Dependency Parsing
Lecture 9

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Summer semester 2018

Today

Problems:

- Spurious ambiguity (several optimal transition sequences possible)
- Error propagation (single mistake causes more mistakes)
- Parser not trained with suboptimal decisions

Solutions:

- Beam search: consider multiple alternatives
- Easy first: give up left-to-right incremental search
- Dynamic oracles: learn from errors at train time

(with slides from EACL 2014 tutorial by McDonald & Nivre)

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- **Dynamic oracles: learn from errors at train time**

(with slides from EACL 2014 tutorial by McDonald & Nivre)

Online Learning with a Conventional Oracle

```
Learn($\{T_1, \ldots, T_N\}$)
1   $\mathbf{w} \leftarrow 0.0$
2   for $i$ in $1..K$
3       for $j$ in $1..N$
4           $c \leftarrow ([\ ], [0, 1, \ldots, n_j], \{\ \})$
5           while $B_c \neq [\ ]$
6               $t^* \leftarrow \text{argmax}_t\, \mathbf{w} \cdot \mathbf{f}(c, t)$
7               $t_o \leftarrow o(c, T_i)$
8               if $t^* \neq t_o$
9                   $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{f}(c, t_o) - \mathbf{f}(c, t^*)$
10              $c \leftarrow t_o(c)$
11  return $\mathbf{w}$
```

