Description Logics:
an Introductory Course on a Nice Family of Logics

Day 4, Part 2: Justifications and Understanding Entailments

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Are Standard Reasoning Problems/Services Everything?

So far, we have talked a lot about **standard reasoning problems**

- consistency
- satisfiability
- entailments
- ...is this all that is relevant?

Next, we will look at 1 reasoning problem that

- cannot be polynomially reduced to any of the above standard reasoning problems
- is relevant when working with a non-trivial ontology
- ...justifications – close relatives to **kernels** in belief revision!

Building Ontologies for Real

Imagine you are building, possibly with your colleagues, an ontology $\mathcal{O}$:

non-trivial, with say 500 axioms, or 5,000 (NCI has $\geq$ 300,000)

(S1) $\mathcal{O} \models C \sqsubseteq \bot$ and you want to know why

(S2) 27 classes C_i are unsatisfiable w.r.t. $\mathcal{O}$

- imagine $\mathcal{O}$ is coherent, but $\mathcal{O} \cup \{\alpha\}$ contains 27 unsatisfiable classes
- ...even for a very sensible, small, harmless axiom α

(S3) $\mathcal{O}$ is inconsistent

- imagine $\mathcal{O}$ is consistent, but $\mathcal{O} \cup \{\alpha\}$ is inconsistent
- ...even for a very sensible, small, harmless axiom α

? what do you do?

? how do you go about **repairing** $\mathcal{O}$?

? which tool support would help you to **repair** $\mathcal{O}$?

Building Ontologies for Real II

Imagine you are building, possibly with your colleagues, an ontology $\mathcal{O}$:

non-trivial, with say 500 axioms, or 5,000 (NCI has $\geq$ 300,000)

(S4) $\mathcal{O} \models \alpha$, and you want to know **why**

- e.g., so that you can trust $\mathcal{O}$ and α
- e.g., so that you understand how $\mathcal{O}$ models its domain

? what do you do?

? how do you go about **understanding** this entailment?

? which tool support would help you to **understand** this entailment?

? would this tool support be the same/similar to the one to support repair?

Justifications

In all scenarios (Si), we clearly want to know at least the **reasons** for $\mathcal{O} \models \alpha$,

which axioms can I/should I

(S1) **change** so that C' becomes satisfiable w.r.t. $\mathcal{O}'$?

(S2) **change** so that $\mathcal{O}'$ becomes coherent?

(S3) **change** so that $\mathcal{O}'$ becomes consistent?

(S4) **look** at to understand $\mathcal{O} \models \alpha$?

Definition: Let $\mathcal{O}$ be an ontology with $\mathcal{O} \models \alpha$.
Then $\mathcal{J} \subseteq \mathcal{O}$ is a **justification for α in $\mathcal{O}$** if

- $\mathcal{J} \models \alpha$ and
- $\mathcal{J}$ is minimal, i.e., for each $\mathcal{J}' \subsetneq \mathcal{J}$: $\mathcal{J}' \not\models \alpha$

An Example

Consider the following ontology $\mathcal{O}$ with $\mathcal{O} \models C \sqsubseteq \bot$:

$$\begin{aligned}
\mathcal{O} := \{ & C \sqsubseteq D \sqcap E && (1)\\
& D \sqsubseteq A \sqcap \exists r.B_1 && (2)\\
& E \sqsubseteq A \sqcap \forall r.B_2 && (3)\\
& B_1 \sqsubseteq \neg B_2 && (4)\\
& D \sqsubseteq \neg E && (5)\\
& G \sqsubseteq B \sqcap \exists s.C\} && (6)
\end{aligned}$$

Find a justification for $C \sqsubseteq \bot$ in $\mathcal{O}$.
How many justifications are there?

More about Justifications

Facts:

1. for each entailment of $\mathcal{O}$, there exists at least one justification
2. one entailment can have several justifications in $\mathcal{O}$
3. justifications can overlap
4. let $\mathcal{O}'$ be obtained as follows from $\mathcal{O}$ with $\mathcal{O} \models \alpha$:
   - for each justification $\mathcal{J}_i$ of the n justifications for α in $\mathcal{O}$, pick some $\beta_i \in \mathcal{J}_i$
   - set $\mathcal{O}' := \mathcal{O} \setminus \{\beta_1, \ldots, \beta_n\}$

   then $\mathcal{O}' \not\models \alpha$, i.e., $\mathcal{O}'$ is a **repair** of $\mathcal{O}$.
5. if $\mathcal{J}$ is a justification for α and $\mathcal{O}' \supseteq \mathcal{J}$, then $\mathcal{O}' \models \alpha$.
   Hence any repair of α must touch **all** justifications.
6. if $\mathcal{O} \models \alpha$, $\mathcal{O} \models \beta$, and
   $\forall$ justification $\mathcal{J}$ for α $\exists$ a justification $\mathcal{J}'$ for β with $\mathcal{J}' \subseteq \mathcal{J}$,
   then repairing β repairs α.

