Part 3: Main Statistical Methods

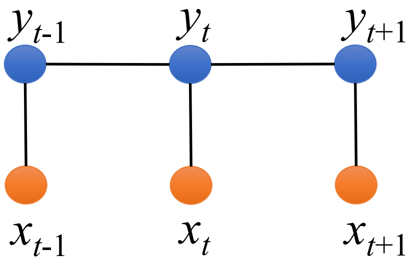
Part 3.1: Graph-based Methods

Graph-based Methods

- Training: Score ⇔ Correctness
- Decoding model score
  - enumerate all candidate structures; scoring each and selecting the highest scored structure

Sequence Labeling Models

CRF $$P(y_{[1:n]}|x_{[1:n]}) \propto \frac{1}{Z_{y_{[1:n]}}} \prod_{t=1}^{n} \exp\begin{pmatrix} \sum_j \lambda_j f_j(y_t, y_{t-1}) \\ + \sum_k \mu_k g_k(y_t, x_t) \end{pmatrix}$$



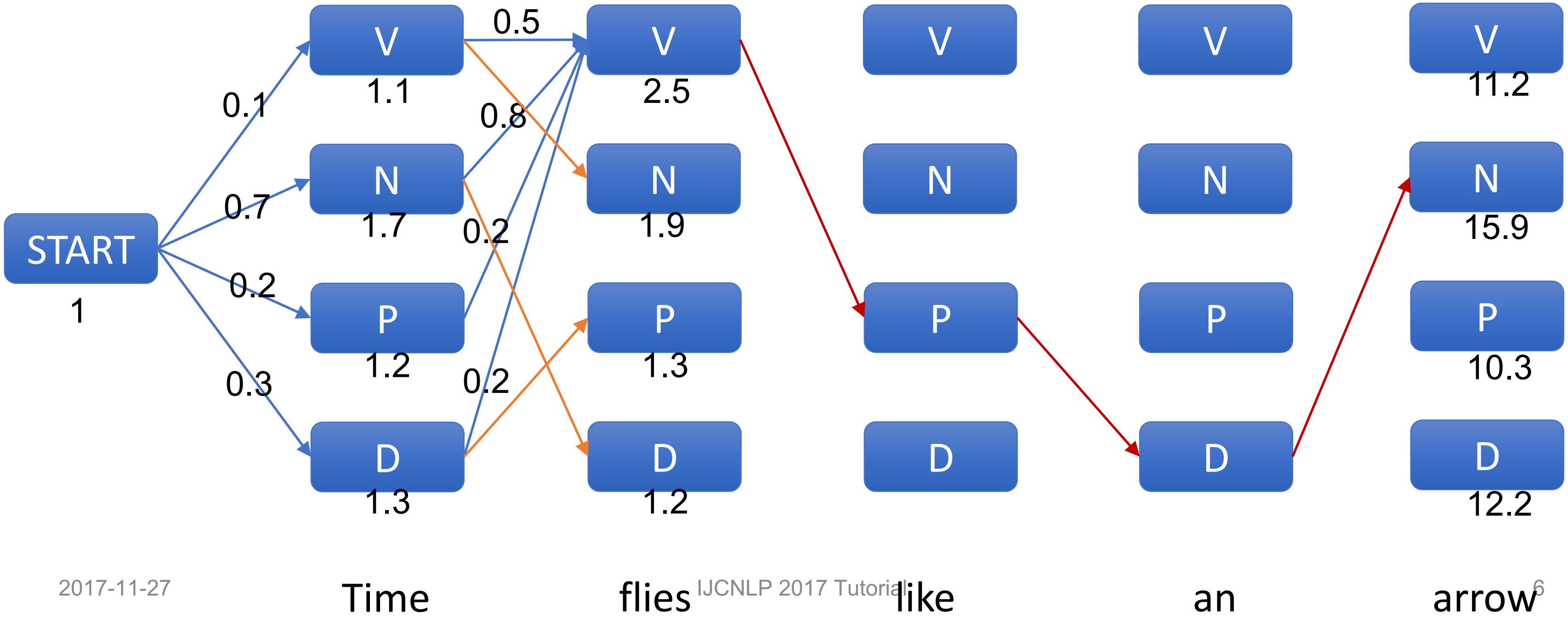
CRF Decoding

$$\mathop{\arg\max}_{y_{[1:n]} \in \mathbf{GEN}(x_{[1:n]})} \sum_{i=1}^{n} \mathbf{w} \cdot \mathbf{f}(x_{[1:n]}, y_i, y_{i-1})$$

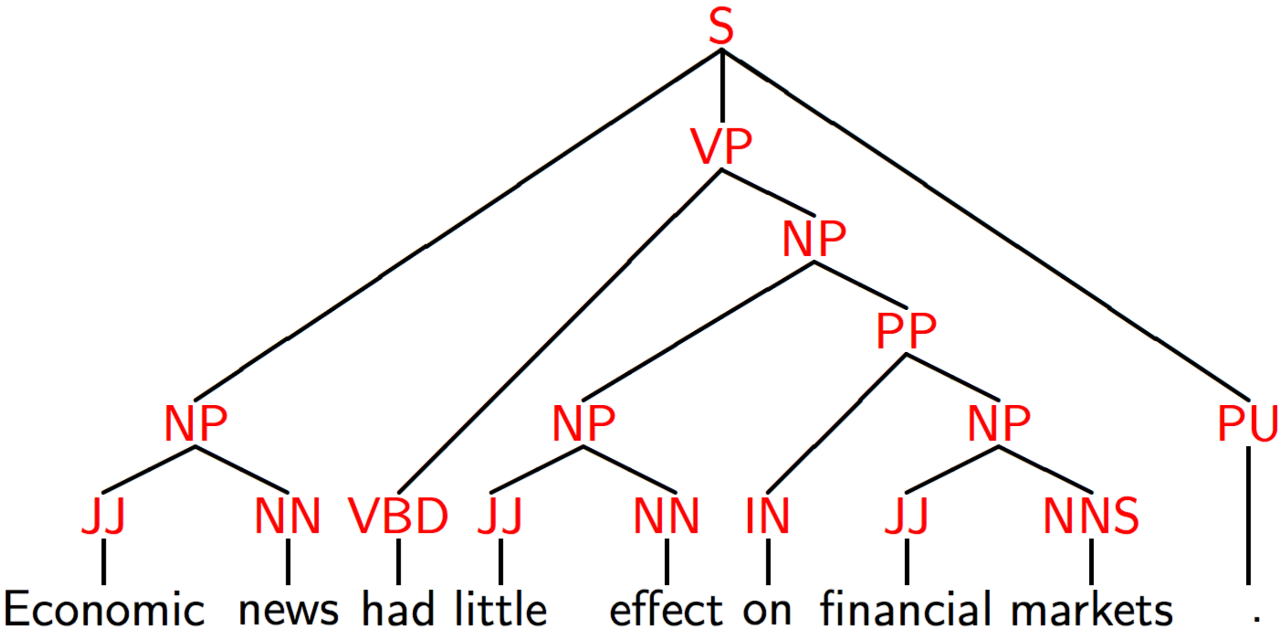
where $\mathrm{GEN}(x_{[1:n]})$ is all possible tag sequences

Viterbi Algorithm

- Define a dynamic programming table
  - $\pi(i, y)$ = maximum score of a tag sequence ending in tag *y* at position *i*
- Recursive definition: $\pi(i, y) = \max_t \left(\pi(i-1, t) + \mathbf{w} \cdot \mathbf{f}\left(x_{[1:n]}, y, t\right)\right)$



Constituency Parsing

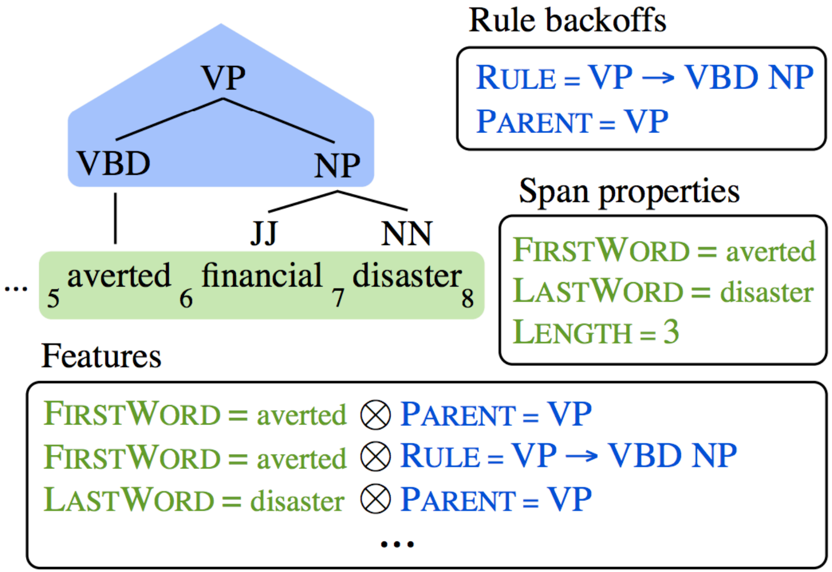


Constituency Parsing with CRF

- Probability of a tree *T* conditioned on a sentence **w**

$$p(T|\mathbf{w}) \propto \exp\left(\theta^{\mathsf{T}} \sum_{r \in T} f(r, \mathbf{w})\right)$$

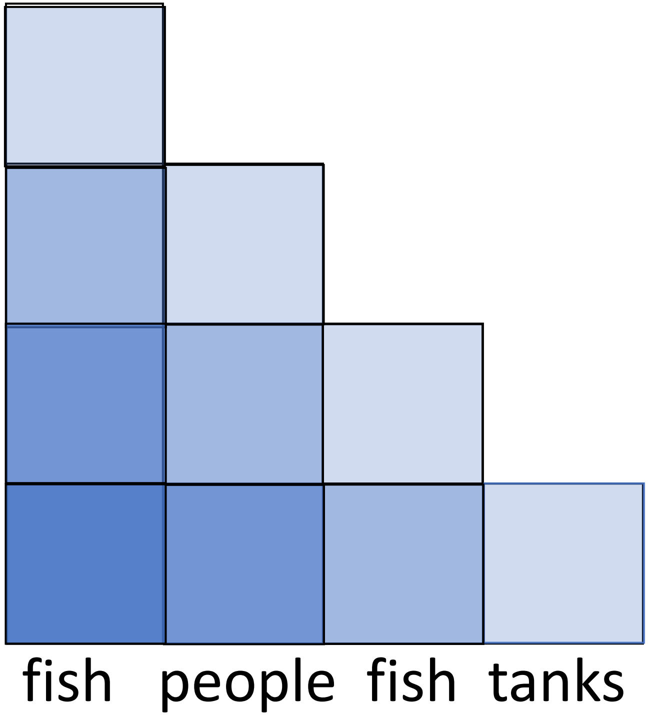
- More features


Rule backoffs
RULE = VP → VBD NP
PARENT = VP
VP
VBD
NP
JJ
NN
... 5 averted 6 financial 7 disaster 8
Span properties
FIRSTWORD = averted
LASTWORD = disaster
LENGTH = 3
Features
FIRSTWORD = averted ⊗ PARENT = VP
FIRSTWORD = averted ⊗ RULE = VP → VBD NP
LASTWORD = disaster ⊗ PARENT = VP
...

Hall D, Durrett G, Klein D (2014) Less grammar, more features. ACL.

Chart-based Method

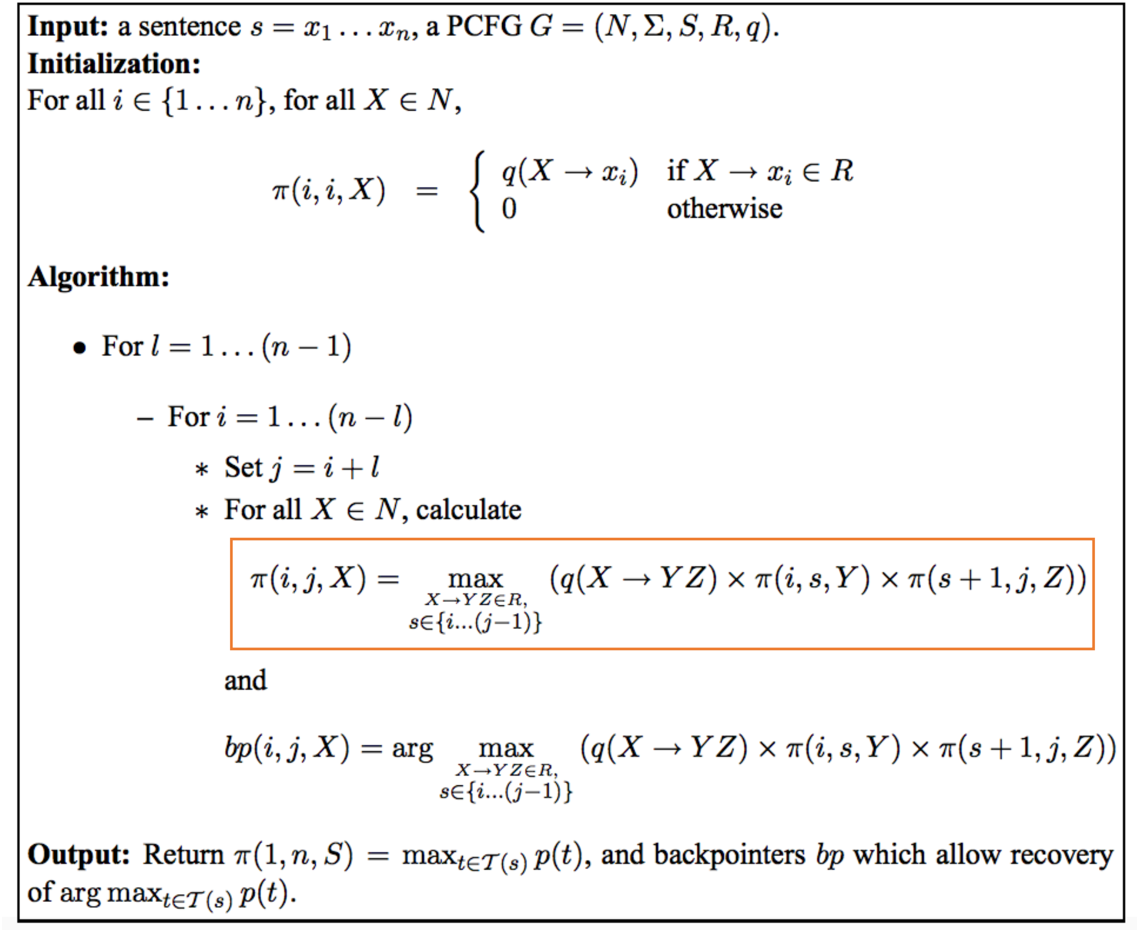
- E.g. Cocke–Younger–Kasami algorithm (CYK or CKY)
  - A kind of Dynamic Programming



PCFG

Rule	**Prob θ_i**
S → NP VP	θ_0
NP → NP NP	θ_1
…	
N → fish	θ_{42}
N → people	θ_{43}
V → fish	θ_{44}

CKY Parsing Algorithm



Input: a sentence $s = x_1 \ldots x_n$, a PCFG $G = (N, \Sigma, S, R, q)$.

