Word Sense Disambiguation

CS-585

Natural Language Processing

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Word Sense Disambiguation

- Many words have multiple meanings
  - E.g, river *bank,* financial *bank*

- **Problem:** Assign proper sense to each ambiguous word in text

- **Applications:**
  - Machine translation
  - Information retrieval
  - Semantic interpretation of text

Sense Tagging

- Idea: Treat sense disambiguation like POS tagging, just with "semantic tags"

Distributional Similarity

- The problems differ:
  - POS tags depend on specific structural cues (mostly neighboring tags)
  - Senses depend on **semantic context** – less structured, longer distance dependency

Wordnet and Synsets

- **Wordnet** is a manually-compiled machine-readable dictionary for English (and a few other languages), maintained by Princeton University
  - https://wordnet.princeton.edu/
- It can be used programmatically to look up word "**synsets**" (senses related to a set of words)

shoe

shoe.n.01: footwear shaped to fit the foot (below the ankle) with a flexible upper of leather or plastic and a sole and heel of heavier material

shoe.n.02: (card games) a case from which playing cards are dealt one at a time

horseshoe.n.02: U-shaped plate nailed to underside of horse's hoof

Slide from Session 05

Approaches

- Dictionary-Based Learning
  - Learn to distinguish senses from dictionary entries
- Supervised learning
  - Learn from a pretagged corpus
- Unsupervised Learning
  - Automatically cluster word occurrences into different senses
  - "Clustering": Partioning of datapoints into related groups or clusters

WSD Evaluation

- Train and test on pretagged texts is difficult to obtain
- **Pseudowords** - Artificial data: ‘merge’ two words to form an ‘ambiguous’ word with two ‘senses’
- Example, replace all occurrences of "*door*" and of "*banana*" with "*doorbanana*" and see if the system figures out which is which

"*The jasmine, almond, **doorbanana**, cork and coco-nut palm are among the trees*"