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10              $c \leftarrow t_o(c)$
11  return $\mathbf{w}$
```

T_j

- Oracle $o(c, T_i)$ returns the optimal transition for c and T_i

Conventional Oracle for Arc-Eager Parsing

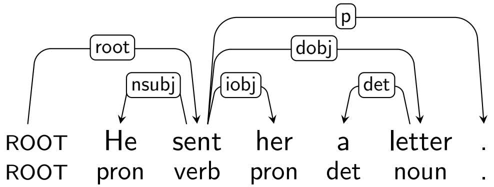
$$o(c, T) = \begin{cases} \text{Left-Arc} & \text{if top}(S_c) \leftarrow \text{first}(B_c) \text{ in } T \\ \text{Right-Arc} & \text{if top}(S_c) \rightarrow \text{first}(B_c) \text{ in } T \\ \text{Reduce} & \text{if } \exists v < \text{top}(S_c) : v \leftrightarrow \text{first}(B_c) \text{ in } T \\ \text{Shift} & \text{otherwise} \end{cases}$$

- Correct:
  - Derives T in a configuration sequence $C_{o,T} = c_0, \ldots, c_m$
- Problems:
  - Deterministic: Ignores other derivations of T
  - Incomplete: Valid only for configurations in $C_{o,T}$

Oracle Parse

Transitions:

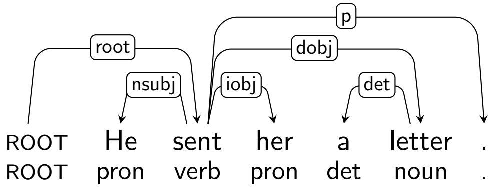
Stack	**Buffer**	**Arcs**
[ ]	[ROOT, He, sent, her, a, letter, .]	



Oracle Parse

Transitions: SH

Stack	**Buffer**	**Arcs**
[ROOT]	[He, sent, her, a, letter, .]	



Oracle Parse

Transitions: SH-RA

Stack

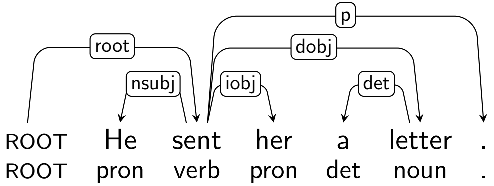
[ROOT, He]

Buffer

[sent, her, a, letter, .]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$



Oracle Parse

Transitions: SH-RA-LA

Stack

[ROOT]

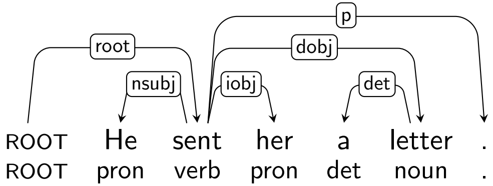
Buffer

[sent, her, a, letter, .]

Arcs

ROOT $\xrightarrow{\text{root}}$ sent

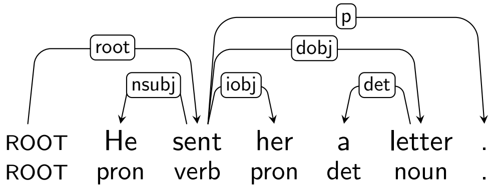
He $\xleftarrow{\text{sbj}}$ sent



Oracle Parse

Transitions: SH-RA-LA-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent]	[her, a, letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA

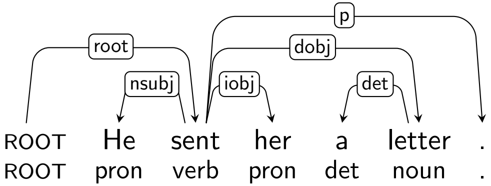
Stack	**Buffer**
[ROOT, sent, her]	[a, letter, .]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH

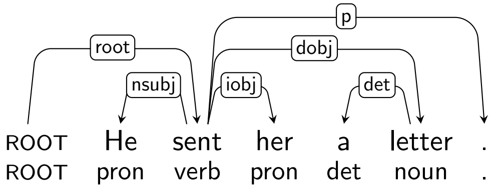
Stack	**Buffer**
[ROOT, sent, her, a]	[letter, .]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

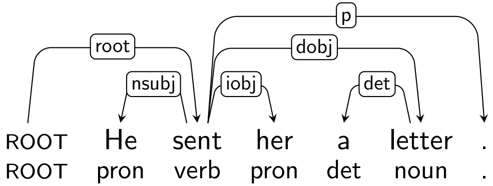
$\text{sent} \xrightarrow{\text{iobj}} \text{her}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH-LA

Stack	**Buffer**	**Arcs**
[ROOT, sent, her]	[letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{sent} \xrightarrow{\text{iobj}} \text{her}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH-LA-RE

Stack

[ROOT, sent]

Buffer

[letter, .]

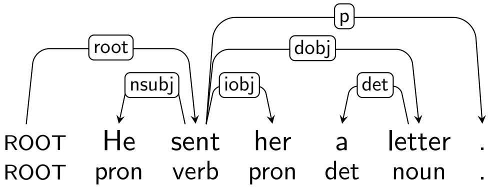
Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA

Stack	Buffer
[ROOT, sent, letter]	[.]

Arcs

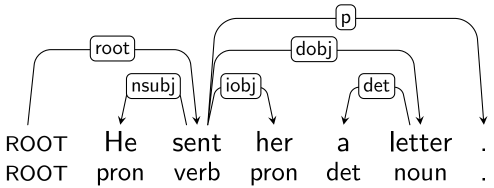
$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE

Stack [ROOT, sent]