Initialization:

For all $i \in \{1 \ldots n\}$, for all $X \in N$,

$$\pi(i, i, X) = \begin{cases} q(X \rightarrow x_i) & \text{if } X \rightarrow x_i \in R \\ 0 & \text{otherwise} \end{cases}$$

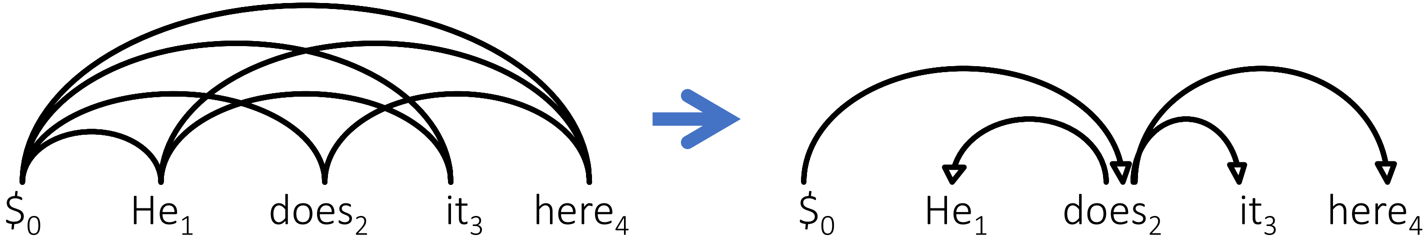
Algorithm:

```
• For $l = 1 \ldots (n-1)$
    – For $i = 1 \ldots (n-l)$
        * Set $j = i + l$
        * For all $X \in N$, calculate
              $\boxed{\pi(i, j, X) = \max_{X \rightarrow YZ \in R, s \in \{i \ldots (j-1)\}} (q(X \rightarrow YZ) \times \pi(i, s, Y) \times \pi(s+1, j, Z))}$
          and
              $bp(i, j, X) = \arg\max_{X \rightarrow YZ \in R, s \in \{i \ldots (j-1)\}} (q(X \rightarrow YZ) \times \pi(i, s, Y) \times \pi(s+1, j, Z))$
```

Output: Return $\pi(1, n, S) = \max_{t \in \mathcal{T}(s)} p(t)$, and backpointers bp which allow recovery of $\arg\max_{t \in \mathcal{T}(s)} p(t)$.

Graph-based Dependency Parsing

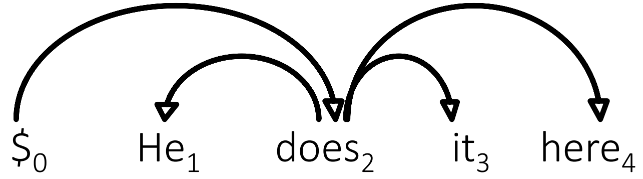
- Find the highest scoring tree from a complete dependency graph



$$Y^{*} = \arg\max_{Y\in\Phi(X)} score(X,Y)$$

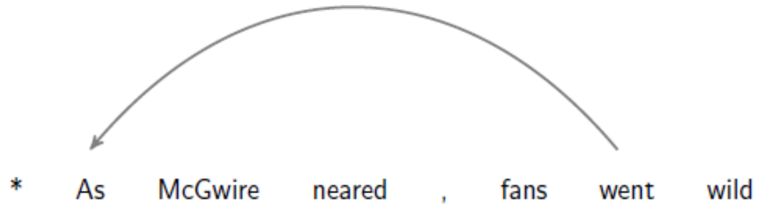
First-order as an Example

- The first-order graph-based method assumes that arcs in a tree are independent from each other (arc-factorization)



$$score(X,Y) = \sum_{(h,m)\in Y} score(X,h,m)$$

Features for an Arc



[went]
[VERB]
[went, As]
[VERB, IN]
[ADJ, *, ADP]
[NNS, VBD, ADP]
[NNS, ADP, NNP]
[ADP, left, 5]
[JJ, *, IN]
[NOUN, VERB, IN]
[NOUN, IN, NOUN]
[IN, left, 5]
[NNS, VBD, ADP, NNP]
[went, VERB, As, IN]
[went, VERB, left, 5]
[went, As, ADP, left, 5]
[VBD, ADJ, ADP, left, 5]
[ADJ, ADP, NNP, left, 5]
[VERB, As, IN, left, 5]
[VERB, *, IN, left, 5]

[VBD]
[As]
[VBD, ADP]
[VBD, As, ADP]
[VBD, *, ADP]
[NNS, VBD, *]
[NNS, VBD, NNP]
[VERB, As, IN]
[VERB, *, IN]
[NOUN, VERB, *]
[NOUN, VERB, NOUN]
[went, VBD, As, ADP]
[went, VBD, left, 5]
[VERB, JJ, *, IN]
[As, IN, left, 5]
[went, VBD, ADP, left, 5]
[VBD, ADJ, *, left, 5]
[VBD, ADP, NNP, left, 5]
[went, As, IN, left, 5]
[VERB, JJ, IN, left, 5]

[As]
[IN]
[went, VERB]
[went, As, ADP]
[VBD, ADJ, ADP]
[ADJ, ADP, NNP]
[went, left, 5]
[went, As, IN]
[VERB, JJ, IN]
[JJ, IN, NOUN]
[went, left, 5]
[VBD, ADJ, *, ADP]
[As, ADP, left, 5]
[NOUN, VERB, *, IN]
[went, As, left, 5]
[went, VBD, As, left, 5]
[NNS, *, ADP, left, 5]
[VBD, ADJ, NNP, left, 5]
[went, VERB, IN, left, 5]
[VERB, JJ, *, left, 5]

[ADP]
[went, VBD]
[As, IN]
[went, VBD, ADP]
[VBD, ADJ, *]
[VBD, ADP, NNP]
[VBD, left, 5]
[went, VERB, IN]
[VERB, JJ, *]
[VERB, IN, NOUN]
[VERB, left, 5]
[NNS, VBD, *, ADP]
[went, As, left, 5]
[VERB, JJ, IN, NOUN]
[VERB, IN, left, 5]
[ADJ, *, ADP, left, 5]
[NNS, VBD, ADP, left, 5]
[NNS, ADP, NNP, left, 5]
[went, VERB, As, left, 5]
[NOUN, *, IN, left, 5]

[went]
[As, ADP]
[went, As]
[went, VBD, As]
[NNS, *, ADP]
[VBD, ADJ, NNP]
[As, left, 5]
[went, VERB, As]
[NOUN, *, IN]
[VERB, JJ, NOUN]
[As, left, 5]
[VBD, ADJ, ADP, NNP]
[VBD, ADP, left, 5]
[NOUN, VERB, IN, NOUN]
[VBD, As, ADP, left, 5]
[VBD, *, ADP, left, 5]
[NNS, VBD, *, left, 5]
[NNS, VBD, NNP, left, 5]
[JJ, *, IN, left, 5]
[NOUN, VERB, IN, left, 5]

Decoding for first-order model

- Maximum Spanning Tree (MST) Algorithm
- Eisner (2000) described a **dynamic programming** based decoding algorithm for bilexical grammar
- McDonald et al. (2005) applied this algorithm to the search problem of the second-order model
- Koo et al. (2010) investigate third-order model

Part 3.2: Transition-based Methods

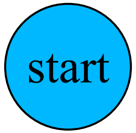
Transition Systems

A transition system

- Automata
  - State
    - Start state —— an empty structure
    - End state —— the output structure
    - Intermediate states —— partially constructed structures
  - Actions
    - Change one state to another

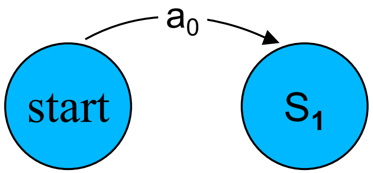
A transition system

- Automata



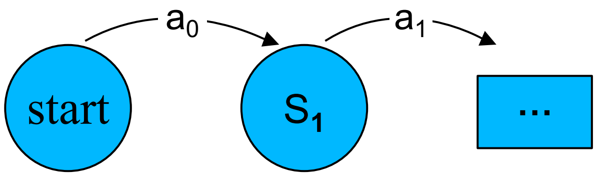
A transition system

- Automata



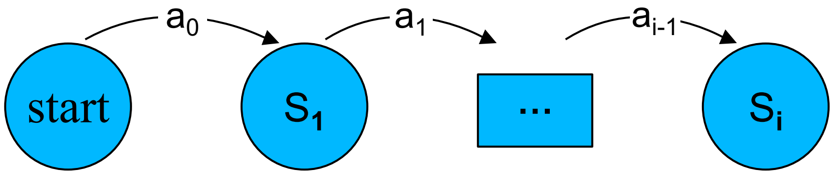
A transition system

- Automata



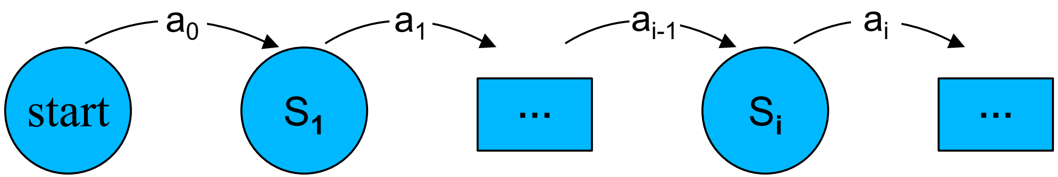
A transition system

- Automata



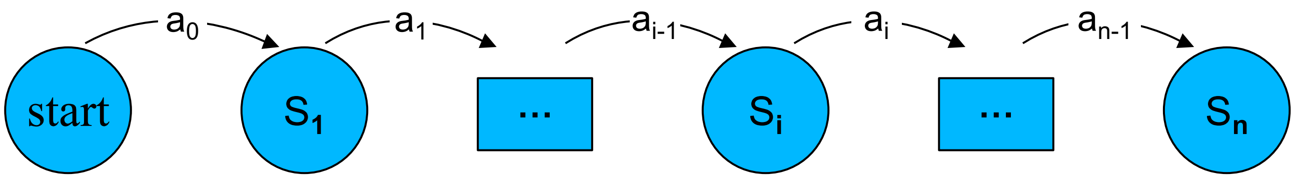
A transition system

- Automata



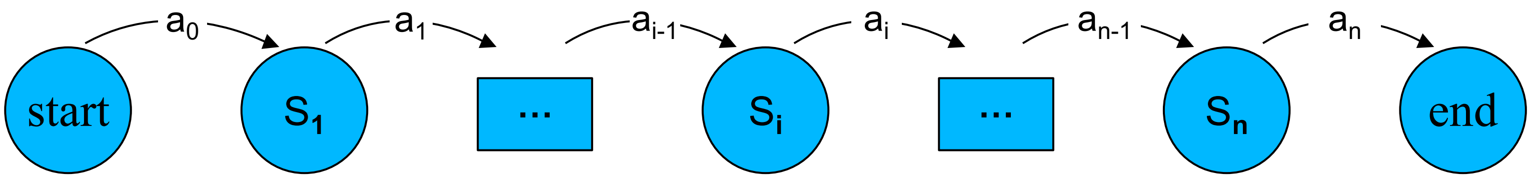
A transition system

- Automata



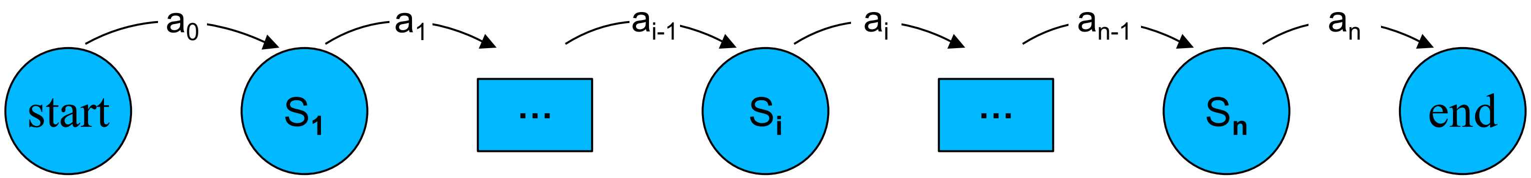
A transition system

- Automata



A transition system

- State
  - Corresponds to partial results during decoding
    - start state, end state, S_i



