Hierarchical Bracketing Encodings for Dependency Parsing as Tagging

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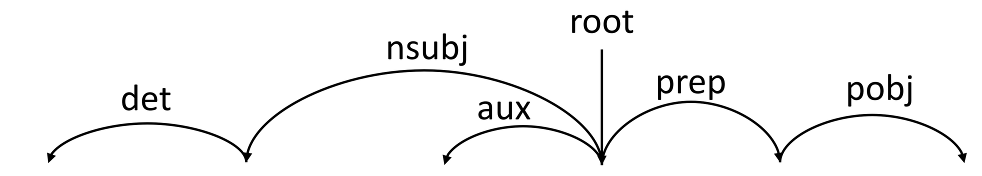
Dependency Parsing as Sequence Labeling

Contribution: Novel SL approach for projective dependency parsing (12 labels).



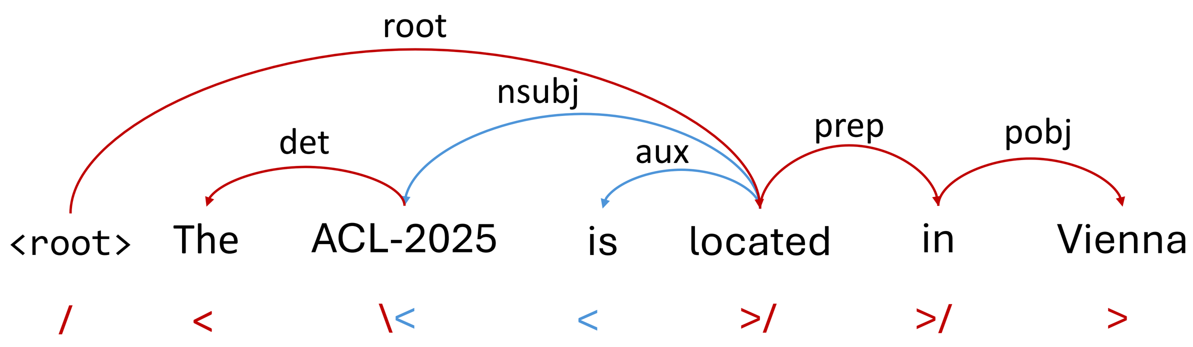
	The	ACL-2025	is	located	in	Vienna	**Label Space**
Bracketing: Strzyz et al. (2020)	<	\<	<	\\>/	>/	>	unbounded
Hexatagging: Amini et al. (2023)	↗↗R	↖↗R	↖↗R	↖↗L	↗↖L	↖	bounded (8)
4-bit: Gómez-Rodríguez et al. (2023)	0100	0110	0000	1111	1101	1100	bounded (16)
NEW! (ours):	<	\<	<	>/	>/	>	bounded (12)

Preliminaries

Let $G = (W, A)$ be a dependency tree. The *proper rope cover* is $R \subseteq A$ such that:

1. Every $a \in A - R$ leans on some $a' \in R$.
2. No $a \in R$ leans on any other $a' \in R - \{a\}$.

Yli-Jyrä (2019) proves that the proper rope cover of a graph is unique.



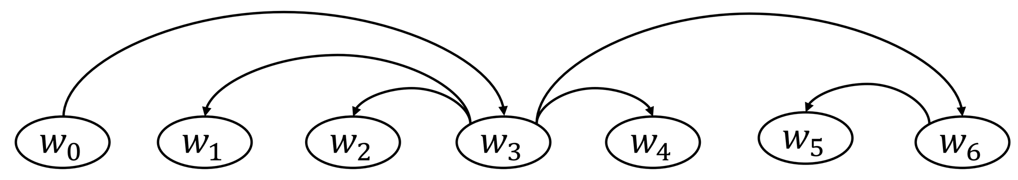
Superbrackets
> \ / <

Auxiliary brackets
> <

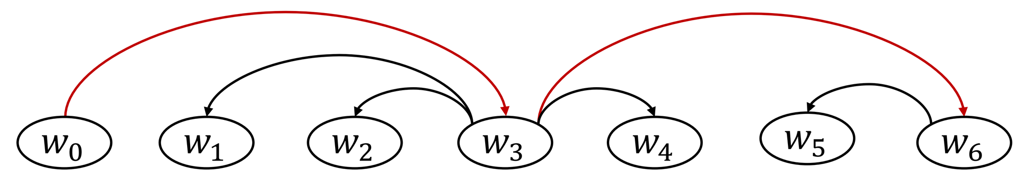
Optimal Hierarchical Bracketing Encoding