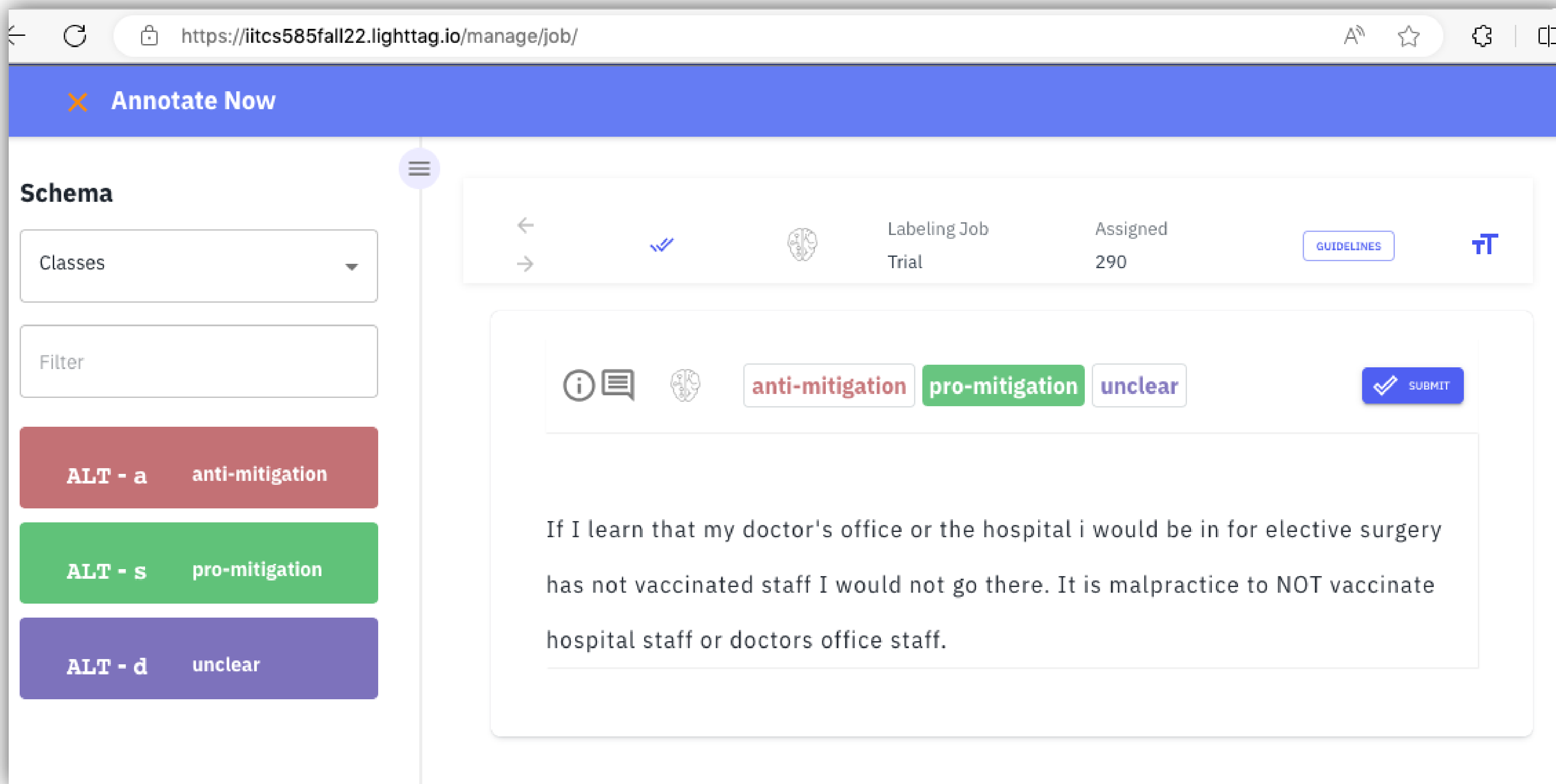
Performance Bounds

- How good is (say) 80%?
- Evaluate performance relative to lower and upper bounds:
  - Baseline performance: how well does the simplest "reasonable" algorithm do?
    - Majority class → What if we always assign most common label? Serves as <u>lower bound</u>
  - Human performance: what percentage of the time do people agree on classification?
    - Lower agreement → Harder problem
    - Serves as <u>upper bound</u> for machine learning

ANNOTATION & INTER-RATER RELIABILTY (AGREEMENT)

