UNIVERSITY OF CAMBRIDGE

Formality and Accessibility in Ontology Representation and Reasoning: A Diagrammatic Approach

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Motivation

Problem

- Ontologies: common knowledge representation paradigm
- Inaccessibility issues: unfamiliarity of domain experts with symbolic notations
- Addressing inaccessibility: visualisation facilities
- Focus of visualisation: expressing and editing ontologies vs. reasoning with and about ontologies

Proposed Solution

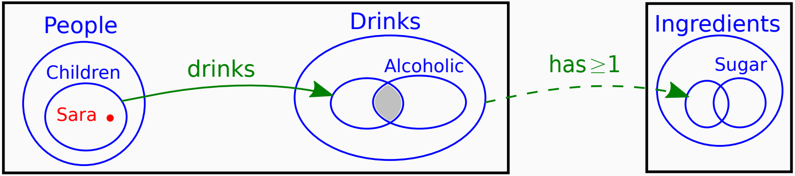
- Diagrammatic language: Concept Diagrams
- Diagrammatic inference rules
- Reasoner: iCon
- Empirical studies: formality and accessibility

Language

Concept Diagrams

- Diagrammatic
- Fully formalised
- Highly expressive
  - Empirical: coverage of all of OWL 2 except assertions involving ObjectHasSelf, DatatypeRestriction or constraining facets
  - Theoretical: (Conjecture) Existential Monadic Second-Order

Syntax



Sara is a child.

Children only drink drinks and only those drinks that are not alcoholic.

All drinks have at least one ingredient.

Accessibility: Language

- Cognitive theories support effectiveness of CDs over common node-link ontology representation approaches [1]
- CDs compared to textual representation [2]
- CDs compared to symbolic logics (DL and OWL) [3]

[1] A. Shimojima: Semantic Properties of Diagrams and Their Cognitive Potentials. CSLI Publications (2015)

[2] T. Hou, P. Chapman and A. Blake, Antipattern Comprehension: An Empirical Evaluation, in: Formal Ontology in Information Systems, Frontiers in Artificial Intelligence, Vol. 283, IOS Press, 2016, pp. 211224.

[3] E. Alharbi, J. Howse, G. Stapleton, A. Hamie and A. Touloumis, Visual Logics Help People: An Evaluation of Diagrammatic, Textual and Symbolic Notations, in: IEEE Symposium on Visual Languages and Human-Centric Computing, IEEE, 2017, pp. 255259.

Reasoning

Inference Rules

- OWL 2 RL
  - Trades the full expressivity of OWL 2 for efficiency
  - Restriction: existential quantification to a class; union and disjoint union to class expressions
  - These restrictions allow OWL 2 RL to be implemented using rule-based technologies

Inference Rules

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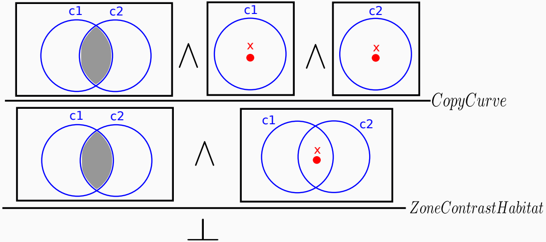
  - Restriction: existential quantification to a class; union and disjoint union to class expressions
  - These restrictions allow OWL 2 RL to be implemented using rule-based technologies
- 80 inference rules: (i) equality, (ii) properties, (iii) classes, (iv) class axioms, (v) datatypes, and (vi) schema vocabulary

Name	If	then
$cax - sco$	$T(?c_1, rdfs : subClassOf, ?c_2)$ $T(?x, rdf : type, ?c_1)$	$T(?x, rdf : type, ?c_2)$
$cax - dw$	$T(?c_1, owl : disjointWith, ?c_2)$ $T(?x, rdf : type, ?c_1)$ $T(?x, rdf : type, ?c_2)$	$false$

From Symbolic to Diagrammatic Inference Rules

- Inference rules related to the semantics of classes and class axioms (24 in total)
- The mapping: atomic diagrmmatic inference rules

$cax-dw$	$T(?c_1, owl:disjointWith, ?c_2)$ $T(?x, rdf:type, ?c_1)$ $T(?x, rdf:type, ?c_2)$	$false$



Accessibility: Reasoning and Inference Rules

- Reasoning in CDs (topo-spatial) compared to SOVA (topological) [4]
- Comparing alternative mappings of symbolic to diagrammatic inference rules [5]
- Guidance for Designing Multi-Premise Inference Rules

[4] Y. Sato, G. Stapleton, M. Jamnik and Z. Shams, Human inference beyond syllogisms: an approach using external graphical representations, Cognitive Processing 20(1) (2019), 103115.