1. Identify proper rope cover (R).
2. Assign superbrackets (>, \, /, <).
3. For each arc $a \in R$, find those arcs that lean on a (auxiliary arcs) and assign auxiliary brackets (>, <).

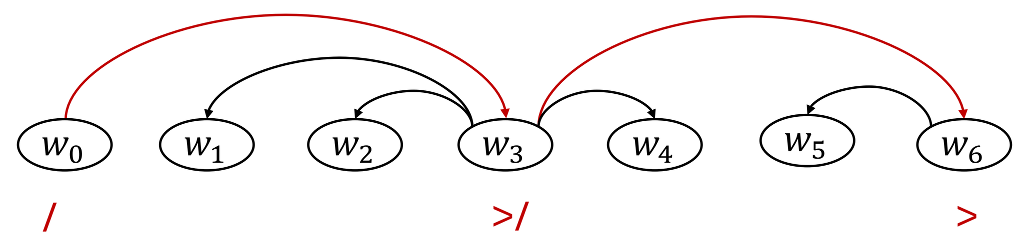
Projective dependency tree



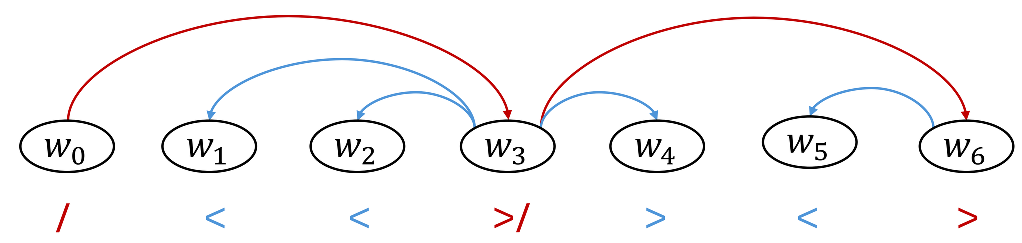
Step 1: Identify R



Step 2: Assign superbrackets



Step 3: Assign auxiliary brackets



Note that $(w_0 \rightarrow w_3) \in R$ is represented with / and >, but $(w_3 \rightarrow w_2)$ is represented with < and >.

The Bounded Space of Optimal Hierarchical Brackets (OHB)

Proof from 4-bit encoding (2^4 = 16 labels)

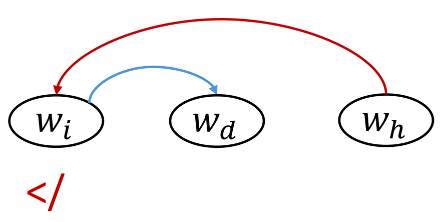
- $b_0 = w_i$ has a left head.
- $b_1 = w_i$ is the outermost dependent.
- $b_2 = w_i$ has left dependents.
- $b_3 = w_i$ has right dependents.

from Gómez-Rodríguez et al. (2023).

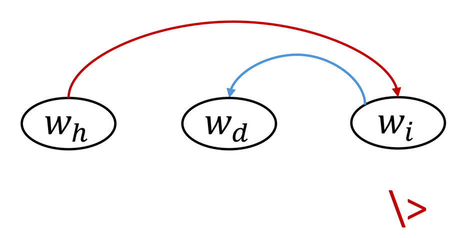
b_0b_1 \ b_2b_3	00	01	10	11
00	<	</	\<	\</
01	<	</	\<	\</
10	>	>/	\>	\>/
11	>	>/	\>	\>/

But {\</, \>/, </, \>} **cannot** occur in OHB since no $a \in R$ leans on $a' \in R - \{a\}$.

