Hierarchical Bracketing Encodings for Dependency Parsing as Tagging

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UNIVERSIDADE DA CORUÑA

INDITEX UDC Cátedra de IA en Algoritmos Verdes

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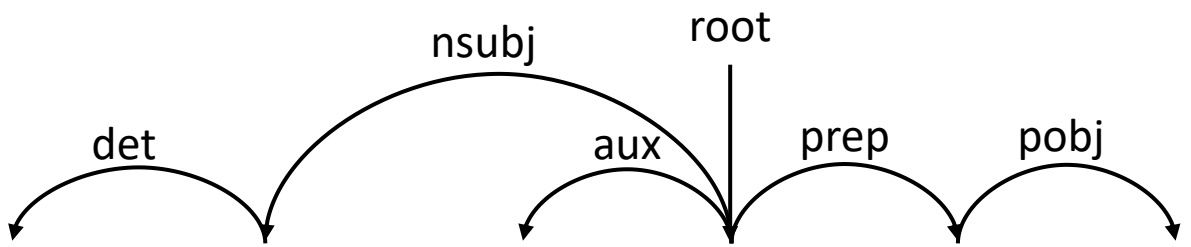
Motivation: Dependency Parsing as Sequence Labeling (SL)

SL reframes the dependency parsing task (graph-based prediction) as token-level classification.



	The	ACL-2025	is	located	in	Vienna	**LABEL SPACE:**
Strzyz et al. (2020): *brackets*	<	\<	<	\\/	>/	>	unbounded
Gómez-Rodríguez et al. (2023): *4-bit (and 7-bit)*	0100	0110	0000	1111	1101	1100	bounded (16)
Amini et al. (2023): *hexatag*	↗↗^{R}	↖↗^{R}	↖↗^{R}	↖↗^{L}	↗ ↖^{L}	↖	bounded (8)
Hierarchical (ours):	<	\<	<	>/	>/	>	**bounded (12)**

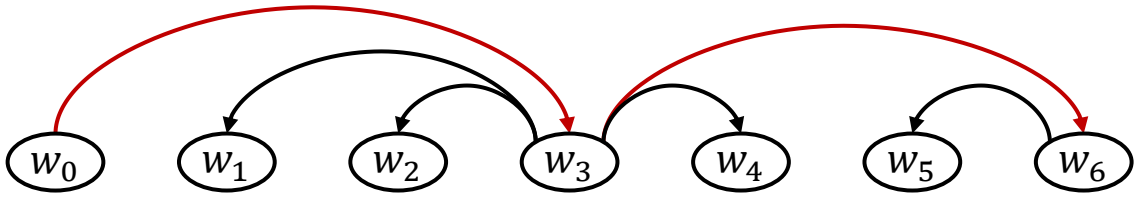
super vs auxiliary brackets

Optimal Hierarchical Bracketing Encodings (OHB)

- Contribution: Novel SL approach for dependency trees (bounded label space).
- Key concepts: (1) *rope cover* (2) *superbrackets* (3) *auxiliary brackets.*

How to encode?
1. Identify the *proper rope cover*.
2. Assign superbrackets (>, \, /, <).
3. Assign auxiliary brackets (>, <).

Projective dependency tree



Bracketing:	<	<	\\>//	>	<	\>
Superbrackets:			>/			>
Auxiliary brackets:	<	<	>/	>	<	>

The head of the auxiliary arcs is paired with a superbracket

Step 1: Given a dependency tree $G = (W, A)$, 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 $a' \in R - \{a\}$.

Step 2: Encode R with superbrackets.

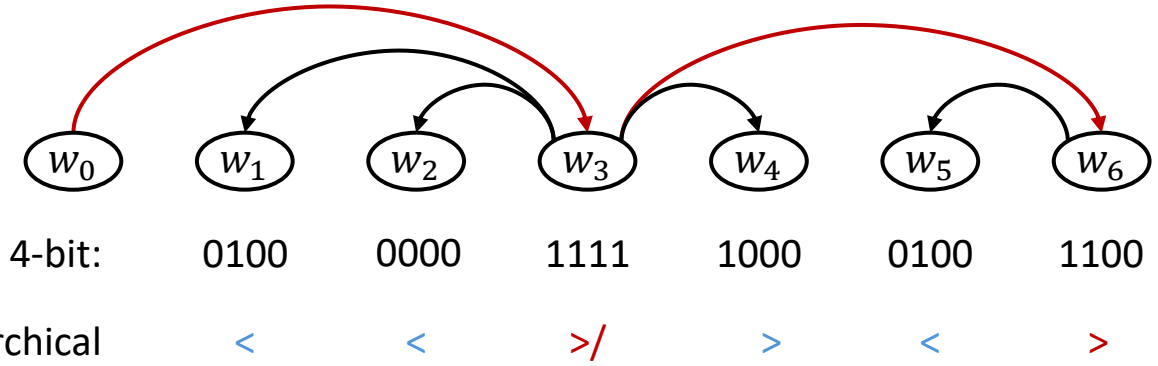
Step 3: Encode $A - R$ with auxiliary brackets.

