CS5740: Natural Language Processing
Spring 2017

Dependency Parsing

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Slides adapted from Dan Klein, Luke Zettlemoyer, Chris Manning, and Dan Jurafsky, and David Weiss

Overview

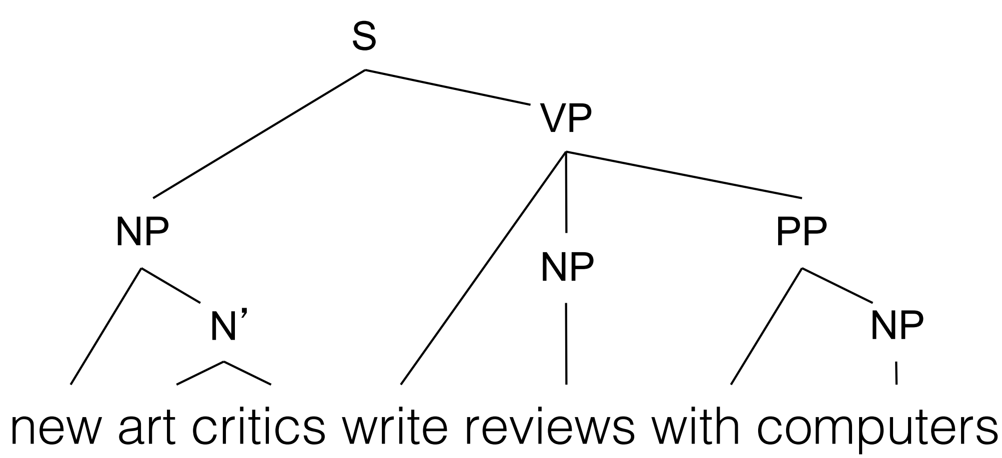
- The parsing problem
- Methods
  - Transition-based parsing
- Evaluation
- Projectivity

Parse Trees

- Part-of-speech Tagging:
  - Word classes
- Parsing:
  - From words to phrases to sentences
  - Relations between words
- Two views
  - Constituency
  - Dependency

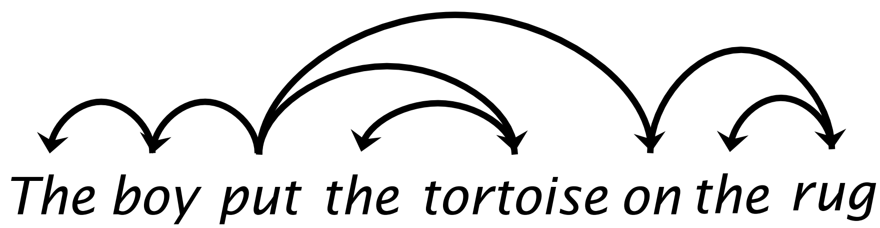
Constituency (Phrase Structure) Parsing

- Phrase structure organizes words into nested constituents
- Linguists can, and do, argue about details
- Lots of ambiguity



Dependency Parsing

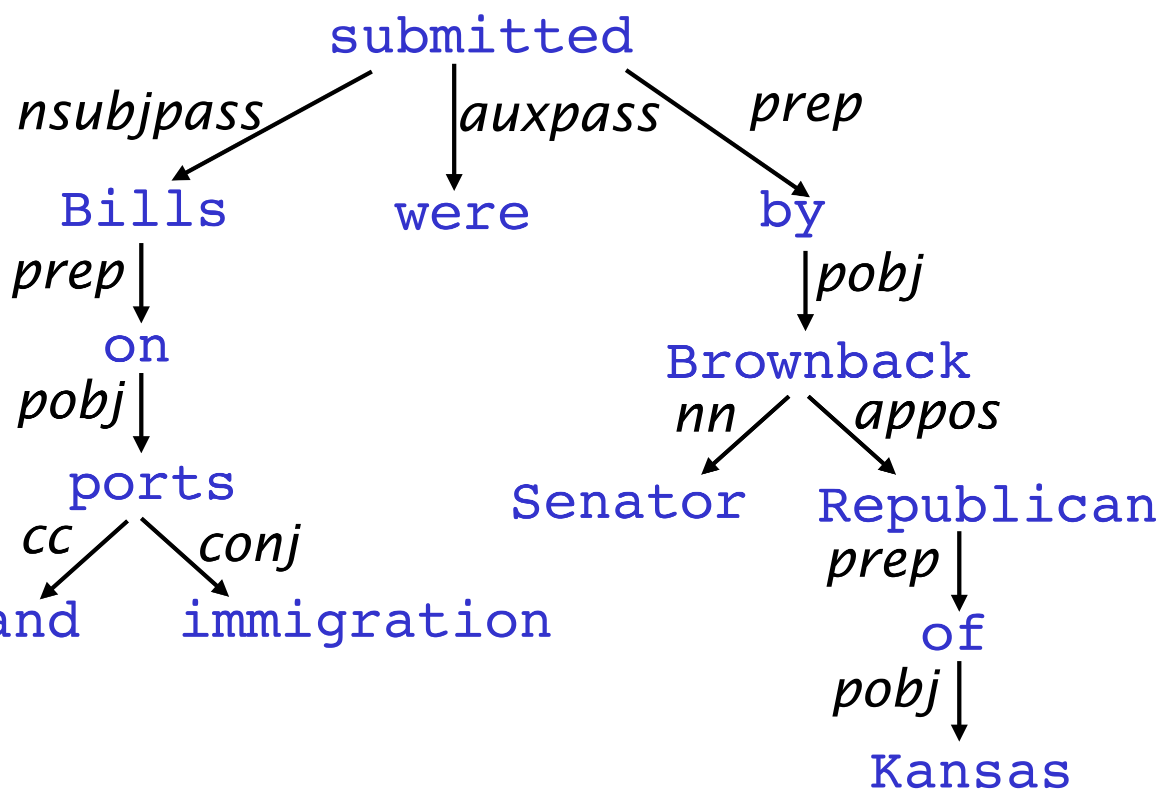
- Dependency structure shows which words depend on (modify or are arguments of) which other words.