Never happens since $(w_i \rightarrow w_d)$ is auxiliary.



Never happens since $(w_d \leftarrow w_i)$ is auxiliary.

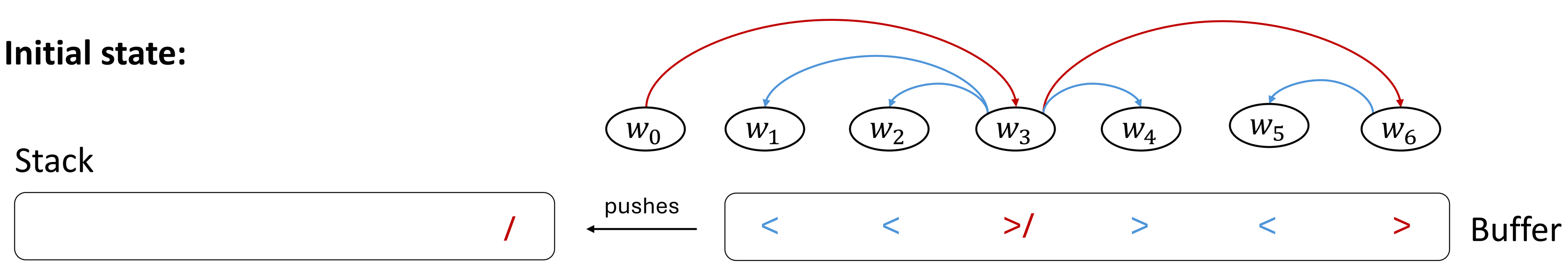


Note that \</ and \>/ cannot occur since they contain </ and \>.

Optimal Hierarchical Bracketing Decoding

- Similar to the standard bracketing decoding (Strzyz et al., 2020).
- Stack-based system that parses the bracket sequence:
  - Matching opening (<, /) with closing (\, >) super brackets.
  - Matching < with (>, \) and > with (<, /).
- The brackets are processed from left to right until the buffer is empty.
- In the initial state the first element in the stack is always /.

Initial state:



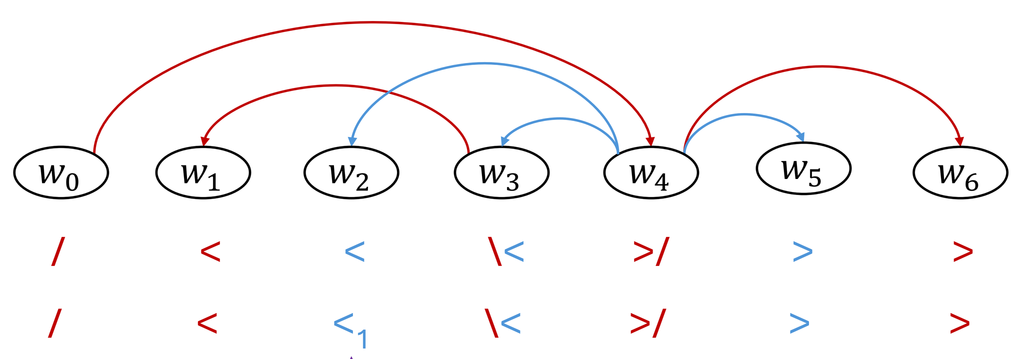
Example: < matches > to recover $(w_2 \leftarrow w_3)$

