall S.C_1 \in DSC(C)$ and $S_1 \sqsubset S$, **THEN** $\forall S_1.C_1 \in DSC(C)$
(b) **IF** $\leq nS \in DSC(C)$ and $S_1 \sqsubset S$, **THEN** $\leq nS_1.C_1 \in DSC(C)$
(c) **IF** $\exists S.C_1 \in DSC(C)$ and $S_1 \sqsupset S$, **THEN** $\exists S_1.C_1 \in DSC(C)$
(d) **IF** $\geq nS \in DSC(C)$ and $S_1 \sqsupset S$, **THEN** $\geq nS \in DSC(C)$

Rule 10: Other inference Rule
IF C_1 can be inferred by any subset of $UC(C)$, where C is a named class
THEN $C_1 \in DSC(C)$

Fig. 3. Rules for the membership of Debugging Super Conditions (DSC).