Deterministic Incremental Dependency Parsing

Joakim Nivre, 2008

Jacob Louis Hoover

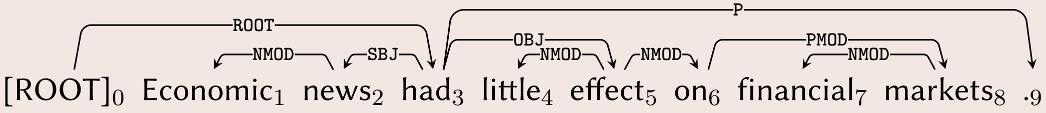
2021.04.16

Outline

Dependency structures:

Examples

- A projective English dependency tree from the Penn Treebank (converted to dependency parse with Nivre’s Penn2Malt).



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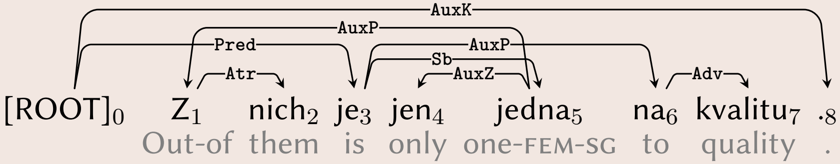

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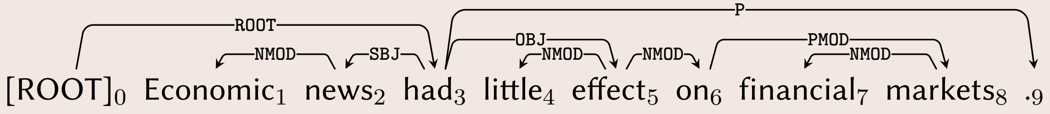

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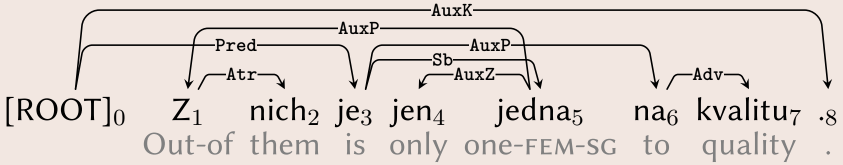

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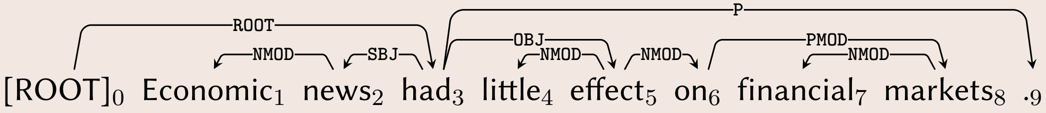

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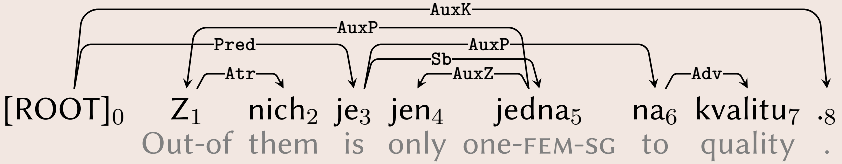

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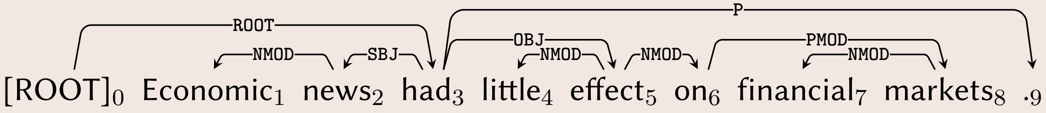

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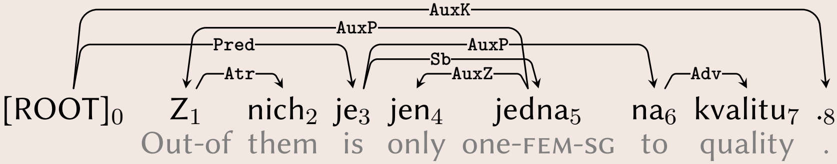

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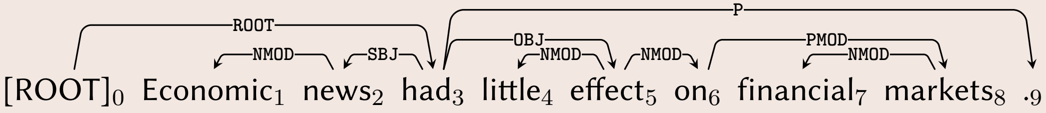

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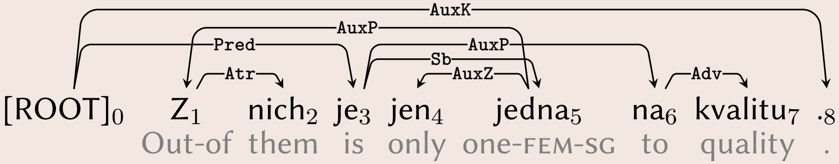

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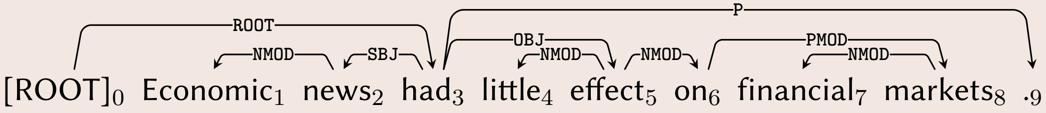

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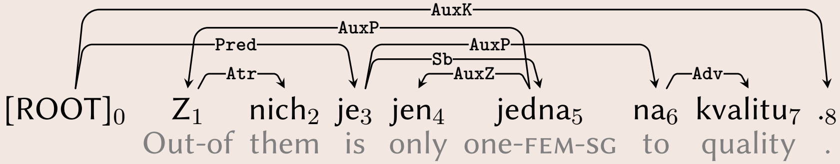

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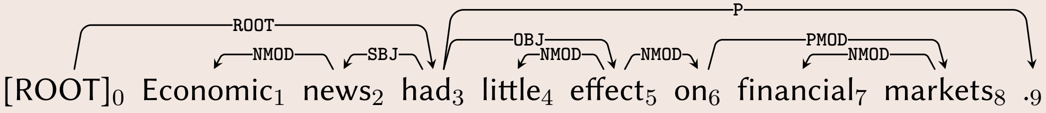

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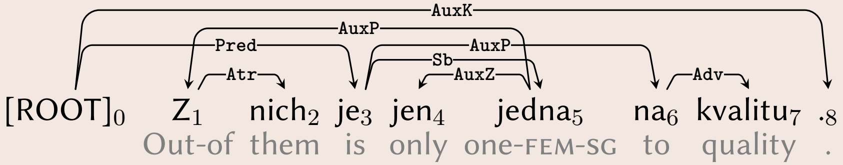

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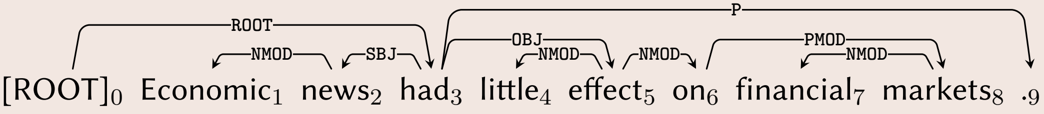

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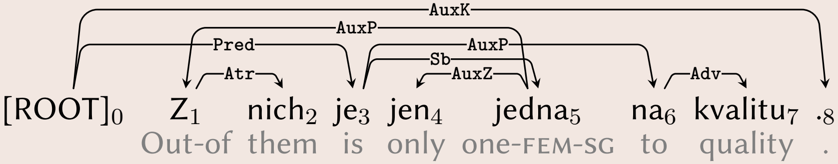

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- define notion of well-formedness
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  - there exists a path from the head of an arc to any node inside the span of the arc

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- Stack-based Algorithms (for projective structures)
  - arc-standard
  - arc-eager
- List-based Algorithms
  - non-projective
  - projective

Stack-based Algorithms

Definition

A stack-based configuration for a sentence $x = (w_0, w_1, \ldots, w_n)$ is a triple $c = (\sigma, \beta, A)$, where

1. σ is a stack of tokens $i \leq k$ (for some $k \leq n$) ← *will represent as a list with head to right*
2. β is a buffer of tokens $j > k$, ← *will represent as a list with head to left*
3. A is a set of dependency arcs such that $G = (\{0, 1, \ldots, n\}, A)$ is a dependency graph for x.

Definition

A stack-based transition system is a quadruple $S = (C, T, c_{\text{start}}, C_{\text{terminal}})$, where

1. C is the set of all stack-based configurations,
2. $c_{\text{start}}(x = (w_0, w_1, \ldots, w_n)) = ([0], [1, \ldots, n], \varnothing)$,
3. T is a set of transitions, each of which is a function $t : C \to C$,
4. $C_{\text{terminal}} = \{c \in C \mid c = (\sigma, [], A)\}$.

Arc-standard stack-based algorithm

Transitions

LEFT-ARC_l	$(\sigma\|i, j\|\beta, A) \Rightarrow (\sigma, j\|\beta, A \cup \{(j, l, i)\})$
RIGHT-ARC^s_l	$(\sigma\|i, j\|\beta, A) \Rightarrow (\sigma, i\|\beta, A \cup \{(i, l, j)\})$
SHIFT	$(\sigma, i\|\beta, A) \Rightarrow (\sigma\|i, \beta, A)$

Preconditions

LEFT-ARC_l	$\neg[i = 0]$ $\neg\exists k \exists l'[(k, l', i) \in A]$
RIGHT-ARC^s_l	$\neg\exists k \exists l'[(k, l', j) \in A]$

Figure: Transitions for the arc-standard stack-based parsing algorithm.

> “ ”
>
> The arc-standard parser is the closest correspondent to the familiar shift-reduce parser for context-free grammars (Aho, Sethi, and Ullman 1986).
> The LEFT-ARC_l and RIGHT-ARC^s_l transitions correspond to reduce actions, replacing a head-dependent structure with its head, whereas the SHIFT transition is exactly the same as the shift action.
> One peculiarity of the transitions, as defined here, is that the “reduce” transitions apply to one node on the stack and one node in the buffer, rather than two nodes on the stack. The reason for this formulation is to facilitate comparison with the arc-eager parser and to simplify the definition of terminal configurations.

