Context Dependent Reasoning for Semantic Documents in Sindice

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enabling the web of entities

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Motivations

- Sindice Semantic Web Index
  - + 30 million of documents
- Reasoning to find documents
  - Materialise implicit knowledge: IFPs, membership (sc, sp)

find someone called "Giovanni Tummarello" ignoring the wording:

```
(* <http://xmlns.com/foaf/0.1/givenname> "Giovanni"  AND
* <http://xmlns.com/foaf/0.1/family_name> "Tummarello")
OR * <http://xmlns.com/foaf/0.1/name> "Giovanni Tummarello"
```

  - Goal: Increase Precision/Recall (also find implicit information)
- But
  - Deal with real-world web data (heterogeneous, messy)
  - Computationally expensive (slow down indexing process)

→ Efficient&effective reasoning methodology required

Caching Ontologies

- Naive approach:
  - Cache all fetched ontologies + RDF data in one triple store
  - Compute and cache deductive closure
- Problem:
  - Leads to innapproriate deductive closure (too much)
  - Ontology is meant to be shared and reused
  - Diverging reuse reflects diverving points of view
    → divergent semantics
- Example:
  - **MY** ontology can redefine `foaf:name`, e.g. as IFP
    - May lead to owl:sameAs inferences
    - valid in the **context** of **MY** RDF graphs, but not for everybody

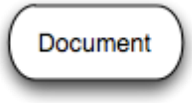
Context-Dependent Reasoning

- Context-Dependent Reasoning:
  - Ensure context is preserved when aggregating documents
  - "Quarantined Reasoning" approach:
    - Confine inference results to their context
    - Inferred axioms are invalid outside their context

- Partition the Web of Data into smaller contexts (on a "**per document"** basis) ...
- ... and aggregate contexts based on dependencies

- Prevents undesirable results ...
- ... while preserving **intended** meaning of the document

Reasoning over Linked Data



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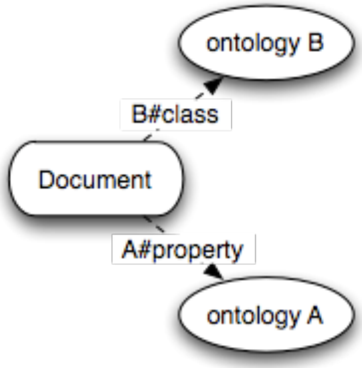

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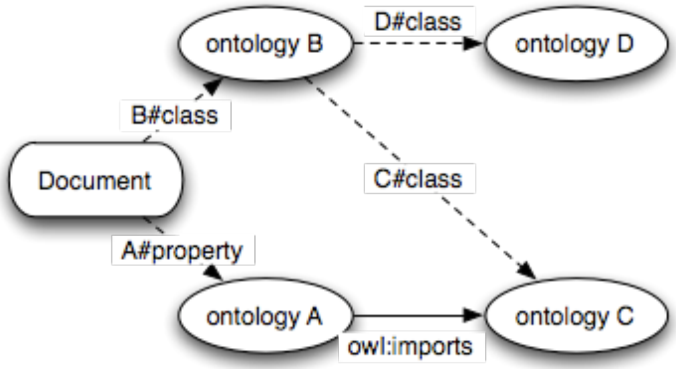
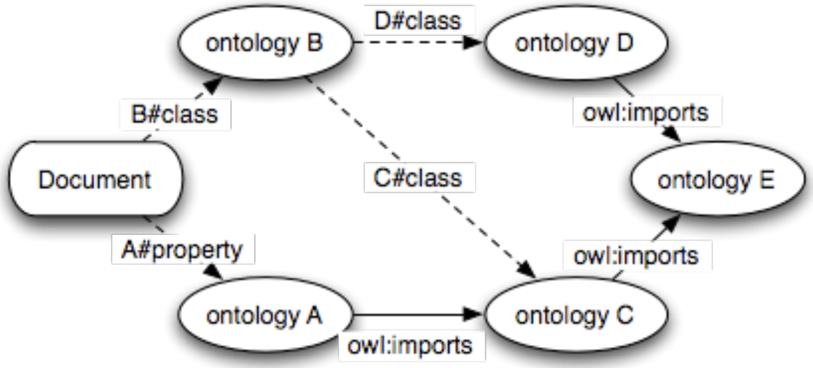


Reasoning over Linked Data



- Document taken alone : no semantics
- Recursive fetching of ontologies is mandatory
- Make use of
  - Explicit owl:imports
  - Implicit imports "by namespace" – make use of W3C best practices where possible.
- Intensive data processing
  - Data fetching, pre-processing
  - Deductive closure computing