Non-Projective Extension for Hierarchical Bracketing

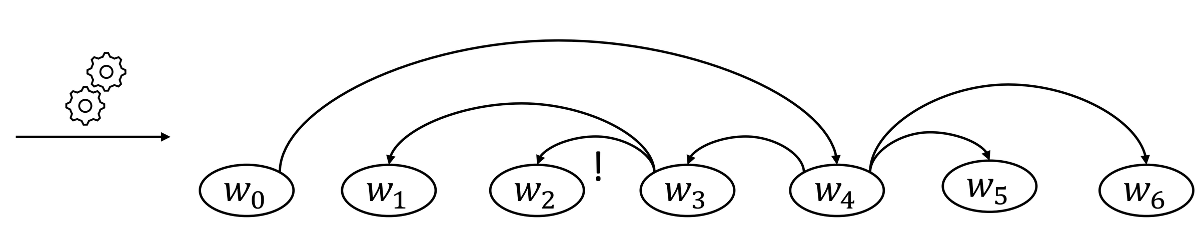
The OHB encoding does not recover crossing arcs.
Solution: Add indices to closing superbrackets (\, >) and auxiliary brackets (>, \, /, <) to skip matches during the decoding step.
Drawback: The label space becomes unbounded.

Use subindex 1 to indicate that $<_1$ matches with the second superbracket found (> at w_4).

Non-Projective Dependency Tree



Decoded Tree with the projective decoding



Error: $(w_2 \leftarrow w_4)$ is not recovered since it crosses $(w_1 \leftarrow w_3)$

Experiments and Results

- PTB and UD (9 languages) with XLM✧/XLNet ☐.
- Baselines: Hexatagging (H^+) and Biaffine (DM).
- 4-bit (B_4) and projective OHB (O_p) with pseudo-projectivity (+).
- 7-bit (B_7) and non-projective OHB (O_{np}).

Close performance:

- LAS: $O_p < O_{np} < B_4 < O_p^+ < B_4^+ < B_7$.
- LCM: $O_p^+ < B_4 < O_p < B_4^+ < O_{np} < B_7$.

Code and Materials: https://github.com/anaezquerro/separ.

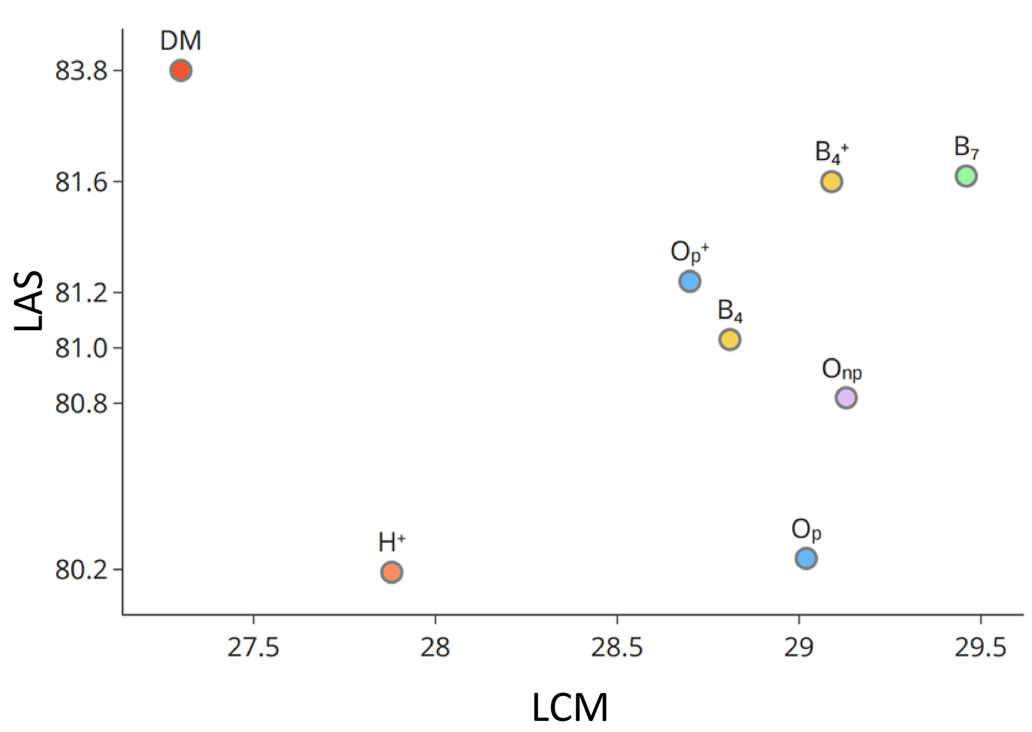
But O_p/O_{np} are faster (compact label space).

