A Transformation Approach for Classifying ALCHI(D) Ontologies with a Consequence-based ALCH Reasoner

Weihong Song, Bruce Spencer, Weichang Du
{song.weihong, bspencer, wdu}@unb.ca

Faculty of Computer Science
University of New Brunswick
Canada

Overview

- Background: CB-based techniques provide efficient classification for limited DL languages such as ALCH but not ALCHI(D)
- Goal: create an ALCHI(D) reasoner using a CB-based ALCH reasoner (ConDOR) as a black box
- Approach: transform inverse role axioms and (a subset of) OWL2 datatypes and facets into ALCH axioms and classify transformed ontology with ConDOR
- We can guarantee soundness and completeness of classification results for I and a subset of D

Overall Procedure

- Three Stages:

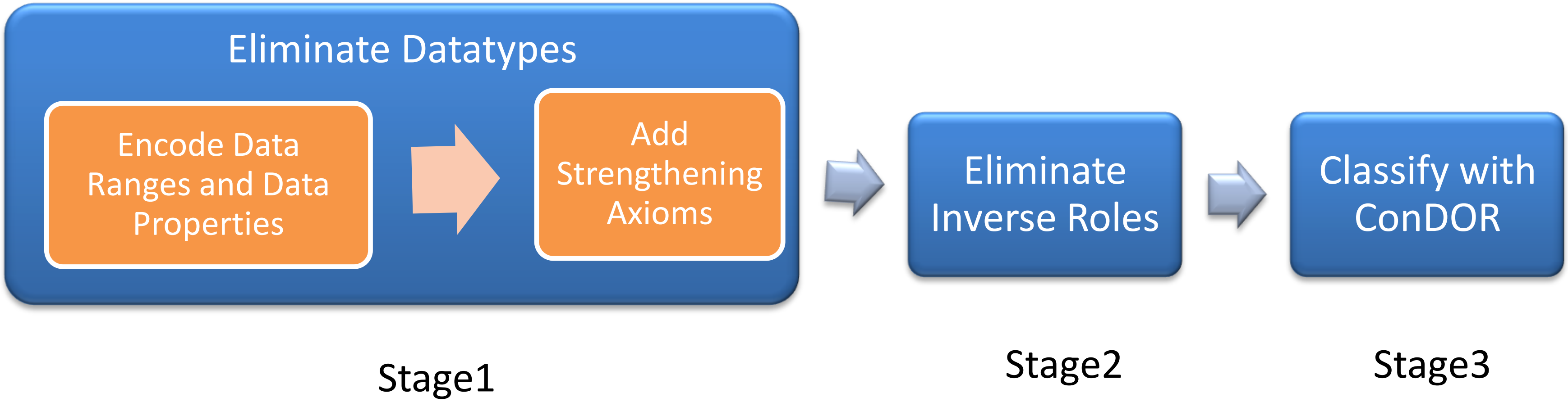
  Stage 1: Transform ALCHI(D) ontology O into an ALCHI ontology

  $\mathcal{O}_{\mathcal{D}}^{-}$ s.t. $\mathcal{O} \models A \sqsubseteq B$ iff $\mathcal{O}_{\mathcal{D}}^{-} \models A \sqsubseteq B$

  Stage2: Transform the ALCHI ontology $\mathcal{O}_{\mathcal{D}}^{-}$ into an ALCH ontology

  $\mathcal{O}_{\mathcal{ID}}^{-}$ s.t. $\mathcal{O}_{\mathcal{D}}^{-} \models A \sqsubseteq B$ iff $\mathcal{O}_{\mathcal{ID}}^{-} \models A \sqsubseteq B$

  Stage3: Classify the ALCH ontology $\mathcal{O}_{\mathcal{ID}}^{-}$ with ConDOR



The supported datatype features are:

- datatypes owl:real
  - facets
    - owl:rational, xsd:decimal, xsd:integer
  - comparison facets
    - xsd:minInclusive, xsd:maxInclusive, xsd:minExclusive, xsd:maxExclusive
- datatype xsd:string
- datatype xsd:boolean

Stage 1: Eliminate Datatypes

- Step1: encode features and data ranges
  - Encode features into roles and data ranges into concepts
    - Three types of atomic data ranges:
      - **d,** e.g., real
      - **d[f]**, e.g., real[rational], real[>2]
      - **{v}**, e.g., {1}

Encoding φ for atomic concepts/roles/features/data ranges

$$\varphi(\top_{\mathcal{D}}) = \top \qquad \varphi(d[f]) = A_d \sqcap A_f \qquad \varphi(\top) = \top \qquad \varphi(A) = A$$

$$\varphi(d) = A_d \qquad \varphi(\{v\}) = A_v \qquad \varphi(R) = R \qquad \varphi(F) = R_F$$