Context on the Semantic Web

- Based on **Guha**'s ideas on a context mechanism
- Context = Scope of validity of a statement
- Aggregate context
  - Composed by the content lifted from other contexts
  - Contains specification of what it imports
  - **RDF document = aggregate context** (as we will see later)
- Lifting rules
  - Expressive formulas
  - Enable to lift axioms from one context to another
  - At the moment, we only use the simplest lifting rule (simple import):

$$ist(c_2, p) \wedge ist(c1, importsFrom(c_1, c_2)) \rightarrow ist(c_1, p)$$

Import closure of Documents

- Explicit import
  - `owl:imports` primitive
  - Transitive: *if O_A imports O_B and O_B imports O_C, then O_A imports O_C*
  - When reasoning on an ontology O, one should consider the entire import closure of O.
- But, it is not a common practice
  - Only 5.56 thousand over 30 million of documents use `owl:imports`

Import closure of Documents

- Implicit import
  - Based on W3C best practices – Linked Data Principles
  - By dereferencing class or property URI

```
:me rdf:type foaf:Person .
:me foaf:name "Renaud Delbru" .
```

`http://www.w3.org/1999/02/22-rdf-syntax-ns`

`http://xmlns.com/foaf/spec/`

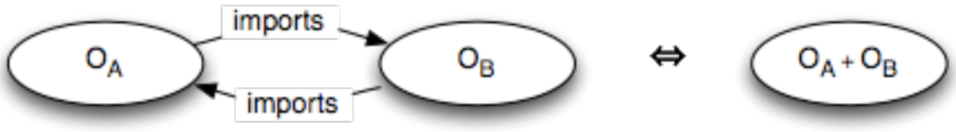
→ `foaf:name rdf:type owl:DatatypeProperty .`

`http://www.w3.org/2002/07/owl`

→ `owl:DatatypeProperty rdf:type rdf:Property .`

Import Lifting Rule

- `owl:imports` primitive and implicit imports
  - mapped to Guha's *importsFrom* lifting rule
  - See ***Definition 1***
- Cyclic import relations may occur:
  - if O_A imports O_B and O_B imports O_A, then $\mathbf{O_A \Leftrightarrow O_B}$
  - Extend Guha's definition to allow cycles
  - See ***Definition 2***



Deductive closure of Documents

- Reminder: aggregate context =
  - Document content
  - + ontology import closure (explicit and implicit imports)
- Deductive closure of an aggregate context
  - Computes full materialisation of aggregate context
  - Original content + inferred statements
- Inference based on a **finite** entailment regime
  - Rule-based inference engine
  - ter Horst's pD* fragment (RDFS + subset of OWL)

Deductive closure of Documents

- Deductive closure of aggregate context
  - Lead to inferred statements that are not true in any of the source contexts alone
  - See ***Definition 3***

Context C1:

```
:me rdf:type foaf:Person .
```

Context C2:

```
foaf:Person rdfs:subClassOf yago:Human .
```

$\wedge$

$\Delta_{C1,\ C2} =$

```
:me rdf:type yago:Human .
```

Ontology Base: Conceptual Model

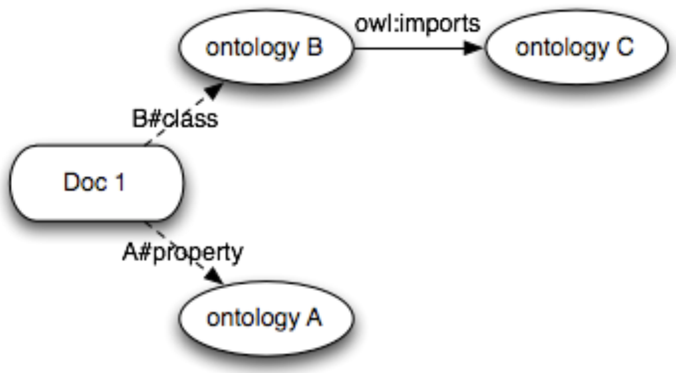
- Ontology Base
  - Persistent TBox
  - Materialise import relations between ontology
  - Store inference results that has been performed
- Concepts
  - ***Ontology entity:***

    `rdfs:Property` or `rdfs:Class` identified by a resolvable URI
  - ***Ontology context:***