Illustration Arc-standard transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

		σ	β	A	
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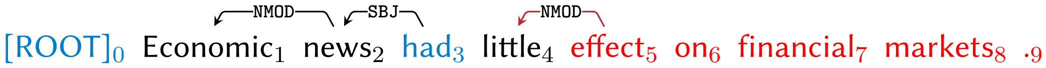

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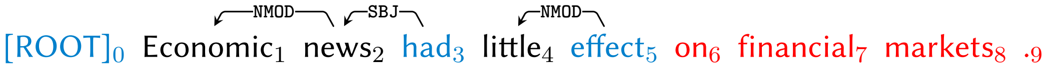
4.	SHIFT	$\Longrightarrow$	(	$[0,2],$	$[3,\ldots,9],$	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0],$	$[3,\ldots,9],$	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	SHIFT	$\Longrightarrow$	(	$[0,3],$	$[4,\ldots,9],$	A_2	)
7.	SHIFT	$\Longrightarrow$	(	$[0,3,4],$	$[5,\ldots,9],$	A_2	)
8.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3],$	$[5,\ldots,9],$	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)

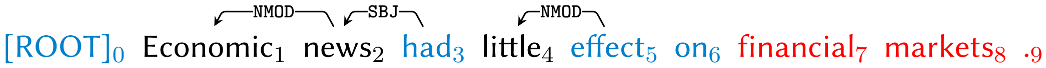
Illustration Arc-standard transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

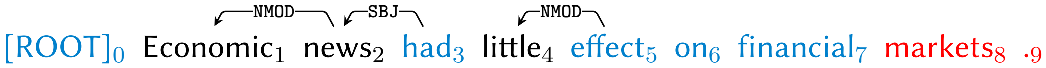
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)

Illustration Arc-standard transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	$\text{LEFT-ARC}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	$\text{LEFT-ARC}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	SHIFT	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	A_2	)
7.	SHIFT	$\Longrightarrow$	(	$[0, 3, 4]$,	$[5, \ldots, 9]$,	A_2	)
8.	$\text{LEFT-ARC}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[5, \ldots, 9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	SHIFT	$\Longrightarrow$	(	$[0, 3, 5]$,	$[6, \ldots, 9]$,	A_3	)
10.	SHIFT	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[7, 8, 9]$,	A_3	)

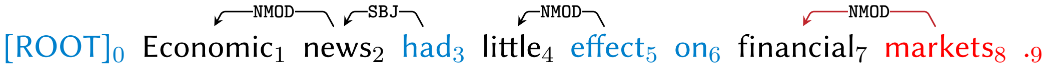
Illustration Arc-standard transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0, 3, 4]$,	$[5, \ldots, 9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[5, \ldots, 9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0, 3, 5]$,	$[6, \ldots, 9]$,	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[7, 8, 9]$,	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0, 3, 5, 6, 7]$,	$[8, 9]$,	A_3	)

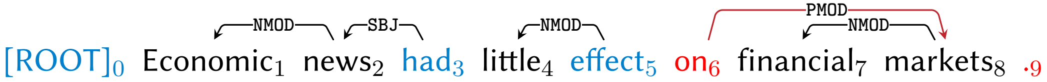
Illustration Arc-standard transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	SHIFT	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	A_2	)
7.	SHIFT	$\Longrightarrow$	(	$[0, 3, 4]$,	$[5, \ldots, 9]$,	A_2	)
8.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[5, \ldots, 9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	SHIFT	$\Longrightarrow$	(	$[0, 3, 5]$,	$[6, \ldots, 9]$,	A_3	)
10.	SHIFT	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[7, 8, 9]$,	A_3	)
11.	SHIFT	$\Longrightarrow$	(	$[0, 3, 5, 6, 7]$,	$[8, 9]$,	A_3	)
12.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[8, 9]$,	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)

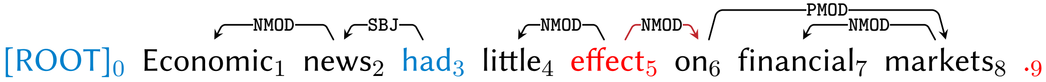
Illustration Arc-standard transition sequence for English example sentence:



$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

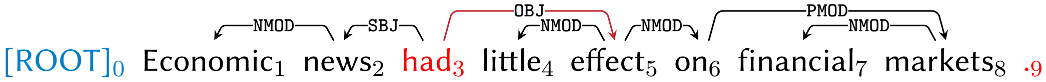
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)
10.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	$\textsc{Right-Arc}^{s}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6, \texttt{PMOD}, 8)\}$	)

Illustration Arc-standard transition sequence for English example sentence:



			σ	β	A	
1.		(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift} \Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}} \Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift} \Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}} \Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Shift} \Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	$\textsc{Shift} \Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}} \Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Shift} \Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)
10.	$\textsc{Shift} \Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	$\textsc{Shift} \Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	$\textsc{Left-Arc}_{\texttt{NMOD}} \Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{s}_{\texttt{PMOD}} \Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{Right-Arc}^{s}_{\texttt{NMOD}} \Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)

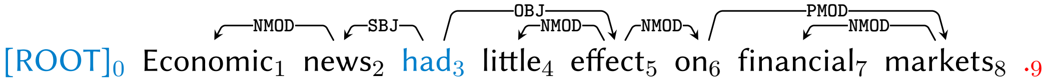
Illustration Arc-standard transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

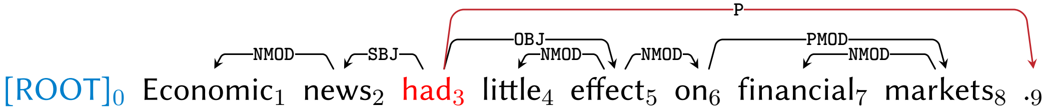
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	Right-Arc$^{s}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	Right-Arc$^{s}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
15.	Right-Arc$^{s}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,9]$,	$A_7 = A_6 \cup \{(3, \texttt{OBJ}, 5)\}$	)

Illustration Arc-standard transition sequence for English example sentence:



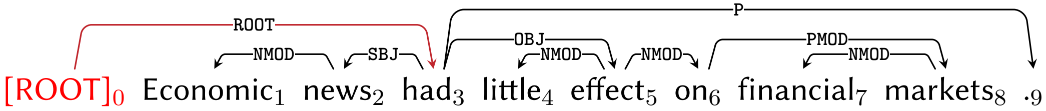
			σ	β	A	
1.		(	$[0]$,	$[1,\dots,9]$,	$\varnothing$	)
2.	Shift $\Longrightarrow$	(	$[0,1]$,	$[2,\dots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0]$,	$[2,\dots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift $\Longrightarrow$	(	$[0,2]$,	$[3,\dots,9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$ $\Longrightarrow$	(	$[0]$,	$[3,\dots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Shift $\Longrightarrow$	(	$[0,3]$,	$[4,\dots,9]$,	A_2	)
7.	Shift $\Longrightarrow$	(	$[0,3,4]$,	$[5,\dots,9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0,3]$,	$[5,\dots,9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Shift $\Longrightarrow$	(	$[0,3,5]$,	$[6,\dots,9]$,	A_3	)
10.	Shift $\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	Shift $\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	Right-Arc$^{s}_{\texttt{PMOD}}$ $\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	Right-Arc$^{s}_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
15.	Right-Arc$^{s}_{\texttt{OBJ}}$ $\Longrightarrow$	(	$[0]$,	$[3,9]$,	$A_7 = A_6 \cup \{(3, \texttt{OBJ}, 5)\}$	)
16.	Shift $\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_7	)

Illustration Arc-standard transition sequence for English example sentence:



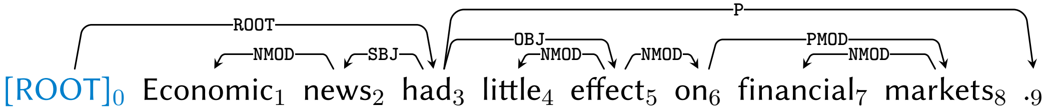
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	Right-Arc$^{s}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	Right-Arc$^{s}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
15.	Right-Arc$^{s}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,9]$,	$A_7 = A_6 \cup \{(3,\texttt{OBJ},5)\}$	)
16.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_7	)
17.	Right-Arc$^{s}_{\texttt{P}}$	$\Longrightarrow$	(	$[0]$,	$[3]$,	$A_8 = A_7 \cup \{(3,\texttt{P},9)\}$	)

Illustration Arc-standard transition sequence for English example sentence:



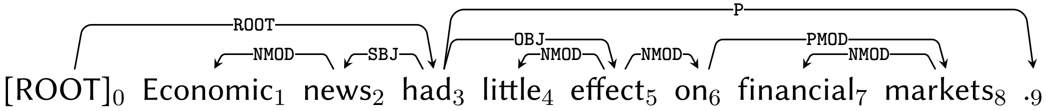
				σ	β	A	
1.			(	$[0]$,	$[1,\dots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\dots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\dots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\dots,9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\dots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[4,\dots,9]$,	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\dots,9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\dots,9]$,	$A_3 = A_2 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\dots,9]$,	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	Right-Arc$^{s}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	Right-Arc$^{s}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
15.	Right-Arc$^{s}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,9]$,	$A_7 = A_6 \cup \{(3,\texttt{OBJ},5)\}$	)
16.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_7	)
17.	Right-Arc$^{s}_{\texttt{P}}$	$\Longrightarrow$	(	$[0]$,	$[3]$,	$A_8 = A_7 \cup \{(3,\texttt{P},9)\}$	)
18.	Right-Arc$^{s}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[]$,	$[0]$,	$A_9 = A_8 \cup \{(0,\texttt{ROOT},3)\}$	)