The Bounded Space of Optimal Hierarchical Brackets (OHB)

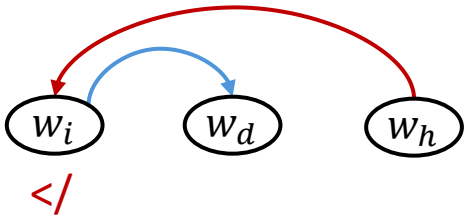
- The rope cover is the set of arcs corresponding to the highest hierarchy level.
- OHB compresses the brackets of sub-dependencies with the superbrackets of the rope cover.
- There are a total of 12 labels. **How?**

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

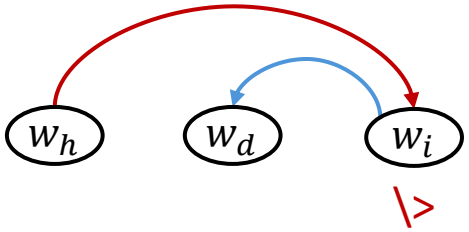
- $b_0 = w_i$ has a left head.
- $b_1 = w_i$ is the outermost dependent.
- $b_2 = w_i$ has left dependents.
- $b_3 = w_i$ has right dependents.



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



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



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

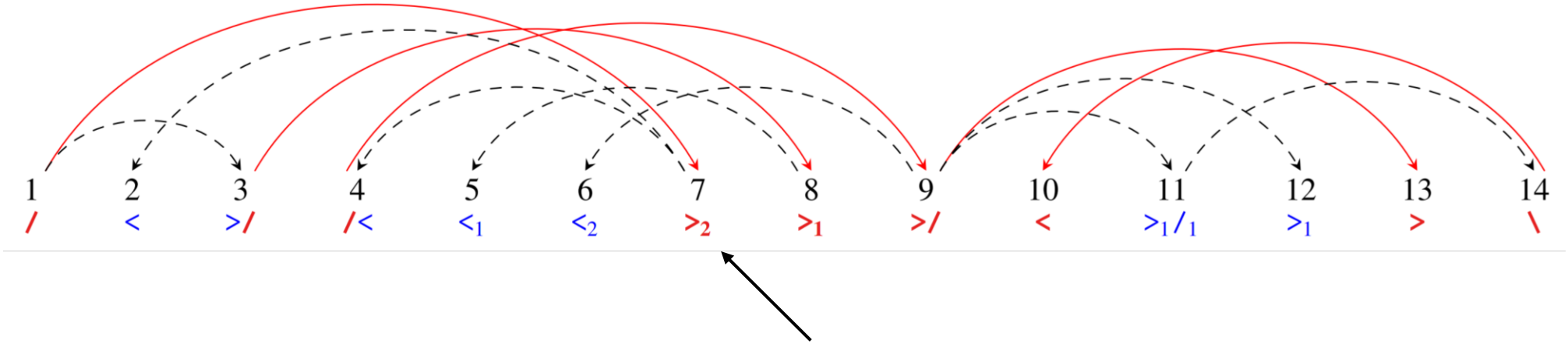
But { \</, \>/, </, \> } **cannot** occur in OHB since no $a \in R$ leans on $a' \in R - \{a\}$.

Expanding Hierarchical Brackets to Non-Projective Dependency Trees

- Hexatagging, 4-bit and HB encodings do not support non-projective trees.

We expand HB with **subindices** to support non-projective trees (unbounded space).

- Only closing superbrackets (>, \) have subindices.
- More auxiliary brackets is expanded (>, \, /, <).



Subindices indicate the number of superbrackets that need to be skipped in the decoding process until matching.

