Splitting Compounds By Semantic Analogy

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Introduction

Compound words...

- ... make life hard for standard NLP applications, incl. MT
- ... are often modeled with shallow information (e.g. Moses frequency-based splitter)

Question: Can we use distributional semantics to do deeper processing of compounds in a simple way?

Splitting compounds for SMT

- Koehn and Knight (2003) showed PBMT systems can better deal with compounds if they are split into their meaningful parts
- Difficulty: many possible splits, we need to choose the correct ones

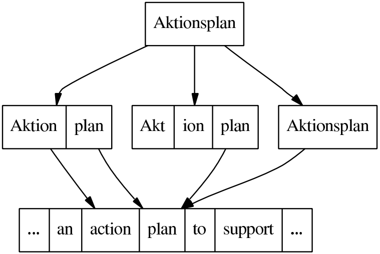


Figure: Compound splitting example from Koehn and Knight (2003).

Compounds and the semantic vector space

Semantic vector space

- Word embeddings saw surge of successful applications recently
- Basic idea: "You shall know a word by the company it keeps"
  - Words are mapped to vectors of real numbers in low dimensional space
  - These vectors are estimated on large amounts of text data using a neural network

Compounds and the semantic vector space

Semantic vector space

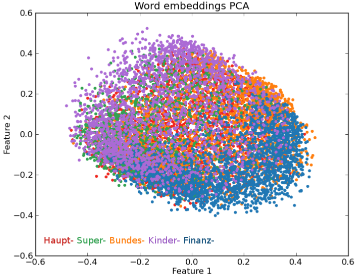
- Mikolov et al. (2013) showed that word embeddings capture some linguistic phenomena:
  - *king* is to *man* what *queen* is to *woman*
    $v(\text{king}) - v(\text{man}) + v(\text{woman}) \approx v(\text{queen})$
  - *cars* is to *car* what *dogs* is to *dog*
    $v(\text{cars}) - v(\text{car}) + v(\text{dog}) \approx v(\text{dogs})$

Compounds and the semantic vector space

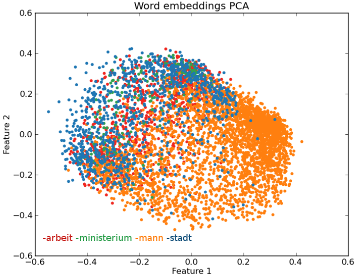
Morphology induction from word embeddings

- Soricut and Och (2015) exploit these regularities to induce morphology from word embeddings
- Method:
  - Extract prefix and suffix replacement rules from the vocabulary
  - Keep 1000 examples of each rule
  - Judge how well each pair explains the other pairs: *cars* is to *car* what *dogs* is to *dog*?
  - Find most representative examples for each rule

Compounds and the semantic vector space



(a) Compounds with same modifier.



(b) Compounds with the same head.

The analogy test

- We model compounds based on their modifiers
- Potential compound splits are judged by how similar they are to a set of prototypical compounds for each modifier

Analogy test: *Mauszeiger* is to *Zeiger* what *Mausklick* is to *Klick*?

(mouse pointer) (pointer) (mouse click) (click)

Extracting potential compound splits

For all words in the vocabulary:

- Extract all possible string prefixes ≥ 4:
  Bundespräsident $\rightarrow$ *Bund, Bunde, Bundes, ...*
- Judge each Modifier+Compound pair by how well it explains others

Judging potential compound splits

All potential compounds with prefix *Maus*

Maus|kostüm
Maus|zeiger
Maus|stämme
Maus|klick
Maus|hirn
Maus|tasten
Maus|ersatz
Maus|mutanten
Maus|knopf
Maus|steuerung
Maus|bewegung
Maus|gene
Maus|klicks
Maus|hirns
Maus|zeiger
Maus|hirnen
Maus|bedienung

...
(up to 500)

Judging potential compound splits

All potential compounds $\times$ All potential compounds

Maus|kostüm	Maus|kostüm
Maus|zeiger	Maus|zeiger
Maus|stämme	Maus|stämme
Maus|klick	Maus|klick
Maus|hirn	Maus|hirn
Maus|tasten	Maus|tasten
Maus|ersatz	Maus|ersatz
Maus|mutanten	Maus|mutanten
Maus|knopf	Maus|knopf
Maus|steuerung	Maus|steuerung
Maus|bewegung	Maus|bewegung
Maus|gene	Maus|gene
Maus|klicks	Maus|klicks
Maus|hirns	Maus|hirns
Maus|zeiger	Maus|zeiger
Maus|hirnen	Maus|hirnen
Maus|bedienung	Maus|bedienung
...	...
(up to 500)	(up to 500)