- Actions
  - The operations that can be applied for state transition
  - Construct output incrementally

Examples

A transition-based POS-tagging example

- POS tagging

  I like reading books → I/PRON like/VERB reading/VERB books/NOUN

- Transition system
  - State
    - Partially labeled word-POS pairs
    - Unprocessed words
  - Actions
    - TAG(t) $w_1/t_1 \cdots wi/t_i \rightarrow w_1/t_1 \cdots w_i/t_i\, w_{i+1}/t$

A transition-based POS-tagging example

- Start State

I like reading books

A transition-based POS-tagging example

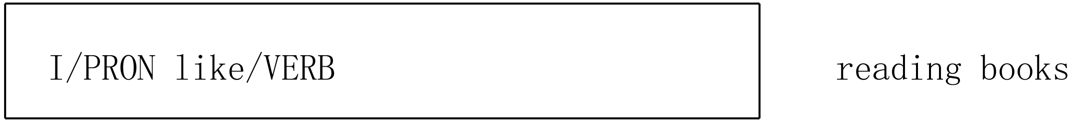
- TAG(PRON)

I/PRON

like reading books

A transition-based POS-tagging example

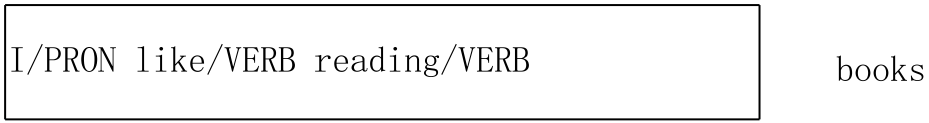
- TAG(VERB)



```
I/PRON like/VERB          reading books
```

A transition-based POS-tagging example

- TAG(VERB)

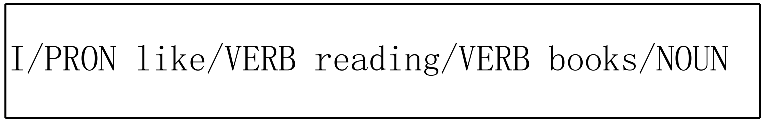


I/PRON like/VERB reading/VERB

books

A transition-based POS-tagging example

- TAG (NOUN)



I/PRON like/VERB reading/VERB books/NOUN

A transition-based POS-tagging example

- End State

I/PRON like/VERB reading/VERB books/NOUN

Word segmentation

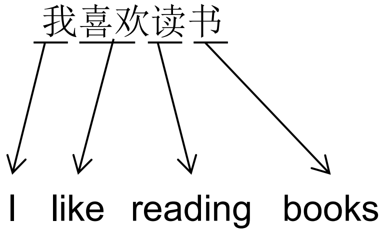
- State
  - Partially segmented results
  - Unprocessed characters

- Two candidate actions
  - Separate ## ## → ## ## #
  - Append ## ## → ## ## #

Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

Word segmentation

- Initial State



Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

Word segmentation

- Separate

我

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Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

Word segmentation

- Separate

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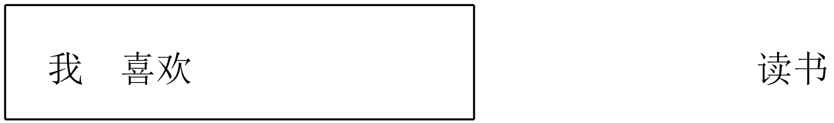
Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

Word segmentation

- Append



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Word segmentation

- Separate

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Word segmentation

- Separate

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Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

Word segmentation

- End State

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Zhang, Y., & Clark, S. (2007). Chinese Segmentation Using a Word-Based Perceptron Algorithm. ACL.

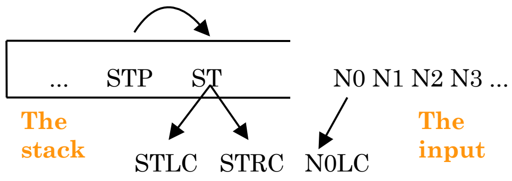
Transition-based Dependency Parsing

- State
  - A stack to hold partial structures
  - A queue of next incoming words
- Actions
  - SHIFT, REDUCE, ARC-LEFT, ARC-RIGHT

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

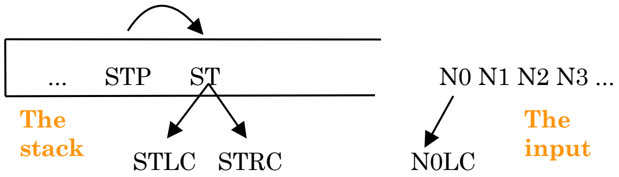
- State



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

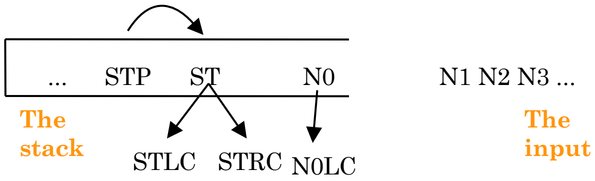
- Actions
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

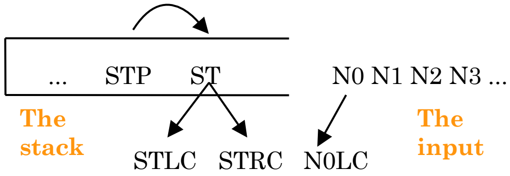
- Actions
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

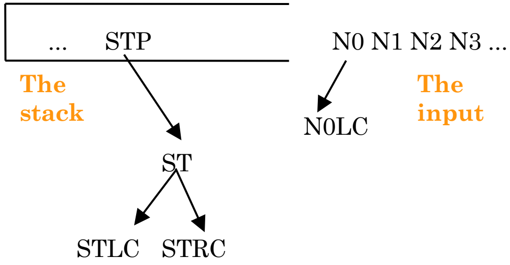
- Actions
    - REDUCE



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

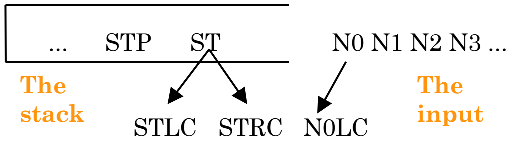
- Actions
  - REDUCE



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

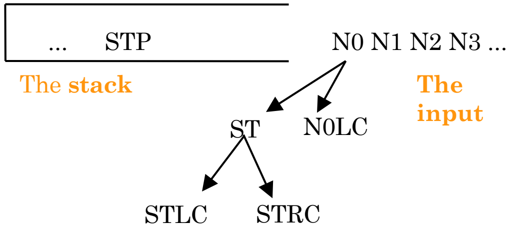
- Actions
  - ARC-LEFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

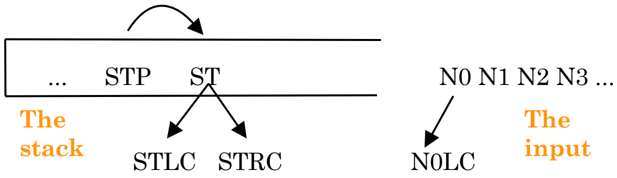
- Actions
  - ARC-LEFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

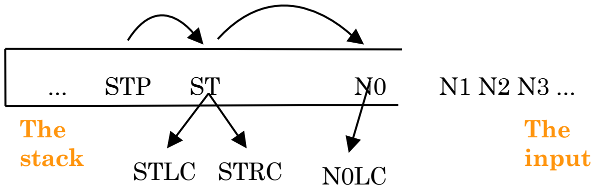
- Actions
  - ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

- Actions
  - ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

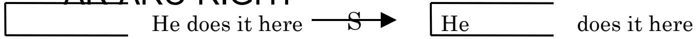
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT

He does it here

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT

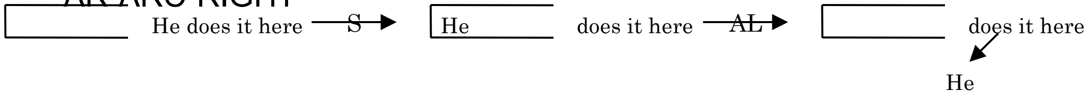


He does it here $\xrightarrow{S}$ He does it here

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



He does it here

S

He

does it here

AL

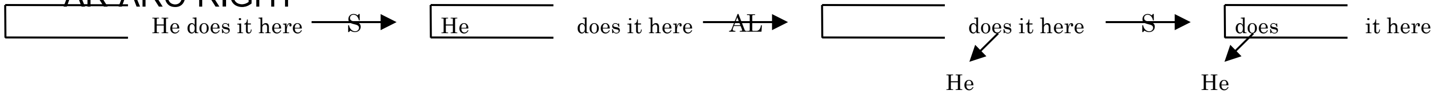
does it here

He

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

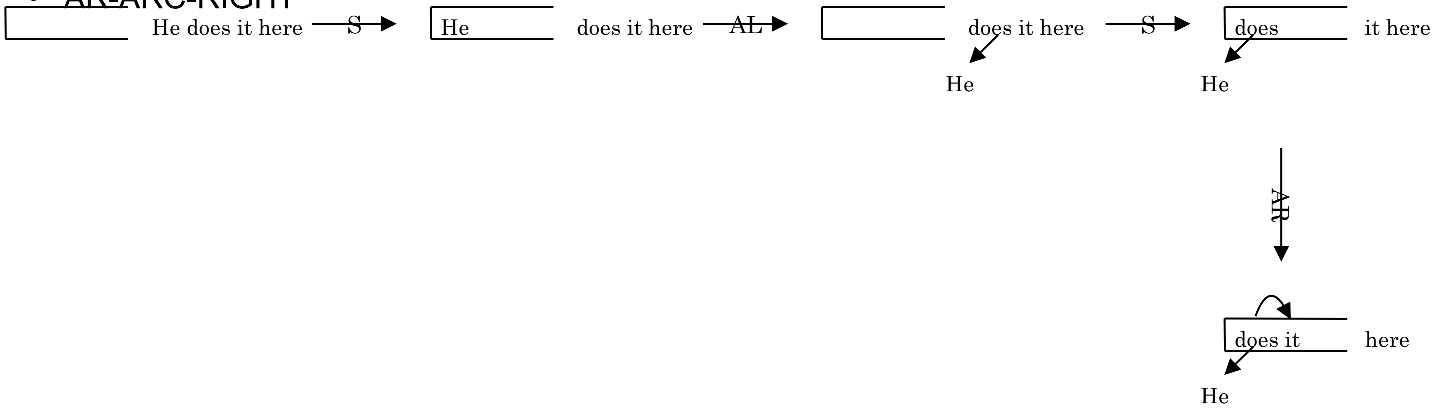
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

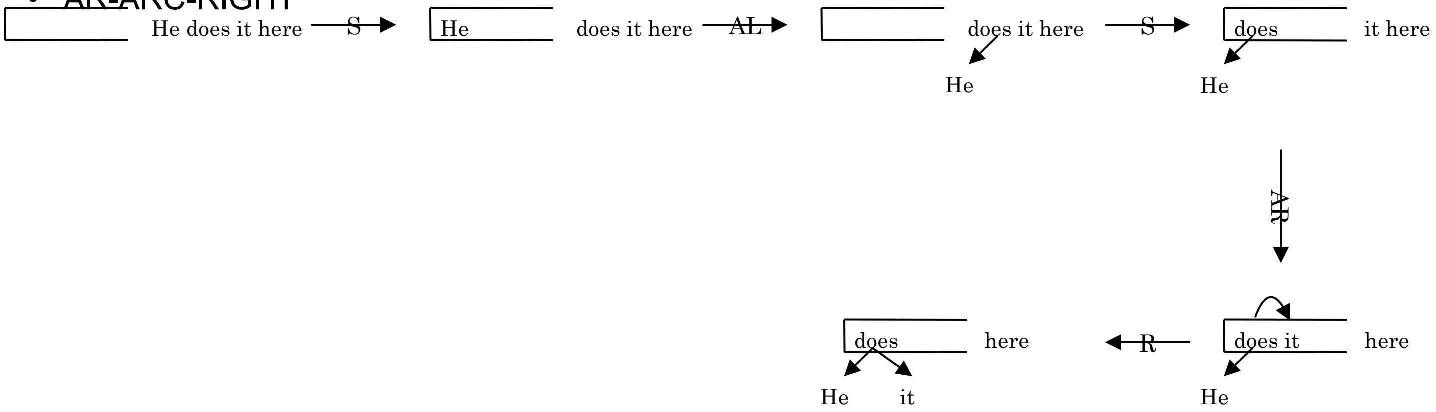
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