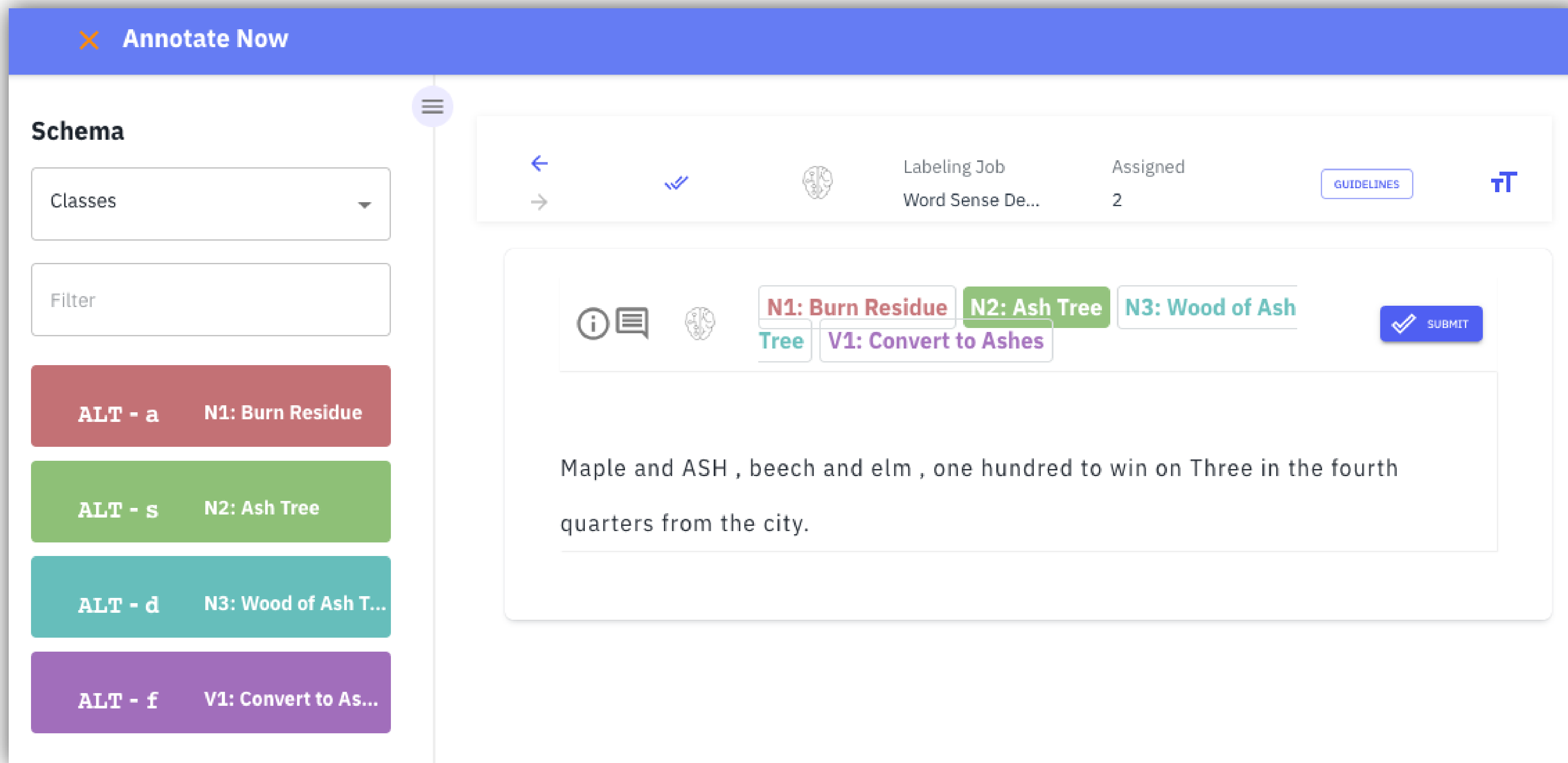
Annotation for NLP

Annotation for Text Classification (3-class task)



Annotation for NLP

Word Sense Disambiguation: "*Ash*" (4 Synsets)



Inter-rater Reliability (Agreement)

Measure how often humans agree on annotations

– If they don't often agree, then the task is ill-defined

- Agreement probability - P(agree)

  Number of times raters agree / Number of ratings

  – But if 90% of things are annotated as X, then agreement could be high by chance

- Cohen's Kappa

$$\frac{P_{agree} - P_{chance}}{1 - P_{chance}}$$

Inter-rater Reliability (Agreement)

- Cohen's Kappa

$$\frac{P_{agree} - P_{chance}}{1 - P_{chance}}$$

- P_{agree}: Observed agreement rate between annotators (or annotator/system)
- P_{chance}: Expected agreement rate between two annotators assigning labels randomly, but using the true class distribution

Inter-rater Reliability (Agreement)

- For a binary classification task with equiprobable outcomes, P_{chance} is 0.5. We'd expect raters using the two classes with equal frequency to agree half the time.
- So in this case, if $P_{agree} = 0.7$, then

$$\begin{aligned}\kappa &= \frac{P_{agree} - P_{chance}}{1 - P_{chance}} \\ &= \frac{0.7 - 0.5}{1 - 0.5} \\ &= 0.4\end{aligned}$$

Inter-rater Reliability (Agreement)

- For a distribution with N classes, $P_{chance} = \sum_{i=1}^{N} P_i^2$
- For example, for labels distributed according to $\langle 0.1, 0.3, 0.4, 0.2 \rangle$:

	A (0.1)	B (0.3)	C (0.4)	D (0.2)
A (0.1)	0.01	0.03	0.04	0.02
B (0.3)	0.03	0.09	0.12	0.06
C (0.4)	0.04	0.12	0.16	0.08
D (0.2)	0.02	0.06	0.08	0.04

$$P_{chance} = 0.01 + 0.09 + 0.16 + 0.04 = 0.3$$

Inter-rater Reliability (Agreement)

- For labels distributed according to $\langle 0.1, 0.3, 0.4, 0.2 \rangle$, $P_{chance} = 0.3$
- So if $P_{agree} = 0.7$,

$$\begin{aligned} \kappa &= \frac{P_{agree} - P_{chance}}{1 - P_{chance}} \\ &= \frac{0.7 - 0.3}{1 - 0.3} \\ &\approx 0.57 \end{aligned}$$

Question: Can Cohen's Kappa be negative?