Buffer [.]

Arcs

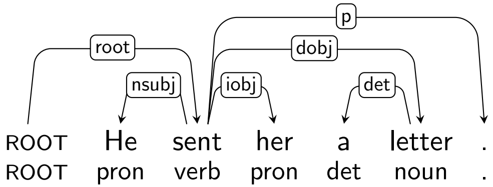
$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$



Oracle Parse

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Stack	**Buffer**
[ROOT, sent, .]	[ ]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

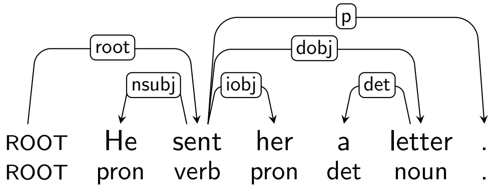
$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$

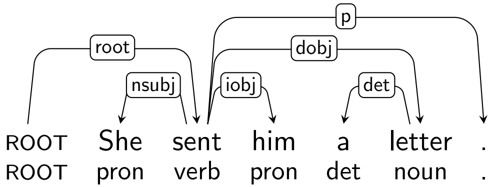
$\text{sent} \xrightarrow{\text{p}} .$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA

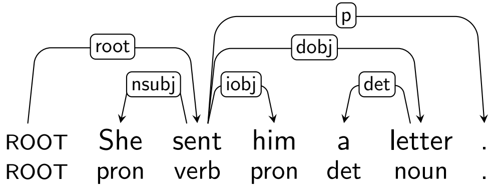
Stack	**Buffer**	**Arcs**
[ROOT, sent, her]	[a, letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{sent} \xrightarrow{\text{iobj}} \text{her}$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA-RE

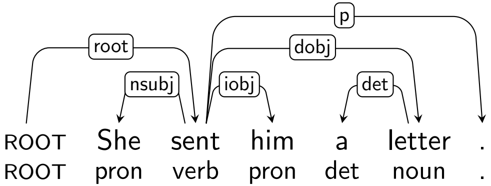
Stack	**Buffer**	**Arcs**
[ROOT, sent]	[a, letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{sent} \xrightarrow{\text{iobj}} \text{her}$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA-RE-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent, a]	[letter, .]	ROOT $\xrightarrow{\text{root}}$ sent
		He $\xleftarrow{\text{sbj}}$ sent
		sent $\xrightarrow{\text{iobj}}$ her

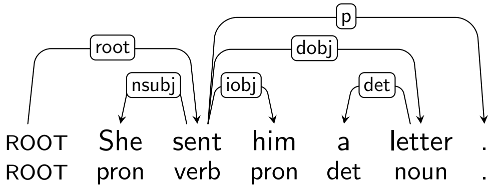


Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

SH-RA-LA-SH-RA-RE-SH-LA

Stack	**Buffer**	**Arcs**
[ROOT, sent]	[letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{sent} \xrightarrow{\text{iobj}} \text{her}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA-RE-SH-LA-RA

Stack	**Buffer**
[ROOT, sent, letter]	[.]

Arcs

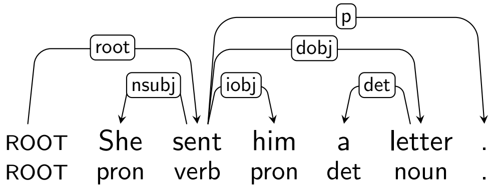
$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA-RE-SH-LA-RA-RE

Stack	**Buffer**
[ROOT, sent]	[.]

Arcs

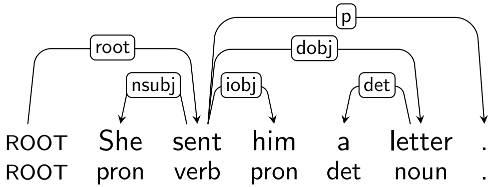
$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$



Non-Determinisim

Transitions: SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA
SH-RA-LA-SH-RA-RE-SH-LA-RA-RE-RA

Stack	**Buffer**
[ROOT, sent, .]	[ ]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

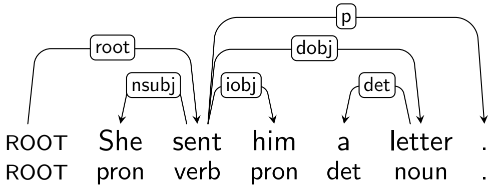
$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{sent} \xrightarrow{\text{iobj}} \text{her}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$

$\text{sent} \xrightarrow{\text{p}} .$

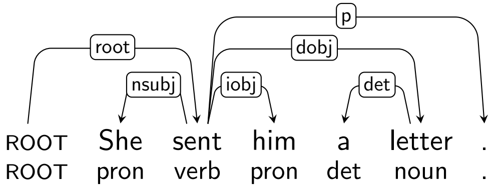


Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent]	[her, a, letter, .]	ROOT $\xrightarrow{\text{root}}$ sent
		He $\xleftarrow{\text{sbj}}$ sent

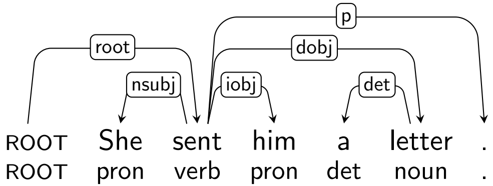


Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent, her]	[a, letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