Illustration Arc-standard transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0],$	$[1,\ldots,9],$	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1],$	$[2,\ldots,9],$	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0],$	$[2,\ldots,9],$	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2],$	$[3,\ldots,9],$	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0],$	$[3,\ldots,9],$	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0,3],$	$[4,\ldots,9],$	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4],$	$[5,\ldots,9],$	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3],$	$[5,\ldots,9],$	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0,3,5],$	$[6,\ldots,9],$	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0,3,5,6],$	$[7,8,9],$	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7],$	$[8,9],$	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6],$	$[8,9],$	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	Right-Arc$^{s}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5],$	$[6,9],$	$A_5 = A_4 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	Right-Arc$^{s}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3],$	$[5,9],$	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
15.	Right-Arc$^{s}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0],$	$[3,9],$	$A_7 = A_6 \cup \{(3, \texttt{OBJ}, 5)\}$	)
16.	Shift	$\Longrightarrow$	(	$[0,3],$	$[9],$	A_7	)
17.	Right-Arc$^{s}_{\texttt{P}}$	$\Longrightarrow$	(	$[0],$	$[3],$	$A_8 = A_7 \cup \{(3, \texttt{P}, 9)\}$	)
18.	Right-Arc$^{s}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[\,],$	$[0],$	$A_9 = A_8 \cup \{(0, \texttt{ROOT}, 3)\}$	)
19.	Shift	$\Longrightarrow$	(	$[0],$	$[\,],$	A_9	)

Illustration Arc-standard transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	A_2	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_2	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_3 = A_2 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Shift	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	A_3	)
10.	Shift	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	A_3	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_3	)
12.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_4 = A_3 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	Right-Arc$^s_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,9]$,	$A_5 = A_4 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	Right-Arc$^s_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
15.	Right-Arc$^s_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,9]$,	$A_7 = A_6 \cup \{(3, \texttt{OBJ}, 5)\}$	)
16.	Shift	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_7	)
17.	Right-Arc$^s_{\texttt{P}}$	$\Longrightarrow$	(	$[0]$,	$[3]$,	$A_8 = A_7 \cup \{(3, \texttt{P}, 9)\}$	)
18.	Right-Arc$^s_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[]$,	$[0]$,	$A_9 = A_8 \cup \{(0, \texttt{ROOT}, 3)\}$	)
19.	Shift	$\Longrightarrow$	(	$[0]$,	$[]$,	A_9	)

Arc-eager stack-based algorithm

Transitions	
Left-Arc$_l$	$(\sigma\|i, j\|\beta, A) \Rightarrow (\sigma, j\|\beta, A \cup \{(j, l, i)\})$
Right-Arc^e_l	$(\sigma\|i, j\|\beta, A) \Rightarrow (\sigma\|i\|j, \beta, A \cup \{(i, l, j)\})$
Reduce	$(\sigma\|i, \beta, A) \Rightarrow (\sigma, \beta, A)$
Shift	$(\sigma, i\|\beta, A) \Rightarrow (\sigma\|i, \beta, A)$
Preconditions	
Left-Arc$_l$	$\neg[i = 0]$ $\neg\exists k \exists l'[(k, l', i) \in A]$
Right-Arc^e_l	$\neg\exists k \exists l'[(k, l', j) \in A]$
Reduce	$\exists k \exists l[(k, l, i) \in A]$

Figure: Transitions for the arc-eager stack-based parsing algorithm.

> “ ”
>
> The arc-eager parser differs from the arc-standard one by attaching right dependents (using Right-Arc^e_l transitions) as soon as possible, that is, before the right dependent has found all its right dependents.
> As a consequence, the Right-Arc^e_l transitions cannot replace the head-dependent structure with the head, as in the arc-standard system, but must store both the head and the dependent on the stack for further processing. The dependent can be popped from the stack at a later time through the Reduce transition, which completes the reduction of this structure.

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

		σ	β	A	
1.	(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

			σ	β	A	
1.		(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT $\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

			σ	β	A	
1.		(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT $\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)

Illustration Arc-eager transition sequence for English example sentence:

			σ	β	A	
1.		(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	Shift $\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift $\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

			σ	β	A	
1.		(	$[0]$,	$[1, \dots, 9]$,	$\varnothing$	)
2.	Shift $\Longrightarrow$	(	$[0, 1]$,	$[2, \dots, 9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0]$,	$[2, \dots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift $\Longrightarrow$	(	$[0, 2]$,	$[3, \dots, 9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$ $\Longrightarrow$	(	$[0]$,	$[3, \dots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)

Illustration Arc-eager transition sequence for English example sentence:

				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

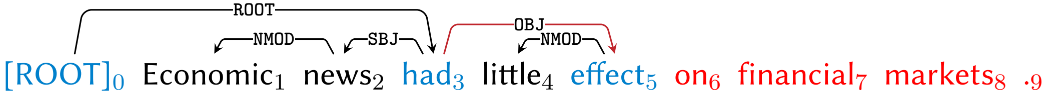
				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	SHIFT	$\Longrightarrow$	(	$[0, 3, 4]$,	$[5, \ldots, 9]$,	A_3	)

Illustration Arc-eager transition sequence for English example sentence:

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

			σ	β	A	
1.		(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	SHIFT $\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	SHIFT $\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$ $\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$ $\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	SHIFT $\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	LEFT-ARC$_{\texttt{NMOD}}$ $\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)

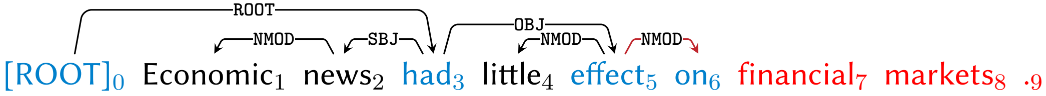
Illustration Arc-eager transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

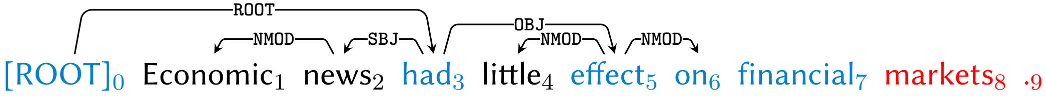
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1=\{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2=A_1\cup\{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3=A_2\cup\{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4=A_3\cup\{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5=A_4\cup\{(3,\texttt{OBJ},5)\}$	)

Illustration Arc-eager transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0, 1]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0, 2]$,	$[3, \ldots, 9]$,	A_1	)
5.	Left-Arc$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	Right-Arc$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	Shift	$\Longrightarrow$	(	$[0, 3, 4]$,	$[5, \ldots, 9]$,	A_3	)
8.	Left-Arc$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[5, \ldots, 9]$,	$A_4 = A_3 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	Right-Arc$^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0, 3, 5]$,	$[6, \ldots, 9]$,	$A_5 = A_4 \cup \{(3, \texttt{OBJ}, 5)\}$	)
10.	Right-Arc$^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[7, 8, 9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)

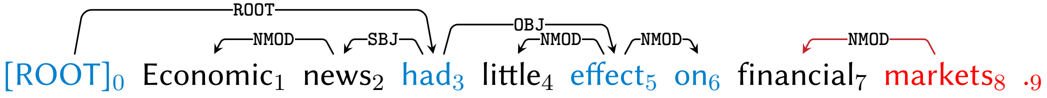
Illustration Arc-eager transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

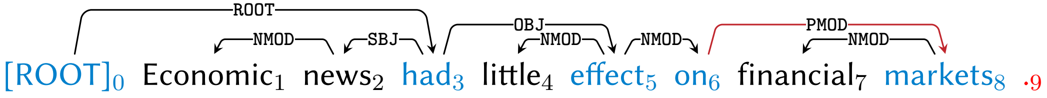
				σ	β	A	
1.			(	$[0],$	$[1,\ldots,9],$	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0,1],$	$[2,\ldots,9],$	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0],$	$[2,\ldots,9],$	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0,2],$	$[3,\ldots,9],$	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0],$	$[3,\ldots,9],$	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3],$	$[4,\ldots,9],$	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	SHIFT	$\Longrightarrow$	(	$[0,3,4],$	$[5,\ldots,9],$	A_3	)
8.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3],$	$[5,\ldots,9],$	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	RIGHT-ARC$^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5],$	$[6,\ldots,9],$	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	RIGHT-ARC$^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6],$	$[7,8,9],$	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	SHIFT	$\Longrightarrow$	(	$[0,3,5,6,7],$	$[8,9],$	A_6	)

Illustration Arc-eager transition sequence for English example sentence:



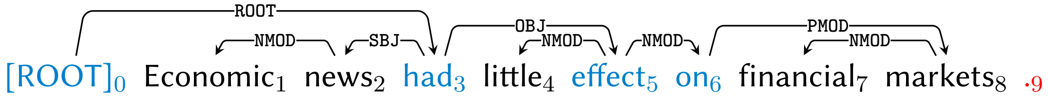
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)

Illustration Arc-eager transition sequence for English example sentence:



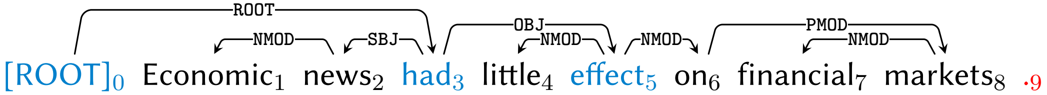
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{e}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)

Illustration Arc-eager transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{e}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{Reduce}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[9]$,	A_8	)

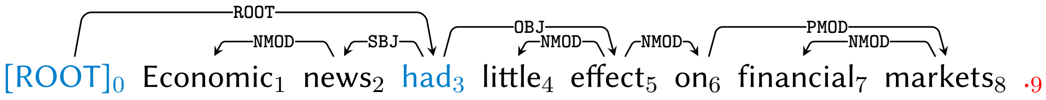
Illustration Arc-eager transition sequence for English example sentence:



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

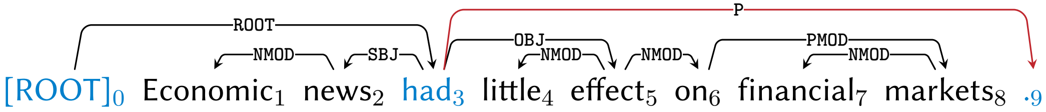
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	Left-Arc$_{\mathtt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\mathtt{NMOD},1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	Left-Arc$_{\mathtt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\mathtt{SBJ},2)\}$	)
6.	Right-Arc$^{e}_{\mathtt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\mathtt{ROOT},3)\}$	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	Left-Arc$_{\mathtt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\mathtt{NMOD},4)\}$	)
9.	Right-Arc$^{e}_{\mathtt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\mathtt{OBJ},5)\}$	)
10.	Right-Arc$^{e}_{\mathtt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\mathtt{NMOD},6)\}$	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	Left-Arc$_{\mathtt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\mathtt{NMOD},7)\}$	)
13.	Right-Arc$^{e}_{\mathtt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\mathtt{PMOD},8)\}$	)
14.	Reduce	$\Longrightarrow$	(	$[0,3,5,6]$,	$[9]$,	A_8	)
15.	Reduce	$\Longrightarrow$	(	$[0,3,5]$,	$[9]$,	A_8	)

Illustration Arc-eager transition sequence for English example sentence:



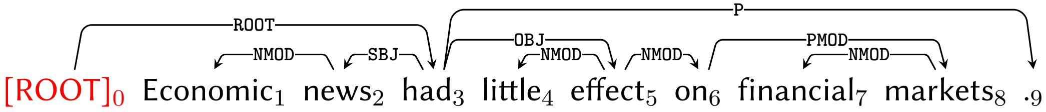
				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	SHIFT	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	RIGHT-ARC$^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	RIGHT-ARC$^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	SHIFT	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	RIGHT-ARC$^{e}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	REDUCE	$\Longrightarrow$	(	$[0,3,5,6]$,	$[9]$,	A_8	)
15.	REDUCE	$\Longrightarrow$	(	$[0,3,5]$,	$[9]$,	A_8	)
16.	REDUCE	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_8	)

Illustration Arc-eager transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1,\dots,9]$,	$\varnothing$	)
2.	Shift	$\Longrightarrow$	(	$[0,1]$,	$[2,\dots,9]$,	$\varnothing$	)
3.	$\text{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\dots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	Shift	$\Longrightarrow$	(	$[0,2]$,	$[3,\dots,9]$,	A_1	)
5.	$\text{Left-Arc}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\dots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\text{Right-Arc}^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\dots,9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	Shift	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\dots,9]$,	A_3	)
8.	$\text{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\dots,9]$,	$A_4 = A_3 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	$\text{Right-Arc}^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\dots,9]$,	$A_5 = A_4 \cup \{(3, \texttt{OBJ}, 5)\}$	)
10.	$\text{Right-Arc}^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
11.	Shift	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	$\text{Left-Arc}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	$\text{Right-Arc}^{e}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	Reduce	$\Longrightarrow$	(	$[0,3,5,6]$,	$[9]$,	A_8	)
15.	Reduce	$\Longrightarrow$	(	$[0,3,5]$,	$[9]$,	A_8	)
16.	Reduce	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_8	)
17.	$\text{Right-Arc}^{e}_{\texttt{P}}$	$\Longrightarrow$	(	$[0,3,9]$,	$[]$,	$A_9 = A_8 \cup \{(3, \texttt{P}, 9)\}$	)

Illustration Arc-eager transition sequence for English example sentence:



				σ	β	A	
1.			(	$[0]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	SHIFT	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	SHIFT	$\Longrightarrow$	(	$[0,2]$,	$[3,\ldots,9]$,	A_1	)
5.	LEFT-ARC$_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	RIGHT-ARC$^{e}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	SHIFT	$\Longrightarrow$	(	$[0,3,4]$,	$[5,\ldots,9]$,	A_3	)
8.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	RIGHT-ARC$^{e}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	RIGHT-ARC$^{e}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	SHIFT	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[8,9]$,	A_6	)
12.	LEFT-ARC$_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	RIGHT-ARC$^{e}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	REDUCE	$\Longrightarrow$	(	$[0,3,5,6]$,	$[9]$,	A_8	)
15.	REDUCE	$\Longrightarrow$	(	$[0,3,5]$,	$[9]$,	A_8	)
16.	REDUCE	$\Longrightarrow$	(	$[0,3]$,	$[9]$,	A_8	)
17.	RIGHT-ARC$^{e}_{\texttt{P}}$	$\Longrightarrow$	(	$[0,3,9]$,	$[\,]$,	$A_9 = A_8 \cup \{(3,\texttt{P},9)\}$	)

List-based Algorithms

Definition

A list-based configuration for a sentence $x = (w_0, w_1, \ldots, w_n)$ is a quadruple $c = (\lambda_1, \lambda_2, \beta, A)$, where

1. λ_1 is a list of tokens $i_1 \leq k_1$ (for some $k_1 \leq n$)
    - *will represent as a list with head to right (nodes in decreasing order)*
2. λ_2 is a list of tokens $i_2 \leq k_2$ (for some k_2, such that $k_1 < k_2 \leq n$)
    - *will represent as a list with head to left (nodes in increasing order)*
3. β is a buffer of tokens $j > k_2$,
    - *will represent as a list with head to left*
4. A is a set of dependency arcs such that $G = (\{0, 1, \ldots, n\}, A)$ is a dependency graph for x.

Write $\lambda_1.\lambda_2$ for the concatenation of lists λ_1 and λ_2. Ex., $[0, 1].[2, 3, 4] = [0, 1, 2, 3, 4]$.

Definition

A list-based transition system is a quadruple $S = (C, T, c_{\text{start}}, C_{\text{terminal}})$, where

1. C is the set of all list-based configurations,
2. $c_{\text{start}}(x = (w_0, w_1, \ldots, w_n)) = ([0], [], [1, \ldots, n], \varnothing)$,
3. T is a set of transitions, each of which is a function $t : C \to C$,
4. $C_{\text{terminal}} = \{c \in C \mid c = (\lambda_1, \lambda_2, [], A)\}$.

(Note, only difference from stack-based system is: two lists instead of a single stack)

Non-projective list-based algorithm

Transitions

Left-Arc$_l^n$	$(\lambda_1\|i,\lambda_2,j\|\beta,A) \Rightarrow (\lambda_1,i\|\lambda_2,j\|\beta,A\cup\{(j,l,i)\})$
Right-Arc$_l^n$	$(\lambda_1\|i,\lambda_2,j\|\beta,A) \Rightarrow (\lambda_1,i\|\lambda_2,j\|\beta,A\cup\{(i,l,j)\})$
No-Arc^n	$(\lambda_1\|i,\lambda_2,\beta,A) \Rightarrow (\lambda_1,i\|\lambda_2,\beta,A)$
Shift$^\lambda$	$(\lambda_1,\lambda_2,i\|\beta,A) \Rightarrow (\lambda_1.\lambda_2\|i,[\,],\beta,A)$

Preconditions

Left-Arc$_l^n$	$\neg[i = 0]$ $\neg\exists k\exists l'[(k,l',i) \in A]$ $\neg[i \to^* j]_A$
Right-Arc$_l^n$	$\neg\exists k\exists l'[(k,l',j) \in A]$ $\neg[j \to^* i]_A$

Figure: Transitions for the arc-eager stack-based parsing algorithm.

> “ ”
>
> The fact that both the head and the dependent are kept in either λ_2 or β makes it possible to construct non-projective dependency graphs, because the No-Arc^n transition allows a node to be passed from λ_1 to λ_2 even if it does not (yet) have a head.

Illustration Transition sequence for non-projective Czech example sentence:

$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

		λ_1	λ_2	β	A	
1.	(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)

Illustration Transition sequence for non-projective Czech example sentence:

[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \ldots, 8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 8]$,	$\varnothing$	)

Illustration Transition sequence for non-projective Czech example sentence:

$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \dots, 8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \dots, 8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2, \dots, 8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)

Illustration Transition sequence for non-projective Czech example sentence:

$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

			λ_1	λ_2	β	A	
1.		(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}} \Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)

Illustration Transition sequence for non-projective Czech example sentence:

[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \ldots, 8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2, \ldots, 8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1, 2]$,	$[]$,	$[3, \ldots, 8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0, 1]$,	$[2]$,	$[3, \ldots, 8]$,	A_1	)

Illustration Transition sequence for non-projective Czech example sentence:

[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)

Illustration Transition sequence for non-projective Czech example sentence:

$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)

Illustration Transition sequence for non-projective Czech example sentence:

[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

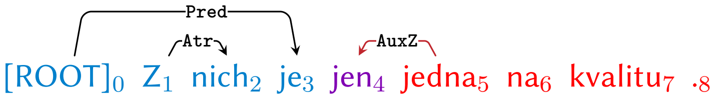
				λ_1	λ_2	β	A	
1.			(	$[0],$	$[],$	$[1,\dots,8],$	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1],$	$[],$	$[2,\dots,8],$	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0],$	$[1],$	$[2,\dots,8],$	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2],$	$[],$	$[3,\dots,8],$	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1],$	$[2],$	$[3,\dots,8],$	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0],$	$[1,2],$	$[3,\dots,8],$	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[],$	$[0,1,2],$	$[3,\dots,8],$	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,3],$	$[],$	$[4,\dots,8],$	A_2	)

Illustration Transition sequence for non-projective Czech example sentence:

[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)

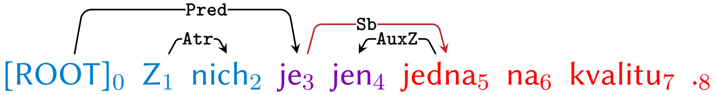
Illustration Transition sequence for non-projective Czech example sentence:



[ROOT]$_0$ Z$_1$ nich$_2$ je$_3$ jen$_4$ jedna$_5$ na$_6$ kvalitu$_7$.$_8$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)

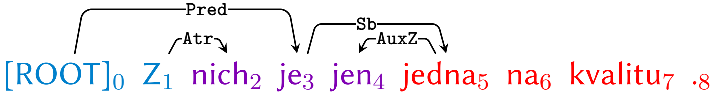
Illustration Transition sequence for non-projective Czech example sentence:



$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

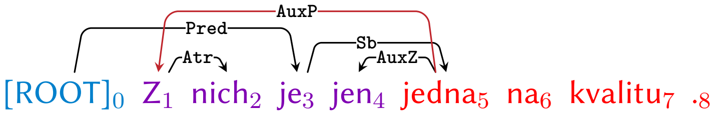
			λ_1	λ_2	β	A	
1.		(	$[0],$	$[],$	$[1,\ldots,8],$	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,1],$	$[],$	$[2,\ldots,8],$	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}} \Longrightarrow$	(	$[0],$	$[1],$	$[2,\ldots,8],$	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,1,2],$	$[],$	$[3,\ldots,8],$	A_1	)
5.	$\textsc{No-Arc}^{n} \Longrightarrow$	(	$[0,1],$	$[2],$	$[3,\ldots,8],$	A_1	)
6.	$\textsc{No-Arc}^{n} \Longrightarrow$	(	$[0],$	$[1,2],$	$[3,\ldots,8],$	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}} \Longrightarrow$	(	$[],$	$[0,1,2],$	$[3,\ldots,8],$	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,\ldots,3],$	$[],$	$[4,\ldots,8],$	A_2	)
9.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,\ldots,4],$	$[],$	$[5,\ldots,8],$	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}} \Longrightarrow$	(	$[0,\ldots,3],$	$[4],$	$[5,\ldots,8],$	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}} \Longrightarrow$	(	$[0,1,2],$	$[3,4],$	$[5,\ldots,8],$	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)

Illustration Transition sequence for non-projective Czech example sentence:



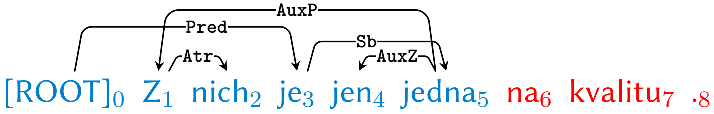
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\dots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\dots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\dots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\dots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\dots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\dots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\dots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[]$,	$[4,\dots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[]$,	$[5,\dots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[4]$,	$[5,\dots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\dots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\dots,8]$,	A_4	)

Illustration Transition sequence for non-projective Czech example sentence:



				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	Shift^{λ}	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\text{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	Shift^{λ}	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	No-Arc^{n}	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	No-Arc^{n}	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\text{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	Shift^{λ}	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	Shift^{λ}	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\text{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\text{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	No-Arc^{n}	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\text{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)

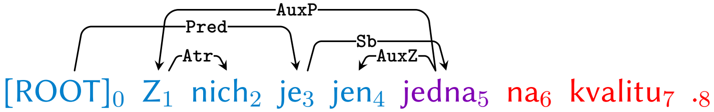
Illustration Transition sequence for non-projective Czech example sentence:



$[\text{ROOT}]_0$ Z_1 nich_2 je_3 jen_4 jedna_5 na_6 kvalitu_7 $._8$

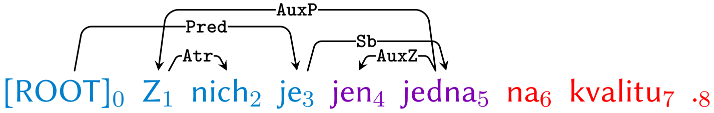
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)

Illustration Transition sequence for non-projective Czech example sentence:



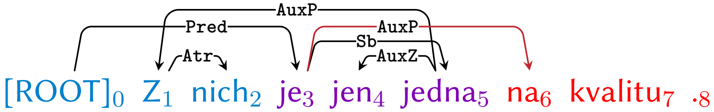
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\dots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\dots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\dots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\dots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\dots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\dots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\dots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[]$,	$[4,\dots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[]$,	$[5,\dots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[4]$,	$[5,\dots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\dots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\dots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\dots,4]$,	$[5,\dots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)

Illustration Transition sequence for non-projective Czech example sentence:



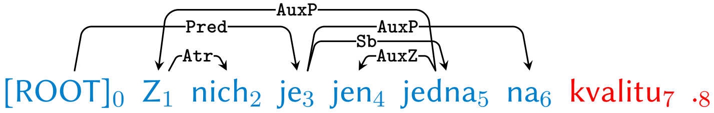
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)

Illustration Transition sequence for non-projective Czech example sentence:



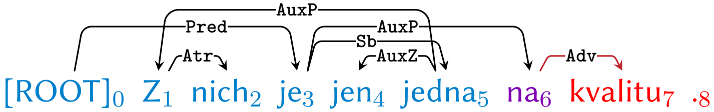
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)

Illustration Transition sequence for non-projective Czech example sentence:



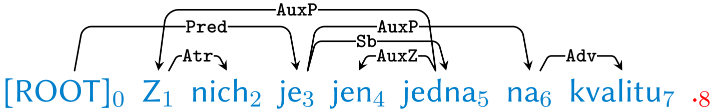
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)

Illustration Transition sequence for non-projective Czech example sentence:



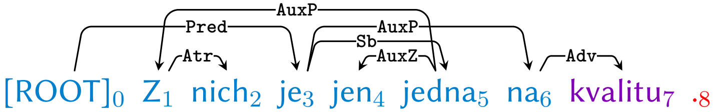
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)

Illustration Transition sequence for non-projective Czech example sentence:



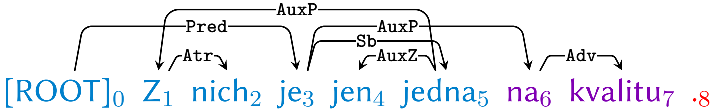
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



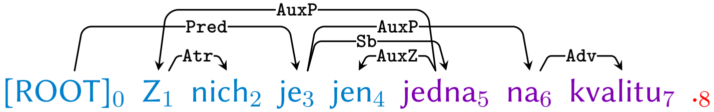
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



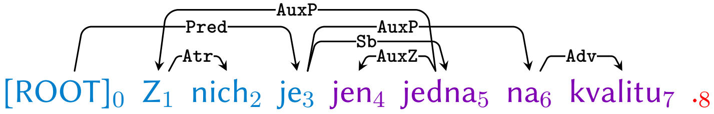
			λ_1	λ_2	β	A	
1.		(	$[0]$,	$[]$,	$[1, \ldots, 8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, 1]$,	$[]$,	$[2, \ldots, 8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$ (	$[0]$,	$[1]$,	$[2, \ldots, 8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, 1, 2]$,	$[]$,	$[3, \ldots, 8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, 1]$,	$[2]$,	$[3, \ldots, 8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0]$,	$[1, 2]$,	$[3, \ldots, 8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$ (	$[]$,	$[0, 1, 2]$,	$[3, \ldots, 8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, \ldots, 3]$,	$[]$,	$[4, \ldots, 8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, \ldots, 4]$,	$[]$,	$[5, \ldots, 8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$ (	$[0, \ldots, 3]$,	$[4]$,	$[5, \ldots, 8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$ (	$[0, 1, 2]$,	$[3, 4]$,	$[5, \ldots, 8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, 1]$,	$[2, 3, 4]$,	$[5, \ldots, 8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$ (	$[0]$,	$[1, \ldots, 4]$,	$[5, \ldots, 8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, \ldots, 5]$,	$[]$,	$[6, 7, 8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, \ldots, 4]$,	$[5]$,	$[6, 7, 8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, \ldots, 3]$,	$[4, 5]$,	$[6, 7, 8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$ (	$[0, 1, 2]$,	$[3, 4, 5]$,	$[6, 7, 8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, \ldots, 6]$,	$[]$,	$[7, 8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$ (	$[0, \ldots, 5]$,	$[6]$,	$[7, 8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$ (	$[0, \ldots, 7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, \ldots, 6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$ (	$[0, \ldots, 5]$,	$[6, 7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



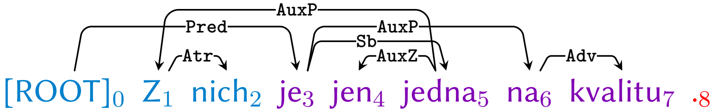
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



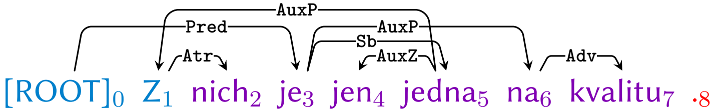
				λ_1	λ_2	β	A	
1.			(	$[0],$	$[],$	$[1,\ldots,8],$	$\varnothing$	)
2.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,1],$	$[],$	$[2,\ldots,8],$	$\varnothing$	)
3.	$\textsc{Right-Arc}^n_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0],$	$[1],$	$[2,\ldots,8],$	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,1,2],$	$[],$	$[3,\ldots,8],$	A_1	)
5.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,1],$	$[2],$	$[3,\ldots,8],$	A_1	)
6.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0],$	$[1,2],$	$[3,\ldots,8],$	A_1	)
7.	$\textsc{Right-Arc}^n_{\texttt{Pred}}$	$\Longrightarrow$	(	$[],$	$[0,1,2],$	$[3,\ldots,8],$	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,\ldots,3],$	$[],$	$[4,\ldots,8],$	A_2	)
9.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,\ldots,4],$	$[],$	$[5,\ldots,8],$	A_2	)
10.	$\textsc{Left-Arc}^n_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3],$	$[4],$	$[5,\ldots,8],$	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^n_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2],$	$[3,4],$	$[5,\ldots,8],$	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,1],$	$[2,3,4],$	$[5,\ldots,8],$	A_4	)
13.	$\textsc{Left-Arc}^n_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0],$	$[1,\ldots,4],$	$[5,\ldots,8],$	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,\ldots,5],$	$[],$	$[6,7,8],$	A_5	)
15.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,4],$	$[5],$	$[6,7,8],$	A_5	)
16.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,3],$	$[4,5],$	$[6,7,8],$	A_5	)
17.	$\textsc{Right-Arc}^n_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2],$	$[3,4,5],$	$[6,7,8],$	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,\ldots,6],$	$[],$	$[7,8],$	A_6	)
19.	$\textsc{Right-Arc}^n_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5],$	$[6],$	$[7,8],$	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^\lambda$	$\Longrightarrow$	(	$[0,\ldots,7],$	$[],$	$[8],$	A_7	)
21.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,6],$	$[7],$	$[8],$	A_7	)
22.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,5],$	$[6,7],$	$[8],$	A_7	)
23.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,4],$	$[5,6,7],$	$[8],$	A_7	)
24.	$\textsc{No-Arc}^n$	$\Longrightarrow$	(	$[0,\ldots,3],$	$[4,\ldots,7],$	$[8],$	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



