Testing OWL Axioms Against RDF Facts
A possibilistic approach

Andrea G. B. Tettamanzi, Catherine Faron-Zucker, and Fabien Gandon

Univ. Nice Sophia Antipolis, CNRS, INRIA, I3S, UMR 7271, France

EKAW 2014, Linköping

Introduction: Ontology Learning

Top-down construction of ontologies has limitations

- aprioristic and dogmatic
- does not scale well
- does not lend itself to a collaborative effort

Bottom-up, *grass-roots* approach to ontology and KB creation

- start from RDF facts and learn OWL 2 axioms

Recent contributions towards OWL 2 ontology learning

- FOIL-like algorithms for learning concept definitions
- statistical schema induction via association rule mining
- light-weight schema enrichment (DL-Learner framework)

All these methods apply and extend ILP techniques.

Introduction: Ontology validation, Axiom Scoring

Need for evaluating and validating ontologies

- General methodological investigations, surveys
- Tools like OOPS! for detecting pitfalls
- Integrity constraint validation

Ontology learning and validation rely on axiom scoring

- We tackle the problem of testing a single axiom
- Most popular scoring heuristics based on statistical inference

Research Questions:

1. Can we apply a possibilistic approach to axiom testing for ontology learning?
2. Could this be beneficial to ontology and KB validation?

Count-Based Axiom Scoring

Given axiom ϕ, let us define

u_ϕ the support or sample size for ϕ

u_ϕ^+ the number of confirmations of ϕ

u_ϕ^- the number of counterexamples (falsifiers) of ϕ

Score from statistical inference: $\Pr(\phi \text{ is true} \mid \text{evidence})$

- Simple statistics: $\hat{p}_\phi = u_\phi^+ / u_\phi$
- Refinements are possible, e.g., confidence intervals

Implicit assumption that we know how to estimate $\Pr(e \mid \phi)$ in

$$\Pr(\phi \mid e) = \frac{\Pr(e \mid \phi)\Pr(\phi)}{\Pr(e \mid \phi)\Pr(\phi) + \Pr(e \mid \neg\phi)\Pr(\neg\phi)}$$

$\Rightarrow$ Alternative scoring heuristics based on possibility theory, weaker than probability theory

Possibility Theory

Definition (Possibility Distribution)

$$\pi : \Omega \to [0, 1]$$

Definition (Possibility and Necessity Measures)

$$\begin{aligned} \Pi(A) &= \max_{\omega \in A} \pi(\omega); \\ N(A) &= 1 - \Pi(\bar{A}) = \min_{\omega \in \bar{A}} \{1 - \pi(\omega)\}. \end{aligned}$$

For all subsets $A \subseteq \Omega$,

1. $\Pi(\emptyset) = N(\emptyset) = 0, \quad \Pi(\Omega) = N(\Omega) = 1;$
2. $\Pi(A) = 1 - N(\bar{A})$ (duality);
3. $N(A) > 0$ implies $\Pi(A) = 1, \quad \Pi(A) < 1$ implies $N(A) = 0$.

In case of complete ignorance on A, $\Pi(A) = \Pi(\bar{A}) = 1$.

Support of an Axiom

BS: finite set of *basic statements*, i.e.,
assertions that may be tested by a SPARQL `ASK` query.

Definition (Content of Axiom ϕ)

$$\mathrm{content}(\phi) = \{\psi : \phi \models \psi\} \cap \mathrm{BS}.$$

- $\mathrm{content}(\phi)$ is finite $\Leftarrow$ BS is finite
- every $\psi \in \mathrm{content}(\phi)$ may be tested by a SPARQL `ASK` query