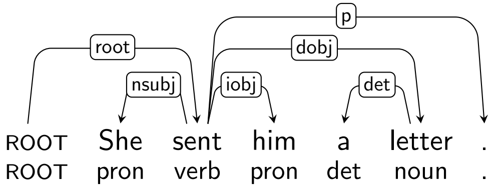


Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH-SH-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent, her, a]	[letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$



Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH-SH-SH-LA

Stack

[ROOT, sent, her]

Buffer

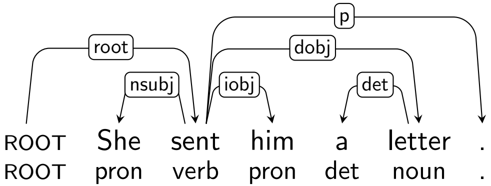
[letter, .]

Arcs

$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$

$\text{He} \xleftarrow{\text{sbj}} \text{sent}$

$\text{a} \xleftarrow{\text{det}} \text{letter}$

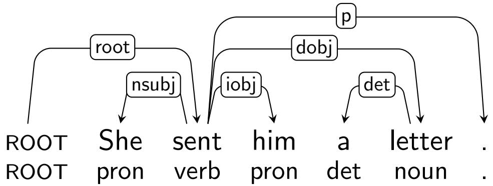


Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH-SH-SH-LA-SH

Stack	**Buffer**	**Arcs**
[ROOT, sent, her, letter]	[.]	ROOT $\xrightarrow{\text{root}}$ sent
		He $\xleftarrow{\text{sbj}}$ sent
		a $\xleftarrow{\text{det}}$ letter

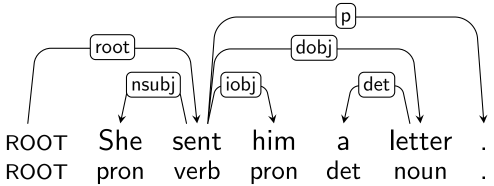


Non-Optimality

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

Transitions: SH-RA-LA-SH-SH-SH-LA-SH-SH [3/6]

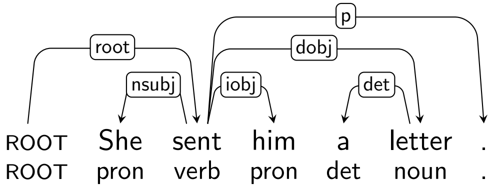
Stack	**Buffer**	**Arcs**
[ROOT, sent, letter, .]	[ ]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$



Non-Optimality

	SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA	
Transitions:	SH-RA-LA-SH-SH-SH-LA-SH-SH	[3/6]
	SH-RA-LA-SH-SH-SH-LA	

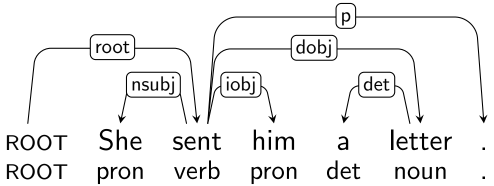
Stack	**Buffer**	**Arcs**
[ROOT, sent, her]	[letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$



Non-Optimality

	SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA	
Transitions:	SH-RA-LA-SH-SH-SH-LA-SH-SH	[3/6]
	SH-RA-LA-SH-SH-SH-LA-LA	

Stack	**Buffer**	**Arcs**
[ROOT, sent]	[letter, .]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$
		$\text{her} \xleftarrow{?} \text{letter}$



Non-Optimality

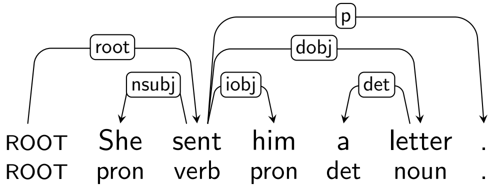
Transitions:

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

SH-RA-LA-SH-SH-SH-LA-SH-SH [3/6]

SH-RA-LA-SH-SH-SH-LA-LA-RA

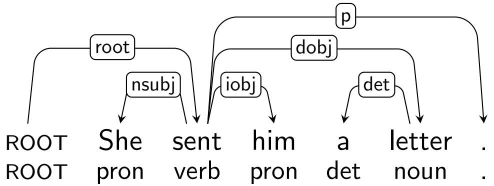
Stack	**Buffer**	**Arcs**
[ROOT, sent, letter]	[.]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$
		$\text{her} \xleftarrow{?} \text{letter}$
		$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$



Non-Optimality

	SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA	
Transitions:	SH-RA-LA-SH-SH-SH-LA-SH-SH	[3/6]
	SH-RA-LA-SH-SH-SH-LA-LA-RA-RE	

Stack	**Buffer**	**Arcs**
[ROOT, sent]	[.]	ROOT $\xrightarrow{\text{root}}$ sent
		He $\xleftarrow{\text{sbj}}$ sent
		a $\xleftarrow{\text{det}}$ letter
		her $\xleftarrow{?}$ letter
		sent $\xrightarrow{\text{dobj}}$ letter



Non-Optimality

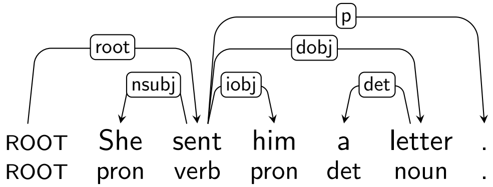