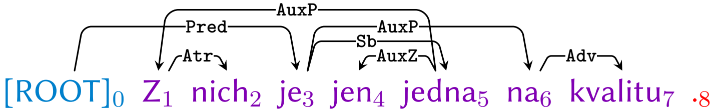
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,\ldots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\ldots,7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



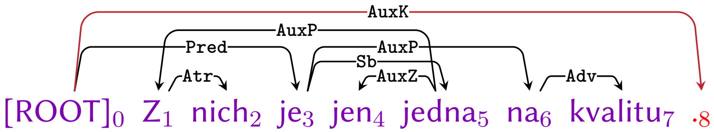
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,\ldots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\ldots,7]$,	$[8]$,	A_7	)
26.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



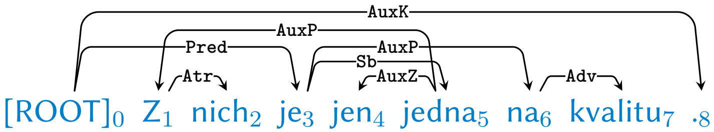
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,\ldots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\ldots,7]$,	$[8]$,	A_7	)
26.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,7]$,	$[8]$,	A_7	)
27.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,7]$,	$[8]$,	A_7	)

Illustration Transition sequence for non-projective Czech example sentence:



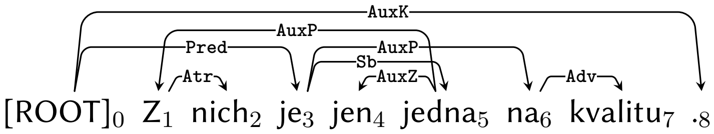
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\dots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\dots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\dots,8]$,	$A_1 = (1,\texttt{Atr},2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\dots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\dots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\dots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\dots,8]$,	$A_2 = A_1 \cup (0,\texttt{Pred},3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[]$,	$[4,\dots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[]$,	$[5,\dots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[4]$,	$[5,\dots,8]$,	$A_3 = A_2 \cup (5,\texttt{AuxZ},4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\dots,8]$,	$A_4 = A_3 \cup (3,\texttt{Sb},5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\dots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\dots,4]$,	$[5,\dots,8]$,	$A_5 = A_4 \cup (5,\texttt{AuxP},1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3,\texttt{AuxP},6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\dots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6,\texttt{Adv},7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\dots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\dots,3]$,	$[4,\dots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\dots,7]$,	$[8]$,	A_7	)
26.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\dots,7]$,	$[8]$,	A_7	)
27.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,\dots,7]$,	$[8]$,	A_7	)
28.	$\textsc{Right-Arc}^{n}_{\texttt{AuxK}}$	$\Longrightarrow$	(	$[]$,	$[0,\dots,7]$,	$[8]$,	$A_8 = A_7 \cup (0,\texttt{AuxK},8)$	)

Illustration Transition sequence for non-projective Czech example sentence:



				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,\ldots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\ldots,7]$,	$[8]$,	A_7	)
26.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,7]$,	$[8]$,	A_7	)
27.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,7]$,	$[8]$,	A_7	)
28.	$\textsc{Right-Arc}^{n}_{\texttt{AuxK}}$	$\Longrightarrow$	(	$[]$,	$[0,\ldots,7]$,	$[8]$,	$A_8 = A_7 \cup (0, \texttt{AuxK}, 8)$	)
29.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,8]$,	$[]$,	$[]$,	A_8	)

Illustration Transition sequence for non-projective Czech example sentence:



				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,8]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,8]$,	$\varnothing$	)
3.	$\textsc{Right-Arc}^{n}_{\texttt{Atr}}$	$\Longrightarrow$	(	$[0]$,	$[1]$,	$[2,\ldots,8]$,	$A_1 = (1, \texttt{Atr}, 2)$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1,2]$,	$[]$,	$[3,\ldots,8]$,	A_1	)
5.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2]$,	$[3,\ldots,8]$,	A_1	)
6.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,2]$,	$[3,\ldots,8]$,	A_1	)
7.	$\textsc{Right-Arc}^{n}_{\texttt{Pred}}$	$\Longrightarrow$	(	$[]$,	$[0,1,2]$,	$[3,\ldots,8]$,	$A_2 = A_1 \cup (0, \texttt{Pred}, 3)$	)
8.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[]$,	$[4,\ldots,8]$,	A_2	)
9.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[]$,	$[5,\ldots,8]$,	A_2	)
10.	$\textsc{Left-Arc}^{n}_{\texttt{AuxZ}}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4]$,	$[5,\ldots,8]$,	$A_3 = A_2 \cup (5, \texttt{AuxZ}, 4)$	)
11.	$\textsc{Right-Arc}^{n}_{\texttt{Sb}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4]$,	$[5,\ldots,8]$,	$A_4 = A_3 \cup (3, \texttt{Sb}, 5)$	)
12.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,3,4]$,	$[5,\ldots,8]$,	A_4	)
13.	$\textsc{Left-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,4]$,	$[5,\ldots,8]$,	$A_5 = A_4 \cup (5, \texttt{AuxP}, 1)$	)
14.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[]$,	$[6,7,8]$,	A_5	)
15.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5]$,	$[6,7,8]$,	A_5	)
16.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,5]$,	$[6,7,8]$,	A_5	)
17.	$\textsc{Right-Arc}^{n}_{\texttt{AuxP}}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,4,5]$,	$[6,7,8]$,	$A_6 = A_5 \cup (3, \texttt{AuxP}, 6)$	)
18.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[]$,	$[7,8]$,	A_6	)
19.	$\textsc{Right-Arc}^{n}_{\texttt{Adv}}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6]$,	$[7,8]$,	$A_7 = A_6 \cup (6, \texttt{Adv}, 7)$	)
20.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,7]$,	$[]$,	$[8]$,	A_7	)
21.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,6]$,	$[7]$,	$[8]$,	A_7	)
22.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,5]$,	$[6,7]$,	$[8]$,	A_7	)
23.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,4]$,	$[5,6,7]$,	$[8]$,	A_7	)
24.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,\ldots,3]$,	$[4,\ldots,7]$,	$[8]$,	A_7	)
25.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1,2]$,	$[3,\ldots,7]$,	$[8]$,	A_7	)
26.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0,1]$,	$[2,\ldots,7]$,	$[8]$,	A_7	)
27.	$\textsc{No-Arc}^{n}$	$\Longrightarrow$	(	$[0]$,	$[1,\ldots,7]$,	$[8]$,	A_7	)
28.	$\textsc{Right-Arc}^{n}_{\texttt{AuxK}}$	$\Longrightarrow$	(	$[]$,	$[0,\ldots,7]$,	$[8]$,	$A_8 = A_7 \cup (0, \texttt{AuxK}, 8)$	)
29.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,\ldots,8]$,	$[]$,	$[]$,	A_8	)

Projective list-based algorithm

Transitions

LEFT-ARC$_l^p$	$(\lambda_1 \vert i, \lambda_2, j \vert \beta, A) \Rightarrow (\lambda_1, [\,], j \vert \beta, A \cup \{(j, l, i)\})$
RIGHT-ARC$_l^p$	$(\lambda_1 \vert i, \lambda_2, j \vert \beta, A) \Rightarrow (\lambda_1 \vert i \vert j, [\,], \beta, A \cup \{(i, l, j)\})$
NO-ARC^p	$(\lambda_1 \vert i, \lambda_2, \beta, A) \Rightarrow (\lambda_1, i \vert \lambda_2, \beta, A)$
SHIFT$^\lambda$	$(\lambda_1, \lambda_2, i \vert \beta, A) \Rightarrow (\lambda_1 . \lambda_2 \vert i, [\,], \beta, A)$

Preconditions

LEFT-ARC$_l^p$	$\neg[i = 0]$ $\neg\exists k \exists l'[(k, l', i) \in A]$
RIGHT-ARC$_l^p$	$\neg\exists k \exists l'[(k, l', j) \in A]$
NO-ARC^p	$\exists k \exists l[(k, l, i) \in A]$

Figure: Transitions for the arc-eager stack-based parsing algorithm.

“ ”

The projective, list-based parser uses the same basic strategy as its non-projective counterpart, but skips any pair (i, j) that could give rise to a non-projective dependency arc.
Skipping many node pairs makes it more efficient in practice, although the worst-case time complexity remains the same.

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

		λ_1	λ_2	β	A	
1.	(	$[0]$,	$[]$,	$[1, \ldots, 9]$,	$\varnothing$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

			λ_1	λ_2	β	A	
1.		(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^\lambda \Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

			λ_1	λ_2	β	A	
1.		(	$[0]$,	$[]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}} \Longrightarrow$	(	$[0]$,	$[]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

			λ_1	λ_2	β	A	
1.		(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}} \Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda} \Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	SHIFT^{λ}	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	$\text{LEFT-ARC}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	SHIFT^{λ}	$\Longrightarrow$	(	$[0, 2]$,	$[]$,	$[3, \ldots, 9]$,	A_1	)
5.	$\text{LEFT-ARC}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\text{RIGHT-ARC}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

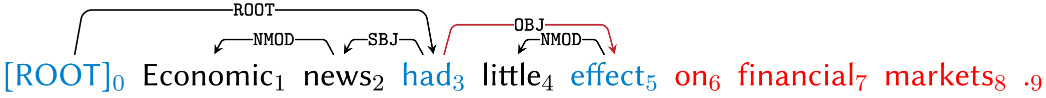
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):

$[\text{ROOT}]_0$ Economic_1 news_2 had_3 little_4 effect_5 on_6 financial_7 markets_8 $._9$

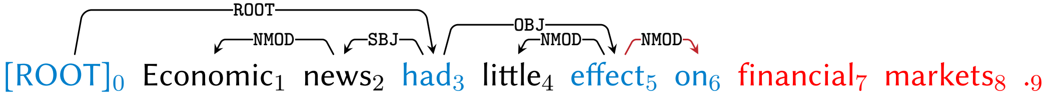
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 2]$,	$[]$,	$[3, \ldots, 9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 3, 4]$,	$[]$,	$[5, \ldots, 9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[]$,	$[5, \ldots, 9]$,	$A_4 = A_3 \cup \{(5, \texttt{NMOD}, 4)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