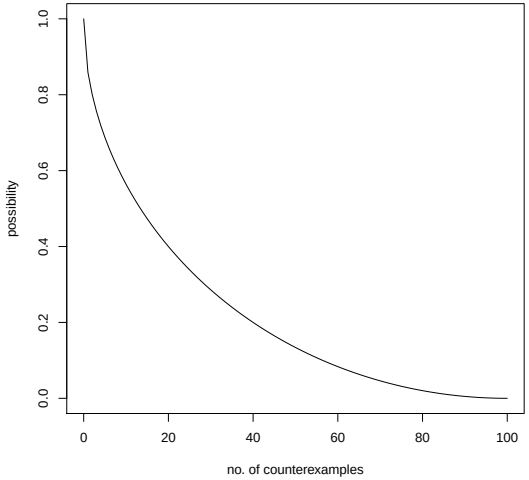
Definition (Support of Axiom ϕ)

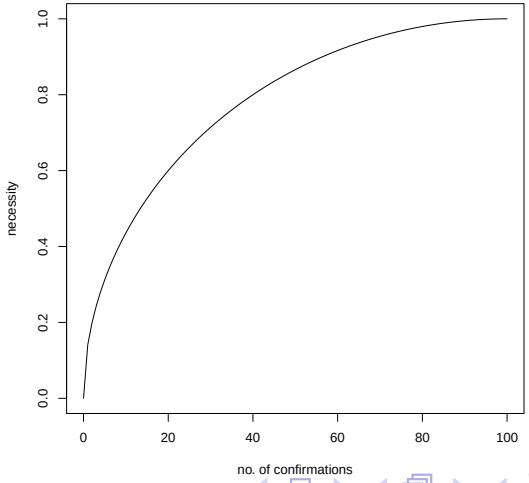
$$u_\phi = |\mathrm{content}(\phi)|.$$

Possibility and Necessity of an Axiom

$$\Pi(\phi) = 1 - \sqrt{1 - \left(\frac{u_\phi - u_\phi^-}{u_\phi}\right)^2}$$

$$N(\phi) = \sqrt{1 - \left(\frac{u_\phi - u_\phi^+}{u_\phi}\right)^2} \quad \text{if } \Pi(\phi) = 1,\ 0 \text{ otherwise.}$$





Acceptance/Rejection Index

Combination of possibility and necessity of an axiom:

Definition

$$\mathrm{ARI}(\phi) = N(\phi) - N(\neg\phi) = N(\phi) + \Pi(\phi) - 1$$

- $-1 \leq \mathrm{ARI}(\phi) \leq 1$ for all axiom ϕ
- $\mathrm{ARI}(\phi) < 0$ suggests rejection of ϕ ($\Pi(\phi) < 1$)
- $\mathrm{ARI}(\phi) > 0$ suggests acceptance of ϕ ($N(\phi) > 0$)
- $\mathrm{ARI}(\phi) \approx 0$ reflects ignorance about the status of ϕ

OWL 2 → SPARQL

To test axioms, we define a mapping $Q(E, x)$ from OWL 2 expressions to SPARQL graph patterns such that

$$\texttt{SELECT DISTINCT ?x WHERE } \{ \; Q(E, \texttt{?x}) \; \}$$

returns $[Q(E, x)]$, all known instances of class expression E and

$$\texttt{ASK } \{ \; Q(E, a) \; \}$$

checks whether $E(a)$ is in the RDF base.

For an atomic concept A (a valid IRI),

$$Q(A, \texttt{?x}) = \texttt{?x a } A \texttt{ .}$$

Concept Negation: $Q(\neg C, ?x)$

$$Q(\neg C, ?x) = \{ \texttt{?x ?p ?o .} \; \texttt{FILTER NOT EXISTS} \; Q(C, ?x) \; \} \quad (1)$$

has the problem of treating negation as failure.

