Deep Learning for Natural Language Processing

Introduction to dependency parsing

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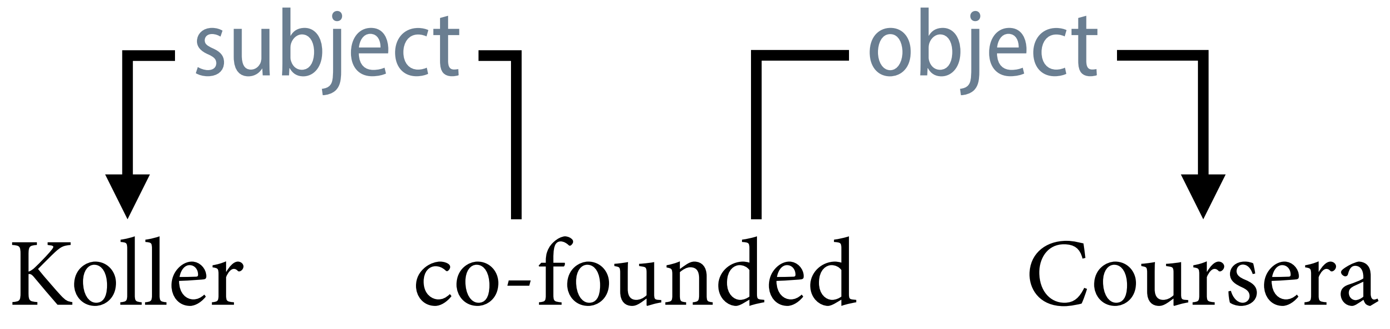
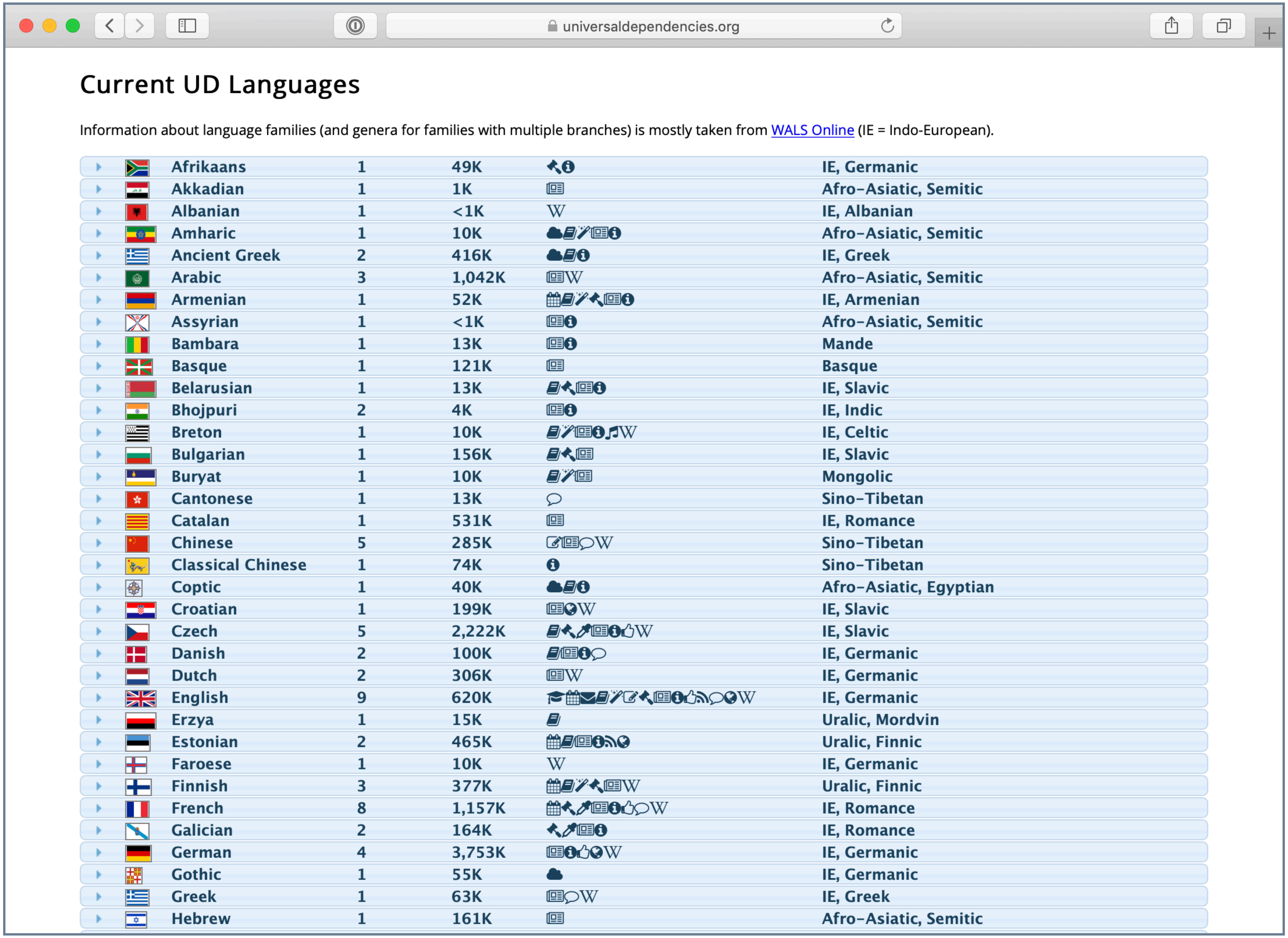
Dependency parsing