[5] Z. Shams, M. Jamnik, G. Stapleton and Y. Sato, Accessible Reasoning with Diagrams: from Cognition to Automation, in: Diagrams, LNCS, Springer, 2018, pp. 247263.

Explanation

Explanation in Ontology Reasoning

- Justification algorithms:[6] select minimal set of axioms responsible for an entailment
- Empirical evidence:[7] difficult to get from justification to explanation
- Theorem proving: construct symbolic explanation for justification-entailment pairs
- Inaccessibility issues: domain experts unfamiliar with symbolic notations

[6] Kalyanpur, A. 2006. Debugging and repair of OWL ontologies. Ph.D. Dissertation, The University of Maryland.

[7] Horridge, M., Parsia, B., Sattler, U.: Lemmas for justifications in OWL. In: 22nd International Workshop on Description Logics. vol. 477. CEUR-WS.org (2009)

Example: Symbolic Proof

Justification axioms for an inconsistency (i.e., false entailment)

$$Cat \sqsubseteq \forall isPetOf.Female \quad isPetOf(Rex, Alex)$$
$$Dis(Male, Female) \quad Cat(Rex) \quad Male(Alex)$$

$$\cfrac{\cfrac{Cat \sqsubseteq \forall isPetOf.Female \wedge Cat(Rex) \wedge isPetOf(Rex, Alex) \wedge Male(Alex) \wedge Dis(Male, Female)}{Female(Alex) \wedge Male(Alex) \wedge Dis(Male, Female)}\ cls{-}avf}{\bot}\ cax{-}dw$$

where

$$\frac{X \sqsubseteq \forall P.Y \wedge X(u) \wedge P(u, v)}{Y(v)}\ cls-avf$$

$$\frac{Dis(X, Y) \wedge X(u) \wedge Y(u)}{\bot}\ cax-dw$$

Implementation: iCon

iCon

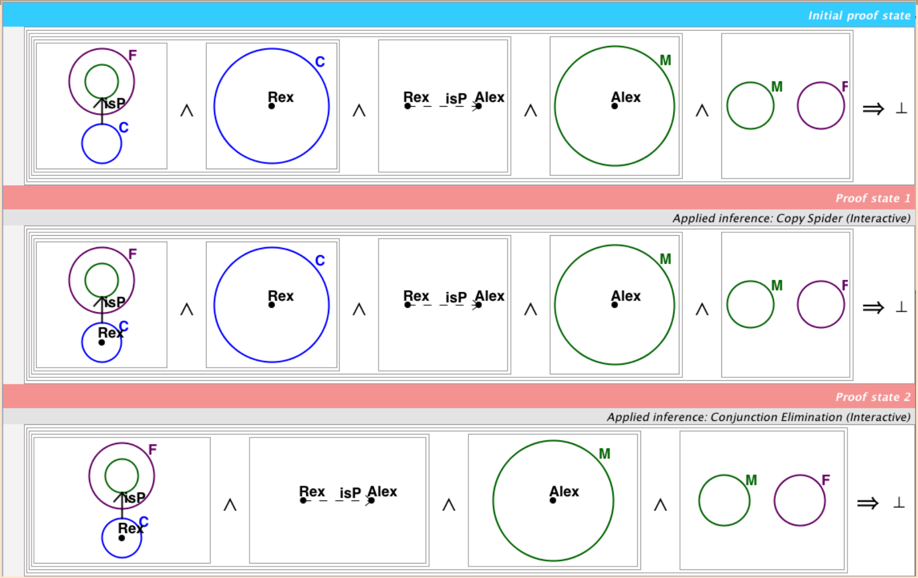
An interactive theorem prover: [8]

- Input: A theorem of form $\Delta_0 : (d_1 \wedge \cdots \wedge d_m) \Rightarrow d$
- Inference rule application: $\frac{\Delta}{\Delta'} Rule$
- Basic Proof State: $\Delta_{basic} : d \Rightarrow d$
- Output: a formally verified diagrammatic proof

$$\cfrac{\cfrac{\cfrac{\cfrac{\Delta_0}{\Delta_1}\,Rule_1}{\vdots}\,Rule_2}{\Delta_{basic}}\,Rule_n}{\top}\,Identity$$

[8] Z. Shams, M. Jamnik, G. Stapleton and Y. Sato, iCon: A Diagrammatic Theorem Prover for Ontologies, in: KR 2018. AAAI Press, 2018, pp. 204-209.