DICTIONARY-BASED LEARNING

Dictionary-Based Disambiguation

- Idea: Choose between senses of a word given in a dictionary based on the **words** in the definitions

- ash:
  - s_1: a tree of the olive family
  - s_2: the solid residue left when combustible material is burned

Algorithm (Lesk 1986)

- Define $D_i(w)$ as the bag of words in the ith definition for w
- Define $E(w)$ as $\bigcup_i D_i(w)$
- For all senses s_k of w, do:

$$Score(s_k) = similarity\left(D_k(w), \left[\bigcup_{v \in c} E(v)\right]\right)$$

- Choose

$$s = \underset{s_k}{\operatorname{argmax}}\, Score(s_k)$$

Similarity Metrics

$$similarity(X,Y) = \begin{cases} \text{Matching coefficient } |X \cap Y| \\ \text{Dice coefficient } \dfrac{2|X \cap Y|}{|X|+|Y|} \\ \text{Jaccard coefficient } \dfrac{|X \cap Y|}{|X \cup Y|} \\ \text{Overlap coefficient } \dfrac{|X \cap Y|}{\min(|X|,|Y|)} \end{cases}$$

Simple Example

ash:

s_1: a tree of the olive family

s_2: the solid residue left when combustible material is burned

The **fire** had left behind nothing but a pile of ash$_2$

The ash$_1$ can be recognized by its serrated **leaves**

After being struck by **lightning** the **maple** was reduced to ash$_?$

Simple Example

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fire:

1. **combustion** or **burning**, in which substances combine chemically with oxygen from the air
2. the shooting of projectiles from weapons

Simple Example

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leaf:

1. a flattened structure of a higher plant or **tree**, typically green and blade-like
2. a thing that resembles a leaf in being flat and thin

Simple Example

ash:

s_1: a tree of the olive family

s_2: the solid residue left when combustible material is burned

lightning:

1. the occurrence of a natural electrical discharge of between a cloud and the ground, often causing **combustion**
2. very fast

The **fire** had left behind nothing but a pile of ash.

The ash$_1$ can be recognized by its serrated **leaves**

After being struck by **lightning** the **maple** was reduced to

ash$_?$

Simple Example

ash:

s_1: a tree of the olive family

s_2: the solid residue left when combustible material is burned

maple:

1. a **tree** or shrub with lobed leaves, winged fruits, and colorful autumn foliage
2. maple syrup or maple sugar

The **fire** had left behind nothing but a pile of ash$_2$

The ash$_1$ can be recognized by its serrated **leaves**

After being struck by **lightning** the **maple** was reduced to

ash$_?$

Some Improvements

- Lesk obtained results of 50-70% accuracy
- Possible improvements:
  - Run iteratively, each time only using definitions of "appropriate" senses for context words
  - Expand each word to a set of synonyms

SUPERVISED LEARNING

Supervised Learning

- Each ambiguous word token w_i in the training is tagged with a sense from $\text{Senses}(w_i) = s_1, \ldots, s_k$
- Each word token occurs in a context c_i
  - (usually defined as a window around the word occurrence – up to ~100 words long)
- Each context contains a set of words used as features v_{ij}

Bayesian Classification

- Bayes decision rule:
  - Classify $s(w_i) = \text{argmax}_s P(s \mid c_i)$
- Minimizes probability of error
- How to compute? Use Bayes' Theorem:

$$P(s_k|c) = \frac{P(c|s_k)P(s_k)}{P(c)}$$

Bayes' Classifier (cont.)