Dependency Structure

- Syntactic structure consists of:
  - Lexical items
  - Binary asymmetric relations →dependencies

Dependencies are typed with name of grammatical relation



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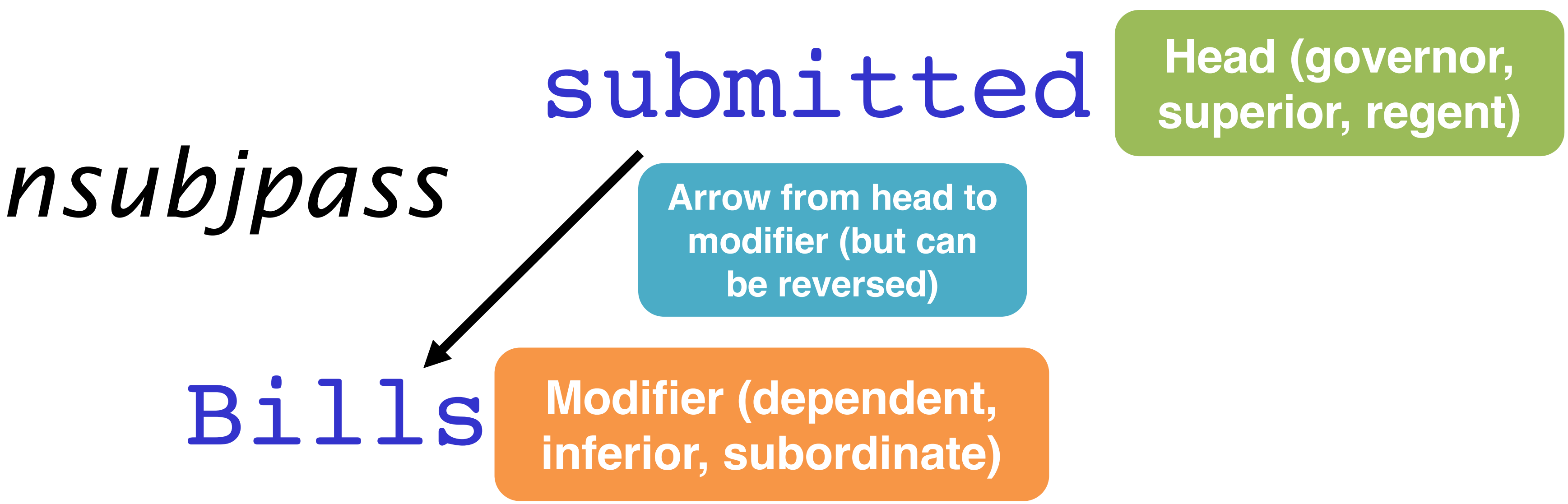