    Named graph composed by ontology statements
  - ***Ontology network:***

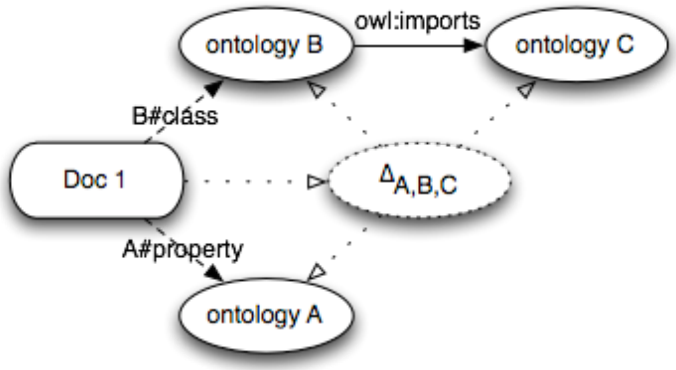
    directed graph of ontology contexts where edges are import relations (see ***Definition 4***)

Ontology Base: Update Strategy



1. Import closure of Doc1 is materialised

Ontology Base: Update Strategy



1. Import closure of Doc1 is materialised
2. Compute deductive closure of aggregate context O_A, O_B, O_C

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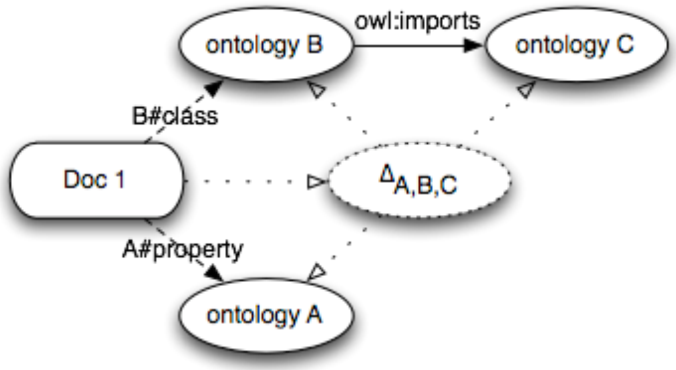

1. Import closure of Doc1 is materialised
2. Compute deductive closure of aggregate context O_A, O_B, O_C
3. Store $\Delta_{A,B,C}$ in a separate named graph

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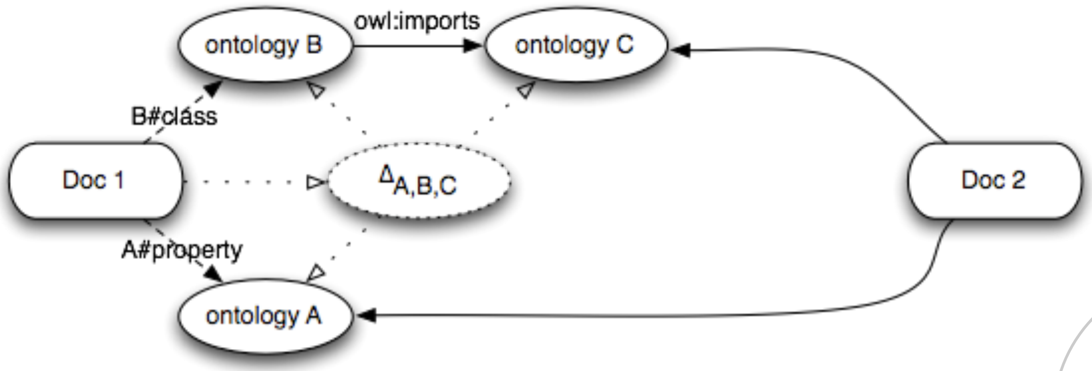
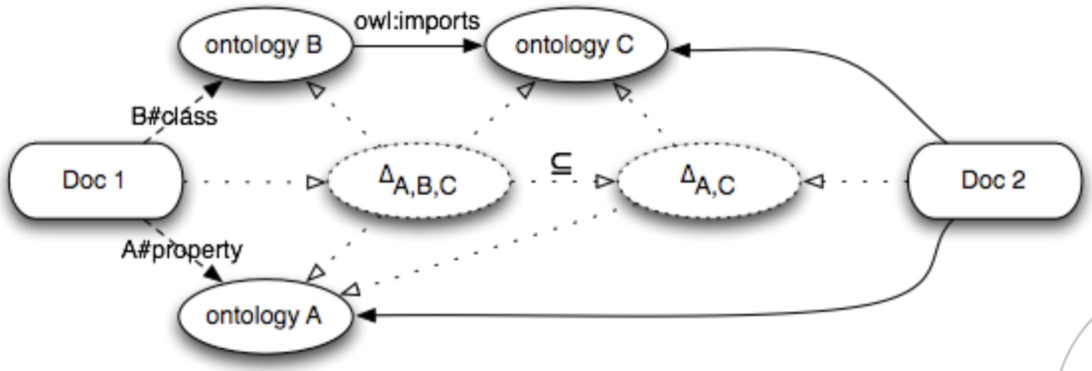