- Note that *P(c)* is constant for all senses, therefore:

$$
\begin{aligned}
s(w_i) &= \operatorname{argmax}_s P(s|c) \\
&= \operatorname{argmax}_s \frac{P(c|s)}{P(c)} P(s\ ) \\
&= \operatorname{argmax}_s P(c|s)P(s)
\end{aligned}
$$

$$s(w_i) = \operatorname{argmax}_s (\log P(c \mid s) + \log P(s\ ))$$

Naïve Bayes

- Assume:
  - Features are conditionally independent, given the example class
  - Feature order doesn't matter
  - (bag of words model – repetition counts)

$$
\begin{aligned}
P(c|s) &= P(\{v_j : v_j \in c\}|s) \\
&= \prod_{v_j \in c} P(v_j|s) \\
\log P(c|s) &= \sum_{v_j \in c} \log P(v_j|s)
\end{aligned}
$$

Naïve Bayes Assumption

Naïve Bayes Training

- For all senses s_k of w, do:
  - For all words v_j in the vocabulary, do:

$$P(v_j|s_k) = \frac{Count(v_j, s_k)}{Count(s_k)}$$

- For all senses s_k of w, do:

$$P(s_k) = \frac{Count(s_k)}{Count(w)}$$

Naïve Bayes Classification

- For all senses s_k of w_i, do:

$$Score(s_k) = \log P(s_k)$$

- For all words v_j in the context window c_i, do:

$$Score(s_k) += \log P(v_i|s_k)$$

- Choose

$$s(w_i) = \underset{s_k}{\operatorname{argmax}} Score(s_k)$$

Significant Features

Senses of “drug” (Gale et al. 1992):

‘medication’ prices, prescription, patent, increase, consumer, pharmaceutical

‘illegal substance’ abuse, paraphernalia, illicit, alcohol, cocaine, traffickers

UNSUPERVISED LEARNING

Why Unsupervised Learning?

Some issues with supervised learning:

- Domain-dependence: In computer manuals, “mouse” will not be evidence for topic “mammal”
- Coverage: “Michael Jordan” will not likely be in a wordnet, but is an excellent indicator for topic “sports”

Tuning for a Specific Corpus

- Use a naïve-Bayes formulation:

$$P(s|\,c) = \frac{P(s)\prod_{v\in c} P(v|s)}{\prod_{v\in c} P(v)}$$

- Initialize probabilities as uniform
- Re-estimate $P(s)$ and $P(v_j \mid s)$ for each sense s and each word v_j by evaluating all contexts in the corpus, assuming the context has sense s if $P(s \mid c) > \theta$ (where θ is a predefined threshold)
- Disambiguate by choosing the highest

LEVERAGING BILINGUAL DATA

Using a Bilingual Corpus

Use correlations between phrases in two languages to disambiguate

E.g, interest =	'legal share'	(acquire an interest)
	'attention'	(show interest)
In German	Beteiligung erwerben	
	Interesse zeigen	

Depending on where the translations of related words occur, determine which sense applies

Scoring

- Given a context c in which a syntactic relation $R(w, v)$ holds between w and a context word v:
  - Score of sense s_k is the number of contexts c' in the second language such that $R(w', v') \in c'$ where w' is a translation of s_k and v' is a translation of v.
  - Choose highest-scoring sense

Using a Bilingual Corpus

Challenges:

- In related languages, senses may share a translation
- No occurrences found for some senses

Translation List for *channel*:

1. **canal, canal de transmisión** : a path over which signals can pass
2. **canal, conducto**: a passage for water (or other fluids)
3. [No Spanish sense]: groove
4. **canal, estrecho**: a relatively narrow body of water linking two larger bodies; "the ship went aground in the channel"
5. [No Spanish sense] : line, communication channel
6. **canal, vía**: bodily passage or tube conveying a secretion or other substance
7. [No Spanish sense] : television channel

RECENT RESEARCH IN WORD SENSE DISAMBIGUATION

Words-in-Context Task

Words-in-Context dataset and task

- Evaluate **context-sensitive** word embeddings
- In SuperGLUE shared task – more difficult NLU tasks
- Evaluate pairs of sentences (different or same sense) rather than assign label to single sentence/context