Experiments and Results

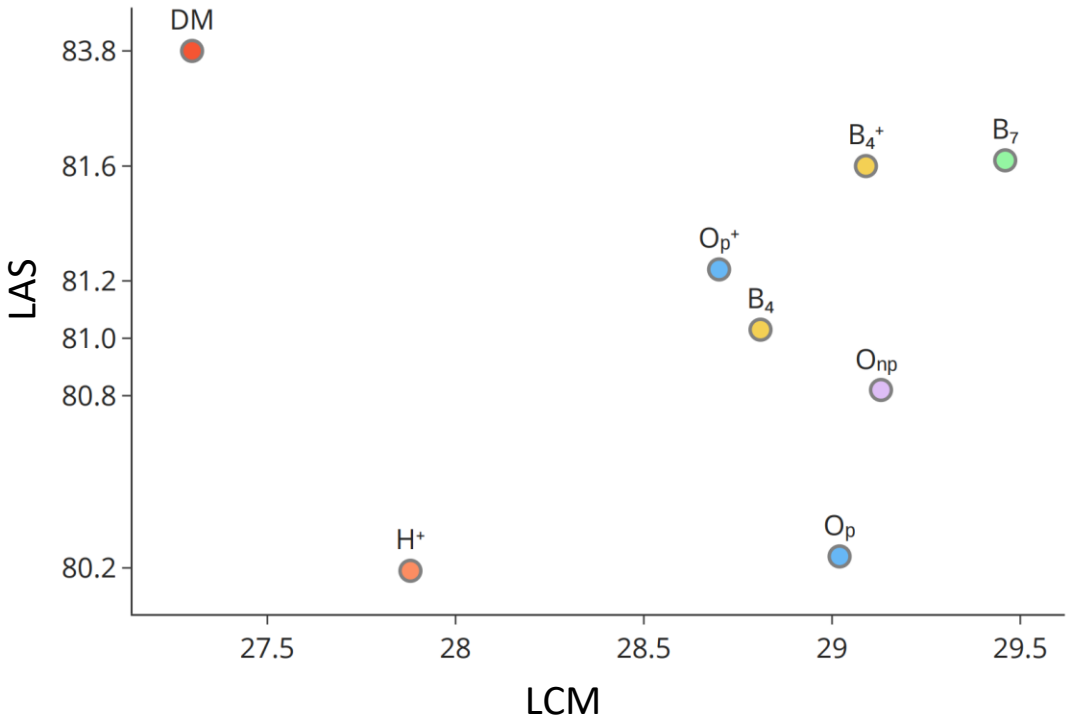
- PTB and UD (9 languages) with XLM✧/XLNet ☐.
- Baselines: Hexatagging (H^+) and Biaffine (DM).
- 4-bit (B_4) and projective OHB (O_p) with pseudo-projectivity (+).
- 7-bit (B_7) and non-projective OHB (O_{np}).

Close performance:

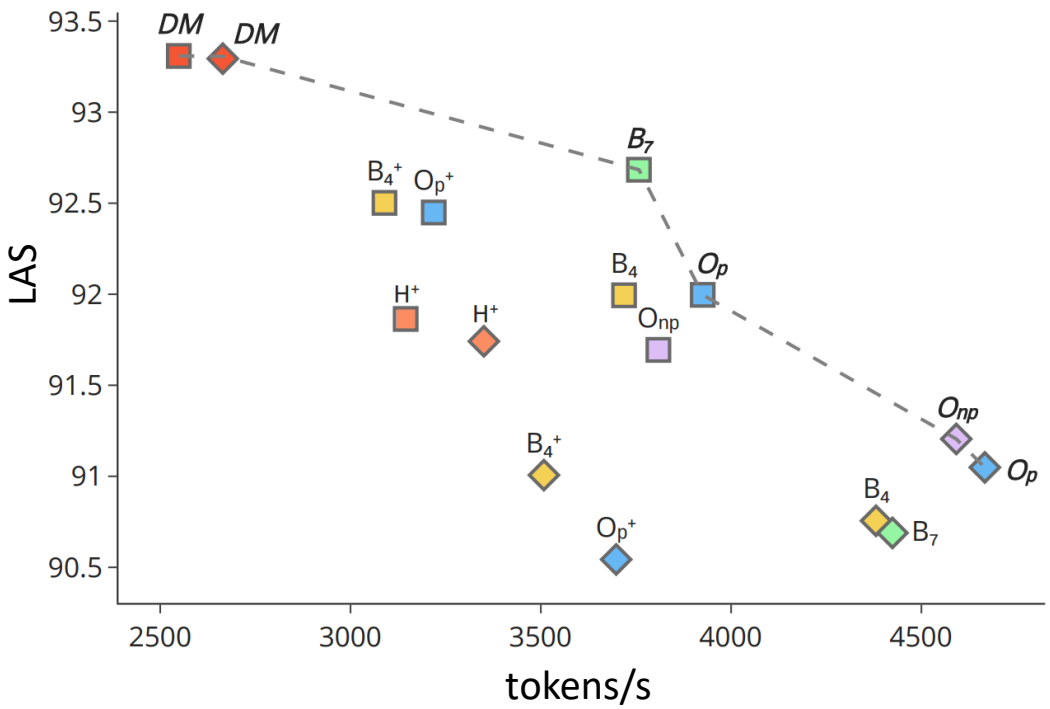
- LAS: $O_p < O_{np} < B_4 < O_p^+ < B_4^+ < B_7$.
- LCM: $O_p^+ < B_4 < O_p < B_4^+ < O_{np} < B_7$.