Stage 1: Eliminate Datatypes

- Step 2: Add strengthening axioms to preserve the subsumptions between atomic concepts in O.
  - The strengthening axioms show the implicit relationships among data ranges before encoding
  - The purpose of strengthening axioms is to ensure **data-range-relationship-preserving property**

For any $ar_1, \ldots, ar_n, ar'_1, \ldots, ar'_m \in ADR_d(\mathcal{O})$, if $\left((\prod_{i=1}^{n} ar_i) \sqcap (\prod_{j=1}^{m} \neg ar'_j)\right)^{\mathcal{D}} = \emptyset$, then $(\prod_{i=1}^{n} \varphi(ar_i)) \sqcap (\prod_{j=1}^{m} \neg\varphi(ar'_j))$ is unsatisfiable

  - The property is sufficient for preserving completeness

Stage 1: Example

Integer 1, 2

Ontology Before Encoding:

(1) $B_1 \sqsubseteq B_{sup}$ (2) $B_1 \equiv C \sqcap \exists F.\{1\}$ (3) $B \equiv C \sqcap \exists F.(real[int] \sqcap real[>0] \sqcap real[\leq 2])$

(4) $B_2 \sqsubseteq B_{sup}$ (5) $B_2 \equiv C \sqcap \exists F.\{2\}$

Normalize data range using only the form $> a$: $real[\leq 2] = real \sqcap \neg real[>2]$;

So axiom (3) changes to : $B \equiv C \sqcap \exists F.(real[int] \sqcap real[>0] \sqcap \neg real[>2])$

Ontology After Encoding:

(1) $B_1 \sqsubseteq B_{sup}$ (2') $B_1 \equiv C \sqcap \exists R_F.A_1$ (3') $B \equiv C \sqcap \exists R_F.(A_{real} \sqcap A_{int} \sqcap A_{>0} \sqcap \neg A_{>2})$

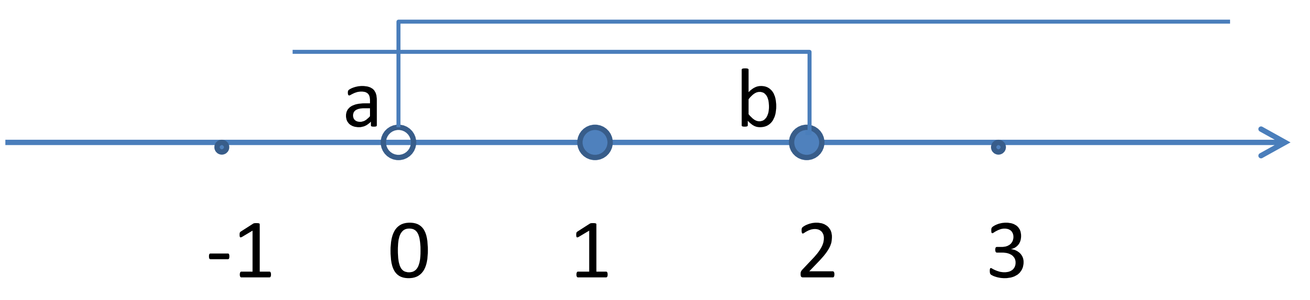
(4) $B_2 \sqsubseteq B_{sup}$ (5') $B_2 \equiv C \sqcap \exists R_F.A_2$

Types of Strengthening Axioms

- Relationships among real[int], real[dec] and real[rat]
  - e.g. $A_{int} \sqsubseteq A_{dec}$
- Relationships among DRs of the form real[>a]
  - e.g. $A_{>2} \sqsubseteq A_{>0}$
- Relationships between {v} and real[int]/real[dec]/real[rat]
  - e.g. $A_1 \sqsubseteq A_{int}$
- Relationships between {v} and real[>a]
  - e.g. $A_1 \sqsubseteq A_{>0}$ $A_1 \sqcap A_{>2} \sqsubseteq \bot$

Types of Strengthening Axioms

- Relationships among DRs of the form {v}
  - e.g. $A_1 \sqcap A_2 \sqsubseteq \bot$
- Other relationships
  - e.g. $A_{real} \sqcap A_{int} \sqcap A_{>0} \sqcap \neg A_{>2} \sqcap (\neg A_1 \sqcap \neg A_2) \sqsubseteq \bot$



Strengthening Axioms for the Example

Normalized Ontology:

(1) $B_1 \sqsubseteq B_{sup}$ (2) $B_1 \equiv C \sqcap \exists F.\{1\}$ (3*) $B \equiv C \sqcap \exists F.(real[int] \sqcap real[>0] \sqcap \neg real[>2])$
(4) $B_2 \sqsubseteq B_{sup}$ (5) $B_2 \equiv C \sqcap \exists F.\{2\}$