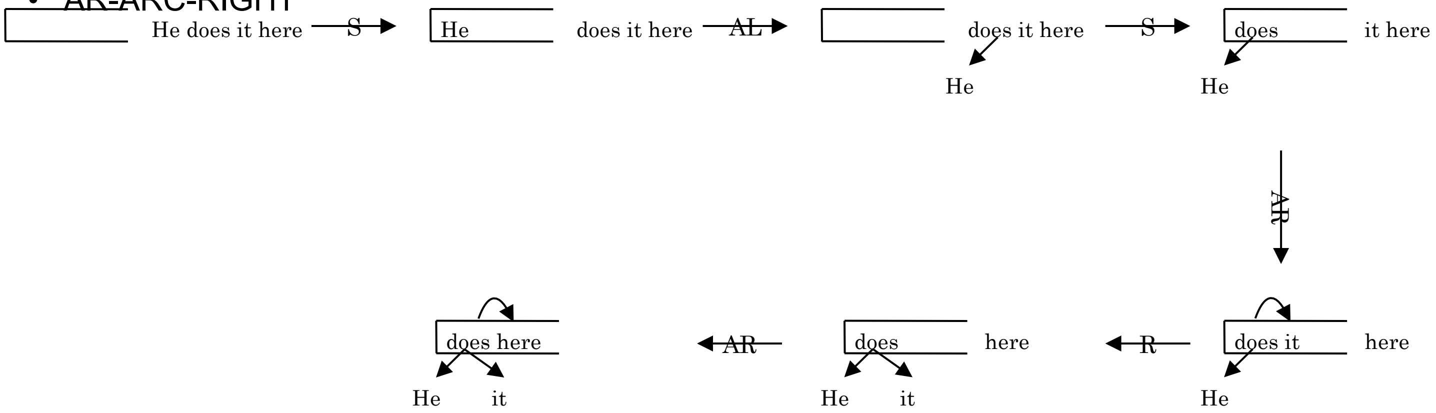
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

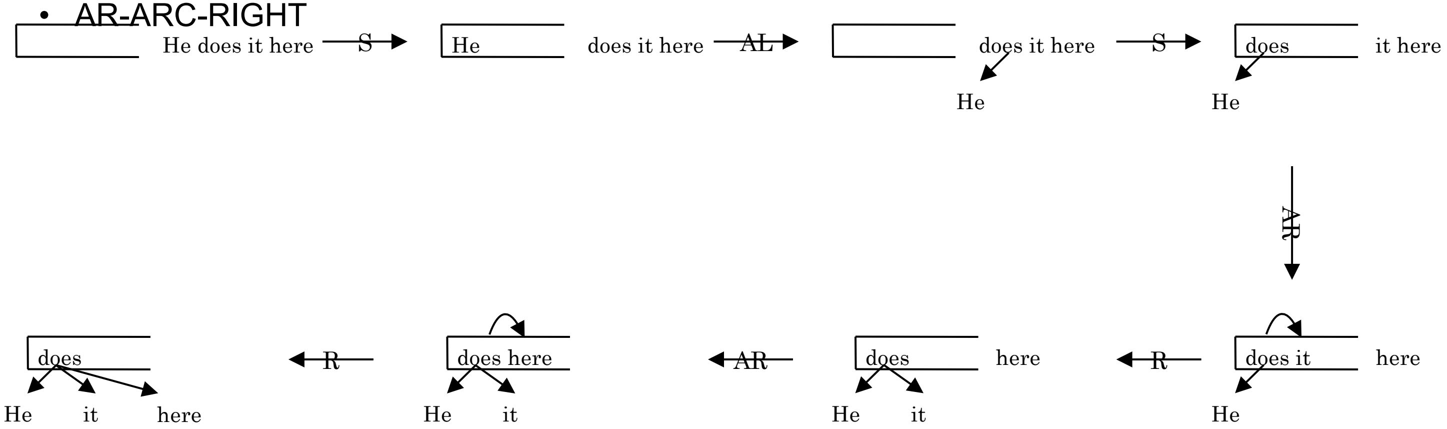
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Dependency Parsing

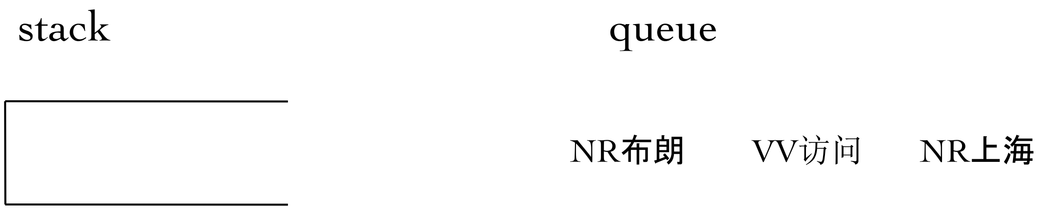
- An Example
  - S-SHIFT
  - R-REDUCE
  - AL-ARC-LEFT
  - AR-ARC-RIGHT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

- Actions
    - SHIFT



stack

queue

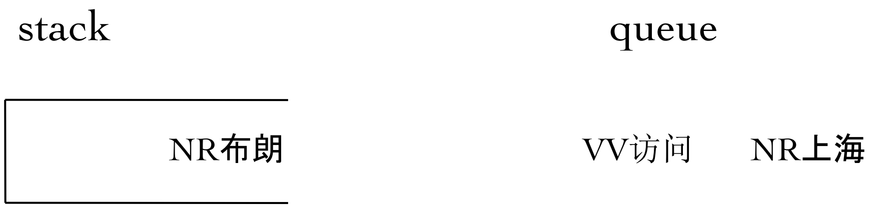
NR布朗 VV访问 NR上海

布朗(Brown) 访问(visits) 上海(Shanghai)

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

- Actions
  - SHIFT



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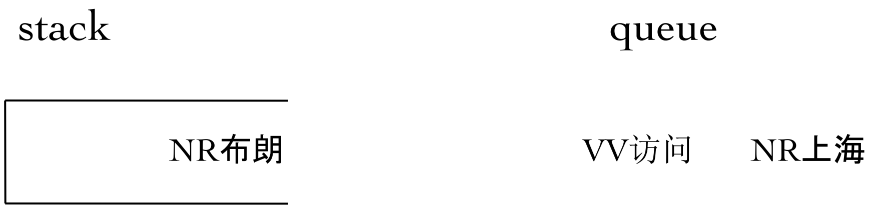
Transition-based Constituent Parsing

- Actions
  - REDUCE-UNARY-X



stack

queue

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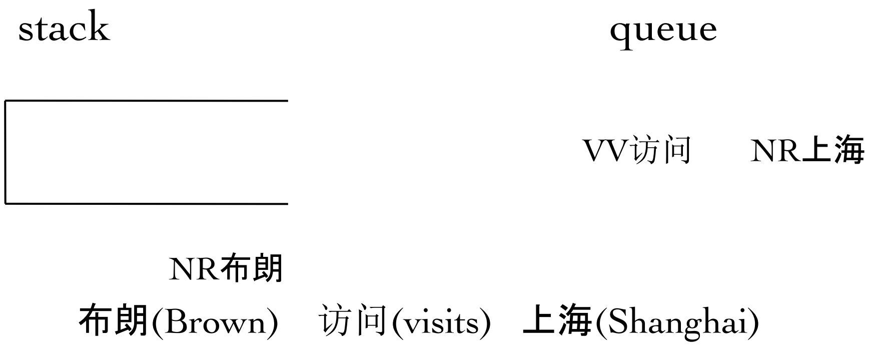
Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

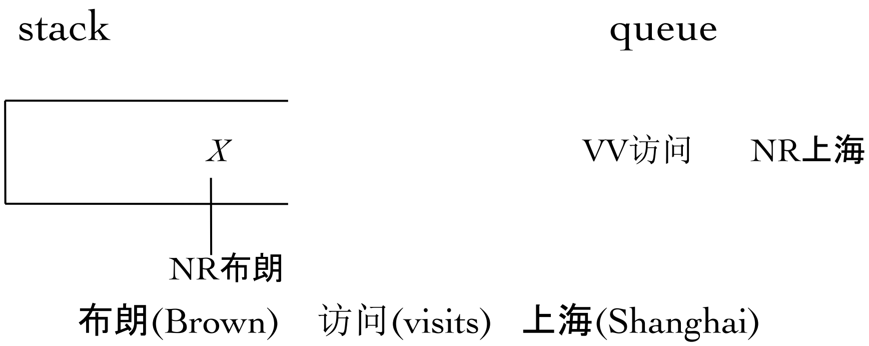
- Actions
  - REDUCE-UNARY-X



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

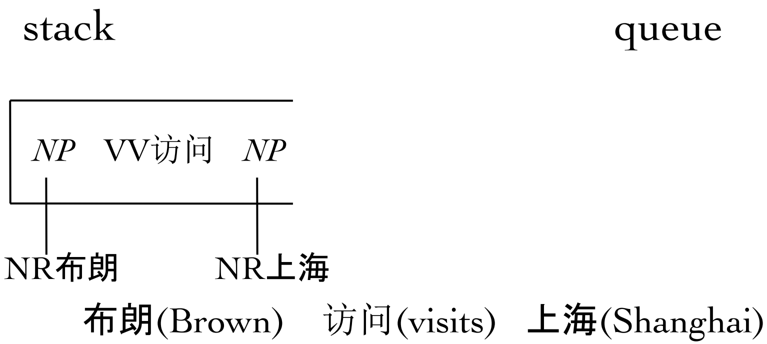
- Actions
  - REDUCE-UNARY-X



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

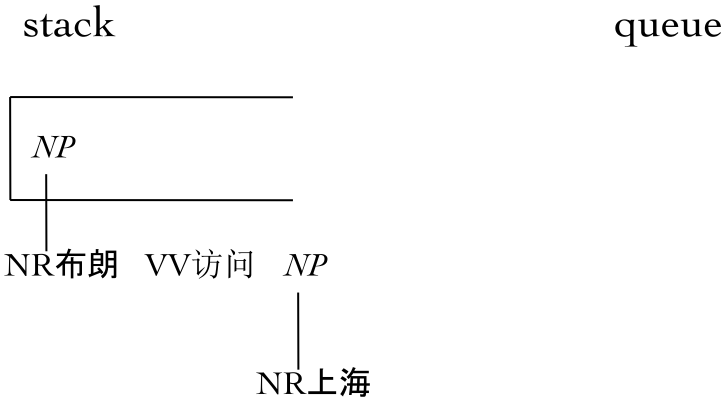
- Actions
  - REDUCE-BINARY-{L/R}-X



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

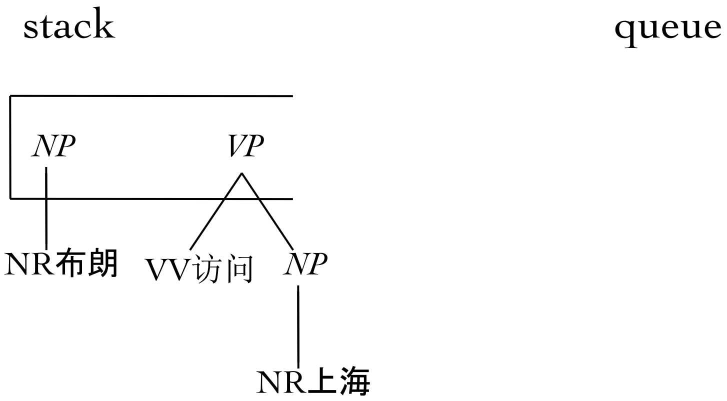
- Actions
  - REDUCE-BINARY-{L/R}-X



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

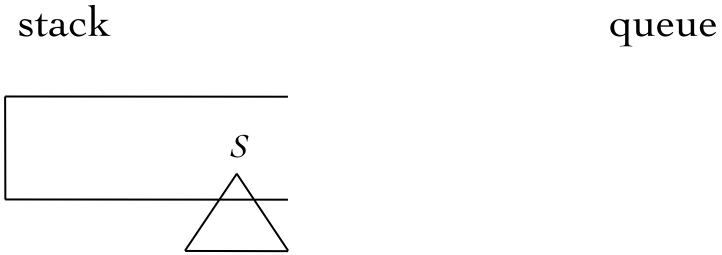
- Actions
  - REDUCE-BINARY-{L/R}-X



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

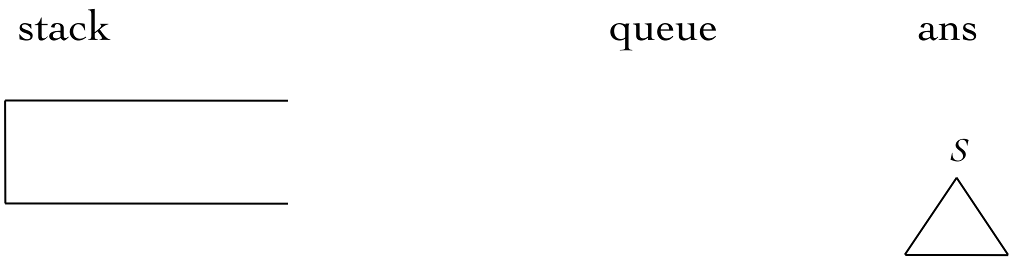
- Actions
  - TERMINATE



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

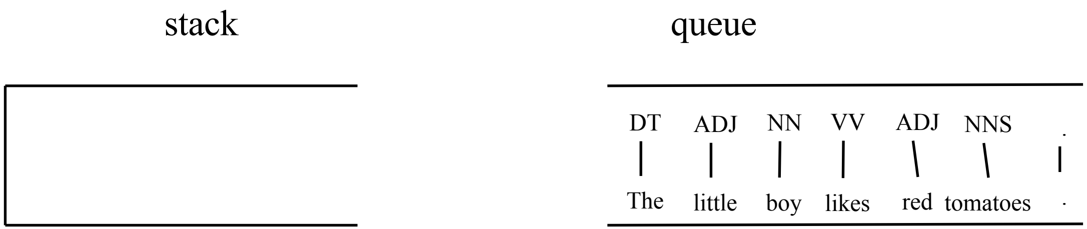
- Actions
  - TERMINATE



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

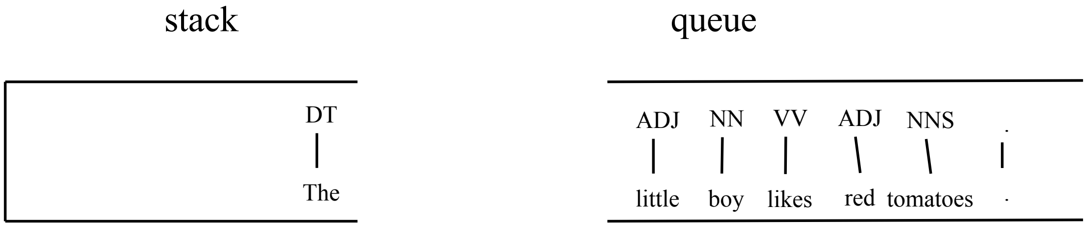
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