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

Performance (average)



Pareto Front (English-EWT)



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

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Thank you for listening!

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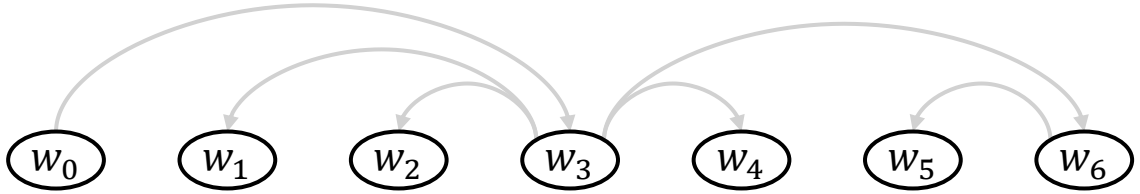
Decoding with Hierarchical Brackets

Stack-based system where:

- Auxiliary brackets only match superbrackets.
- Superbrackets match any bracket.



Stack

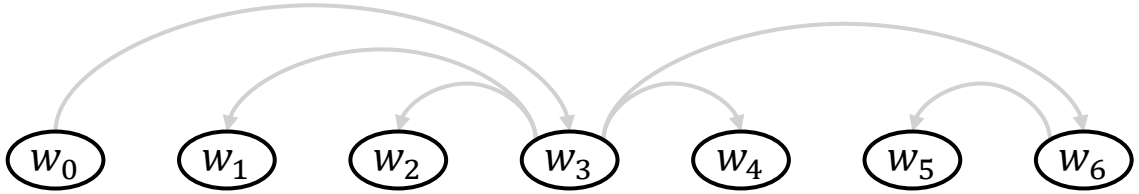
Buffer

(label indices are marked subscripts)

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

$/_0$

Buffer

$<_1$ $<_2$ $>_3 /_3$ $>_4$ $<_5$ $>_6$

(label indices are marked subscripts)

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
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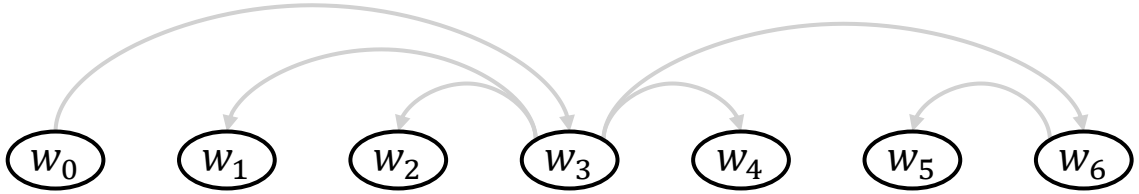
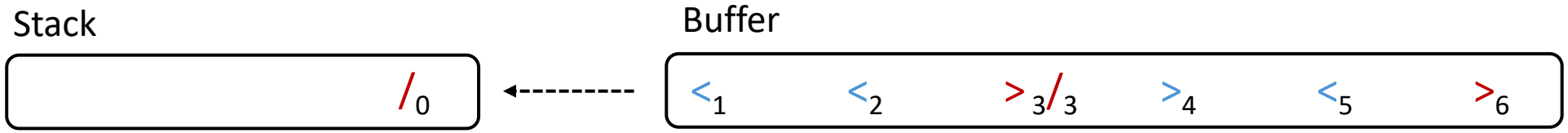


