Position Paper: Paraconsistent Reasoning for the Semantic Web

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Abstract

Due to the Semantic Web's decentralised and distributed management, contradictory information is and will remain frequent. However, classical reasoning systems fail to work properly in the presence of inconsistencies, because they implicitly or explicitly assume the *ex contradictione quod libet (ECQL)* principle stating that anything follows from contradictory premises. *Paraconsistent reasoning* challenges this ECQL principle.

Stressing practical cases of reasoning on the Web, this position paper first argues that paraconsistent reasoning is likely to become a key issue for successful deployment of the Semantic Web. Then, it briefly introduces the main approaches to date to paraconsistent reasoning.

1 Introduction

Classical and other logic, upon which modern computing is based, requires the complete absence of contradictions. With the classical *ex contradictione quod libet* (ECQL) rule (or *principle of explosion*), everything, and thus nothing useful at all, can be inferred from a contradiction. For instance, from a contradiction in a train information system can be derived that the moon is made of green cheese. Nonetheless, inconsistencies play an important role in practice (Section 2).

Paraconsistent logics are a rather novel direction in mathematical logics that challenge the ECQL principle in order to allow "reasonable" reasoning in the presence of inconsistencies without introducing more problems than are already present in the data. Several different approaches to paraconsistent logics exist and are briefly outlined in Section 3.

We conclude this article with a perspective for paraconsistent reasoning on the Semantic Web (Section 4).

2 Cases for Paraconsistent Reasoning

Distributed Information Systems

In distributed information systems, like the online information systems of European railways companies, contradictory information is frequent. For example, the German railway company might give different arrival times for trains to Paris than the French railway company, because construction works on the track in France have not been entered into the German system. Human beings can easily cope with such inconsistencies in various ways (e.g. identify which information is more likely or "don't care"). Reasoning systems on the (Semantic) Web must equally be able to derive useful conclusions from the "inconsistency-free" premises.

Coping with Change

Belief change is the field of artificial intelligence devoted to the rational change of belief in the light of new evidence. E.g., a train timetable might be updated with new train connections that have to be taken into account in further reasoning. Likewise, train connections might have been removed making previously drawn conclusions invalid.

In practice, changes like updates to an information system may cause inconsistencies that cannot be discarded. Standard methods for belief change are based on classical logic and hence accept the ECQL principle. As a consequence, they cannot be used for deriving useful conclusions in presence of updates causing contradictions.

Inconsistencies Welcome!

In some situations, inconsistencies are even desirable. This is, e.g., the case when contradictory viewpoints are present and need to be reconciled. For instance, two ontologies describing appartment rental offers and appartment sale offers might well inconsistently describe preferences and prices for city areas. This obviously should neither prevent considering both ontologies nor deriving *meaningful* conclusions in the same reasoning context (like helping in taking a decision for buying or renting an appartment). Obviously, human beings are capable of doing so without applying the ECQL principle, and so should automated reasoning systems on the Web.

Another example is policy reasoning. At the beginning of a negotiation towards selling/buying a Web service, the policies of the buyer and seller might be contradictory. Instead of applying the ECQL principle, a reasoning system should strive to overcome the inconsistencies, i.e. find a way to pass a contract acceptable for both the service buyer and seller without requiring them to change their policies.

"Dialetheias"

In practice, there are cases where contradictions are inherent to the problem, so-called "dialetheias". Since such cases arise in knowledge modelling, they will also arise on the Semantic Web. This is in particular the case with the well known

Liar's Paradox where a sentence states its own falsity ("this sentence is not true").

On the Semantic Web, dialetheias might easily arise though reification, especially of RDF statements, and through modalities – such as "A believes B" or "A does not believe what B states" – that are needed e.g. for policy reasoning. Liar sentences can also be indirect consequences of statements that are themselves unproblematic, e.g. when combining knowledge from different Web resources.

3 Approaches to Paraconsistent Reasoning

Most approaches to paraconsistent logic and reasoning allow a formula F and its negation $\neg F$ to hold in an interpreation (or "model"). Major approaches of paraconsistent logics and reasoning are stressed below:

Relevant Logics
Relevant logics have been first proposed by Anderson and Belnap. Semantics for such logics based on "different worlds" have been developed by Routley and Meyer. Conjunction and disjunction behave in the usual way, but each world w has an associated world w^* such that $\neg A$ is true in w iff A is false in w^* (not in w). As a consequence, if A is true in w and false in w^*, then $A \wedge \neg A$ is true in w. Note that requiring $w^* = w$ yields the standard classical logic.

Many-Valued Systems
A multi-valued logic is a logic with more than two truth values. The formulas that hold in a multi-valued interpretations are those which have a specific truth-value, the so-called designated formulas. A multi-valued logic is paraconsistent if it allows both a formula and its negation to be designated.

The simplest approach uses three truth values: true and false, like in classical logic, and a third truth-value denoting "both truth and false" such that if a formual F has this third truth-value in an interpreation, then so does also $\neg F$. Considering the real numbers between 0 and 1 instead of discrete values results in a paraconsistent fuzzy logic.

Non-Adjunctive Systems
A non-adjunctive logic is a logic in which one cannot conclude A from $A \wedge B$. The first non-adjunctive logic, and also the first paraconsistent logic, ever proposed is the discussive (or discursive) logic of Jaskowski. In dicussive logic, several contributors state "opinions". Each opinion is consistent in itself but might be inconsistent with another opinion. A modal logic (S5) is used to define interpretations: a world corresponds to a contributor, and in it, all the contributor's sentences are true. Thus, $A \wedge \neg A$ can hold in an interpretation consisting of several worlds, but not in a single world.

Non-Truth-Functional Logics
Non-truth functional logics have been introduced by da Costa. Their idea is to make negation "non-truth-functional" while keeping the other connectives like in standard, e.g. classical, logics. Seeing an interpretation as a function mapping formulas to 0 (false) or 1 (true), a non-truth funtional logic gives rise to defining the truth-value of $\neg A$ independently of that of A (while keeping the usual functional dependencies of the truth-value of $A \wedge B$, $A \vee B$, $A \Rightarrow B$, etc. to the truth values of A and B).

4 Paraconsistency on the Semantic Web

We believe that dealing with inconsistencies will play a central role in the emergence of the Semantic Web. Paraconsistent reasoning provides foundations and techniques that will allow future applications to function properly in the presence of inconsistencies. In particular, we think that paraconsistent reasoning will influence the following areas:

Paraconsistency in Ontology Reasoning
Ontology reasoning (e.g. instance checking) on the Semantic Web is usually based on reasoning techniques, e.g. the tableaux calculus, developed for *description logics*. Therefore, a first step towards an "inconsistency-aware" Semantic Web will be to adapt existing reasoning algorithms using techniques from paraconsistent reasoning.

Paraconsistency in Query Languages
Querying data plays a very important role on the Semantic Web, as indicated by the multitude of existing Semantic Web query languages. Building upon ontology reasoning, Semantic Web query languages will likely need to be adapted so as to work in the presence of inconsistencies.

Paraconsistency and Trust
In a distributed environment like the Semantic Web, where anyone can author content, trust is a key issue. Conflicts with classical logic are apparent: for example, different sources might make conflicting assertions about the trustworthiness of a site, and users might be interested in more fine-grained levels of trust besides the binary "trusted" or "not trusted".

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