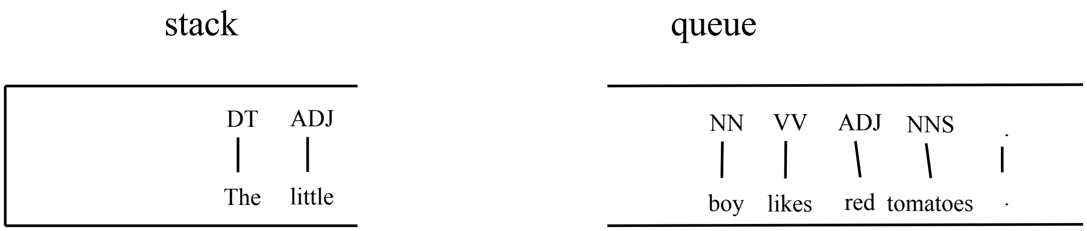
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

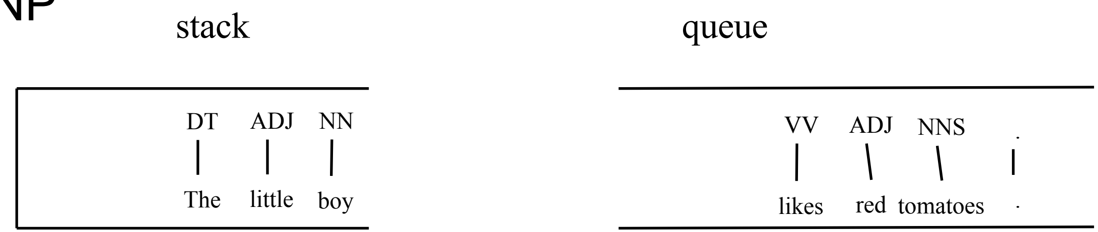
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

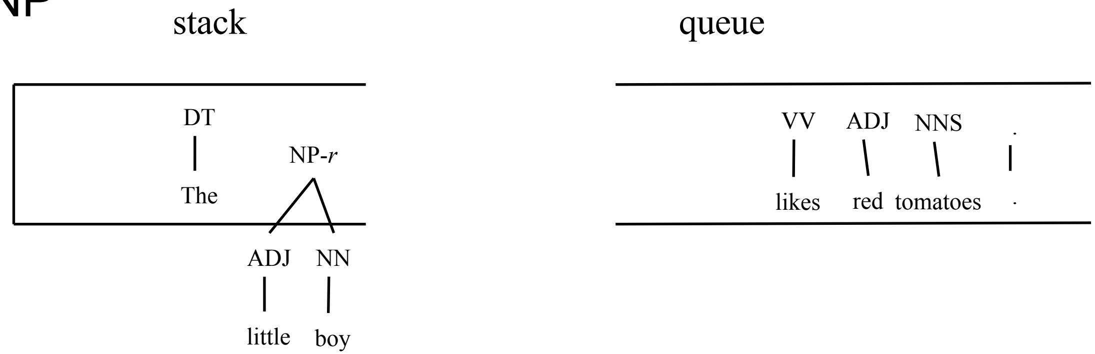
- Example
  - REDUCE-R-NP



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

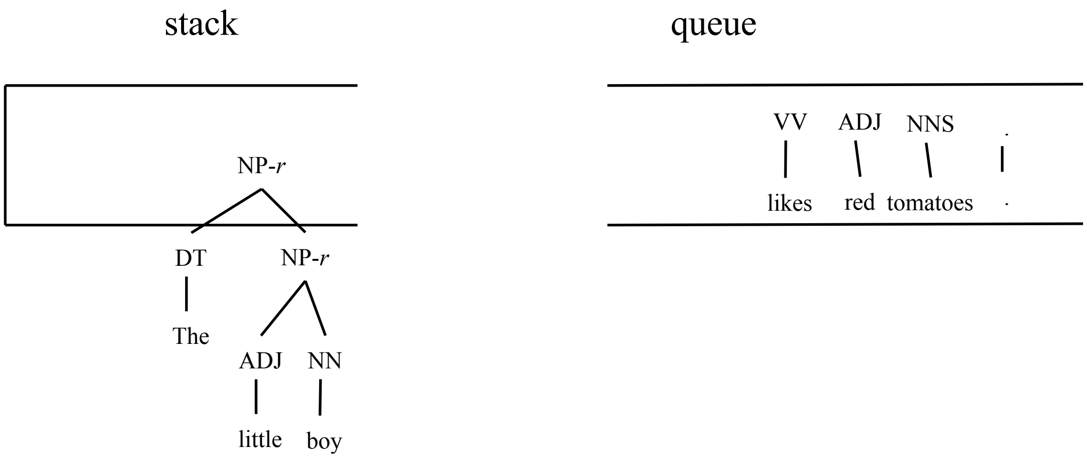
- Example
  - REDUCE-R-NP



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

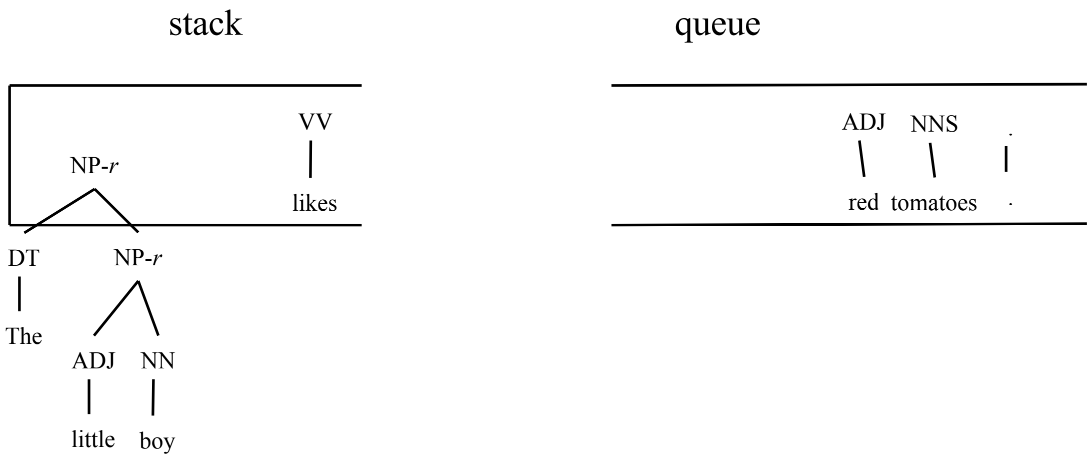
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

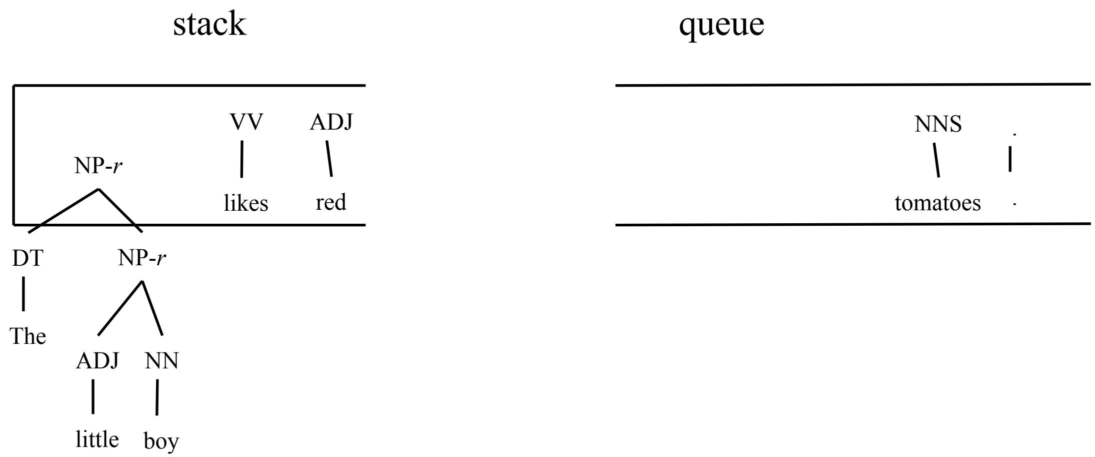
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

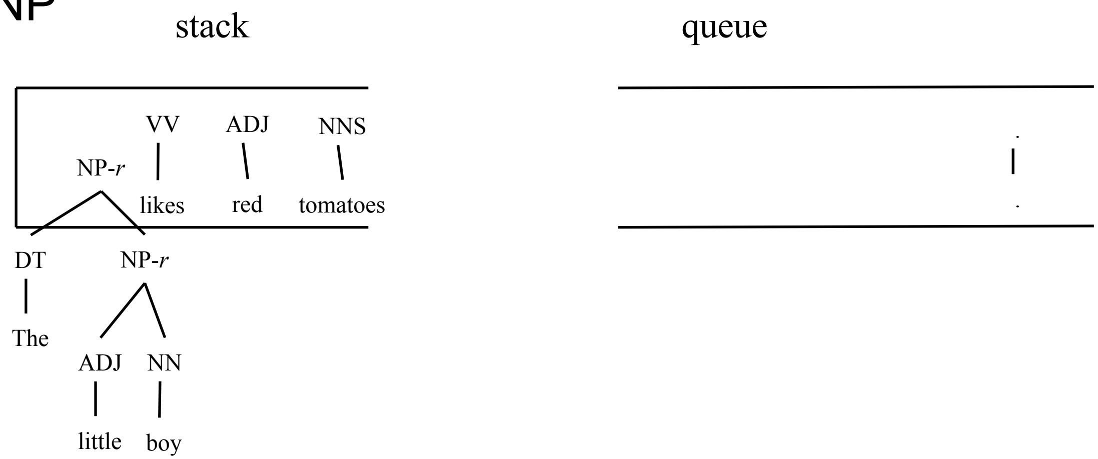
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