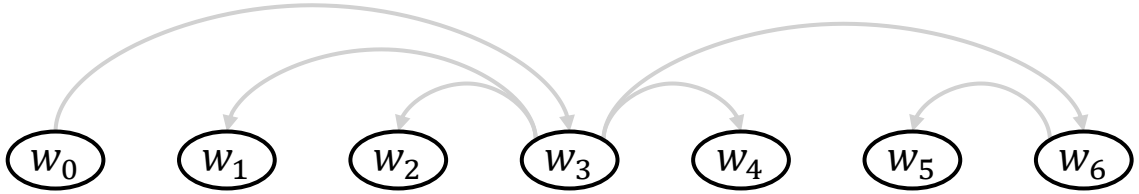


Add $<_1$ to the stack.

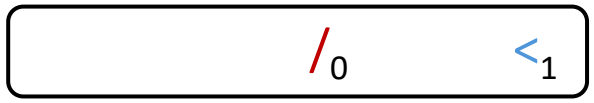
Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack



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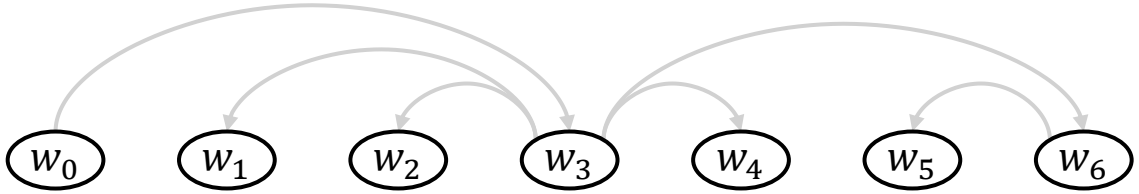
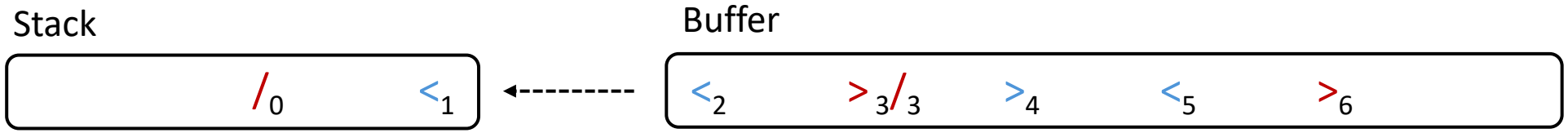
Add $<_1$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



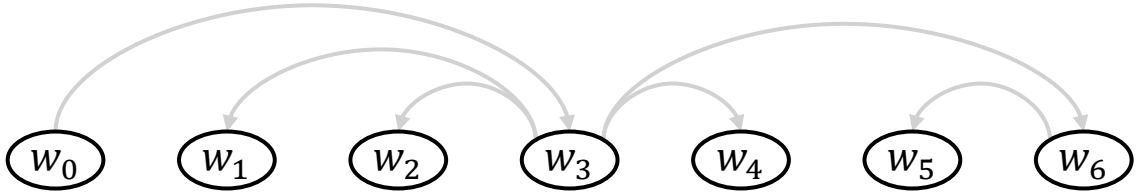


Add $<_2$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

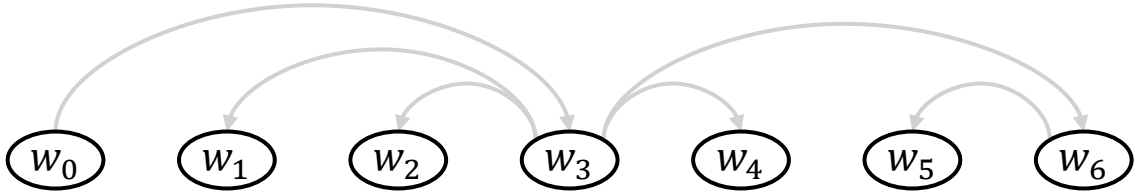
Buffer

Add $<_2$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

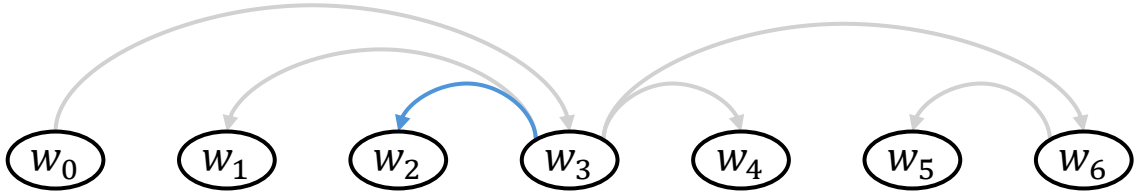
Buffer

Match $>_3$ with the elements in the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