- **Syntactic parsing** is the task of mapping a sentence to a formal representation of its syntactic structure.
- We focus on representations in the form of **dependency trees**.



- A syntactic dependency is an asymmetric relation between a **head** and a **dependent**.



universaldependencies.org

Current UD Languages

Information about language families (and genera for families with multiple branches) is mostly taken from WALS Online (IE = Indo-European).

Afrikaans	1	49K	🔨ℹ	IE, Germanic
Akkadian	1	1K	📰	Afro-Asiatic, Semitic
Albanian	1	<1K	W	IE, Albanian
Amharic	1	10K	☁📖✎📰ℹ	Afro-Asiatic, Semitic
Ancient Greek	2	416K	☁📖ℹ	IE, Greek
Arabic	3	1,042K	📰W	Afro-Asiatic, Semitic
Armenian	1	52K	📅📖✎🔨📰ℹ	IE, Armenian
Assyrian	1	<1K	📰ℹ	Afro-Asiatic, Semitic
Bambara	1	13K	📰ℹ	Mande
Basque	1	121K	📰	Basque
Belarusian	1	13K	📖🔨📰ℹ	IE, Slavic
Bhojpuri	2	4K	📰ℹ	IE, Indic
Breton	1	10K	📖✎📰ℹ♫W	IE, Celtic
Bulgarian	1	156K	📖🔨📰	IE, Slavic
Buryat	1	10K	📖✎📰	Mongolic
Cantonese	1	13K	💬	Sino-Tibetan
Catalan	1	531K	📰	IE, Romance
Chinese	5	285K	📝📰💬W	Sino-Tibetan
Classical Chinese	1	74K	ℹ	Sino-Tibetan
Coptic	1	40K	☁📖ℹ	Afro-Asiatic, Egyptian
Croatian	1	199K	📰🌐W	IE, Slavic
Czech	5	2,222K	📖🔨💉📰ℹ👍W	IE, Slavic
Danish	2	100K	📖📰ℹ💬	IE, Germanic
Dutch	2	306K	📰W	IE, Germanic
English	9	620K	🎓📅✉📖✎📝🔨📰ℹ👍📡💬🌐W	IE, Germanic
Erzya	1	15K	📖	Uralic, Mordvin
Estonian	2	465K	📅📖📰ℹ📡🌐	Uralic, Finnic
Faroese	1	10K	W	IE, Germanic
Finnish	3	377K	📅📖✎🔨📰W	Uralic, Finnic
French	8	1,157K	📅🔨💉📰ℹ👍💬W	IE, Romance
Galician	2	164K	🔨💉📰ℹ	IE, Romance
German	4	3,753K	📰ℹ👍🌐W	IE, Germanic
Gothic	1	55K	☁	IE, Germanic
Greek	1	63K	📰💬W	IE, Greek
Hebrew	1	161K	📰	Afro-Asiatic, Semitic