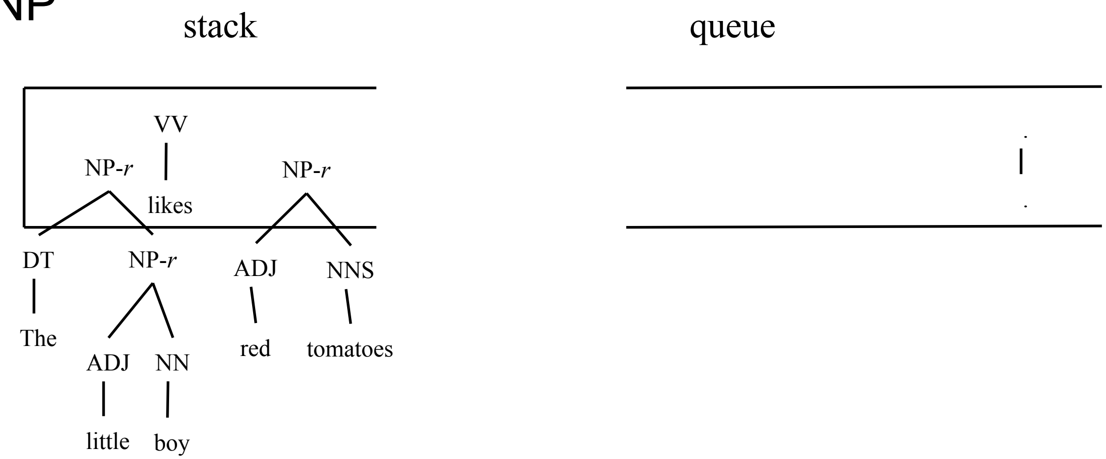
- Example
  - REDUCE-R-NP



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

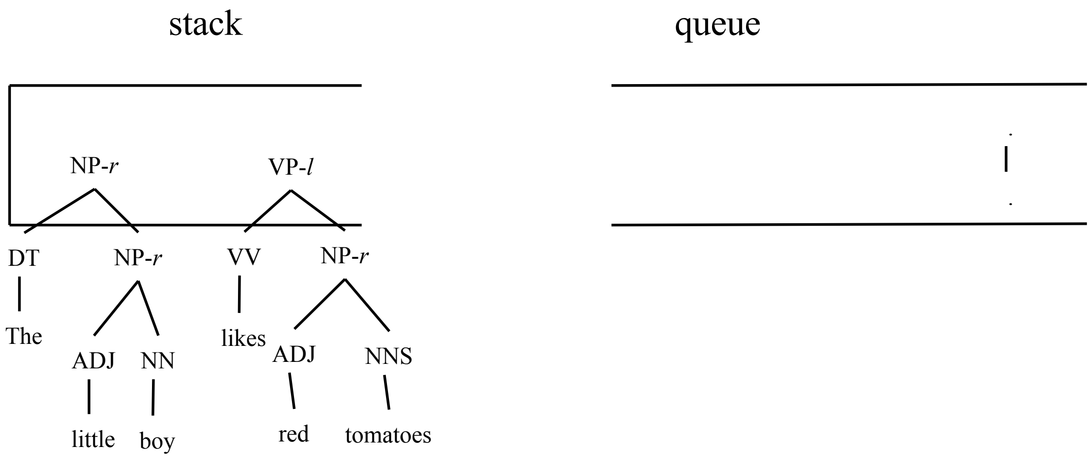
- Example
  - REDUCE-L-NP



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

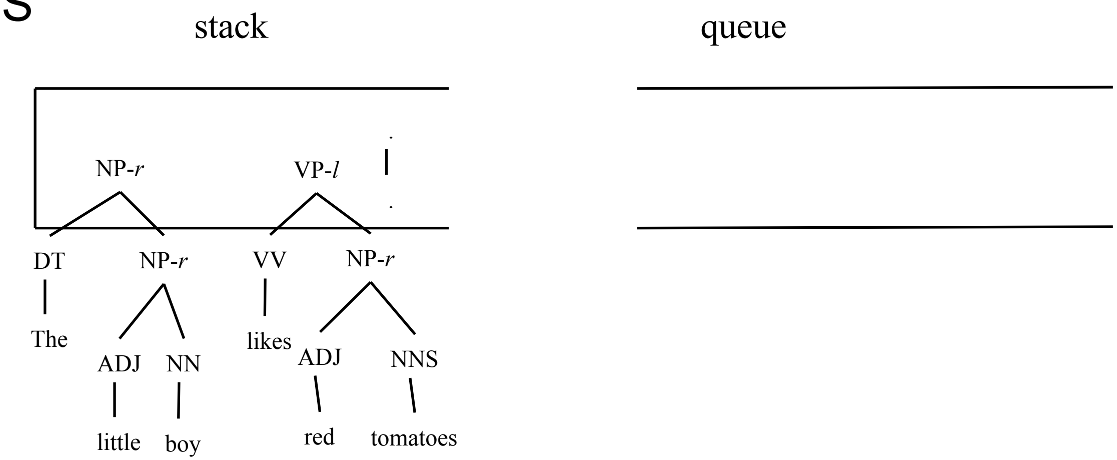
- Example
  - SHIFT



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

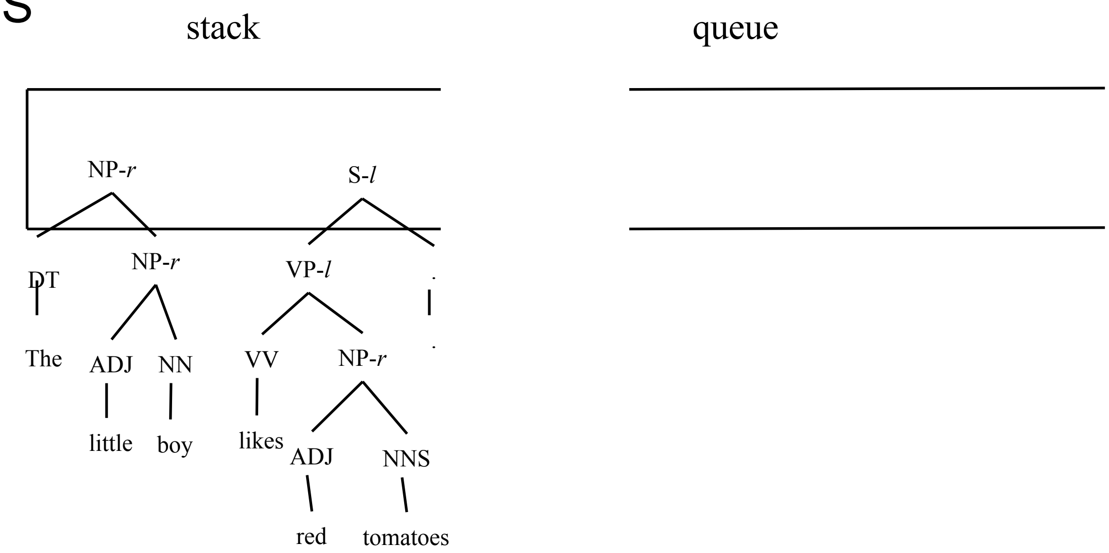
- Example
  - REDUCE-L-S



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

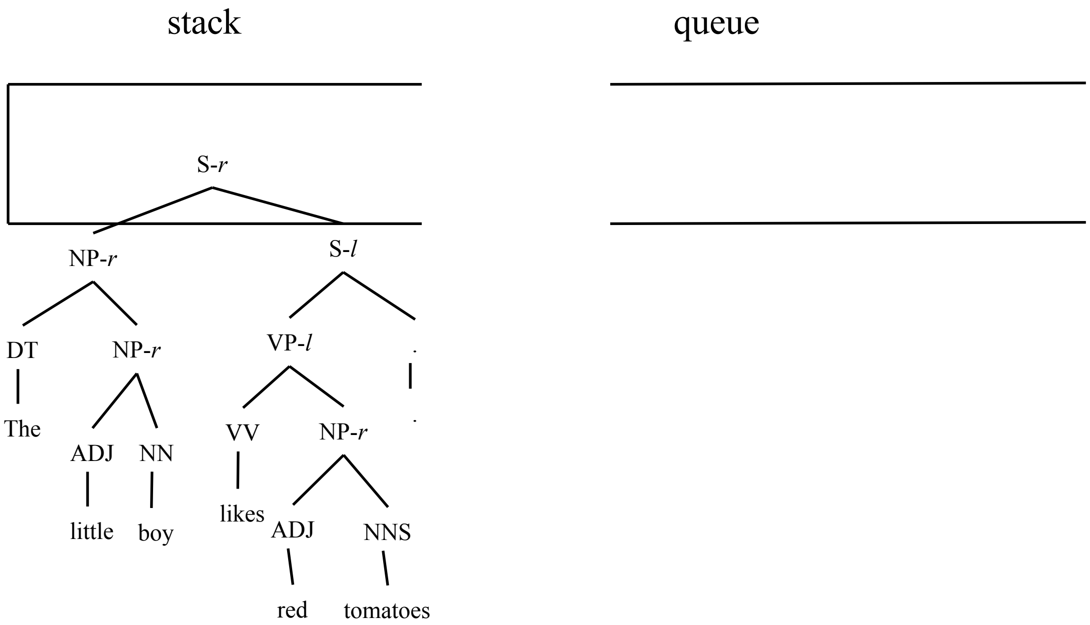
- Example
  - REDUCE-R-S



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Transition-based Constituent Parsing

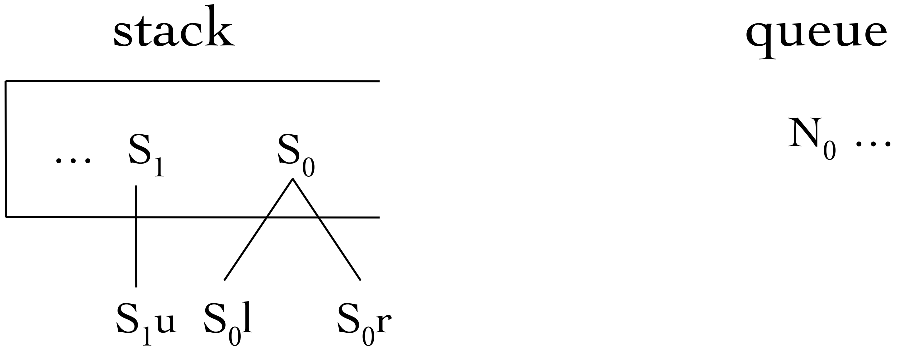
- Example
  - TERMINATE



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Features

- Non-local Features
  - Extracted from top nodes on the stack S0, S1, S2, S3, the left and right or single child of S0 and S1, and the first words on the queue N0, N1, N2, N3.



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

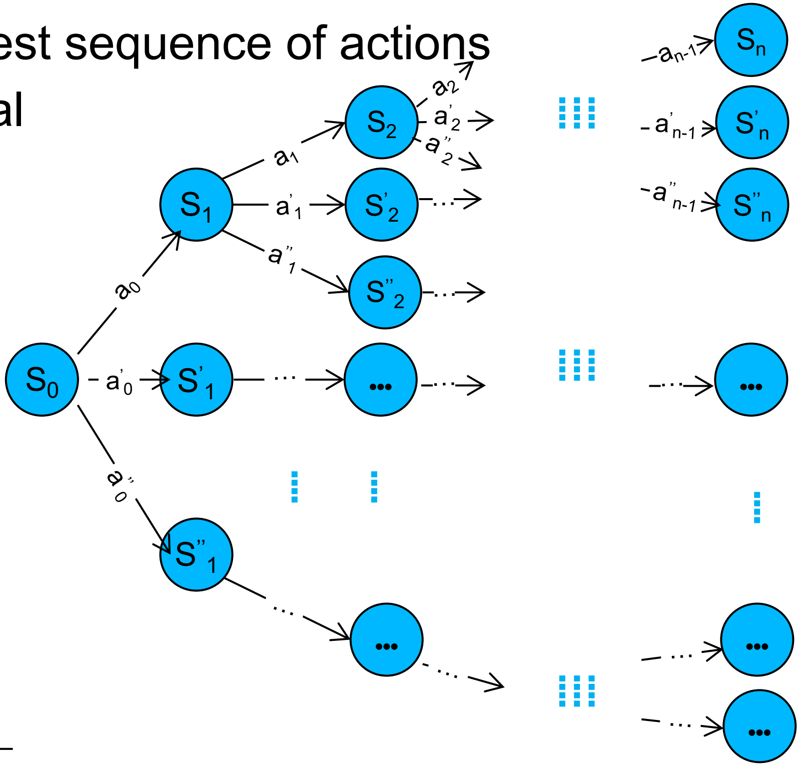
Transition-based Methods

- Rich features
- Fast speed
- Search error

Beam-search Decoding

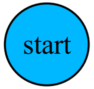
Search Space

- Find the best sequence of actions
- Exponential



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding



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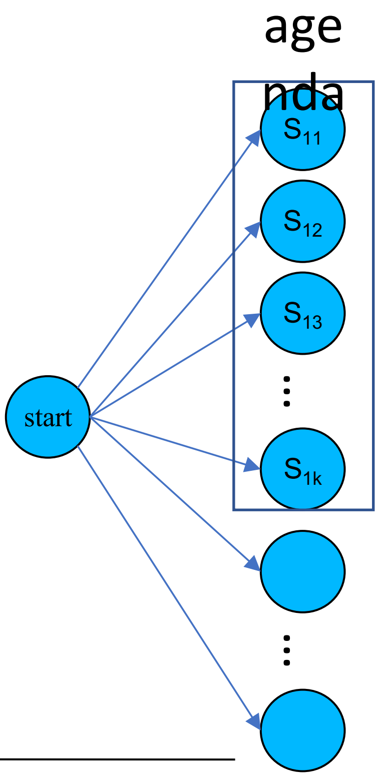
Beam-search decoding



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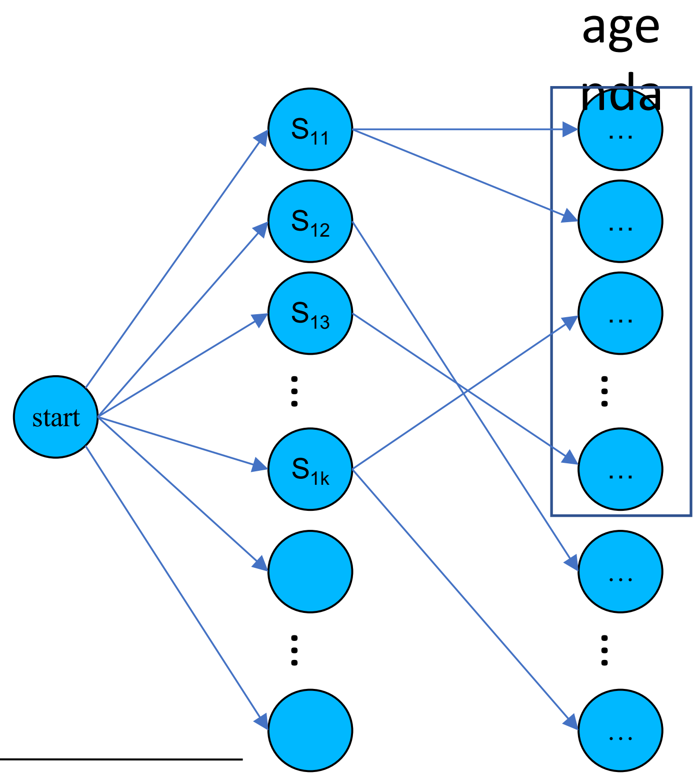
Beam-search decoding