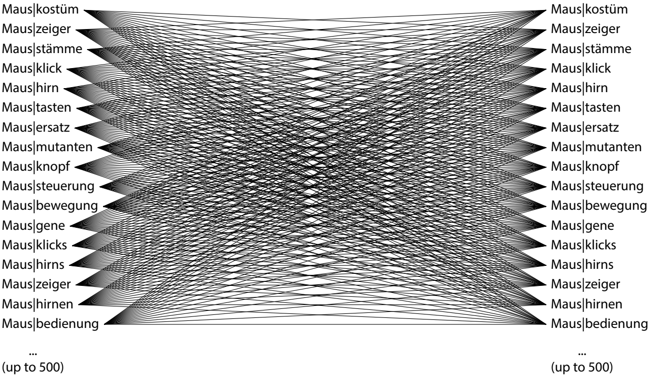
Judging potential compound splits

All potential compounds $\times$ All potential compounds

Maus|kostüm	Maus|kostüm
Maus|zeiger	Maus|zeiger
Maus|stämme	Maus|stämme
Maus|klick	Maus|klick
Maus|hirn	Maus|hirn
Maus|tasten	Maus|tasten
Maus|ersatz	Maus|ersatz
Maus|mutanten	Maus|mutanten
Maus|knopf	Maus|knopf
Maus|steuerung	Maus|steuerung
Maus|bewegung	Maus|bewegung
Maus|gene	Maus|gene
Maus|klicks	Maus|klicks
Maus|hirns	Maus|hirns
Maus|zeiger	Maus|zeiger
Maus|hirnen	Maus|hirnen
Maus|bedienung	Maus|bedienung
...	...
(up to 500)	(up to 500)

Judging potential compound splits

All potential compounds $\times$ All potential compounds



Judging potential compound splits

Maus|zeiger	Maus|zeiger
Maus|stämme	Maus|stämme
Maus|klick	Maus|klick
Maus|hirn	Maus|hirn

Perform analogy test: *Mauszeiger* is to *Zeiger* what *Mausklick* is to *Klick*?
(mouse pointer) (pointer) (mouse click) (click)

Computational considerations

- **Analogy test is expensive!**
- True and predicted vectors:
  - $v_{\text{Mausklick}}$
  - $\hat{v}_{\text{Mausklick}} = \text{Mauszeiger} - \text{Zeiger} + \text{Klick}$
- Two evaluation functions: $\textsc{Rank}$ and $\textsc{Cosine}$

Computational considerations

- Exact but slow implementation:

$$\textsc{Rank}(v_{cmpd}, \hat{v}_{cmpd}) = \textsc{Rank of } v_{cmpd} \textsc{ in } \operatorname*{arg\,sort}_{w \in V} \left[\textsc{Cosine}\left(v_w, \hat{v}_{cmpd}\right) \right]$$

- Approximate but fast implementation:
  - Approximate k-nearest neighbor search
  - We use the Spotify Annoy library (C++) to perform the search

Prototypes

Compounds that are good examples of a compound modifier.

- These are best at explaining other similar modifier+compound pairs
- We call this set the modifier's ***prototypes***

Extracting prototypes

Maus|kostüm
Maus|zeiger
Maus|stämme
Maus|klick
Maus|hirn
Maus|tasten
Maus|ersatz
Maus|mutanten
Maus|knopf
Maus|steuerung
Maus|bewegung
Maus|gene
Maus|klicks
Maus|hirns
Maus|zeiger
Maus|hirnen
Maus|bedienung
...
(up to 500)

Maus|kostüm
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Maus|mutanten
Maus|knopf
Maus|steuerung
Maus|bewegung
Maus|gene
Maus|klicks
Maus|hirns
Maus|zeiger
Maus|hirnen
Maus|bedienung
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(up to 500)

Extracting prototypes

Maus|kostüm	Maus|kostüm
Maus|zeiger	Maus|zeiger
Maus|stämme	Maus|stämme
Maus|klick	Maus|klick
Maus|hirn	Maus|hirn
Maus|tasten	Maus|tasten
Maus|ersatz	Maus|ersatz
Maus|mutanten	Maus|mutanten
Maus|knopf	Maus|knopf
Maus|steuerung	Maus|steuerung
Maus|bewegung	Maus|bewegung
Maus|gene	Maus|gene
Maus|klicks	Maus|klicks
Maus|hirns	Maus|hirns
Maus|zeiger	Maus|zeiger
Maus|hirnen	Maus|hirnen
Maus|bedienung	Maus|bedienung
...	...
(up to 500)	(up to 500)

Extracting prototypes

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Maus|zeiger	Maus|zeiger
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Maus|klick	Maus|klick
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Maus|tasten	Maus|tasten
Maus|ersatz	Maus|ersatz
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Maus|steuerung	Maus|steuerung
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Maus|gene	Maus|gene
Maus|klicks	Maus|klicks
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Extracting prototypes

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Maus|klicks	Maus|klicks
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Extracting prototypes

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Maus|gene	Maus|gene
Maus|klicks	Maus|klicks
Maus|hirns	Maus|hirns
Maus|zeiger	Maus|zeiger
Maus|hirnen	Maus|hirnen
Maus|bedienung	Maus|bedienung
...	...
(up to 500)	(up to 500)

Extracted prototypes for *Maus-*

Prototype	Evidence words
$v_{\text{-Zeiger}}$	-Bewegung -Klicks -Klick -Tasten -Zeiger
$v_{\text{-Stämme}}$	-Mutanten -Gene -Hirnen -Stämme
$v_{\text{-Kostüm}}$	-Knopf -Hirn -Hirns -Kostüm
$v_{\text{-Steuerung}}$	-Ersatz -Bedienung -Steuerung

Compound splitting: *Mausmutation*

Mausmutation

- We start from the left...