Transitions:

SH-RA-LA-SH-RA-SH-LA-RE-RA-RE-RA

SH-RA-LA-SH-SH-SH-LA-SH-SH [3/6]

SH-RA-LA-SH-SH-SH-LA-LA-RA-RE-RA [5/6]

Stack	**Buffer**	**Arcs**
[ROOT, sent, .]	[ ]	$\text{ROOT} \xrightarrow{\text{root}} \text{sent}$
		$\text{He} \xleftarrow{\text{sbj}} \text{sent}$
		$\text{a} \xleftarrow{\text{det}} \text{letter}$
		$\text{her} \xleftarrow{?} \text{letter}$
		$\text{sent} \xrightarrow{\text{dobj}} \text{letter}$
		$\text{sent} \xrightarrow{\text{p}} .$



Dynamic Oracles

- Optimality:
  - A transition is optimal if the best tree remains reachable
  - Best tree = $\text{argmin}_{T'} \mathcal{L}(T, T')$
- Oracle:
  - Boolean function $o(c, t, T) =$ **true** if t is optimal for c and T
  - Non-deterministic: More than one transition can be optimal
  - Complete: Correct for all configurations
- New problem:
  - How do we know which trees are reachable?

Reachability for Arcs and Trees

- Arc reachability:
  - An arc $w_i \rightarrow w_j$ is reachable in c iff $w_i \rightarrow w_j \in A_c$, or $w_i \in S_c \cup B_c$ and $w_j \in B_c$ (same for $w_i \leftarrow w_j$)
- Tree reachability:
  - A (projective) tree T is reachable in c iff every arc in T is reachable in c
- Arc-decomposable systems [Goldberg and Nivre 2013]:
  - Tree reachability reduces to arc reachability
  - Holds for some transition systems but not all
    - Arc-eager and easy-first are arc-decomposable
    - Arc-standard is not decomposable

Oracles for Arc-Decomposable Systems

$$o(c, t, T) = \begin{cases} \textbf{true} & \text{if } [\mathcal{R}(c) - \mathcal{R}(t(c))] \cap T = \emptyset \\ \textbf{false} & \text{otherwise} \end{cases}$$

$$\text{where } \mathcal{R}(c) \equiv \{a \mid a \text{ is an arc reachable in } c\}$$

Arc-Eager

$$o(c, \text{LA}, T) = \begin{cases} \textbf{false} & \text{if } \exists w \in B_c : s \leftrightarrow w \in T \text{ (except } s \leftarrow b) \\ \textbf{true} & \text{otherwise} \end{cases}$$

$$o(c, \text{RA}, T) = \begin{cases} \textbf{false} & \text{if } \exists w \in S_c : w \leftrightarrow b \in T \text{ (except } s \rightarrow b) \\ \textbf{true} & \text{otherwise} \end{cases}$$

$$o(c, \text{RE}, T) = \begin{cases} \textbf{false} & \text{if } \exists w \in B_c : s \rightarrow w \in T \\ \textbf{true} & \text{otherwise} \end{cases}$$

$$o(c, \text{SH}, T) = \begin{cases} \textbf{false} & \text{if } \exists w \in S_c : w \leftrightarrow b \in T \\ \textbf{true} & \text{otherwise} \end{cases}$$

Notation: s = node on top of the stack S
b = first node in the buffer B

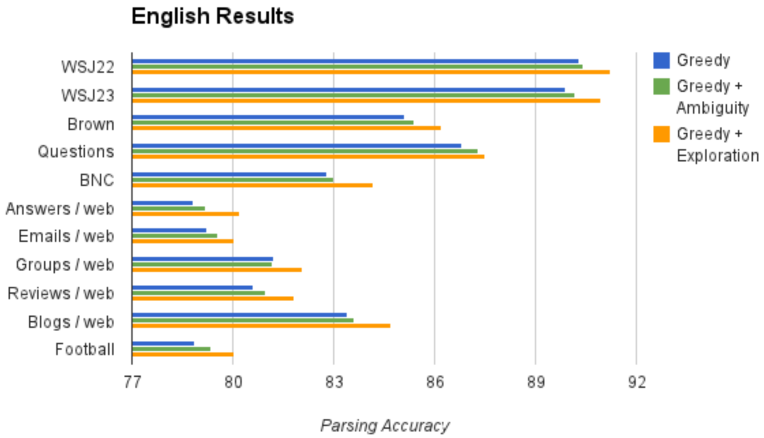
Online Learning with a Dynamic Oracle