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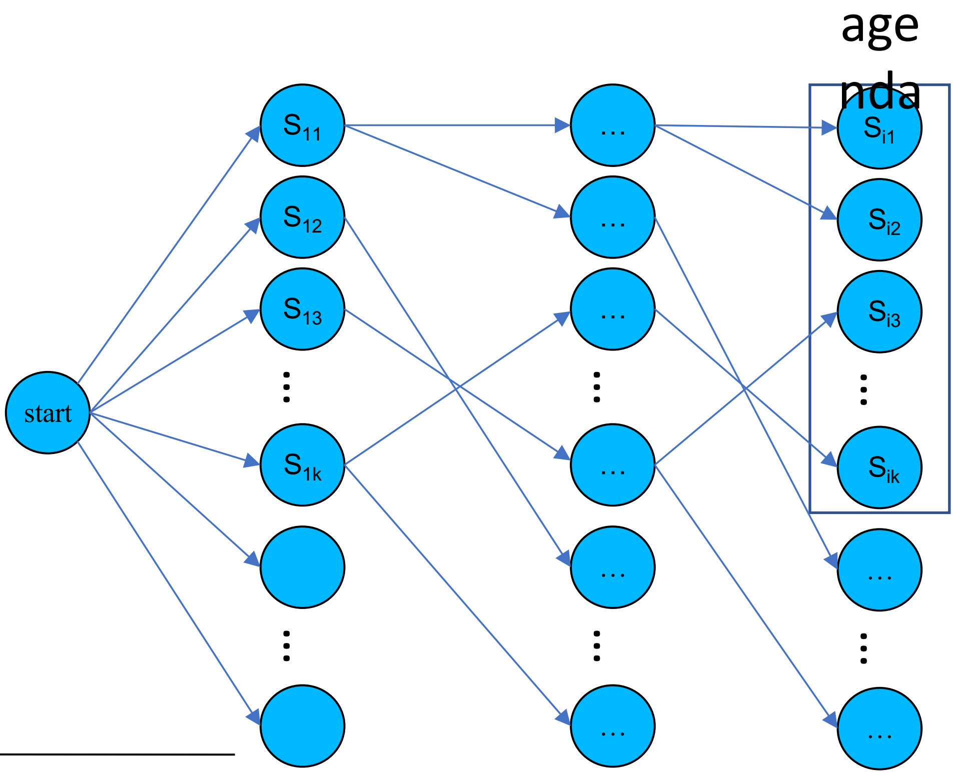
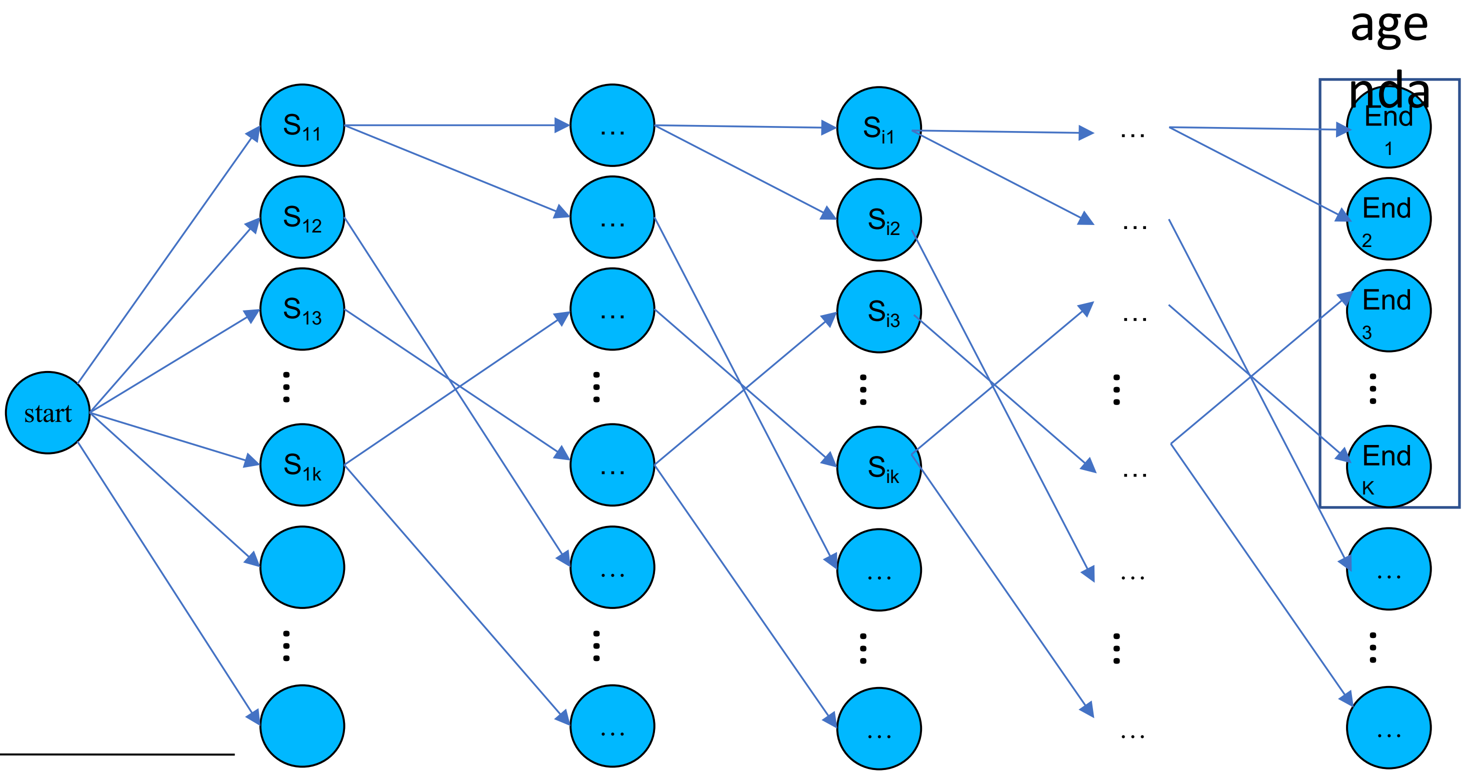
Beam-search decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

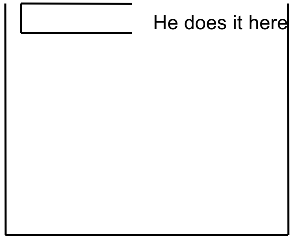
Beam-search decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding

- Dependency Parsing Example
  - Decoding



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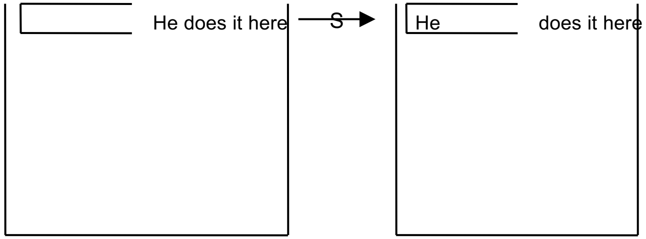
Beam-search decoding

- Dependency Parsing Example
  - Decoding



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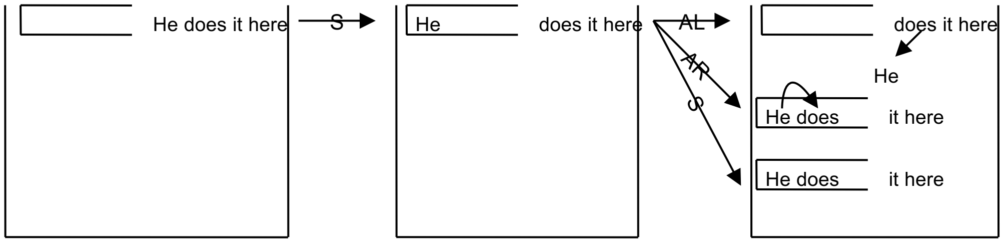
Beam-search decoding

- Dependency Parsing Example
  - Decoding



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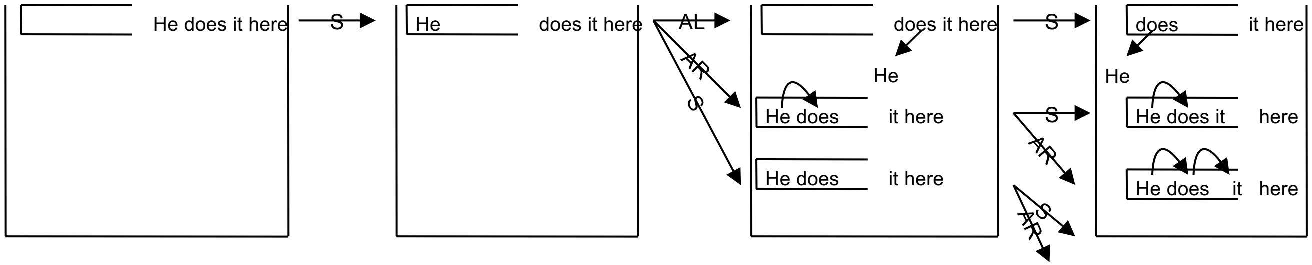
Beam-search decoding

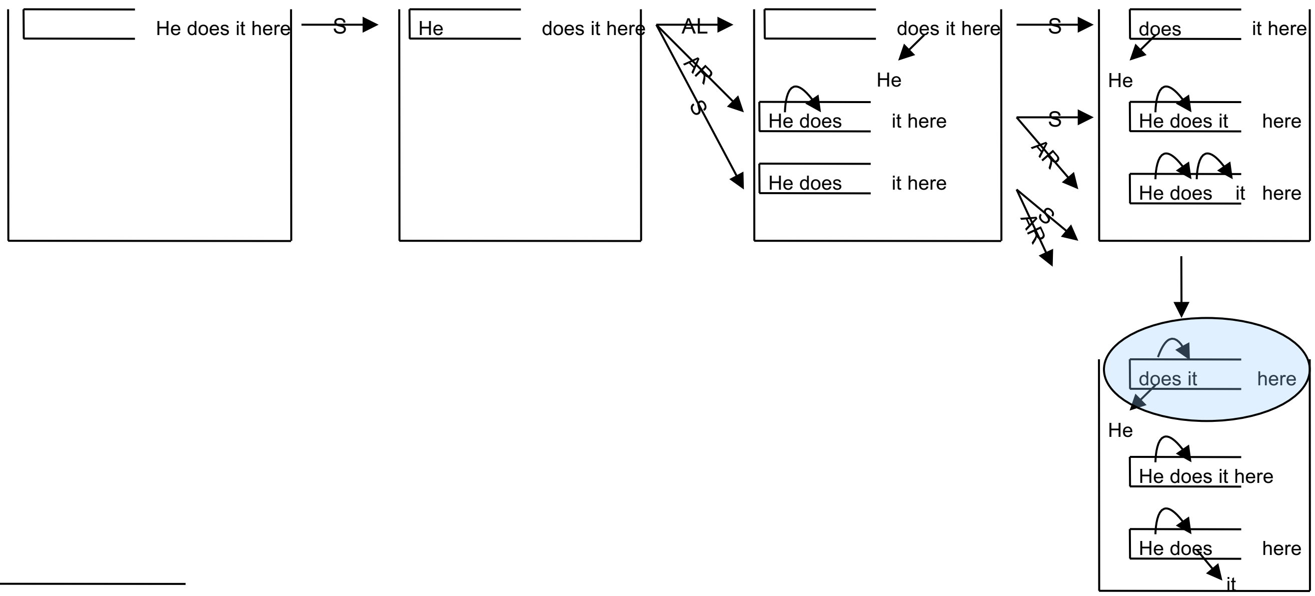
- Dependency Parsing Example
  - Decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding

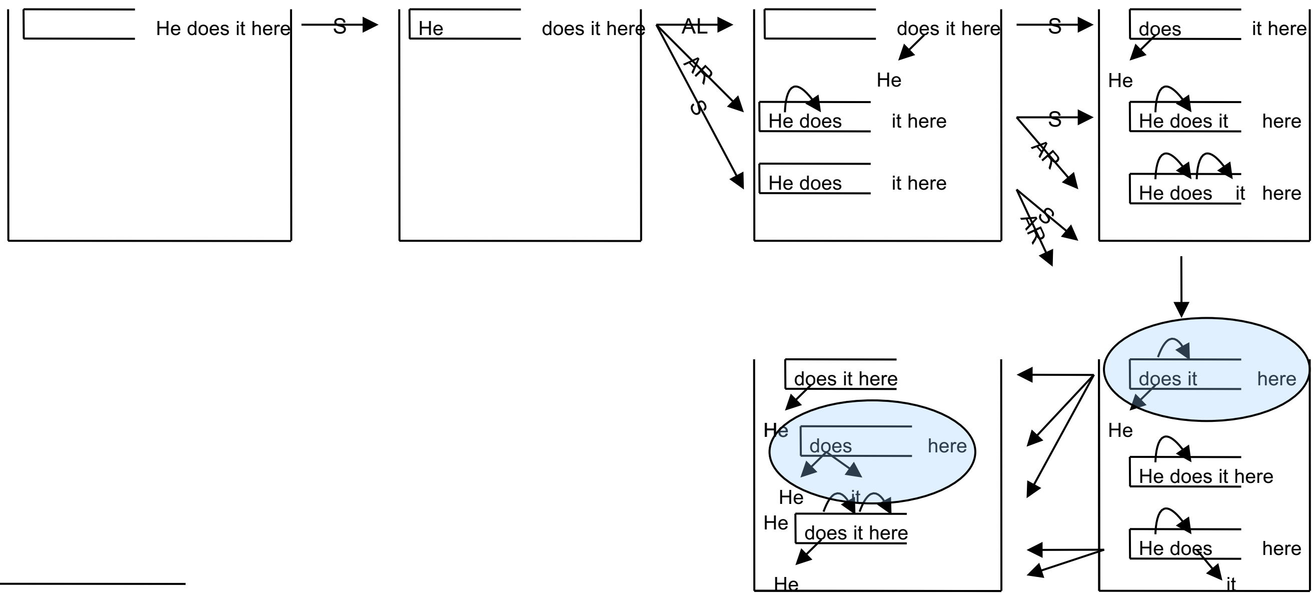
- Dependency Parsing Example
    - Decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding

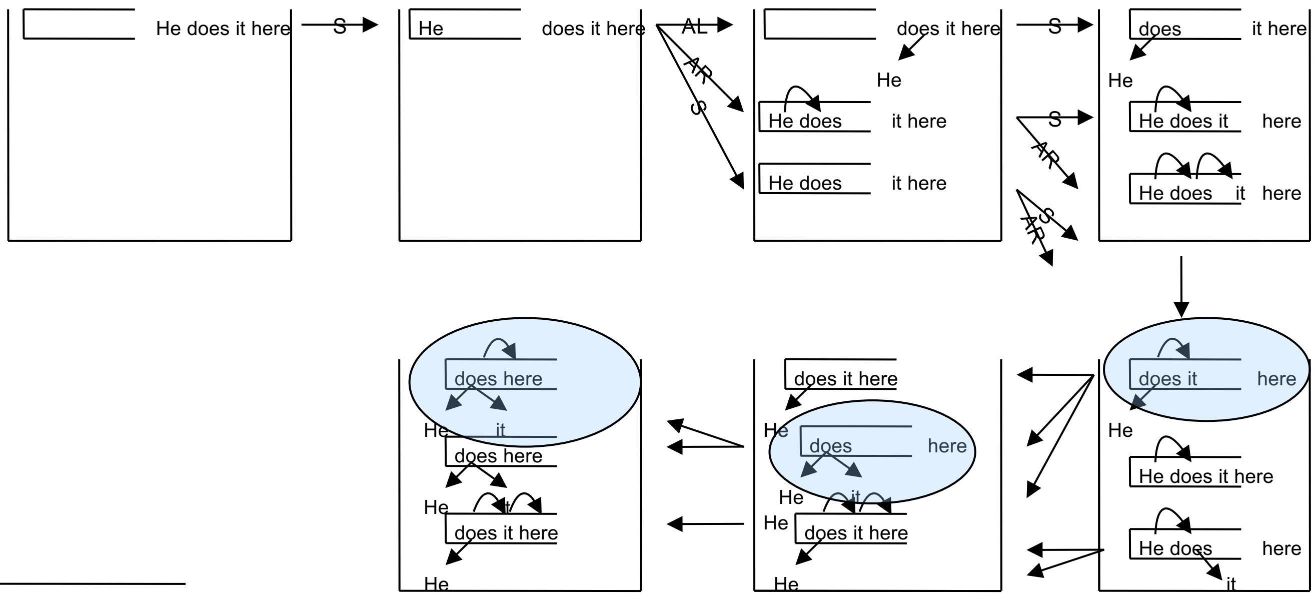
- Dependency Parsing Example
  - Decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding

- Dependency Parsing Example
  - Decoding



He does it here
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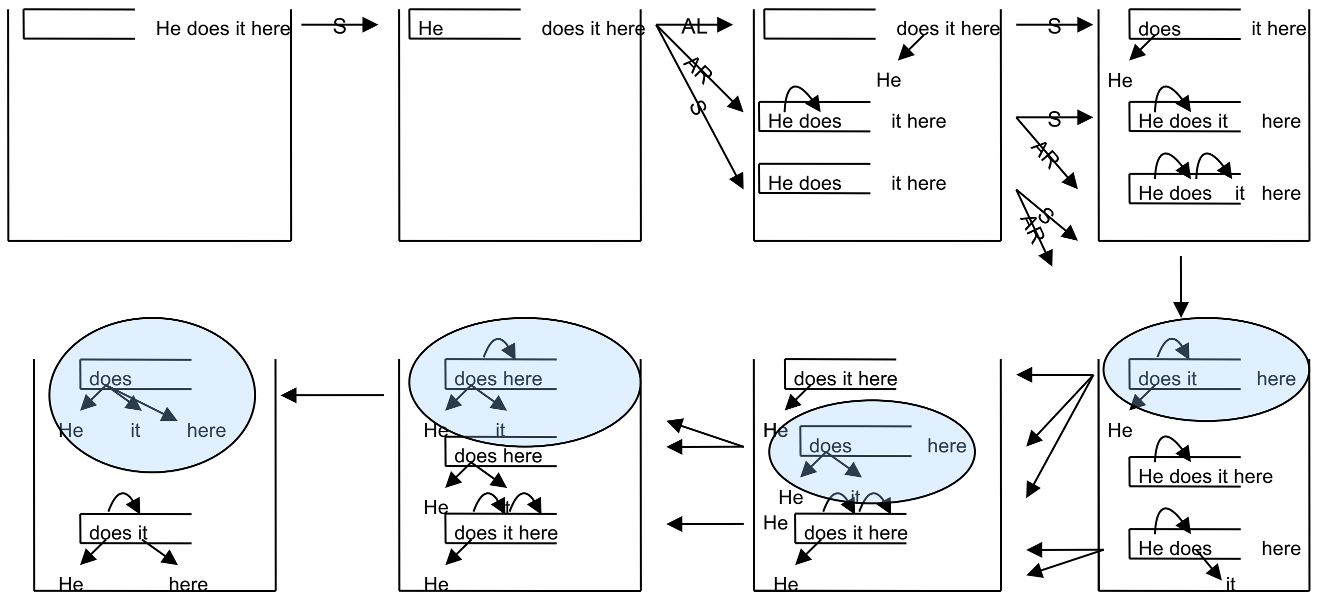
Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

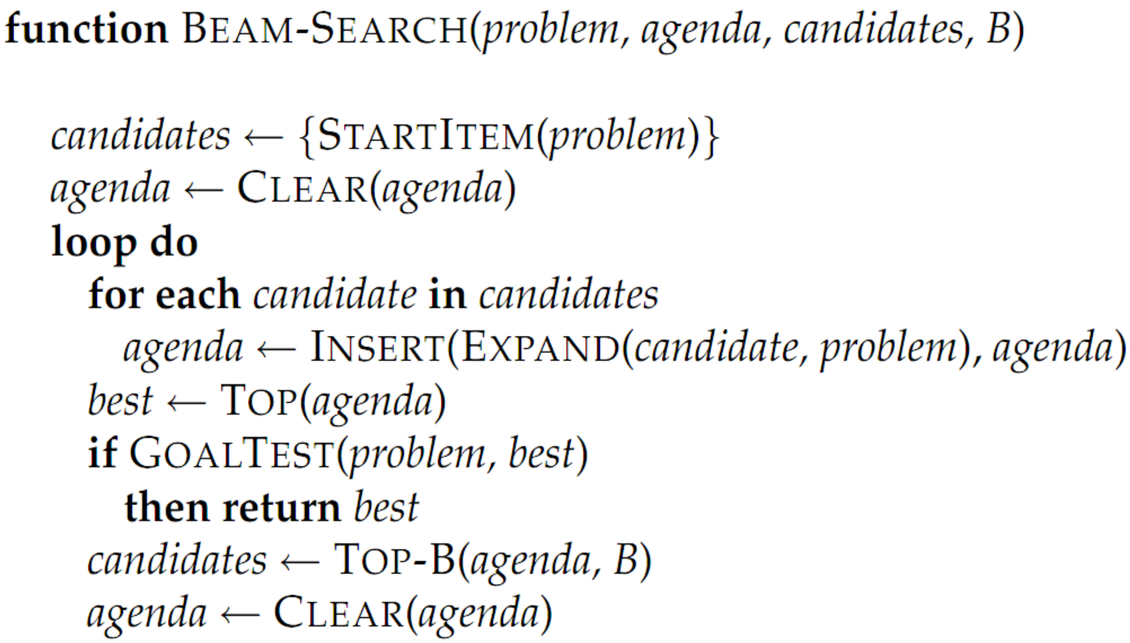
Beam-search decoding

- Dependency Parsing Example
  - Decoding



Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Beam-search decoding



```
function BEAM-SEARCH($problem$, $agenda$, $candidates$, $B$)

  $candidates \leftarrow \{$STARTITEM($problem$)$\}$
  $agenda \leftarrow$ CLEAR($agenda$)
  loop do
    for each $candidate$ in $candidates$
      $agenda \leftarrow$ INSERT(EXPAND($candidate$, $problem$), $agenda$)
    $best \leftarrow$ TOP($agenda$)
    if GOALTEST($problem$, $best$)
      then return $best$
    $candidates \leftarrow$ TOP-B($agenda$, $B$)
    $agenda \leftarrow$ CLEAR($agenda$)
```

Zhang, Y., & Clark, S. (2011). Syntactic Processing Using the Generalized Perceptron and Beam Search. CL.

Global Training

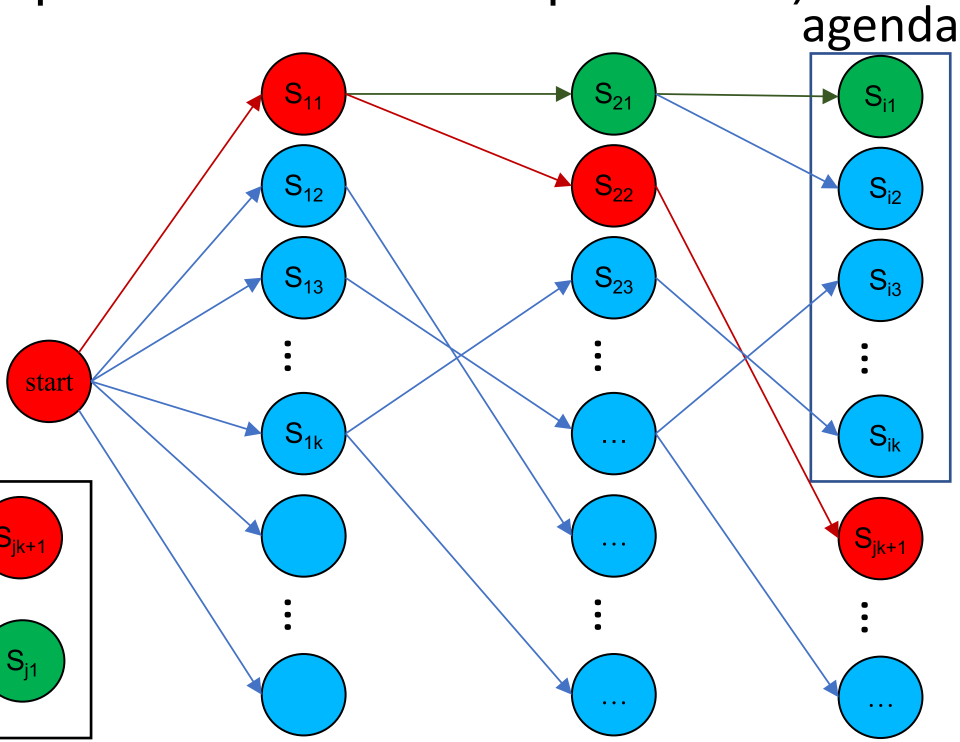
Structured Learning

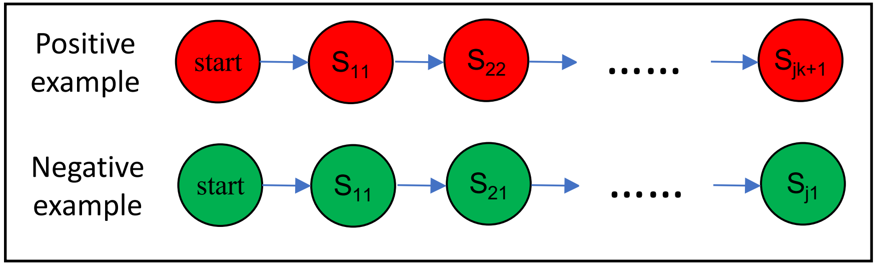
- Model **whole sequences** of actions
    - Correspond to structures

Yue Zhang and Stephen Clark. 2011. *Syntactic Processing Using the Generalized Perceptron and Beam Search*. In *Computational Linguistics*, 37(1), March.

Learning guided search

- Search not optional (vs graph-based structured prediction)
- Learn to fix search errors


agenda
start
S_{11}
S_{12}
S_{13}
S_{1k}
S_{21}
S_{22}
S_{23}
…
…
…
S_{i1}
S_{i2}
S_{i3}
S_{ik}
S_{jk+1}
…


Positive example
start
S_{11}
S_{22}
……
S_{jk+1}
Negative example
start
S_{11}
S_{21}
……
S_{j1}