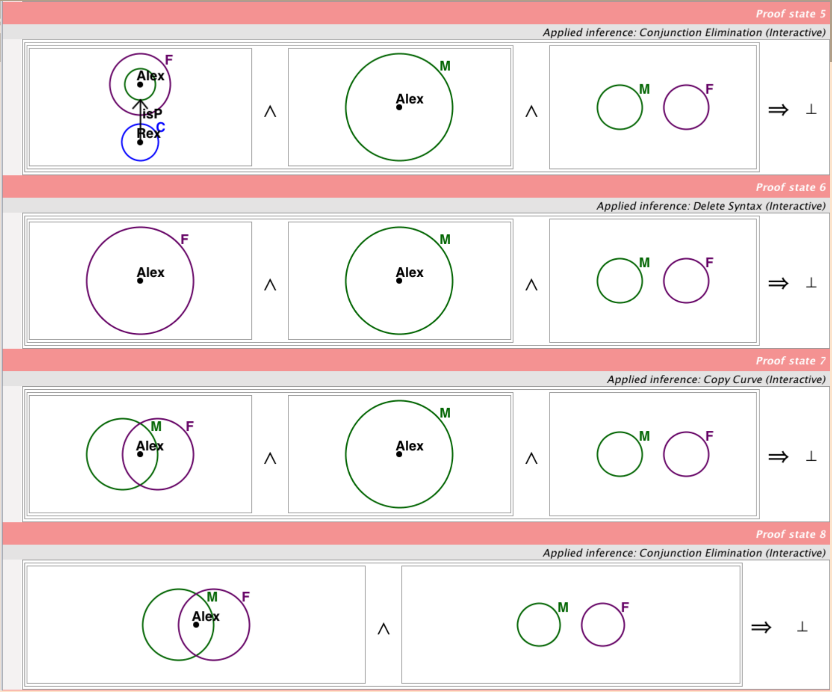
Example


Initial proof state
F
isP
C
Rex
C
Rex isP Alex
Alex
M
M
F
Proof state 1
Applied inference: Copy Spider (Interactive)
F
isP
Rex
C
Rex
C
Rex isP Alex
Alex
M
M
F
Proof state 2
Applied inference: Conjunction Elimination (Interactive)
F
isP
Rex
C
Rex isP Alex
Alex
M
M
F

Exa

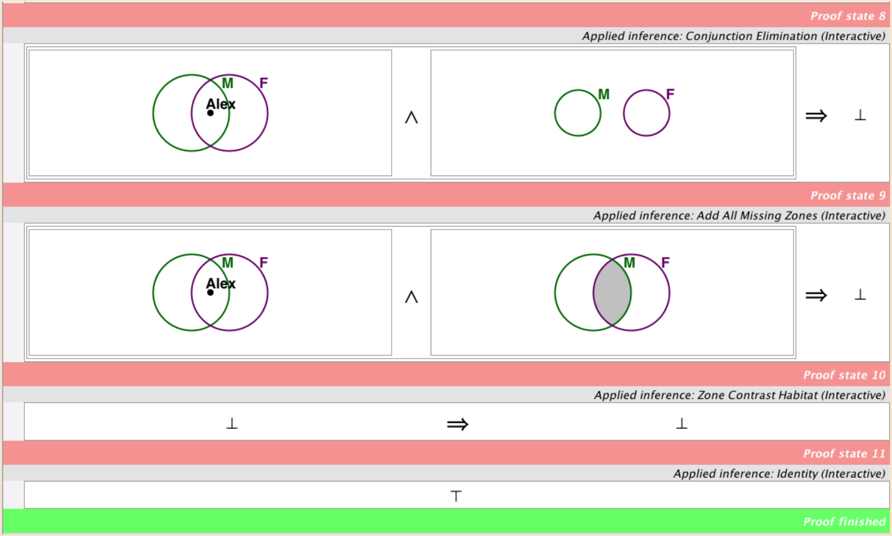

Proof state 2
Applied inference: Conjunction Elimination (Interactive)
F
isP
Rex
C
Rex isP Alex
M
Alex
M
F
∧ ∧ ∧ ⇒ ⊥
Proof state 3
Applied inference: Add Spider Arrow (Interactive)
F
isP
Rex
C
Rex isP Alex
M
Alex
M
F
∧ ∧ ∧ ⇒ ⊥
Proof state 4
Applied inference: Add Spider to Solid Arrow Image (Interactive)
F
Alex
isP
Rex
C
Rex isP Alex
M
Alex
M
F
∧ ∧ ∧ ⇒ ⊥
Proof state 5
Applied inference: Conjunction Elimination (Interactive)
F
Alex
isP
Rex
C
M
Alex
M
F
∧ ∧ ⇒ ⊥