A new document is coming, importing only O_A and O_C :

1. Compute deductive closure of O_A and O_C

Ontology Base: Update Strategy



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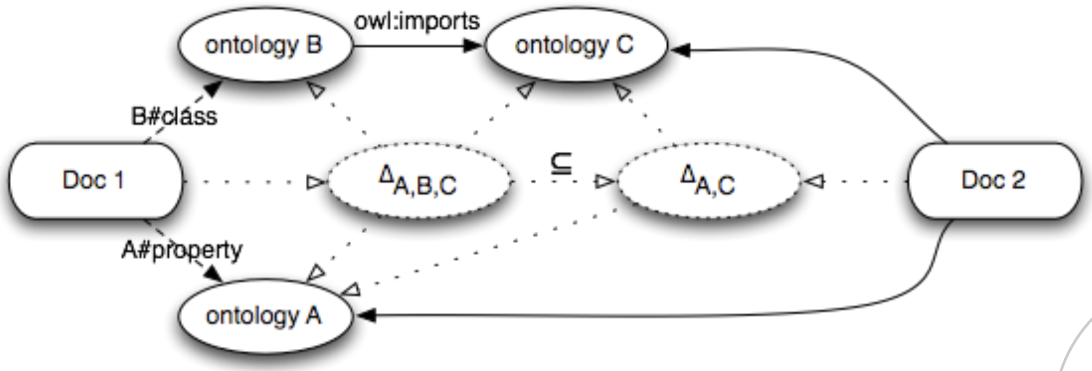
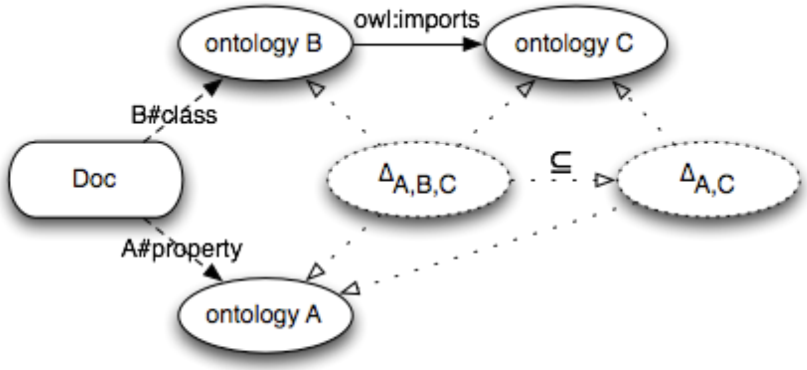


A new document is coming, importing only O_A and O_C :

1. Compute deductive closure of O_A and O_C
2. Store $\Delta_{A,C}$ in a separate named graph
3. Update deductive closure of O_A, O_B, O_C so that the inferred triples are never duplicated
   a) Substract $\Delta_{A,C}$ from $\Delta_{A,B,C}$
   b) add inclusion relation

i.e., $\Delta_{A,B,C} := \Delta_{A,B,C} - \Delta_{A,C} + \Delta_{A,C}$ owl:imports $\Delta_{A,B,C}$

Ontology Base: Querying Strategy



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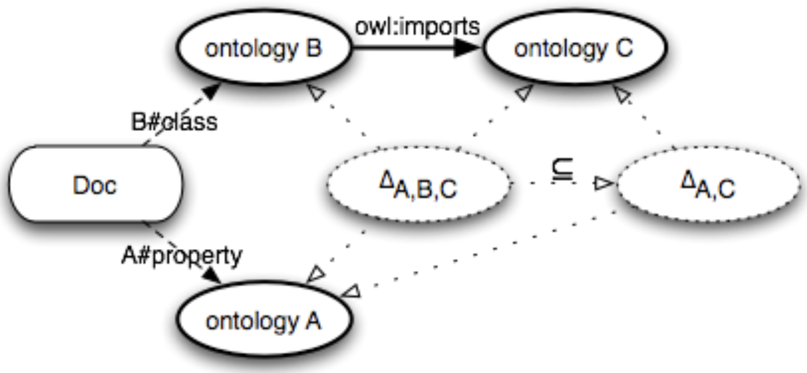