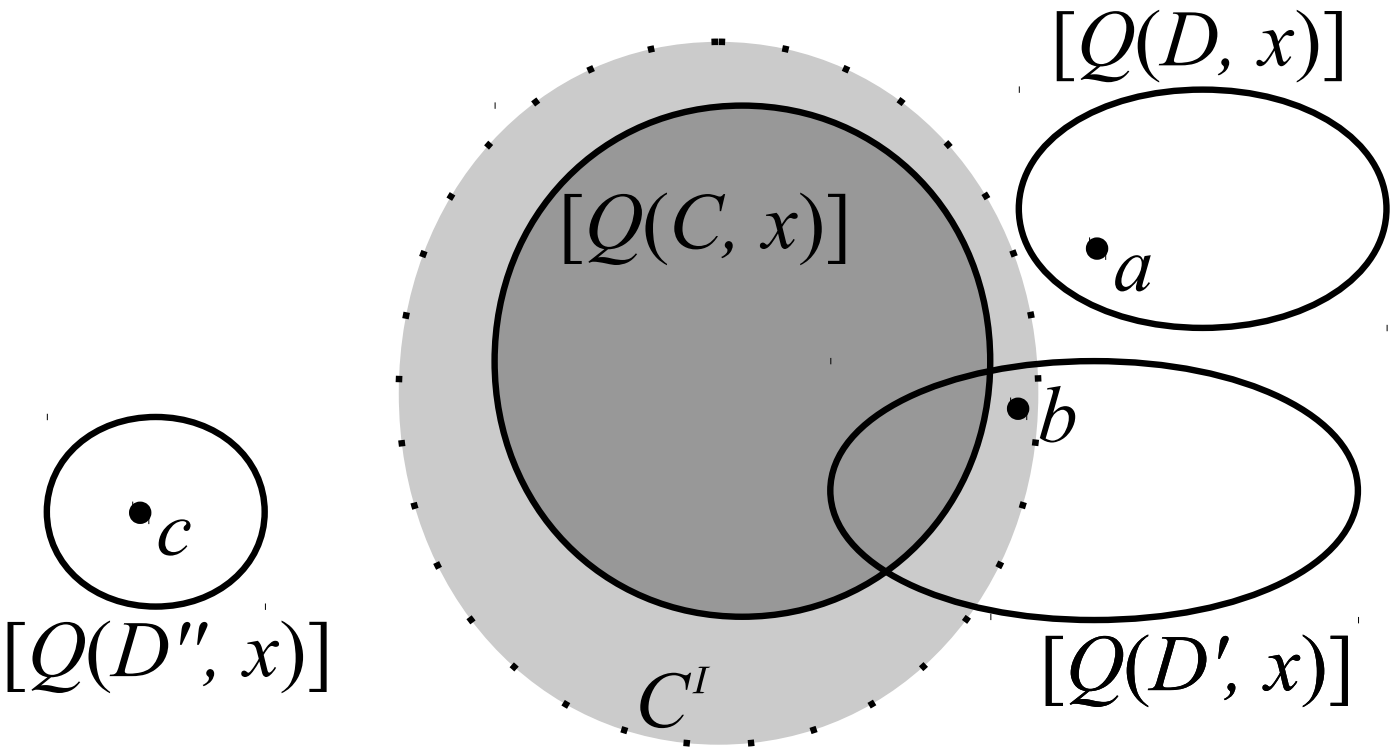
$$Q(\neg C, ?x) = \{ \texttt{?x a ?dc .} \; \texttt{FILTER NOT EXISTS} \; \{ \texttt{?z a ?dc .} \; Q(C, ?z) \} \} \quad (2)$$

Better than (1), but just pushes the problem one step further

$$Q(\neg C, ?x) = \{ \texttt{?x a ?dc . ?dc owl:disjointWith} \; C \; \} \quad (3)$$

OK, but very few DisjointClasses axioms currently found in ontologies!

Concept Negation: Discussion



SubClassOf(C D) Axioms

To test SubClassOf axioms, we must define their logical content based on their OWL 2 semantics:

$$\begin{aligned}(C \sqsubseteq D)^{\mathcal{I}} &= C^{\mathcal{I}} \subseteq D^{\mathcal{I}} \\ &\equiv \forall x \quad x \in C^{\mathcal{I}} \Rightarrow x \in D^{\mathcal{I}}\end{aligned}$$

Therefore,

$$\mathrm{content}(C \sqsubseteq D) = \{D(a) : C(a) \text{ is in the RDF store}\}$$

because, if $C(a)$ holds,

$$C(a) \Rightarrow D(a) \equiv \neg C(a) \vee D(a) \equiv \top \vee D(a) \equiv D(a)$$