Buffer

Match $>_3$ with the elements in the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
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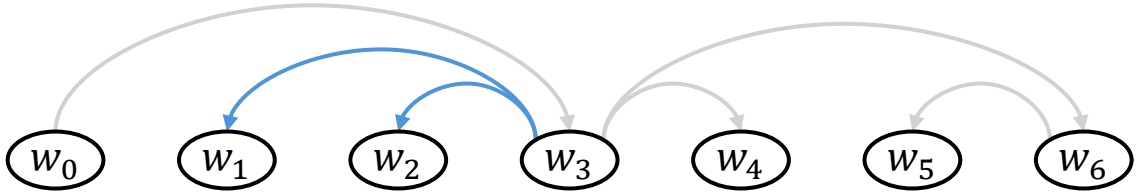


Stack

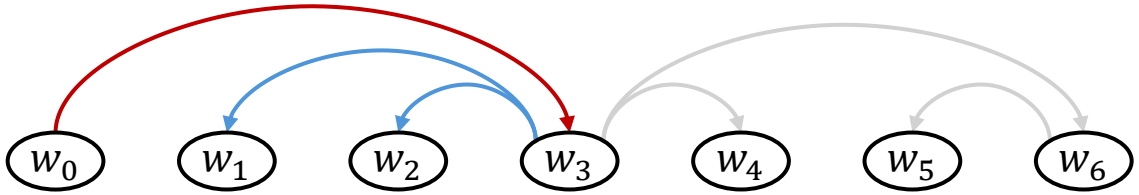
Buffer

Match $>_3$ with the elements in the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

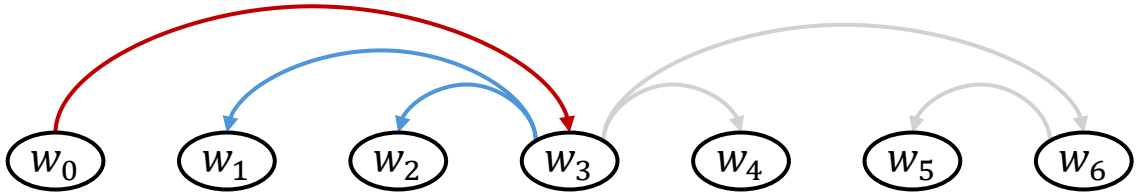
Buffer

Stop when a superbracket is found.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

Buffer

Stop when a superbracket is found.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
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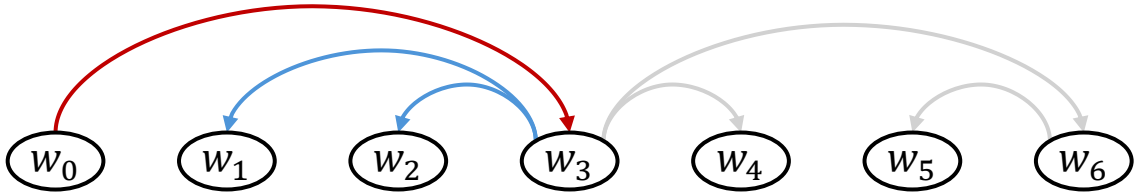
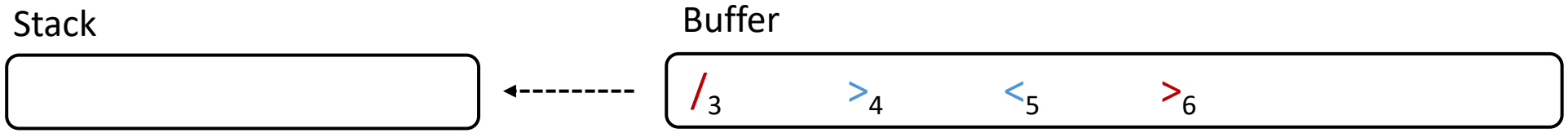