1. A document imports O_A and O_B
2. Import closure is derived, and corresponding ontology network activated

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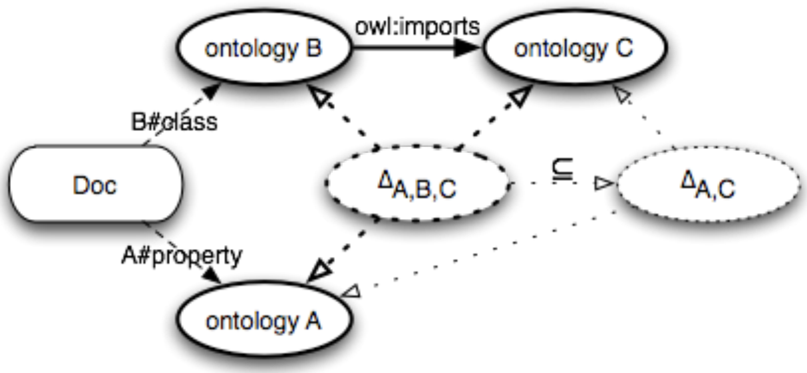

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2. Import closure is derived, and corresponding ontology network activated
3. The related $\Delta_{A,B,C}$ is derived and activated

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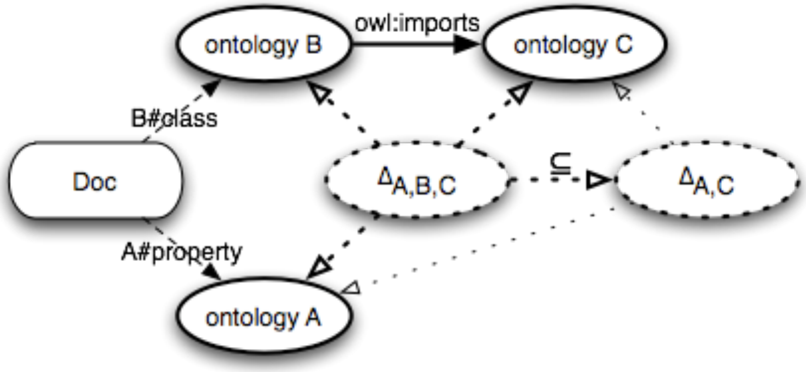

1. A document imports O_A and O_B
2. Import closure is derived, and corresponding ontology network activated
3. The related $\Delta_{A,B,C}$ is derived and activated
4. It is then found that $\Delta_{A,B,C}$ includes $\Delta_{A,C}$ which is also activated

→ Our Observation: "caching" Tbox inferences makes indexing (mostly ABox) much faster

Prototype and Preliminary Results

- Prototype implementation
  - Distributed architecture based on Apache Hadoop
    - Hadoop "worker" (map-job):
      reasoning agent (processing one document at a time)
  - Single ontology base shared among "workers"
    - Ontology base: context aware reasoning SAIL (Aduna Sesame)
    - Receives sets of URIs = aggregate contexts as "queries"
- Experimental setup
  - Cluster of 3 nodes (á 4 cores 2.33GHz, 8GB)
  - 4 Hadoop workers / node
  - No syncing yet done between nodes
- Preliminary Results
  - 40 documents / second on average;
  - up to 80 documents / second for simple datasets (Geonames)
  - Original size: 18GB - 46GB after inference (ratio of 2.5)

Discussions

- Known problems
  - Changing ontologies
  - Possibility to hijack our system:
    - Let d1 and d2 be ABox documents,
    - Observe: if d1 refers to d2 as an ontology entity, e.g.

      ```
      <d1> rdfs:subClassOf <d2> .
      ```

      d2 will be added to the ontology base.
    - An attacker, could query indexed documents and then create a "fake" document making all indexed documents "look like" ontologies.
- Solutions:
  - Add Metadata on the ontology level (last update, etc.)
  - Fine-grained context (on a per-entity basis)
  - By analysing the content of d2, we can detect that it does not contain any ontological statements about an entity d2.

    → The entity context d2 will not be added to the ontology base

Conclusions

- We introduce a context-dependent inference methodology
  - Materialise implicit knowledge “per document”
  - Keep track of provenance of the inferred assertions
  - Inference based on Ter-Horst fragment (but other entailment regime possible)
- Context-dependent Inference Enables Sindice to
  - Be more effective in term of Precision/Recall
  - Avoid the deduction of undesirable assertions
  - Distribute & cache reasoning tasks on a per-document basis
- Future Work:
  - Analyse precise and average time and space complexity
  - Investigate lifting rules on ABox level (`owl:sameAs`)
  - Investigate fine-grained context (on a per-entity basis)