Semantic Textual Similarity

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Introduction

- Based on the data and evaluation frameworks for *SemEval-2012 Task 6: A Pilot on Semantic Textual Similarity*, propose a framework to evaluate semantic similarity between pairs of sentences.

Methodology overview

- Feature extraction:
  - Lexical features (32)
  - Syntactic features (8)
  - String features (18)

- Preprocessing: remove punctuation and convert to lower case.
  - Extra preprocessing:
    - Stop words (for lexical and string feature extraction)
    - Lemmatization (for lexical and string feature extraction)
    - Word sense disambiguation (for lexical feature extraction)

- Training models:
  - Multi-Layer Perceptron (MLP)
  - Support Vector Regressor (SVR)
  - Random Forest Regressor (RFR)

Lexical features

The process of analyzing a sentence's structure through the identification and classification of individual words.

- Jaccard distance
- **Containtment similarity**
- **Pairwise word similarity**
- **Weighted word overlap**
- **WordNet augmented word overlap**
- **Greedy lemma aligning overlap**

Lexical features

The sets S_1 and S_2 will be list of words or n-tuples of n-grams of each sentence.

- Containtment similarity measure (Broder, 1997)

$$csimm(S_1, S_2) = \frac{|S_1 \cap S_2|}{\min\{|S_1|, |S_2|\}}$$

- Pairwise word similarity
  - Mean of the maximum similarity using: Lin similarity and Resnik similarity weighted by Inverse Document Frequency (IDF) coefficient.
- Weighted word overlap

$$wwc(S_1, S_2) = \frac{\sum_{w \in S_1 \cap S_2} ic(w)}{\sum_{w' \in S_2} ic(w')}$$

Lexical features

- WordNet augmented word overlap

$$P_{WN}(S_1, S_2) = \frac{1}{|S_2|} \sum_{w_1 \in S_1} \text{score}(w_1, S_2)$$

$$\text{score}(w, S) = \begin{cases} 1 & \text{if } w \in S \\ \max_{w' \in S}\{\text{pathsim}(w, w')\} & \text{otherwise} \end{cases}$$

- Greedy lemma aligning overlap

$$glao(S_1, S_2) = \frac{\sum_{(l_1, l_2) \in P} \max\{\text{ic}(l_1), \text{ic}(l_2)\} \cdot \text{linsim}(l_1, l_2)}{\max\{|S_1|, |S_2|\}}$$

P is the set of lemma pairs obtained by greedy alignment.

Syntactic Features

Process of analyzing a sentence's structure according to the grammatical rules and how words are related withing the sentence.

- N-grams overlap removing function words (prepositions, conjunctions, articles)

Sentence: "a horse eats carrots" $\Rightarrow$ "horse eats carrots" (content words)

$$ngo(S_1, S_2) = 2 \cdot \left(\frac{|S_1|}{|S_1 \cap S_2|} + \frac{|S_2|}{|S_1 \cap S_2|} \right)^{-1}$$

Syntactic Features

- Syntactic roles similarity

`python library Stanza` (Stanford NLP Group, 2006)

Sentence: "a horse eats carrots and the man cleans the farm for the owner"

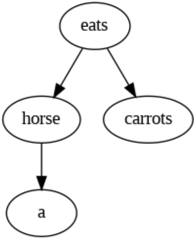
```
'p':  [{'carrot','eat'}, {'owner','farm','for','clean'}],
's':  [{'horse'}, {'man'}],
'o':  [{'carrot'}, {'farm'}, {'for', 'owner'}]
```

$$chunksim(C1, C2) = \sum_{l_1 \in C1} \sum_{l_2 \in C2} ssim(l_1, l_2)$$

Syntactic Features

- Syntactic dependencies overlap

`python library Stanza` (Stanford NLP Group, 2006)
Sentence: "a horse eats carrots"



$$\mathrm{wdrc}(S_1, S_2) = \frac{\sum_{r \in S_1 \cap S_2} \max(\mathrm{ic}(g(r)), \mathrm{ic}(d(r)))}{\sum_{r \in S_2} \max(\mathrm{ic}(g(r)), \mathrm{ic}(d(r)))}$$

String Feature

- Character n-grams (Barrón-Cedeño, 2010)
  - `from sklearn.feature_extraction.text import TfidfVectorizer`

Sentece: "a horse eats carrots"

3-grams strigns: ['a h', ' ho', 'hor', 'ors', 'rse', 'se ', 'e e', ' ea', 'eat', 'ats', 'ts ', 's c', ' ca', 'car', 'arr', 'rro', 'rot', 'ots']

$$\text{cossim(A,B)} = \frac{\text{A} \cdot \text{B}}{\|\text{A}\| \|\text{B}\|}$$

- Greedy String Tailing

$$gstsim(S_1, S_2) = \frac{\sum_{t \in S_1 \cap S_2} \text{len}(t)}{\max\{\text{len}(S_1), \text{len}(S_2)\}}$$

Threshold for the lenght of the tile: 5, 10.

Model & Feature Overview

- Models: MLP, SVR, RFR.
- Features:
  - Lexical, Syntactic, Strings (individually).
  - Unrestricted (Lexical + Syntactic + Strings).
  - FeatureSelection, based on:
    - Pearson correlation for MLP/SVR
    - Feature importance for RFR
- Performance measured using Pearson correlation with the Gold Standard

Results Summary

Features	MLP	SVR	RFR
Lexical	0.607	0.681	0.728
Syntactic	0.666	0.658	0.661
Strings	0.674	0.676	0.685
Unrestricted	0.652	0.744	**0.757**
FeatureSelection	0.744	0.742	0.745

- Best performance: RFR with Unrestricted (0.757)
- Syntactic features less informative than Lexical/Strings
- Feature combination improves SVR/RFR
- MLP suffers from overfitting

Top Features: Pearson Correlation

Top 5 features based on Pearson correlation with the Gold Standard:

Feature	**Correlation**
lemmas_wn_aug_overlap	0.7233
normal_char_2gram	0.7216
lemmas_char_2gram	0.6902
sw_char_2gram	0.6876
sw_gst_5	0.6666

Three key feature types:

- WordNet-Augmented Overlap (Lexical)
- Character n-grams (String-based)
- Greedy String Tiling (String-based)

Top Features: Feature Importance

Top 5 features based on Feature Importance scores from RFR:

Feature	Importance
lemmas_wn_aug_overlap	0.4325
normal_char_2gram	0.1630
chunk_sim_s	0.0413
lemmas_weighted_overlap	0.0275
normal_char_5gram	0.0199

The top 2 features:

- Common with Pearson correlation table.
- Have significantly higher importance, indicating their dominance in sentence similarity prediction

Feature types: 2 Lexical, 1 Syntactic, 2 Strings-related.

Conclusion

- Best performance: RFR with Unrestricted features (0.757 Pearson correlation).
- Key features: *WordNet-Augmented Overlap* and *Character n-grams*.
- Lexical and String-based features encode most of the relevant information for STS.
- Combining feature types (Lexical, Syntactic, Strings) significantly boosts performance.

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