Dependency trees

- A **dependency tree** for a sentence x is a digraph $G = (V, A)$ where $V = \{1, \dots, |x|\}$ and where there exists a $r \in V$ such that every $v \in V$ is reachable from r via exactly one directed path.

- The vertex r is called the **root** of G.

- The arcs of a dependency tree may be labelled to indicate the type of the syntactic relation that holds between the two elements.

  Universal Dependencies v2 uses 37 universal syntactic relations (list).

Two parsing paradigms

- **Graph-based dependency parsing**

  Cast parsing as a combinatorial optimisation problem over a (possibly restricted) set of dependency trees.

- **Transition-based dependency parsing**

  Cast parsing as a sequence of local classification problems: at each point in time, predict one of several parser actions.

Graph-based dependency parsing

- Given a sentence x and a set $Y(x)$ of candidate dependency trees for x, we want to find a highest-scoring tree $\hat{y} \in Y(x)$:

$$\hat{y} = \operatorname*{arg\,max}_{y \in Y(x)} \text{score}(x, y)$$

- The computational complexity of this problem depends on the choice of the set $Y(x)$ and the scoring function.

The arc-factored model

- Under the **arc-factored model**, the score of a dependency tree is expressed as the sum of the scores of its arcs:

$$\hat{y} = \underset{y \in Y(x)}{\arg\max} \sum_{a \in y} \text{score}(x, a) \text{ ——— head–dependent arc}$$

- The score of a single arc can be computed by means of a neural network that receives the head and the dependent as input.

for example, a simple linear layer: $\text{score}(x, h \rightarrow d) = [\boldsymbol{h}\,;\boldsymbol{d}] \cdot \boldsymbol{w} + b$

Computational complexity

- Under the arc-factored model, the highest-scoring dependency tree can be found in $O(n^3)$ time (n = sentence length).

  Chu–Liu/Edmonds algorithm; McDonald et al. (2005)

- Even seemingly minor extensions of the arc-factored model entail intractable parsing.

  McDonald and Satta (2007)

- For some of these extensions, polynomial-time parsing is possible for restricted classes of dependency trees.

Transition-based dependency parsing

- We cast parsing as a sequence of local classification problems such that solving these problems builds a dependency tree.
- In most approaches, the number of classifications required for this is linear in the length of the sentence.

Transition-based dependency parsing

- The parser starts in the **initial configuration**.

  empty dependency tree

- It then calls a classifier, which predicts the **transition** that the parser should make to move to a next configuration.

  extend the partial dependency tree

- This process is repeated until the parser reaches a **terminal configuration**.

  complete dependency tree

Training transition-based dependency parsers

- To train a transition-based dependency parser, we need a treebank with gold-standard dependency trees.
- In addition to that, we need an algorithm that tells us the gold-standard transition sequence for a tree in that treebank.
- Such an algorithm is conventionally called an **oracle**.

Comparison of the two parsing paradigms

Graph-based parsing	**Transition-based parsing**
slow (in practice, cubic in the length of the sentence)	fast (quasi-linear in the length of the sentence)
restricted feature models (in practice, arc-factored)	rich feature models defined on configurations
features and weights directly defined on target structures	indirection – features and weights defined on transitions