Exa



Proof state 5
Applied inference: Conjunction Elimination (Interactive)
F
Alex
isP
C
Rex
∧
M
Alex
∧
M
F
⇒ ⊥
Proof state 6
Applied inference: Delete Syntax (Interactive)
F
Alex
∧
M
Alex
∧
M
F
⇒ ⊥
Proof state 7
Applied inference: Copy Curve (Interactive)
M
F
Alex
∧
M
Alex
∧
M
F
⇒ ⊥
Proof state 8
Applied inference: Conjunction Elimination (Interactive)
M
F
Alex
∧
M
F
⇒ ⊥

Example


Proof state 8
Applied inference: Conjunction Elimination (Interactive)
M
F
Alex
∧
M
F
⇒ ⊥
Proof state 9
Applied inference: Add All Missing Zones (Interactive)
M
F
Alex
∧
M
F
⇒ ⊥
Proof state 10
Applied inference: Zone Contrast Habitat (Interactive)
⊥ ⇒ ⊥
Proof state 11
Applied inference: Identity (Interactive)
⊤
Proof finished

Evaluation

Extensibility

- Covering all OWL 2 RL inference rules
- Comparability of number of symbolic and diagrammatic rules
- Beyond OWL 2 RL
- Empirical studies

Generality

Practical Relevance and Domain Independence:

- Case Study I: Industrial Processed-Based Modelling

  Conceptual Error: A domain expert is trying to find all individuals that are classified as `'model process'`. `WaterTankSimpleIncomplete:process-valveTransmision` is such an individual but it is not clear why because this individual is not of type `'model process'`. This looks like an unintentional entailment that needs debugging.

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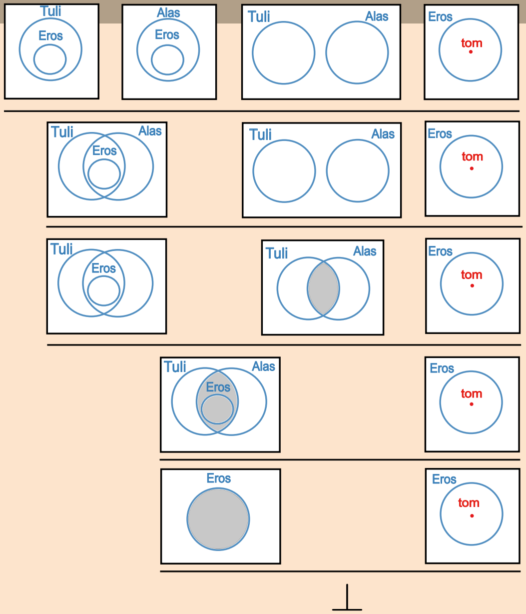
- Case Study II: Neurodegenerative Diseases

  Logical Error: A domain expert would like to express that a specific individual `data_example_1` is not related to anything under a certain property `hasPart`. Thus the expert adds an axiom to the ontology that defines an extra type for the individual as `hasPart max 0`. However adding this axiom appears to make the ontology inconsistent, which needs debugging.

Accessibility

- Language level
- Reasoning and inference rule level
- Proof level
  - Usability
    - Debugging purposes: observational advantages and heuristics
    - Communication purposes: observational advantages and step-wise explanation
  - Layout: sequential vs tree layout

Layout



Tuli
Eros
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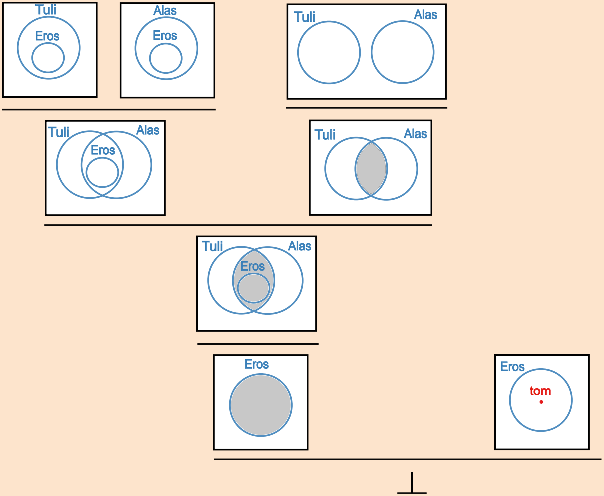
⊥

Layout



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Conclusion and Future Work

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- Unifying diagrammatic ontology representation and reasoning
- Cognitively informed $\rightarrow$ Accessibility

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Thank you