Label Space Analysis:

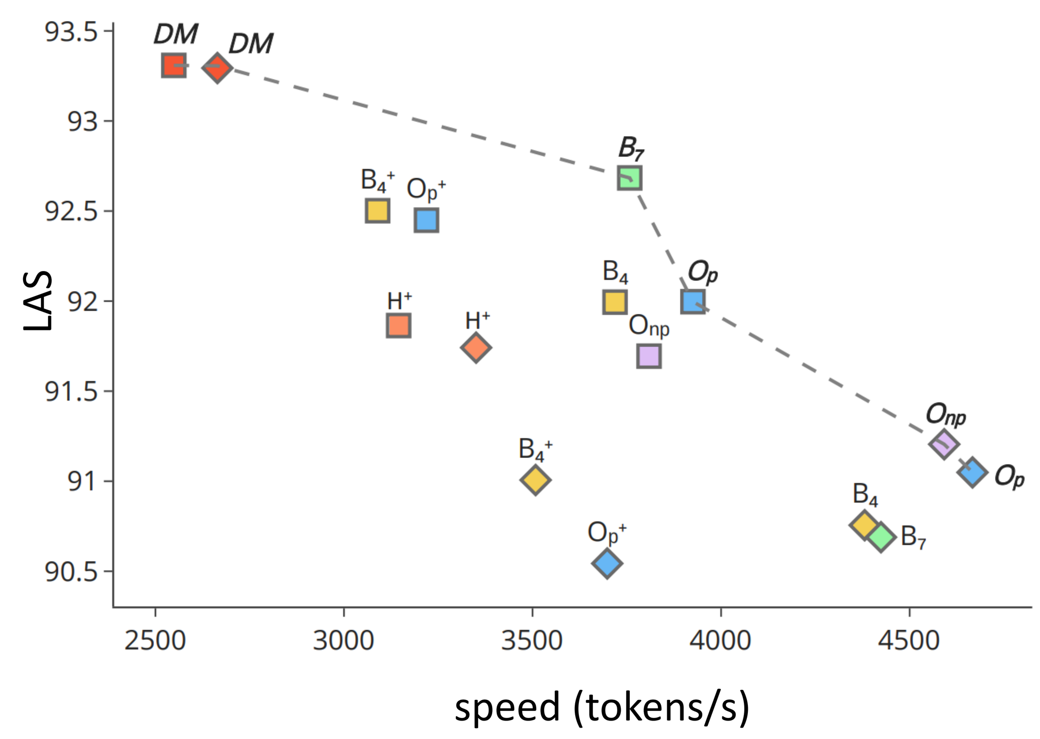
- B_4 always requires 16 labels, while O_p requires 12 labels.
- Except for Ancient-Greek, O_{np} requires less labels than B_7.

	#trees	#labels					#rels		#indices			
		B_4	O_P	B_7	O_{NP}	H^+	O_P	O_P^+	0	1	2	≥ 3
grc	13.9k	16	12	103	168	8	26	248	42.87	51.32	5.50	0.25
en	16.6	16	12	60	55	8	53	169	97.98	1.98	0.04	0
fi	15.1k	16	12	59	56	8	47	150	96.66	2.40	0.93	0
fr	16.3k	16	12	51	50	8	56	142	96.63	3.23	0.14	0
he	6.1k	16	12	37	30	8	37	52	99.22	0.75	0.03	0
ru	5k	16	12	60	52	8	42	153	95.27	4.31	0.42	0
ta	600	16	12	24	17	8	29	35	98.33	1.67	0	0
ug	3.5k	16	12	40	35	8	40	67	93.40	6.57	0.03	0
wo	2.1k	16	12	40	27	8	38	62	97.15	2.85	0	0
PTB	44k	16	12	22	21	8	45	46	99.90	0.10	0	0

Performance (average)



Pareto Front (English-EWT)



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