Support, Confirmations and Counterexamples of $C \sqsubseteq D$

$u_{C \sqsubseteq D}$ can be computed by

```
SELECT (count(DISTINCT ?x) AS ?u) WHERE {Q(C,?x)}.
```

As for the computational definition of $u^{+}_{C \sqsubseteq D}$ and $u^{-}_{C \sqsubseteq D}$:

- confirmations: a s.t. $a \in [Q(C, x)]$ and $a \in [Q(D, x)]$;
- counterexamples: a s.t. $a \in [Q(C, x)]$ and $a \in [Q(\neg D, x)]$.

Therefore,

- $u^{+}_{C \sqsubseteq D}$ can be computed by

```
SELECT (count(DISTINCT ?x) AS ?numConfirmations)
WHERE { Q(C,?x) Q(D,?x) }
```

- $u^{-}_{C \sqsubseteq D}$ can be computed by

```
SELECT (count(DISTINCT ?x) AS ?numCounterexamples)
WHERE { Q(C,?x) Q(¬D,?x) }
```

Experiments

Experimental Setup:

- DBpedia 3.9 in English as RDF fact repository
- Local dump (812,546,748 RDF triples) loaded into Jena TDB
- Method coded in Java, using Jena ARQ and TDB
- 12 6-core Intel Xeon CPUs @2.60GHz (15,360 KB cache), 128 GB RAM, 4 TB HD (128 GB SSD cache), Ubuntu 64-bit OS.

Two experiments:

1. Explorative test of systematically generated subsumption axioms
2. Exhaustive test of all subsumption axioms in the DBpedia ontology.

Results at `http://www.i3s.unice.fr/~tettaman/RDFMining/`.

Explorative Experiment

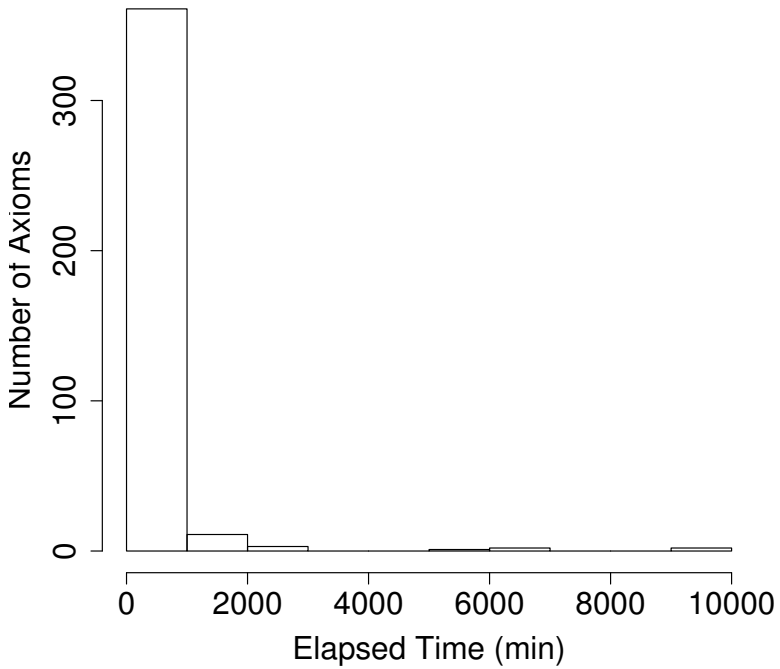
Systematically generate and test SubClassOf axioms involving atomic classes only

