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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 $\mathcal{I} \leq \mathcal{I}'$.

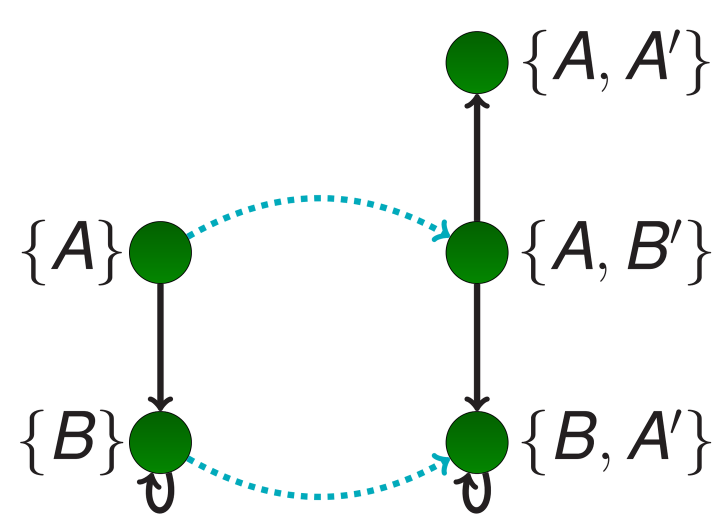

Tableau Calculus

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

$$(TBox)\ \frac{\neg C \sqcup D}{(\neg C \sqcup D)(a)} \qquad (\vee)\ \frac{(C_1 \sqcup \ldots \sqcup C_n)(a) \vee \Phi}{C_1(a) \vee \ldots \vee C_n(a) \vee \Phi}$$

a is on the branch

$$(\beta)\ \frac{\mathcal{C}(a) \vee \Phi^+}{\mathcal{C}(a) \quad \Phi^+ \atop neg(\Phi^+)} \qquad (\exists)\ \frac{(\exists r.C)(a)}{\begin{array}{c} r(a,b) \\ C(b) \end{array}}$$

where b is fresh

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

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.

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