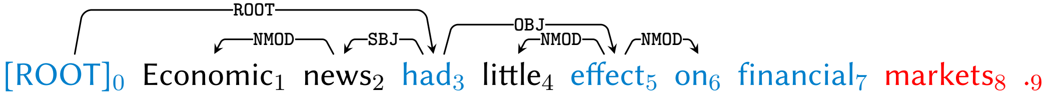
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3, \texttt{OBJ}, 5)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)

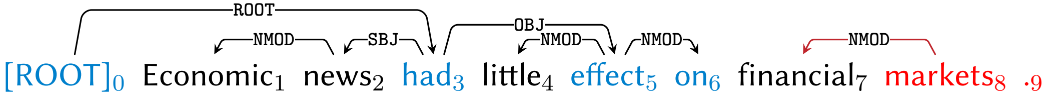
Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



[ROOT]$_0$ Economic$_1$ news$_2$ had$_3$ little$_4$ effect$_5$ on$_6$ financial$_7$ markets$_8$.$_9$

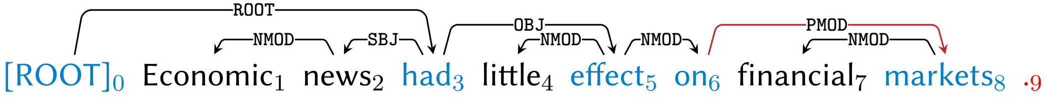
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



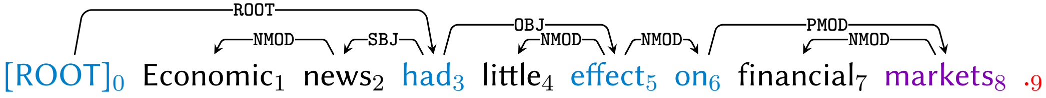
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\dots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\dots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\dots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\dots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\dots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\dots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\dots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\dots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\dots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



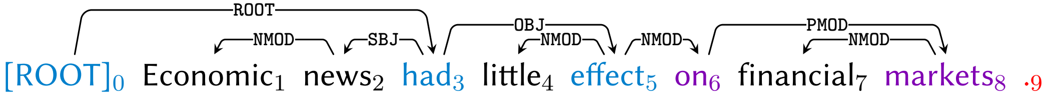
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



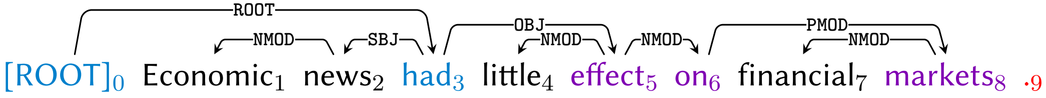
				λ_1	λ_2	β	A	
1.			(	$[0],$	$[],$	$[1,\ldots,9],$	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1],$	$[],$	$[2,\ldots,9],$	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0],$	$[],$	$[2,\ldots,9],$	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2],$	$[],$	$[3,\ldots,9],$	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0],$	$[],$	$[3,\ldots,9],$	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3],$	$[],$	$[4,\ldots,9],$	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4],$	$[],$	$[5,\ldots,9],$	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3],$	$[],$	$[5,\ldots,9],$	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5],$	$[],$	$[6,\ldots,9],$	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6],$	$[],$	$[7,8,9],$	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7],$	$[],$	$[8,9],$	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6],$	$[],$	$[8,9],$	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8],$	$[],$	$[9],$	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{No-Arc}^{p}$	$\Longrightarrow$	(	$[0,3,5,6],$	$[8],$	$[9],$	A_8	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



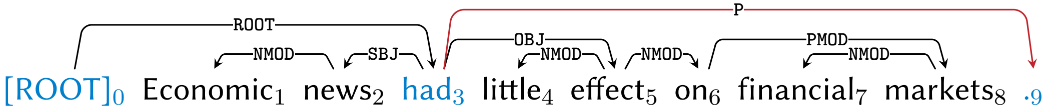
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{No-Arc}^{p}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8]$,	$[9]$,	A_8	)
15.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,8]$,	$[9]$,	A_8	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



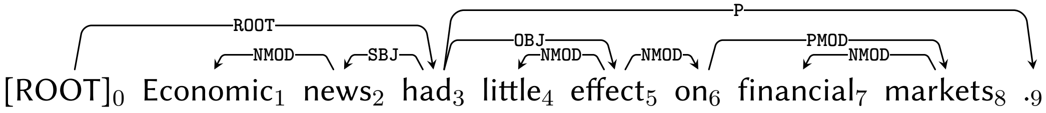
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{No-Arc}^{p}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8]$,	$[9]$,	A_8	)
15.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,8]$,	$[9]$,	A_8	)
16.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0,3]$,	$[5,6,8]$,	$[9]$,	A_8	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1,\ldots,9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,1]$,	$[]$,	$[2,\ldots,9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2,\ldots,9]$,	$A_1 = \{(2,\texttt{NMOD},1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,2]$,	$[]$,	$[3,\ldots,9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3,\ldots,9]$,	$A_2 = A_1 \cup \{(3,\texttt{SBJ},2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[4,\ldots,9]$,	$A_3 = A_2 \cup \{(0,\texttt{ROOT},3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,4]$,	$[]$,	$[5,\ldots,9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3]$,	$[]$,	$[5,\ldots,9]$,	$A_4 = A_3 \cup \{(5,\texttt{NMOD},4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0,3,5]$,	$[]$,	$[6,\ldots,9]$,	$A_5 = A_4 \cup \{(3,\texttt{OBJ},5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[7,8,9]$,	$A_6 = A_5 \cup \{(5,\texttt{NMOD},6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0,3,5,6,7]$,	$[]$,	$[8,9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[]$,	$[8,9]$,	$A_7 = A_6 \cup \{(8,\texttt{NMOD},7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0,3,5,6,8]$,	$[]$,	$[9]$,	$A_8 = A_7 \cup \{(6,\texttt{PMOD},8)\}$	)
14.	$\textsc{No-Arc}^{p}$	$\Longrightarrow$	(	$[0,3,5,6]$,	$[8]$,	$[9]$,	A_8	)
15.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0,3,5]$,	$[6,8]$,	$[9]$,	A_8	)
16.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0,3]$,	$[5,6,8]$,	$[9]$,	A_8	)
17.	$\textsc{Right-Arc}^{p}_{\texttt{P}}$	$\Longrightarrow$	(	$[0,3,9]$,	$[]$,	$[]$,	$A_9 = A_8 \cup \{(3,\texttt{P},9)\}$	)

Illustration Transition sequence for projective English example sentence (nearly identical to the arc-eager stack-based sequence):



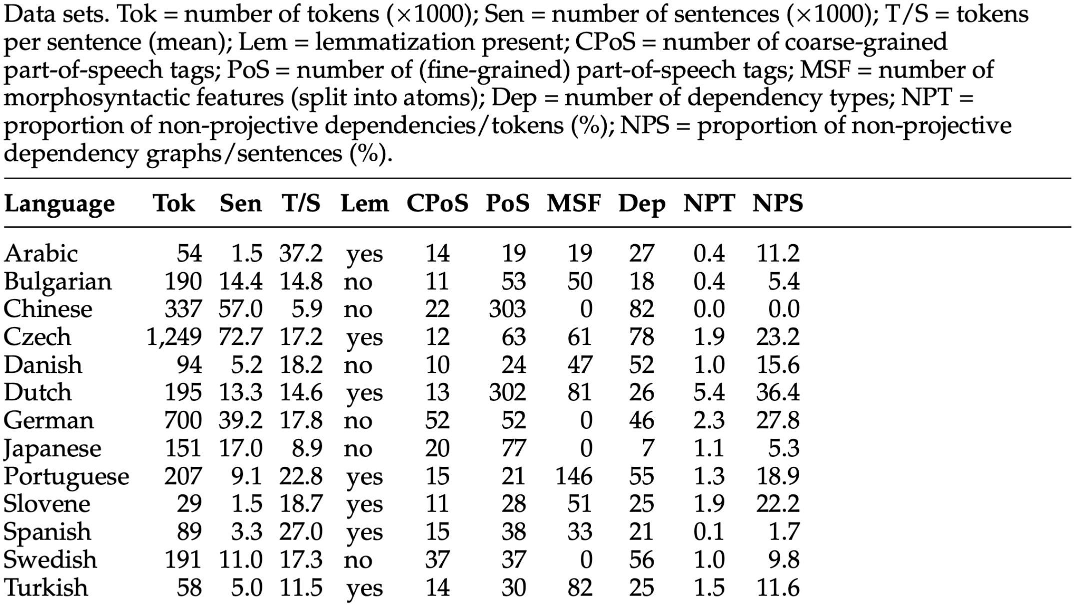
				λ_1	λ_2	β	A	
1.			(	$[0]$,	$[]$,	$[1, \ldots, 9]$,	$\varnothing$	)
2.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 1]$,	$[]$,	$[2, \ldots, 9]$,	$\varnothing$	)
3.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[2, \ldots, 9]$,	$A_1 = \{(2, \texttt{NMOD}, 1)\}$	)
4.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 2]$,	$[]$,	$[3, \ldots, 9]$,	A_1	)
5.	$\textsc{Left-Arc}^{p}_{\texttt{SBJ}}$	$\Longrightarrow$	(	$[0]$,	$[]$,	$[3, \ldots, 9]$,	$A_2 = A_1 \cup \{(3, \texttt{SBJ}, 2)\}$	)
6.	$\textsc{Right-Arc}^{p}_{\texttt{ROOT}}$	$\Longrightarrow$	(	$[0, 3]$,	$[]$,	$[4, \ldots, 9]$,	$A_3 = A_2 \cup \{(0, \texttt{ROOT}, 3)\}$	)
7.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 3, 4]$,	$[]$,	$[5, \ldots, 9]$,	A_3	)
8.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3]$,	$[]$,	$[5, \ldots, 9]$,	$A_4 = A_3 \cup \{(5, \texttt{NMOD}, 4)\}$	)
9.	$\textsc{Right-Arc}^{p}_{\texttt{OBJ}}$	$\Longrightarrow$	(	$[0, 3, 5]$,	$[]$,	$[6, \ldots, 9]$,	$A_5 = A_4 \cup \{(3, \texttt{OBJ}, 5)\}$	)
10.	$\textsc{Right-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[]$,	$[7, 8, 9]$,	$A_6 = A_5 \cup \{(5, \texttt{NMOD}, 6)\}$	)
11.	$\textsc{Shift}^{\lambda}$	$\Longrightarrow$	(	$[0, 3, 5, 6, 7]$,	$[]$,	$[8, 9]$,	A_6	)
12.	$\textsc{Left-Arc}^{p}_{\texttt{NMOD}}$	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[]$,	$[8, 9]$,	$A_7 = A_6 \cup \{(8, \texttt{NMOD}, 7)\}$	)
13.	$\textsc{Right-Arc}^{p}_{\texttt{PMOD}}$	$\Longrightarrow$	(	$[0, 3, 5, 6, 8]$,	$[]$,	$[9]$,	$A_8 = A_7 \cup \{(6, \texttt{PMOD}, 8)\}$	)
14.	$\textsc{No-Arc}^{p}$	$\Longrightarrow$	(	$[0, 3, 5, 6]$,	$[8]$,	$[9]$,	A_8	)
15.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0, 3, 5]$,	$[6, 8]$,	$[9]$,	A_8	)
16.	$\textsc{No-arc}^{p}$	$\Longrightarrow$	(	$[0, 3]$,	$[5, 6, 8]$,	$[9]$,	A_8	)
17.	$\textsc{Right-Arc}^{p}_{\texttt{P}}$	$\Longrightarrow$	(	$[0, 3, 9]$,	$[]$,	$[]$,	$A_9 = A_8 \cup \{(3, \texttt{P}, 9)\}$	)

