NdFluents
An Ontology for Annotated Statements with Inference Preservation

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Introduction

- RDFS and OWL allow to make inferences

```plaintext
ex:Paris --> ex:capitalOf --> ex:France
```
Introduction

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- We want to annotate statements with metadata

ex:Paris \(\xrightarrow{\text{ex:capitalOf}}\) ex:France
Introduction

- We want to annotate statements with metadata

- ex:Paris
  - ex:capitalOf
  - ex:France

  - ex:since
  - “508”^^xsd:year
Introduction

- However, inferences are lost

ex:Paris ⊤ ex:hasRelation ⊤ ex:capitalOf ⊤ ex:hasValue ⊤ ex:France

ex:since

“508”^^xsd:year
Introduction

- However, inferences are lost
However, inferences are lost.

Diagram:

- ex:Paris
- ex:hasRelation
- ex:capitalOf
- ex:hasValue
- ex:France
- ex:hasRelation
- ex:hasCapital
- ex:hasValue
- "508"^^xsd:year
- owl:inverseOf
- ex:capitalOf
- ex:hasCapital
- ex:France
- ex:hasRelation
- ex:hasCapital
- ex:Paris
Outline

1. NdFluents
   a. A bit of history: 4dFluents
   b. The NdFluents Ontology
   c. Problems to Consider

2. Comparing reasoning of NdFluents against other approaches
   a. Other approaches
      i. Reification
      ii. N-ary properties
      iii. Singleton Property
   b. Rule Preservation
   c. Results

3. Conclusions and future work
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3. Conclusions and future work
4dFluents.
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Problems to consider

● Combination of different contexts

● Inference Preservation

● Explosion in the number of triples
Combination of Different Contexts.
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Comparing NdFluents against other approaches.

- ex:Paris
- ex:capitalOf
- ex:France
Reification.

In Manola, Frank, Eric Miller, and Brian McBride. "RDF primer." W3C recommendation
URL: https://www.w3.org/TR/2004/REC-rdf-primer-20040210/#reification
N-ary relations.

ex:Paris ex:hasRelation ex:CapitalOf ex:hasValue ex:France

“508”^^xsd:year

ex:since

Gavin Carothers. RDF 1.1 N-Quads: A line-based syntax for RDF datasets. W3C Recommendation, 2014. URL: https://www.w3.org/TR/n-quads
Singleton Property.

Rule Preservation.

- We use pD* fragments of ter Horst
  - Modified subsets of RDFS and OWL
  - Can be expressed as a complete set of rules (18 for RDFS and 23 for OWL)
  - Computationally feasible

\[
\text{?p a SymmetricProperty} \\
\text{?v ?p ?w} \\
\models \\
\text{?w ?p ?v}
\]
Rule Preservation.

\[ f(?p \ a \ \text{SymmetricProperty} \ ?v \ ?p \ ?w) \]
\[ \models \]
\[ f(?w \ ?p \ ?v) \]
Rule Preservation.

\[
f(?p \ a \ SymmetricProperty\ ?v \ ?p \ ?w) \\
\models \\
f(?w \ ?p \ ?v)
\]
Rule Preservation.

\[ f(\text{SymmetricProperty}, ?v, ?p, ?w) \]

\[ \models \]

\[ f(?w, ?p, ?v) \]
Rule Preservation.

\[ f(\text{a SymmetricProperty}) \]

\[ f(\text{w p v}) \]

\[ \models \text{SymmetricProperty} \]
Non-Contextual Rule Preservation.

\[ f(\text{SymmetricProperty}) \]

\[ ?p \ a \ SymmetricProperty \ ]

\[ ?v \ ?p \ ?w \]

\[ \models \]

\[ ?w \ ?p \ ?v \]
Rule Preservation with conclusion unchanged.

\[
f(\text{f}(\text{p, a, InverseFunctionalProperty}) \text{f}(\text{u, p, v}) \text{f}(\text{u, p, w})) \quad (\ldots)
\]

\[
\models \quad \models
\]

\[
f(\text{f}(\text{v, sameAs, v}))
\]
Rule Preservation with conclusion unchanged.

\[ f(\text{p} \text{ a InverseFunctionalProperty } f(\text{u} \text{ p } \text{v} ) \text{ u } \text{ p } \text{w} ) ) \] (\ldots)

\[ f(\text{v sameAs } \text{v} ) \]

\[
\begin{align*}
\models & \quad \models \\
?p & \quad \text{InverseFunctionalProperty} \\
?u & \quad ?p \quad ?v \\
?u & \quad ?p \quad ?w \\
?v & \quad \text{sameAs} \\
?v & \quad ?v
\end{align*}
\]
Comparing NdFluents against other approaches
Example (rule preservation)

- ex:BarackObama
- ex:brother
- ex:SadamHussein
- ex:statedBy
- ex:ShadyNews
Comparing NdFluents against other approaches
Example (rule preservation)
Comparing NdFluents against other approaches
Example (rule preservation)
Comparing NdFluents against other approaches

Example (non-contextual rule preservation)

```
\text{ex:BarackObama} \xrightarrow{\text{ex:brother}} \text{ex:SadamHussein}
```

```
\text{ex:brother} \xrightarrow{\text{ex:statedBy}} \text{ex:ShadyNews}
```

```
\text{ex:SadamHussein} \xrightarrow{\text{ex:brother}} \text{ex:BarackObama}
```

```
\text{ex:brother} \xrightarrow{\text{rdf:type}} \text{owl:SymmetricProperty}
```

\[ \top \]
Comparing NdFluents against other approaches

Example (non-contextual rule preservation)
Reification.