Label	Target	Context-1	Context-2
F	bed	There's a lot of trash on the bed of the river	I keep a glass of water next to my bed when I sleep
F	land	The pilot managed to land the airplane safely	The enemy landed several of our aircrafts
F	justify	Justify the margins	The end justifies the means
T	beat	We beat the competition	Agassi beat Becker in the tennis championship
T	air	Air pollution	Open a window and let in some air
T	window	The expanded window will give us time to catch the thieves	You have a two-hour window of clear weather to finish working on the lawn

https://pilehvar.github.io/wic/ https://super.gluebenchmark.com/tasks

Words-in-Context Task

WiC: the Word-in-Context Dataset for Evaluating Context-Sensitive Meaning Representation (Pilehvar & Camacho-Collados, NAACL 2019)

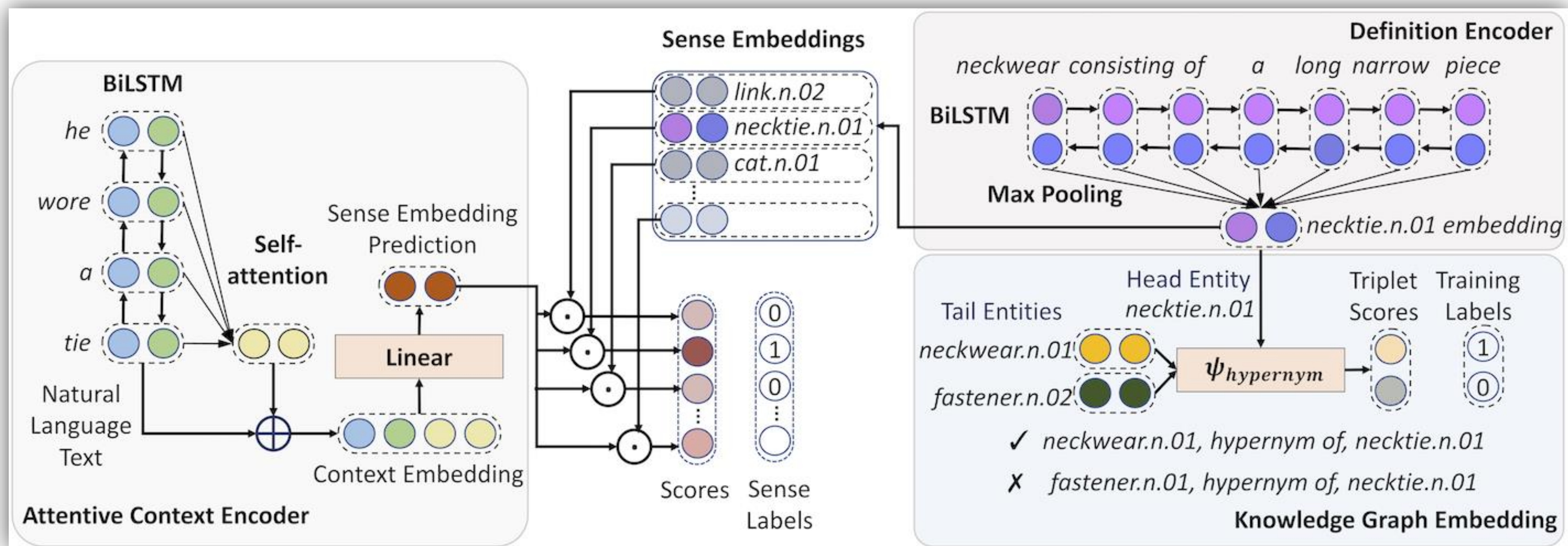
"*Around 22% of the pairs in the test set had at least one of their target words not covered by these models. For such out-of-vocabulary cases, we used BERT's default tokenizer....*"

What is unique about BERT's default tokenizer?

EWISE: Applying Word Embeddings

Zero-shot Word Sense Disambiguation using Sense Definition Embeddings (Kumar et al. 2019)

- WordNet + BiLSTM→ Sense Embeddings



https://arxiv.org/pdf/1808.09121.pdf https://github.com/malllabiisc/EWISE