```
Learn($\{T_1, \ldots, T_N\}$)
 1  $\mathbf{w} \leftarrow 0.0$
 2  for $i$ in $1..K$
 3      for $j$ in $1..N$
 4          $c \leftarrow ([\,]_S, [w_1, \ldots, w_{n_j}]_B, \{\,\})$
 5          while $B_c \neq [\,]$
 6              $t^* \leftarrow \text{argmax}_t\, \mathbf{w} \cdot \mathbf{f}(c, t)$
 7              $t_o \leftarrow \text{argmax}_{t \in \{t | o(c,t,T_i)\}}\, \mathbf{w} \cdot \mathbf{f}(c, t)$
 8              if $t^* \neq t_o$
 9                  $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{f}(c, t_o) - \mathbf{f}(c, t^*)$
10              $c \leftarrow \text{choice}(t_o(c), t^*(c))$
11  return $\mathbf{w}$
```

Online Learning with a Dynamic Oracle

```
Learn($\{T_1, \ldots, T_N\}$)
    $\mathbf{w} \leftarrow 0.0$
    **for** $i$ in $1..K$
        **for** $j$ in $1..N$
            $c \leftarrow ([\,]_S, [w_1, \ldots, w_{n_j}]_B, \{\,\})$
            **while** $B_c \neq [\,]$
                $t^* \leftarrow \text{argmax}_t\, \mathbf{w} \cdot \mathbf{f}(c, t)$
                $t_o \leftarrow \text{argmax}_{t \in \{t | o(c,t,T_i)\}}\, \mathbf{w} \cdot \mathbf{f}(c, t)$
                **if** $t^* \neq t_o$
                    $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{f}(c, t_o) - \mathbf{f}(c, t^*)$
                $c \leftarrow \text{choice}(t_o(c), t^*(c))$
    **return** $\mathbf{w}$
```

- Ambiguity: use model score to break ties
- Exploration: follow model prediction even if not optimal



[Goldberg and Nivre 2012]

T H E

E N D

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