Debugging of $\mathcal{ALC}$-Ontologies via Minimal Model Generation

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Ontology Debugging

Ontologies are the basis for semantic web and knowledge-based systems

Widely used in practice: BBC, NHS, Klappo, ...

Ontology debugging aims to guarantee that an ontology
- is coherent
- models properly (implicit) domain knowledge
- keeps these properties over time

Debugging via Model Generation

Given an ontology $\mathcal{O}$ and a set S_α of properties, check if $\mathcal{O} \models \alpha$ ($\mathcal{O} \cup \{\neg\alpha\} \models \bot$) for all $\alpha \in S_\alpha$.
- if $\mathcal{O} \not\models \alpha$
  - extraction of a model explaining why $\mathcal{O} \not\models \alpha$
  - understanding the model allows to fix the ontology
- if $\mathcal{O} \models \alpha$ then $\mathcal{O}$ is well specified w.r.t. α

Applicable at any stage of the life cycle of an ontology.

Subset-Simulation Minimality

Relation between individuals of two models $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ and $\mathcal{I}' = (\Delta'^{\mathcal{I}'}, \cdot^{\mathcal{I}'})$ s.t. for any two individuals a and a', if $a\ S\ a'$ then the following hold.
- $V(a) \subseteq V'(a')$ (where $V(a) = \{A \in N_C \mid a^{\mathcal{I}} \in A^{\mathcal{I}}\}$), and
- if $r(a,b)$, then there exists a $b^{\mathcal{I}'} \in \Delta^{\mathcal{I}'}$ such that $r(a',b')$ and $b\ S\ b'$.

A model $\mathcal{I}$ of an ontology $\mathcal{O}$ is minimal modulo subset-simulation iff for any model $\mathcal{I}'$ of $\mathcal{O}$, if $\mathcal{I}' \leq \mathcal{I}$, then $\mathcal{I} \leq \mathcal{I}'$.

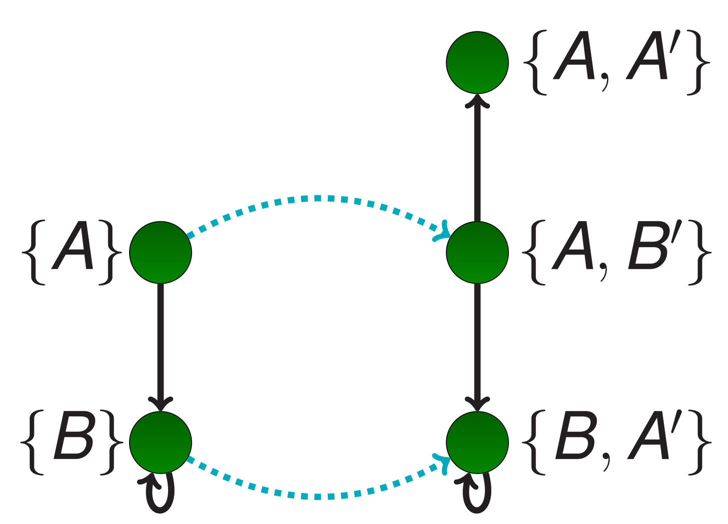

Tableau Calculus

$$(\forall)\ \frac{r(a,b) \quad (\forall r.C)(a)}{C(b)} \qquad (\alpha)\ \frac{(C_1 \sqcap \ldots \sqcap C_n)(a) \vee \Phi^+_\alpha}{\begin{array}{c} C_1(a) \vee \Phi^+_\alpha \\ \vdots \\ C_1(a) \vee \Phi^+_\alpha \end{array}}$$

$$(TBox)\ \frac{\neg C \sqcup D}{(\neg C \sqcup D)(a)} \ \text{a is on the branch} \qquad (\vee)\ \frac{(C_1 \sqcup \ldots \sqcup C_n)(a) \vee \Phi}{C_1(a) \vee \ldots \vee C_n(a) \vee \Phi}$$

$$(\beta)\ \frac{\mathcal{C}(a) \vee \Phi^+}{\begin{array}{c|c} \mathcal{C}(a) & \Phi^+ \\ neg(\Phi^+) & \end{array}} \qquad (\exists)\ \frac{(\exists r.C)(a)}{\begin{array}{c} r(a,b) \\ C(b) \end{array}} \ \text{where b is fresh}$$

$$(SBR)\ \frac{A_1(a_1) \ \ldots \ A_n(a_n)\ r_1(b_1,c_1) \ \ldots \ r_m(b_m,c_m) \quad (\neg A_1)(a_1) \vee \ldots \vee \neg r_m(b_m,c_m) \vee \Phi^+_\alpha}{\Phi^+_\alpha}$$

Table : Rules of the tableau calculus

- $\mathcal{C}$ is of the form $\exists r.C$, $\forall r.C$, or A
- $neg(\Phi^+) = \{(\neg A)(a) \mid A(a)$ is a disjunct of $\Phi^+\}$
- Φ^+_α a disjunction of $\mathcal{C}$ or conjunctions
- Φ^+ a disjunction of $\mathcal{C}$

Features of the calculus:
- lazy clausification ((α) rule) to reduce the number of inferences
- complement splitting ((β) rule) to close "non-minimal" branches as soon as possible
- selection-based resolution to reduce the number of inferences and to close branches
- handling of Boolean ABoxes

The calculus is **refutationally sound and complete**.

The calculus is **minimal model complete**.

Subset-simulation test
- If the model extracted from a branch $\mathcal{B}$ subset-simulates a model extracted from a branch $\mathcal{B}'$, then close $\mathcal{B}$.

The test guarantees **minimal model soundness**.
Easily generalisable to cover more expressive logics.

$$\text{for } \mathcal{ALCH} \qquad (\mathcal{H})\ \frac{r(a,b) \qquad r \sqsubseteq s}{s(a,b)}$$

Termination via dynamic ancestor equality blocking.

References

F. Papacchini and R. A. Schmidt.
Computing minimal models modulo subset-simulation for propositional modal logics.
In P. Fontaine, C. Ringeissen, and R. A. Schmidt, editors, *Proc. FroCoS'13*, volume 8152 of *LNCS*, pages 279–294. Springer, 2013.

F. Papacchini and R. A. Schmidt.
Terminating minimal model generation procedures for propositional modal logics.
In S. Demri, D. Kapur, and C. Weidenbach, editors, *Proc. IJCAR'14*, volume 8562 of *LNAI*, pages 381–395. Springer, 2014.