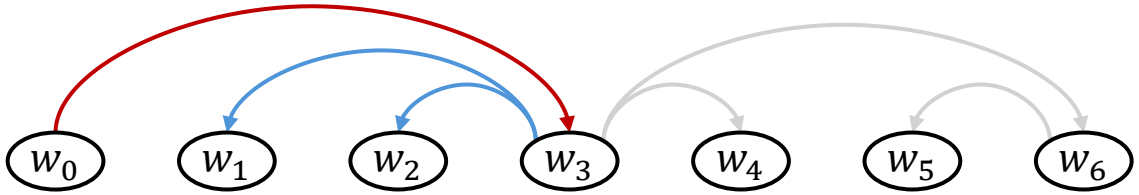


Add $/_3$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

$/_3$

Buffer

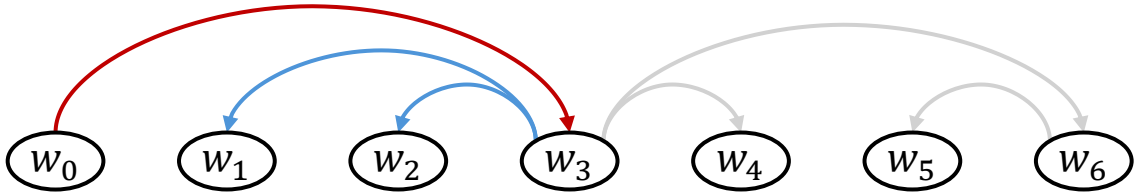
$>_4$ $<_5$ $>_6$

Add $/_3$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

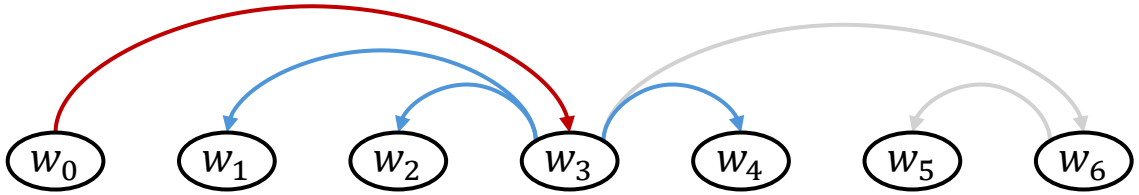
Buffer

Match $>_4$ with the superbracket at the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

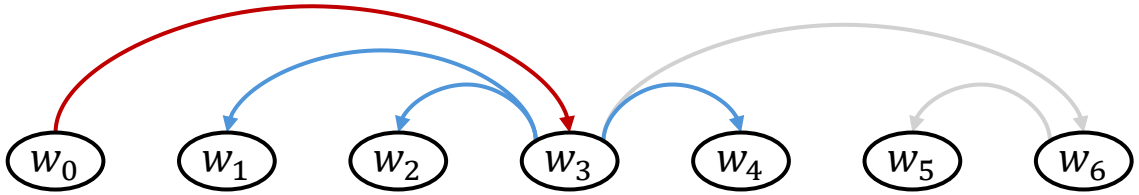
Buffer

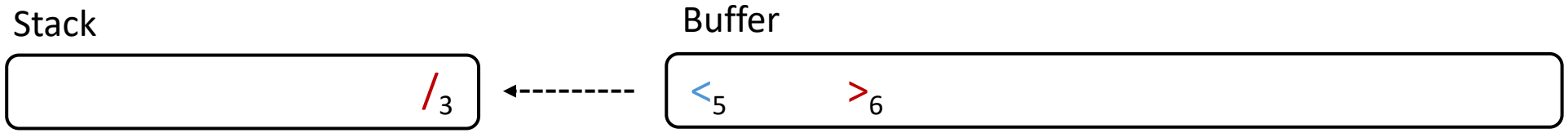
Match $>_4$ with the superbracket at the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



