Towards Cross-checking WordNet and SUMO Using Meronymy

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1 Introduction

2 Cross-checking WordNet and Adimen-SUMO

3 Some Experimental Results

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Cross-checking knowledge sources

- This work is an initial study about:
  - Knowledge representation
  - Common Sense (world knowledge)
  - Reasoning
- In particular, we focus on:
  - WordNet (Fellbaum, 1998)
  - SUMO (Niles and Pease, 2001)
  - WN-SUMO Mapping (Niles and Pease, 2003)
- We expect all these knowledge sources to encode correct world knowledge (true knowledge).
- Despite being created manually, they are not free of errors and discrepancies.
- We apply a new Black-box strategy (Álvez et al., 2017b) to the meronymy information encoded in these resources.
SUMO (Niles and Pease, 2001)

- IEEE Standard Upper Ontology Working Group
- SUMO syntax goes beyond first-order logic (FOL)
- SUMO cannot be directly used by FOL Automated Theorem Provers (ATPs) without a suitable transformation
- Different transformations of SUMO into FOL:
  - TPTP-SUMO (Pease and Sutcliffe, 2007)
  - Adimen-SUMO (Álvez et al., 2012)
Adimen-SUMO I

- Following the line of (Horrocks and Voronkov, 2006)
- Obtained by applying a reengineering process to SUMO
  - With the help of ATPs (*Automated Theorem Provers*)
  - Around an 88% of the *core* of SUMO (top and middle levels) is translated
  - Domain ontologies are not used (by now)
  - The resulting ontology can be used in tasks that involve reasoning with commonsense knowledge
- The process of manually debugging the ontology is very costly
  - Only 64 manually created tests
  - Example:

\[
(\Rightarrow \\
  (\text{and} \\
   (\text{instance } ?\text{BRAIN Brain}) \\
   (\text{instance } ?\text{PLANT Plant})) \\
  (\text{not} \\
   (\text{properPart } ?\text{BRAIN } ?\text{PLANT})))
\]
We have proposed different methodologies for the automatic debugging of ontologies like Adimen-SUMO:

- Black-box testing strategies (Álvez et al., 2015, 2017b)
- White-box testing strategies (Álvez et al., 2017a)

More than 100 axioms from Adimen-SUMO have been improved.
Black-box Testing I

- Introduced in (Álvez et al., 2015) and fully described in (Álvez et al., 2017b)
- Adaptation of the methodology for the design and evaluation of ontologies introduced in (Grüninger and Fox, 1995)
- Based on the use of Competency Questions (CQs):
  - Problems that an ontology is expected to answer
- Its application is automatic by means of the use of ATPs
- Classification of (dual) problems (truth and falsity tests):
  - Passing: the ATPs are able to demonstrate a truth test
  - Non-passing: the ATPs are able to demonstrate a falsity test
  - Unknown: the ATPs produce no answer within a time limit
CQs are automatically created on the basis of few Question Patterns (QPs) by exploiting WordNet and its mapping into SUMO.

In Álvez et al., 2017b:
- antonym and event (agent, instrument and result) relations
- 11 QPs are proposed
- More than 7,500 CQs are created
- More than 43% of CQs are validated
- Example:

\[
\text{(forall } (?Y) \\
\quad (\Rightarrow \\
\quad \quad (\text{instance } ?Y \text{ MusicalComposition}) \\
\quad \quad (\text{exists } (?X) \\
\quad \quad \quad (\text{instance } ?X \text{ ComposingMusic}) \\
\quad \quad \quad \quad (\text{result } ?X ?Y))))
\]
Mapping between WordNet and SUMO

- Described in (Niles and Pease, 2003)
- It connects synsets of WordNet to terms of SUMO using 3 relations:
  - equivalence (=)
  - subsumption (+)
  - instance (@)
- Some examples:

\[
\begin{align*}
\langle \text{calcium}^1_n \rangle & : [\text{Calcium}_c=] \\
\langle \text{calcium}_\text{oxide}^1_n \rangle & : [\text{Compound Substance}_c+] \\
\langle \text{police}_\text{officer}^1_n \rangle & : [\text{PoliceOfficer}_a=] \\
\langle \text{police}_\text{force}^1_n \rangle & : [\text{PoliceOrganization}_c+] \\
\end{align*}
\]
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WordNet v3.0 provides 3 part-whole relations (22,187):

- **part**: the general meronymy relation (9,097)
- **member**: it relates particulars and groups (12,293)
- **substance**: it relates physical matters and things (797)