A Naive Black-Box Algorithm to Compute Justifications

Let $\mathcal{O} = \{\beta_1, \ldots, \beta_m\}$ be an ontology with $\mathcal{O} \models \alpha$.

Get1Just($\mathcal{O}$, α)
Set $\mathcal{J} := \mathcal{O}$ and **Out** $:= \emptyset$
For each $\beta \in \mathcal{O}$
    If $\mathcal{J} \setminus \{\beta\} \models \alpha$ then
        Set $\mathcal{J} := \mathcal{J} \setminus \{\beta\}$ and **Out** $:=$ **Out** $\cup \{\beta\}$
Return $\mathcal{J}$

Claim:

- loop invariants: $\mathcal{J} \models \alpha$ and $\mathcal{O} = \mathcal{J} \cup$ **Out**
- Get1Just(,) returns 1 justification for α in $\mathcal{O}$
- it requires m entailment tests

Other approaches to computing justifications exists, more performant, glass-box (inside reasoner) and black-box (outside).

Linking Justifications to our Scenarios

(S4) 1 justification suffices, but which? A good, easy one...how to find?

(S1-S3) require the computation of **all** justifications, possibly for several entailments

- even for one entailment, search space is exponential

[(S2)] requires even more:

- who wants to look at $x \times 27$ justifications? Where to start?

$\Rightarrow$ A justification $\mathcal{J}$ (for α) is **root** if there is no justification $\mathcal{J}'$ with $\mathcal{J}' \subsetneq \mathcal{J}$

- **start** with root justifications, remove/change axioms in them and
- **reclassify**: you might have repaired several unsatisfiabilities at once!

- Check example on slide 6: both justifications for $C \sqsubseteq \bot$ are root, contained in 2 non-root justifications for $G \sqsubseteq \bot$
- repairing $C \sqsubseteq \bot$ repairs $G \sqsubseteq \bot$

More About Justifications

BOs: **NCBO BioPortal**, a repository of over hundreds of OWL ontologies, gives a nice test case.

- recent, optimised implementation of GetAllJust($\mathcal{O}$, α)
  - behave well in practise
  - can compute one justification for all atomic entailments of **BO**s
  - can compute (almost) all justifications for (almost) all atomic entailments of **BO**s

- recent surveys show that **BO**s have entailments
  - with **large** justifications, e.g., with 37 axioms and
  - with **numerous** justifications, e.g., one entailment had 837 justifications
  - for which justifications can often be understood well by **domain experts**
  - ...for more, see M. Horridge's dissertation

Beyond Justifications

- some justification contain **superfluous parts**
  - that distract the user
  - see example on slide 6
  - identifying these can help user to focus on the **relevant** parts
  - this has led to investigation of **laconic and precise justifications**

- there are still some **hard** justifications that need further explanation
  - e.g., consider $O = \{$
$$\begin{aligned} P &\sqsubseteq \neg M \\ RR &\sqsubseteq CM \\ CM &\sqsubseteq M \\ RR &\equiv \exists h.TS \sqcup \forall v.H \\ \exists v.\top &\sqsubseteq M\} \end{aligned}$$
with $\mathcal{O} \models P \sqsubseteq \bot$
  - this has led to investigation of **lemmatised justifications** (see next slide) with work in **cognitive complexity** of justifications

Some further pointers for reading

- http://dl.kr.org/ for DL proceedings and the DL mailing list
- KR proceedings
- The Description Logic Handbook, Cambridge University Press
- http://www.w3.org/2007/OWL/ for stuff on OWL
  - http://www.w3.org/community/owled/ new community group
- http://owl.cs.manchester.ac.uk/ for stuff on OWL from Manchester
  - http://owl.cs.manchester.ac.uk/about/orientation/a-logics-perspective/
  - http://owl.cs.manchester.ac.uk/tools/

Tomorrow

For tomorrow, we see

- modularity and conservative extensions
- learning TBox axioms from data

Also, if you have

- built some ontology/TBox/ABox and want to discuss it/ask about it, please bring it tomorrow
- any other questions, ask me now or later or tomorrow!