Compound splitting: *Mausmutation*

Mausmutation

$\longrightarrow$

- Do I know the modifier *Mau*? No!

Compound splitting: *Mausmutation*

Maus mutation

$\longrightarrow$

- Do I know the modifier *Maus*? Yes!

Compound splitting: *Mausmutation*

Mausmutation

$\longrightarrow$

- Do I know the modifier *Maus*? Yes!

  Prototypes:

  - -Zeiger
  - -Stämme
  - -Kostüm
  - -Steuerung

Compound splitting: *Mausmutation*

Mausmutation

$\longrightarrow$

- Do I know the modifier *Maus*? Yes!

  Prototypes:

  – ~~-Zeiger~~
  – -Stämme ✓ $\rightarrow$ ***Mausmutation*** is to ***Mutation*** what ***Mausstämme*** is to ***Stämme***.
  – ~~-Kostüm~~
  – ~~-Steuerung~~

Compound splitting: *Mausmutation*

Mausmutation

$\longrightarrow$

- Do I know the modifier *Mausm*? No!

Compound splitting: *Mausmutation*

Mausmutation

- And so on...

Compound splitting: *Mausmutation*

Maus|mutation

- The prototype with the highest score will be our split!
- Recurse...

Compound splitting: *Plantage*

Plantage

- Let's try another example...

Compound splitting: *Plantage*

$$\underline{\text{Plan}}\text{tage}$$
$$\longrightarrow$$

- Do I know the modifier *Plan*? Yes!

Compound splitting: *Plantage*

Plantage

$\longrightarrow$

- Do I know the modifier *Plan*? Yes! Prototypes:
  - -Feststellung
  - -Wert
  - -Fertiger
  - ...

Compound splitting: *Plantage*

Plantage

$\longrightarrow$

- Do I know the modifier *Plan*? Yes! Prototypes:
  - ~~-Feststellung~~
  - ~~-Wert~~
  - ~~-Fertiger~~
  - ...

Compound splitting: *Plantage*

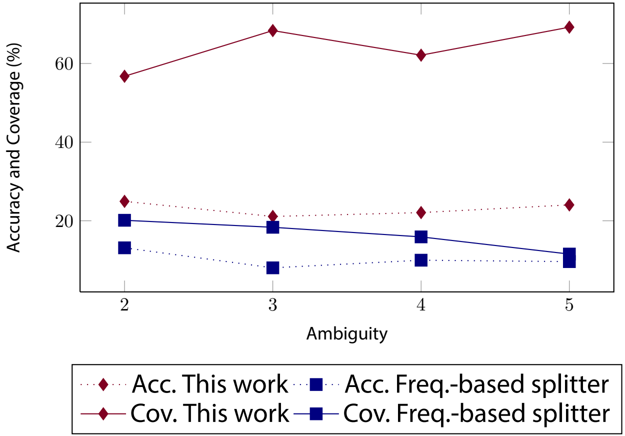
Plantage

- No compound split!

Intrinsic evaluation

- Evaluation on human-annotated dataset (Henrich and Hinrichs, 2011)
  - ~50k compounds
  - only binary splits
- Baseline: Frequency-based Moses compound splitter (Koehn and Knight, 2003)
- We evaluate:
  - Accuracy: $\frac{|\text{correct splits}|}{|\text{compounds}|}$
  - Coverage: $\frac{|\text{compounds split}|}{|\text{compounds}|}$

Intrinsic evaluation



Machine translation experiments (German to English)

	(a) No comp. splitting			(b) Rare: c(w) < 20			(c) All words		
	Splits	BLEU	MTR	Splits	BLEU	MTR	Splits	BLEU	MTR
Moses splitter	0	17.6	25.5	231	17.6	25.7	244	17.9	25.8^{A}
This work				744	$\mathbf{18.2}^{ABC}$	$\mathbf{26.1}^{ABC}$	1616	17.7	26.3^{A}

^{A} Stat. sign. against (a) at $p < 0.05$ ^{B} Stat. sign. against Moses splitter at same c(w) at $p < 0.05$
^{C} Stat. sign. against best Moses splitter (c) at $p < 0.05$

Conclusion

- Regularities in semantic vector space can be used to model composition of compounds
- We can extract modifiers and prototypes (Soricut and Och, 2015)
- Compound splitting algorithm:
  - Good intrinsic performance on gold standard
  - Improved translation quality (standard PBMT setup)
  - Especially adept at splitting highly ambiguous compounds

Thank You!

Any questions?

References

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