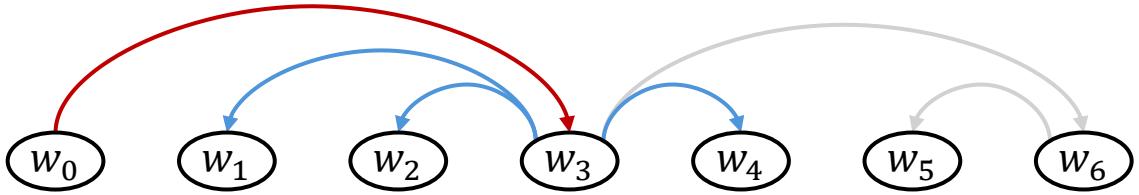


Add $<_5$ to the stack.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

$/_3$ $<_5$

Buffer

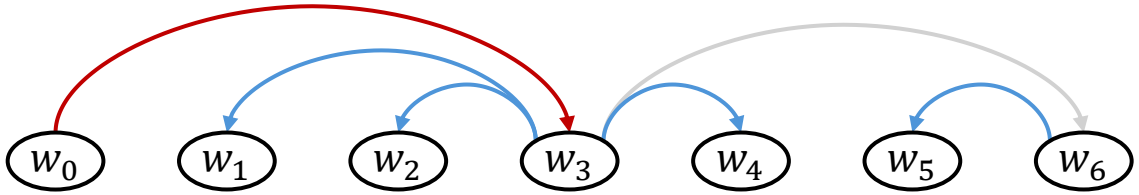
$>_6$

Match $>_6$ with the elements stack.

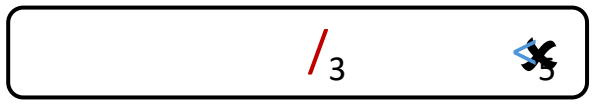
Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack



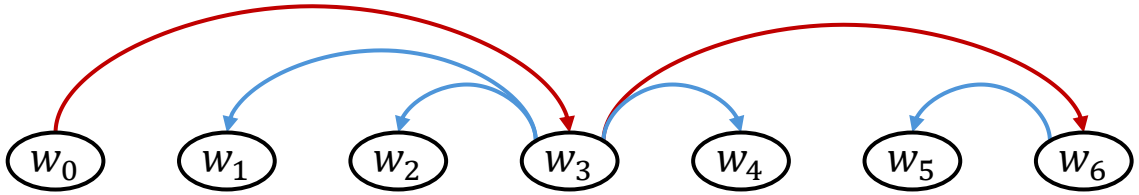
Buffer

Match $>_6$ with the elements stack.

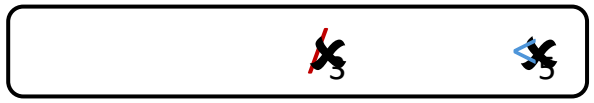
Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack



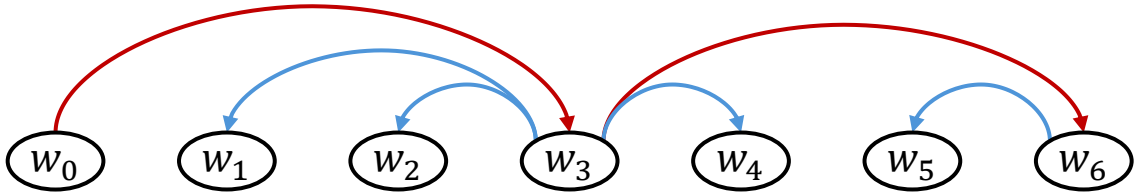
Buffer

Stop iteration when a superbracket is found.

Decoding with Hierarchical Brackets

Stack-based system where:

- Super right dependent (/) matches super-left head (>).
- Super right head (<) matches super-left dependent (\).
- Auxiliary left dependent (<) matches > and \.
- Auxiliary right dependent (>) matches < and /.



Stack

Buffer

Stop iteration when a superbracket is found.

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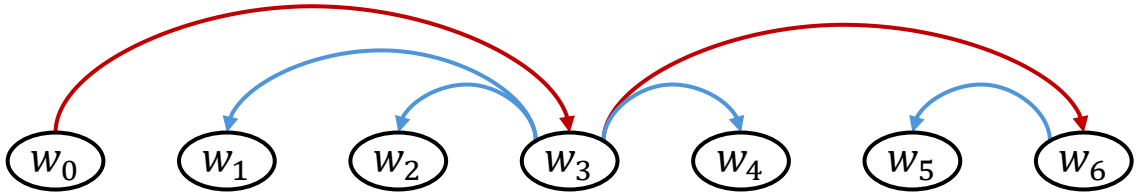

All arcs are recovered!

Stack

Buffer