For example:

\[\langle \text{committee}_n \rangle \leftarrow \langle \text{member} \rangle \leftarrow \langle \text{committee\_member}_n \rangle\]

\[\langle \text{wine}_n \rangle \leftarrow \langle \text{substance} \rangle \leftarrow \langle \text{grape}_n \rangle\]
Exploiting the Mapping between WordNet and SUMO

- First, creating a mapping between WordNet and Adimen-SUMO:

  \[ \text{Cooking}_c^+ \] (Top level)

  \[ \text{Frying}_c = \] (Food ontology)

  \[ \langle frying_n^1 \rangle : \text{Frying}_c \]

- Propose a formal characterization of the mapping information:

  \[ \langle \text{male\_horse}_n^1 \rangle : [\text{Male}_a^+] [\text{Horse}_c^+] \]

  - **Literal interpretation:**
    \[
    (\text{and} (\text{instance} \ ?X \text{Male}) \ (\text{instance} \ ?X \text{Horse}))
    \]

  - **Precise interpretation:**
    \[
    (\text{and} (\text{attribute} \ ?X \text{Male}) \ (\text{instance} \ ?X \text{Horse}))
    \]
Four different QPs depending on the used mapping relations (*precise* interpretation):

- *equivalence*
- *subsumption* or *instance*

QPs are instantiated according to the mapping information of the synsets in the WordNet meronymy pairs.
Applying the first QP (precise interpretation):

\[
(\exists X \exists Y) \\
(\text{and}) \\
<s\_part ?X> \\
<s\_whole ?Y> \\
(<\text{SUMO\_predicate}> ?X ?Y)))
\]

to the following WN-SUMO meronymy relation:

\[
\langle \text{genus\_malacosoma}^1_n \rangle : [\text{Larval}_{a+} ] \\
\langle \text{member} \rangle \\
\langle \text{malacosoma\_americana}^1_n \rangle : [\text{Insect}_{c+} ]
\]
Question patterns for the Creation of CQs (III)

- Creates the following CQ:

\[
(\text{exists} \ (\?X \ ?Y) \\
\quad \text{and} \\
\quad (\text{instance} \ ?X \ \text{Insect}) \\
\quad (\text{attribute} \ ?Y \ \text{Larval}) \\
\quad (\text{member} \ ?X \ ?Y)))
\]
Question patterns for the Creation of CQs (IV)

- Mapping of WordNet relations to Adimen-SUMO predicates, which have domain restrictions:

\[
\langle \text{part} \rangle : \ [ \ part_r(Object_c \times Object_c) ] \\
\langle \text{member} \rangle : \ [ \ member_r(SelfConnectedObject_c \times Collection_c) ] \\
\langle \text{substance} \rangle : \ [ \ material_r(Substance_c \times CorpuscularObject_c) ] \\
\]

- Many discrepancies arise during the instantiation of question patterns.
- 14,513 part relations from 22,187 (65%) do not hold domain conditions.
  - Example:

\[
\langle \text{wine}_{1}^{1} \rangle : \ [ \ Wine_c= ] \\
\langle \text{substance} \rangle : \ [ \text{material}_r ] \\
\langle \text{grape}_{1}^{1} \rangle : \ [ \text{FruitOrVegetable}_c+ ]
\]

  - Reason: the first argument of \text{material}_r is restricted to be \text{Substance}_c, which is incompatible with \text{FruitOrVegetable}_c

- So, we concentrate on the remaining 7,674 relations (35%)
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Creating CQs and applying ATPs

- We apply the 4 QPs to the 7,674 relations allowing to create 2,145 CQs.
- When testing these CQs using ATPs such as Vampire (Kovács and Voronkov, 2013) or E-prover (Schulz, 2002):
  - **Passing**: knowledge validation
  - **Non-passing**: knowledge mismatches
    - WN-SUMO mapping issues
    - WordNet issues
    - SUMO issues
  - **Unknown**: Missing knowledge ... or insufficient execution time?
Some Experimental Results

Knowledge Validation

Example:

\[
\langle \text{police\_force}_{1n} \rangle : \ [ \text{PoliceOrganization}_{c+} ]
\]

\[
\langle \text{member} \rangle \uparrow\quad \quad \quad \quad [\text{member}_r]
\]

\[
\langle \text{police\_officer}_{1n} \rangle : \ [ \text{PoliceOfficer}_{a=} ]
\]

Reason:

- The resulting CQ is entailed by Adimen-SUMO:

\[
(\forall (?Y)
\begin{array}{l}
(\Rightarrow \\
(\text{attribute } ?Y \text{ PoliceOfficer}) \\
(\exists (?X) \\
(\text{and} \\
($\text{instance } ?X \text{ PoliceOrganization}) \\
(\text{member } ?X ?Y)))))
\end{array}
\]

Javier Álvez, German Rigau (UPV/EHU) Towards Cross-checking WordNet and SUMO
Detection of Mapping Mismatches

Example:

\[ \langle \text{genus\_malacosoma}_n \rangle : [ \text{Larval}_a ] \]

\[ \langle \text{member} \rangle \]

\[ \langle \text{malacosoma\_americana}_n \rangle : [ \text{Insect}_c ] \]

Reason:
- The attribute \text{Larval}_a cannot be applied to groups in Adimen-SUMO
Detection of WordNet Issues

- Example:

\[
\langle \text{cell}_n^2 \rangle : \ [ \text{Cell}_c = \ ] \\
\langle \text{part} \rangle : \ [ \text{part}_r ] \\
\langle \text{cell}_{\text{nucleus}}^1_n \rangle : \ [ \text{CellNucleus}_c = \ ]
\]

- Reason:
  - Some cells lack a nucleus, as stated by the following Adimen-SUMO axiom:

\[
(\forall ?C) \rightarrow \\
\quad \quad (\text{instance} \ ?C \ \text{RedBloodCell}) \rightarrow \\
\quad \quad \text{not} \ (\exists ?N) \ (\text{and} \\
\quad \quad \quad (\text{instance} \ ?N \ \text{CellNucleus}) \\
\quad \quad \quad \ (\text{part} \ ?N \ ?C)))
\]
Detection of Adimen-SUMO Issues

- Example:

  \[
  \langle \text{water\_ice}^2 \rangle : \ [\text{Solid}_a + ] \\
  \langle \text{substance} \rangle : \ [\text{material}_r] \\
  \langle \text{water}^1 \rangle : \ [\text{Water}_c = ]
  \]

- Problem:

  - The application of subattributes of \text{PhysicalState}_A (as \text{Solid}_a) was restricted to be only a property of \text{Substance}_c:

  \[
  (\text{forall} \ (?\text{OBJ})) \\
  (\iff) \\
  (\text{instance} \ ?\text{OBJ} \text{Substance}) \\
  (\exists \ (?\text{ATTR})) \\
  (\text{and}) \\
  (\text{instance} \ ?\text{ATTR} \text{PhysicalState}) \\
  (\text{attribute} \ ?\text{OBJ} ?\text{ATTR}))
  \]
Summary

- Reported in (Álvez and Rigau, 2018)

| SUMO relations | CQs | Total |
|----------------|-----|-------|
| | QP #1 | QP #2 | QP #3 | QP #4 |       |
| |       |       |       |       |       |
| part<sub>r</sub> | +599  | +56   | +162  | +8   | +825  |
|                 | -6    | 0     | -1    | -5   | -12   |
| member<sub>r</sub> | +10   | +1    | +1    | +0   | +12   |
|                 | -9    | 0     | 0     | 0    | -9    |
| material<sub>r</sub> | +17   | +1    | +2    | 0    | +17   |
|                 | -0    | -2    | 0     | 0    | -2    |
| Total           | +626  | +58   | +165  | +8   | +857  |
|                 | -15   | -2    | -1    | -5   | -23   |

- 857 Passing CQs (39.95% of total) enable to validate the knowledge of WordNet, SUMO and their mapping.
- **part** is better aligned and covered (825 truth-tests, 42.09%) than **member** (only 12 truth-tests, 9.92%) and **substance** (17 truth-tests, 26.56%).
- Different issues are detected (23 falsity-tests, 1.07%).
- More than 60% of the total is *Unknown*. 
Conclusions and Future Work
Conclusions

- Framework and benchmark for formal commonsense reasoning
- More than 10,000 CQs available (around 60% Unknown)!
- First steps cross-checking of WordNet, Adimen-SUMO and its mapping:
  - Validation of some pieces of knowledge
  - Detection of knowledge mismatches
  - Detection of missing knowledge
- Resources are ready for its application to practical NLP tasks
- http://adimen.si.ehu.es/web/AdimenSUMO
- https://vprover.github.io/
- https://github.com/eprover/eprover
Future Work

- Improving the WN-SUMO mapping
- Extending our proposal to additional WordNet relations
- Automatically derive new SUMO axioms from WordNet knowledge
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