Evaluation of the four algorithms in deterministic data-driven parsing:
Use an oracle approximated by a classifier trained on treebank data to analyze of the accuracy and efficiency of these systems.

- Data: CoNLL-X shared task multilingual dependency parsing

Evaluation of the four algorithms in deterministic data-driven parsing: Use an oracle approximated by a classifier trained on treebank data to analyze of the accuracy and efficiency of these systems.

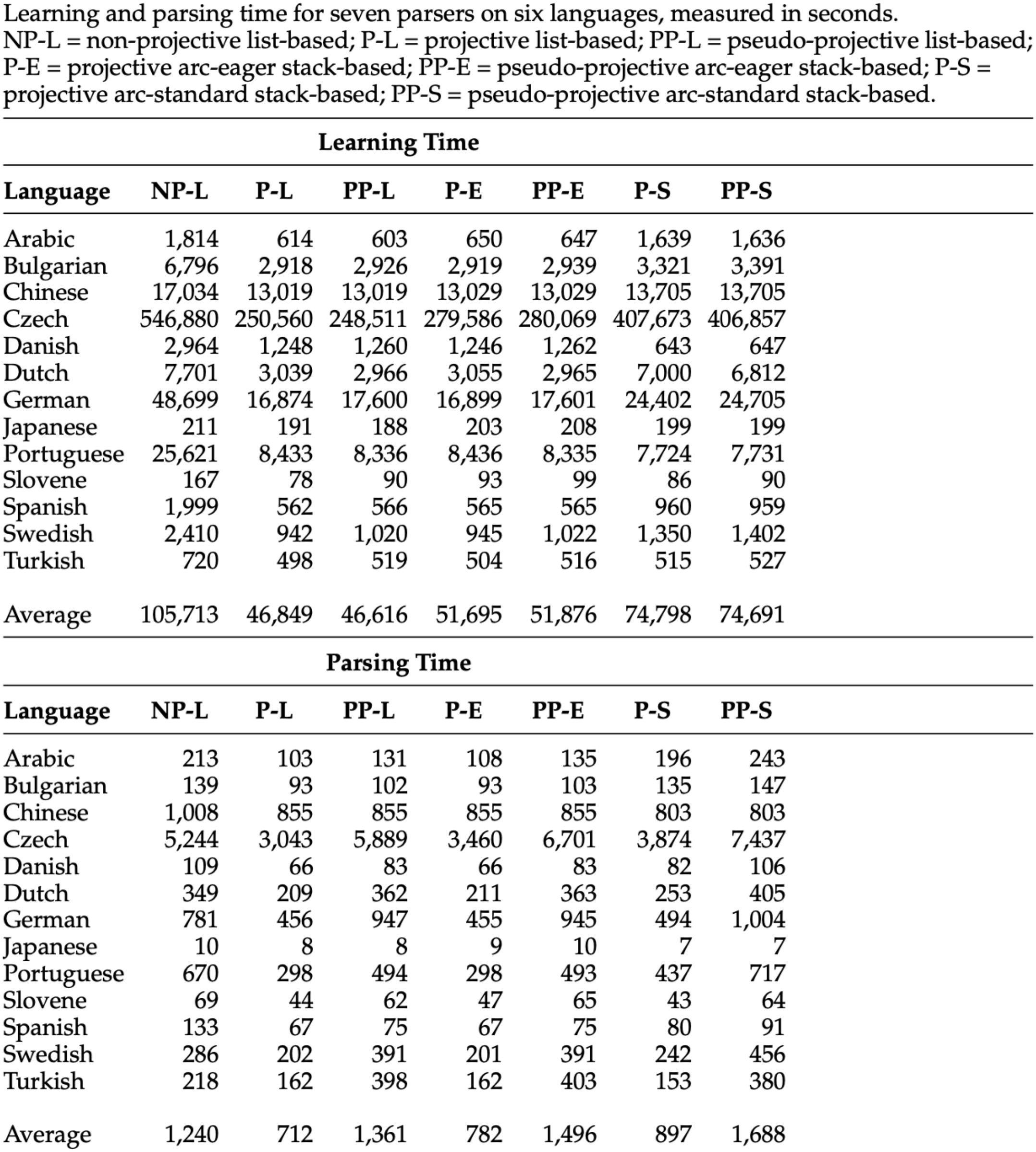
- Data: CoNLL-X shared task multilingual dependency parsing



Data sets. Tok = number of tokens (×1000); Sen = number of sentences (×1000); T/S = tokens per sentence (mean); Lem = lemmatization present; CPoS = number of coarse-grained part-of-speech tags; PoS = number of (fine-grained) part-of-speech tags; MSF = number of morphosyntactic features (split into atoms); Dep = number of dependency types; NPT = proportion of non-projective dependencies/tokens (%); NPS = proportion of non-projective dependency graphs/sentences (%).

Language	**Tok**	**Sen**	**T/S**	**Lem**	**CPoS**	**PoS**	**MSF**	**Dep**	**NPT**	**NPS**
Arabic	54	1.5	37.2	yes	14	19	19	27	0.4	11.2
Bulgarian	190	14.4	14.8	no	11	53	50	18	0.4	5.4
Chinese	337	57.0	5.9	no	22	303	0	82	0.0	0.0
Czech	1,249	72.7	17.2	yes	12	63	61	78	1.9	23.2
Danish	94	5.2	18.2	no	10	24	47	52	1.0	15.6
Dutch	195	13.3	14.6	yes	13	302	81	26	5.4	36.4
German	700	39.2	17.8	no	52	52	0	46	2.3	27.8
Japanese	151	17.0	8.9	no	20	77	0	7	1.1	5.3
Portuguese	207	9.1	22.8	yes	15	21	146	55	1.3	18.9
Slovene	29	1.5	18.7	yes	11	28	51	25	1.9	22.2
Spanish	89	3.3	27.0	yes	15	38	33	21	0.1	1.7
Swedish	191	11.0	17.3	no	37	37	0	56	1.0	9.8
Turkish	58	5.0	11.5	yes	14	30	82	25	1.5	11.6

Figure: Data sets



Learning and parsing time for seven parsers on six languages, measured in seconds. NP-L = non-projective list-based; P-L = projective list-based; PP-L = pseudo-projective list-based; P-E = projective arc-eager stack-based; PP-E = pseudo-projective arc-eager stack-based; P-S = projective arc-standard stack-based; PP-S = pseudo-projective arc-standard stack-based.

Learning Time

Language	NP-L	P-L	PP-L	P-E	PP-E	P-S	PP-S
Arabic	1,814	614	603	650	647	1,639	1,636
Bulgarian	6,796	2,918	2,926	2,919	2,939	3,321	3,391
Chinese	17,034	13,019	13,019	13,029	13,029	13,705	13,705
Czech	546,880	250,560	248,511	279,586	280,069	407,673	406,857
Danish	2,964	1,248	1,260	1,246	1,262	643	647
Dutch	7,701	3,039	2,966	3,055	2,965	7,000	6,812
German	48,699	16,874	17,600	16,899	17,601	24,402	24,705
Japanese	211	191	188	203	208	199	199
Portuguese	25,621	8,433	8,336	8,436	8,335	7,724	7,731
Slovene	167	78	90	93	99	86	90
Spanish	1,999	562	566	565	565	960	959
Swedish	2,410	942	1,020	945	1,022	1,350	1,402
Turkish	720	498	519	504	516	515	527
Average	105,713	46,849	46,616	51,695	51,876	74,798	74,691

Parsing Time

Language	NP-L	P-L	PP-L	P-E	PP-E	P-S	PP-S
Arabic	213	103	131	108	135	196	243
Bulgarian	139	93	102	93	103	135	147
Chinese	1,008	855	855	855	855	803	803
Czech	5,244	3,043	5,889	3,460	6,701	3,874	7,437
Danish	109	66	83	66	83	82	106
Dutch	349	209	362	211	363	253	405
German	781	456	947	455	945	494	1,004
Japanese	10	8	8	9	10	7	7
Portuguese	670	298	494	298	493	437	717
Slovene	69	44	62	47	65	43	64
Spanish	133	67	75	67	75	80	91
Swedish	286	202	391	201	391	242	456
Turkish	218	162	398	162	403	153	380
Average	1,240	712	1,361	782	1,496	897	1,688

Figure: Parsing efficiency

Nivre, Joakim (Dec. 2008). “Algorithms for Deterministic Incremental Dependency Parsing”. In: *Computational Linguistics* 34.4, pp. 513–553.