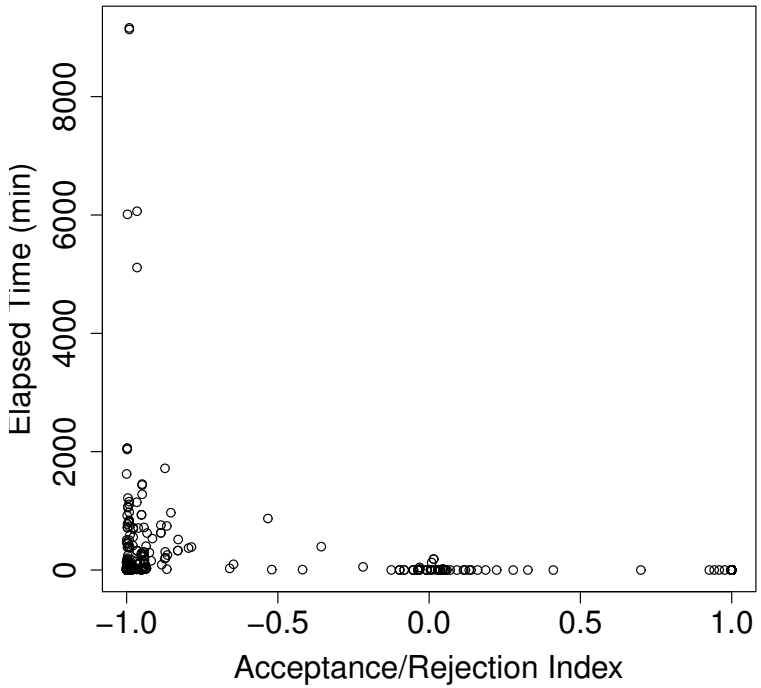
- For each of the 442 classes C referred to in the RDF store
- Construct all $C \sqsubseteq D$: C and D share at least one instance
- Classes D are obtained with query

$$\texttt{SELECT DISTINCT ?D WHERE } \{Q(C, \texttt{?x}).\ \texttt{?x a ?D}\}$$

Due to the sheer number of axioms thus generated and to the long time it takes to test them, this experiment is still underway

Explorative Experiment: Test Time





Time to test an axiom inversely proportional to its ARI

Good news: time-out on test $\Rightarrow \mathrm{ARI}(\phi) < 0$ likely!

Explorative Experiment: Results

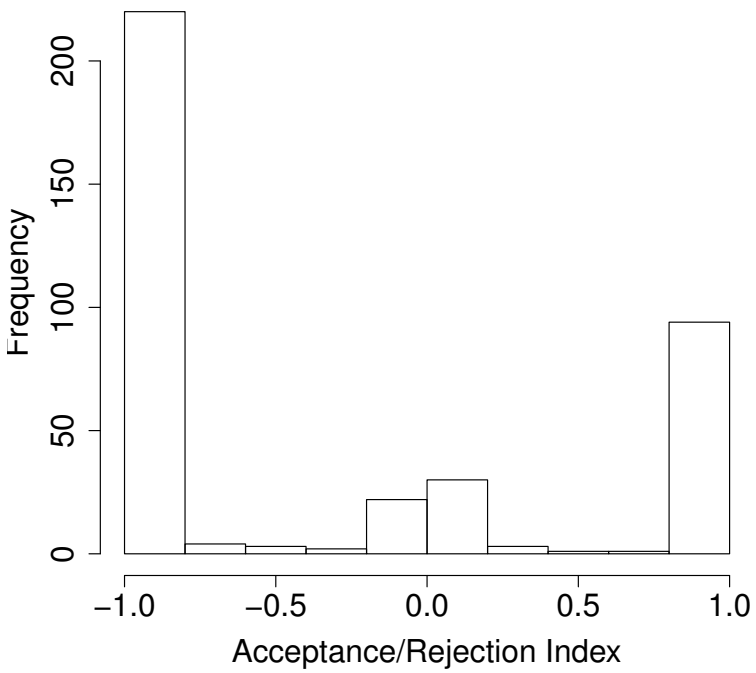
Assessment:

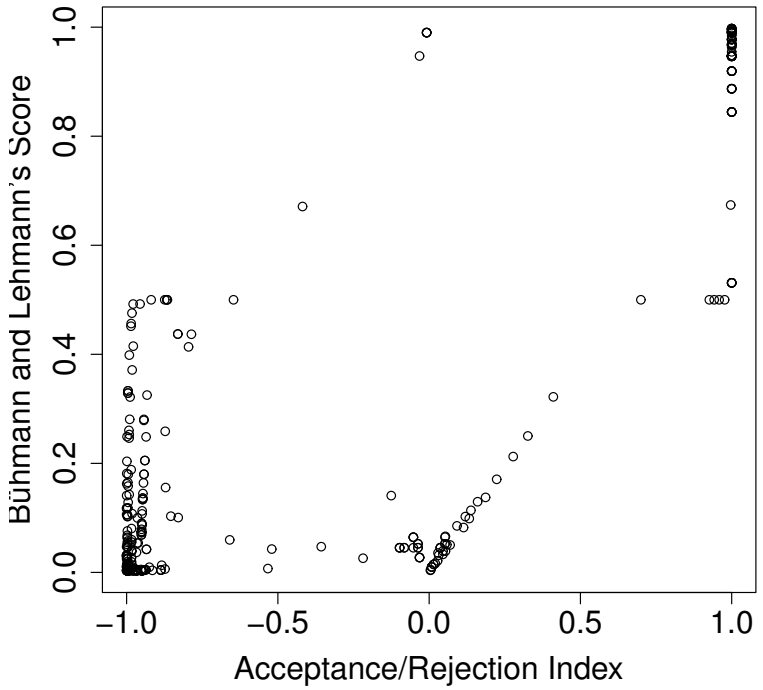
1. sort the 380 tested axioms by their ARI
2. manually tag each of them as either *true* or *false*

Findings:

- $\mathrm{ARI}(\phi) > 1/3$ as the optimal acceptance criterion for ϕ
- This would yield 4 FP and 6 FN (97.37% accuracy)
- Misclassifications to blame on mistakes in DBpedia
- Pr score w/ 0.7 threshold yields 13 FN (+7) and 4 FP (=)

Explorative Experiment: Comparison w/ Probabilistic Score





Exhaustive Experiment

Test all SubClassOf axioms in DBpedia ontology

- Functional syntax, with query

```
SELECT DISTINCT
  concat("SubClassOf(<", str(?x),
         "> <",str(?y),">)")
WHERE { ?x a owl:Class .  ?x rdfs:subClassOf ?y }
```

- 541 axioms
- Testing "only" took 1 h 23 min 31 s

Exhaustive Experiment: Results

- For 143 axioms, $u_\phi = 0$ (empty content!): $\mathrm{ARI}(\phi) = 0$
- For 28 axioms, $\mathrm{ARI}(\phi) < 0 \Rightarrow \exists$ erroneous facts

Examples of axioms $C \sqsubseteq D$ with their conterexamples:

Axiom	**Counterexamples**
dbo:LaunchPad $\sqsubseteq$ dbo:Infrastructure	:USA
dbo:Brain $\sqsubseteq$ dbo:AnatomicalStructure	:Brain [*sic*]
dbo:Train $\sqsubseteq$ dbo:MeanOfTransportation	:New_Jersey_Transit_rail_operations, :ALWEG
dbo:ProgrammingLanguage $\sqsubseteq$ dbo:Software	:Ajax
dbo:PoliticalParty $\sqsubseteq$ dbo:Organisation	:Guelphs_and_Ghibellines, :-, :New_People's_Army, :Syrian

N.B.: counterexamples are instances a such that $C(a)$ and $E(a)$ with $E^{\mathcal{I}} \cap D^{\mathcal{I}} = \emptyset$: in this case, either $C(a)$ is wrong or $E(a)$ is.

Conclusions & Future Work

Contributions

- Axiom scoring heuristics based on possibility theory
- Solid basis for axiom induction, ontology learning
- A framework based on the proposed heuristics

The proposed heuristics

- is suitable for axiom induction
- may be useful for ontology and KB validation
- no less rigorous or objective than probability-based scoring

Future work

- extend experimental evaluation to more general axioms
- enlarge test base w/ additional RDF datasets from the LOD
- improve framework by setting a time-out on query evaluation

The End

Thank you for your attention!