Diagram:
- ex:Statement#2
  - rdf:subject: ex:BarackObama
  - rdf:predicate: ex:brother
  - rdf:object: ex:SadamHussein
  - ex:statedBy: ex:ShadyNews
Reification.
N-Ary Relations.

ex:BarackObama ex:hasRelation ex:brother ex:hasValue ex:SadamHussein

ex:statedBy ex:ShadyNews
N-Ary Relations.

ex:BarackObama ex:hasRelation ex:brother

ex:brother ex:hasValue ex:SadamHussein

ex:statedBy ex:ShadyNews

ex:BarackObama ex:hasRelation ex:Brother

ex:Brother ex:hasValue ex:Paris

ex:statedBy ex:ShadyNews
Singleton Property.
Singleton Property.
Singleton Property.

![Diagram showing relationships between entities and properties.]

- ex:BarackObama
- ex:SadamHussein
- ex:brother#1
- ex:StatedBy
- ex:SingletonPropertyOf
- ex:ShadyNews

This diagram illustrates the singleton property relationships between different entities, showing how entities like ex:BarackObama and ex:SadamHussein are connected through sp:SingletonPropertyOf and ex:StatedBy properties.
NdFluents.

- **ex:BarackObama@SN**
- **ex:SadamHussein@SN**
- **nd:provenancePartOf**
- **nd:provenanceExtent**
- **nd:Provenance**
- **ex:brother**
- **ex:statedBy**
- **ex:ShadyNews**
- **ex:BarackObama**
- **ex:SadamHussein**
NdFluents.
NdFluents.
NdFluents.

Diagram showing relationships between entities:
- ex:BarackObama@SN
- ex:SadamHussein@SN
- ex:brother
- ex:ShadyNews
- ex:BarackObama
- ex:SadamHussein

Relationships:
- ex:BarackObama@SN is a part of nd:provenancePartOf ex:ShadyNews
- ex:SadamHussein@SN is a part of nd:provenancePartOf ex:ShadyNews
- ex:ShadyNews has a statedBy ex:brother connection to ex:SadamHussein
- ex:SadamHussein@SN and ex:BarackObama@SN are connected by ex:brother
NdFluents.

\[\text{ex:BarackObama}@\text{SN}\quad \text{ex:brother}\quad \text{ex:SadamHussein}@\text{SN}\]

\[\text{ex:BarackObama}\quad \text{ex:SadamHussein}\]

\[\text{nd:provenancePartOf}\quad \text{nd:provenancePartOf}\]

\[\text{nd:provenanceExtent}\quad \text{nd:provenanceExtent}\]

\[\text{nd:Provenance}\quad \text{ex:statedBy}\quad \text{ex:ShadyNews}\]

\[\text{ex:BarackObama}\quad \text{ex:SadamHussein}\]
NdFluents. Additional Inferences

\[ f(?p \ a \ \text{InverseFunctionalProperty}) \]  
\[ \equiv \ f(?v \ \text{sameAs} \ ?v) \]
NdFluents. Additional Inferences

\[
f(?p \text{ a InverseFunctionalProperty}) 
\models f(?v \text{ sameAs } ?v)
\]

Diagram:
- ex:JohnSmith@X
- ex:JohnDoe@X
- ex:mailbox@X
- ex:JohnSmith
- ex:JohnDoe
- ex:mailbox
- foaf:mbox
- nd:provenancePartOf
- nd:provenanceExtent
- nd:Provenance
- ?p a InverseFunctionalProperty
- ?u ?p ?v
- ?u ?p ?w
- ?v sameAs ?v
NdFluents. Additional Inferences

\[
f(?p \ a \ InverseFunctionalProperty) \models f(?v \ sameAs \ ?v)\]

\[
(\exists p\ a\ InverseFunctionalProperty)(?u \ ?p \ ?v) \\
(\exists p\ a\ InverseFunctionalProperty)(?u \ ?p \ ?w)
\]
Comparing NdFluents against other approaches

Results

- Compared 10 D* (subset of RDFS) rules and 13 P (subset of OWL) rules.
- Including additional inferences:

<table>
<thead>
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<th>Approach</th>
<th>Preservation</th>
<th>Non-Contextual Preservation</th>
<th>Additional Inferences</th>
<th>Risk</th>
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<td>Singleton Property</td>
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<td>13</td>
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<tr>
<td>NdFluents</td>
<td>14</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>
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Conclusions and Future Work

Conclusions:

- First extension of 4dFluents for arbitrary combinations of any number of contexts
- Standard RDFS and OWL semantics
- 8+2 out of 10 D* rules covered
- 7+4 out of 13 P rules covered
- No risk of undesirable inferences

Future Work:

- Apply to real-world datasets for question answering
- Delve more into rule preservation
- Perform experimental evaluations of the models
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