Encoding: $\{1\} \rightarrow A_1$, $\{2\} \rightarrow A_2$, $real[>0] \rightarrow A_{real} \sqcap A_{>0}$,
$real[>2] \rightarrow A_{real} \sqcap A_{>2}$, $real[int] \rightarrow A_{real} \sqcap A_{int}$

Strengthening axioms added based on our strengthening algorithm for real numbers:

(6) $A_1 \sqsubseteq A_{int}$ (7) $A_2 \sqsubseteq A_{int}$
(8) $A_{>2} \sqsubseteq A_{>0}$
(9) $A_{real} \sqcap A_{int} \sqcap A_{>0} \sqcap \neg A_{>2} \sqcap (\neg A_1 \sqcap \neg A_2) \sqsubseteq \bot$
(10) $A_1 \sqsubseteq A_{>0}$ (11) $A_1 \sqcap A_{>2} \sqsubseteq \bot$
(12) $A_2 \sqsubseteq A_{>0}$ (13) $A_2 \sqcap A_{>2} \sqsubseteq \bot$
(14) $A_1 \sqcap A_2 \sqsubseteq \bot$

Stage 2: Transform Inverse Role

- Polynomial elimination of inverses
  - Calvanese et al[1],
  - Tuned for tableau reasoning, Ding [2]

- We eliminate inverse role using normalized form

  $\bigsqcap A_i \sqsubseteq \bigsqcup B_j$, $A \sqsubseteq \exists r.B$, $\exists r.A \sqsubseteq B$, $A \sqsubseteq \forall r.B$, $r \sqsubseteq s$ and $r^- = r'$

  tuned for consequence-based reasoning.

[1] Diego Calvanese, Giuseppe De Giacomo, Riccardo Rosati: A Note on Encoding Inverse Roles and Functional Restrictions in ALC Knowledge Bases. Description Logics 1998
[2] Yu Ding's PhD Thesis, http://users.encs.concordia.ca/~haarslev/students/Yu_Ding.pdf
[3] Yu Ding, Volker Haarslev, Jiewen Wu: A New Mapping from ALCI to ALC. Description Logics 2007

Stage 2: Transform Inverse Role

- Complement role hierarchy
  - Add $r^* = r'$ if $r^- = r'$, $r^- = r^*$
  - Add $r' \sqsubseteq s'$ if $r^- = r'$, $s^- = s'$ and $r \sqsubseteq s$
- Add axioms based on the equivalence
  $A \sqsubseteq \forall r.B \Leftrightarrow \exists r^-.A \sqsubseteq B$

Proof of Soundness

- For datatypes, encoding ensure a countermodel of $\mathcal{O} \models A \sqsubseteq B$ can be converted to a countermodel of $\mathcal{O}_{\mathcal{D}}^{-} \models A \sqsubseteq B$

- For inverse roles, soundness is obvious since all strengthening axioms are implied by the original ontology

Theoretical Proof of Completeness

- For both datatypes and inverse roles, strengthening axioms enables conversion of countermodels
  - A countermodel for $\mathcal{O}_{\mathcal{ID}}^{-} \models A \sqsubseteq B$ to a countermodel of $\mathcal{O}_{\mathcal{D}}^{-} \models A \sqsubseteq B$ to a countermodel of $\mathcal{O} \models A \sqsubseteq B$

- Proving data-range preserving property: case-by-case analysis of combinations of atomic data ranges

Evaluation

Comparison of classification performance of $\mathcal{ALCHI}(\mathcal{D})$ ontologies

	# Logical Axioms	# Axioms Added for Datatypes	# Axioms Added for Inverse Roles	**HermiT**	**Pellet**	**FaCT++**	**WSClassifier**
Wine	181	2	7	1.160	0.430	0.005	0.400
ACGT	5065	3	366	9.603	2.955	*	1.945
OBI	9899	2	257	3.166	45.261	*	8.835
Galen-Heart	10493	0	569	123.628	–	–	2.779
Full-Galen	36986	68	7547	–	–	–	16.774
FMA-C	116532	9	1027	–	–	–	32.74

Note: "–": out of time or memory "*": some datatypes are not supported

Highly cyclic ontologies

Conclusion and Discussion

- WSClassifier
  - Transforms common OWL2 datatypes, facets and inverse role axioms from ALCHID into ALCH
  - Classifies using an ALCH reasoner
- Results
  - Preserves soundness and completeness for ALCHI(D)
  - Outperforms tableau-based reasoners on large and highly cyclic ontologies.
- Future work
  - Extensions to other datatypes and facets
  - Further optimization

Thank you !