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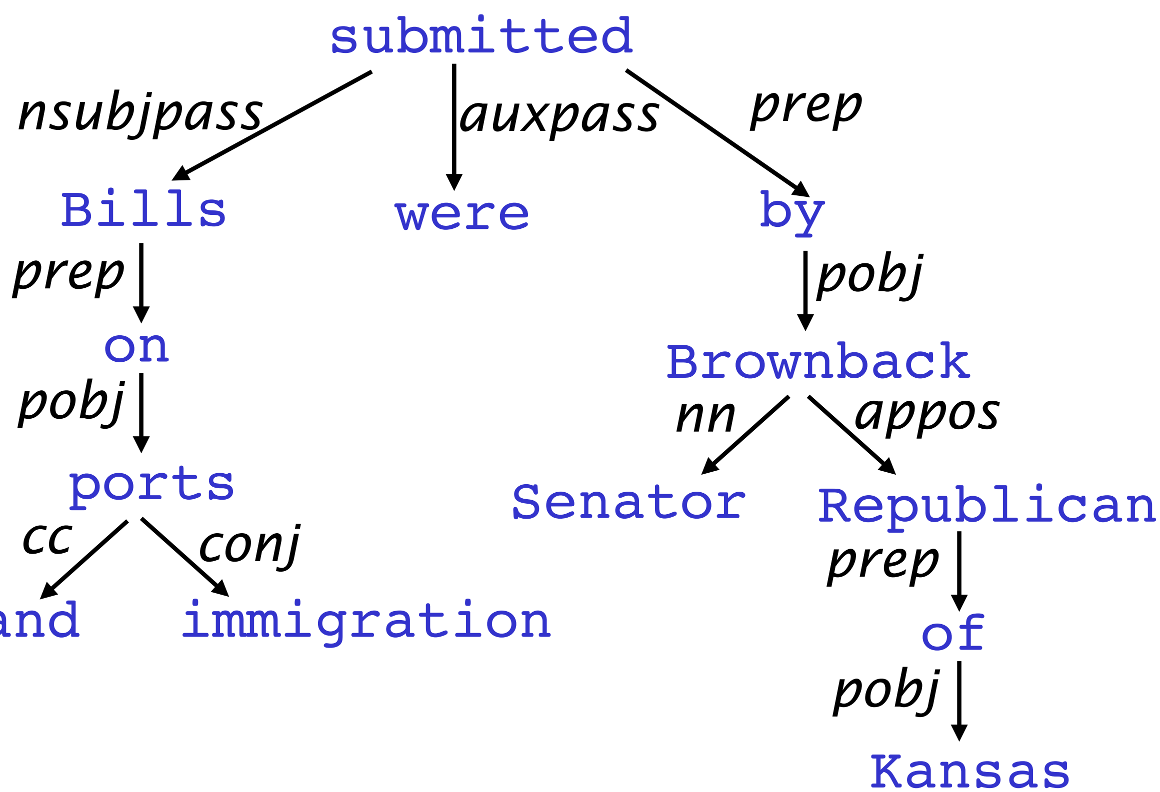
Dependencies form a tree



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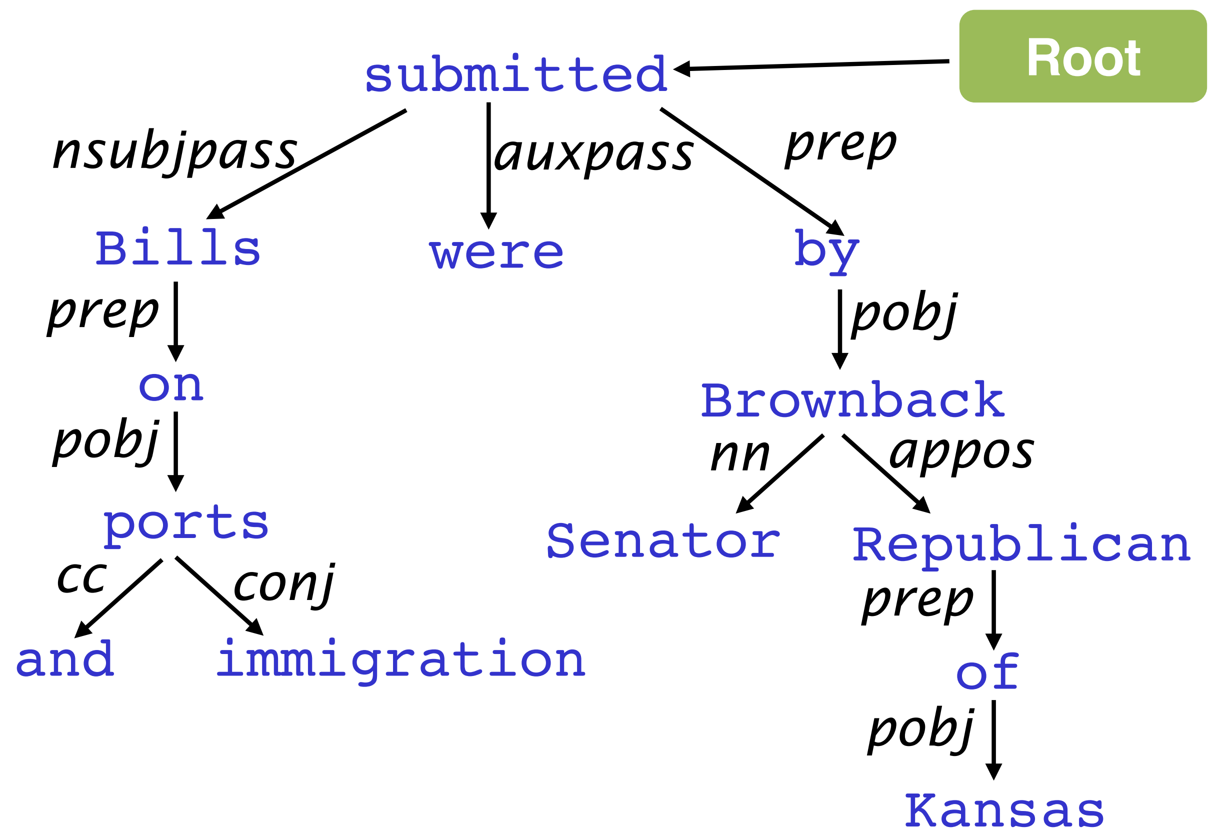


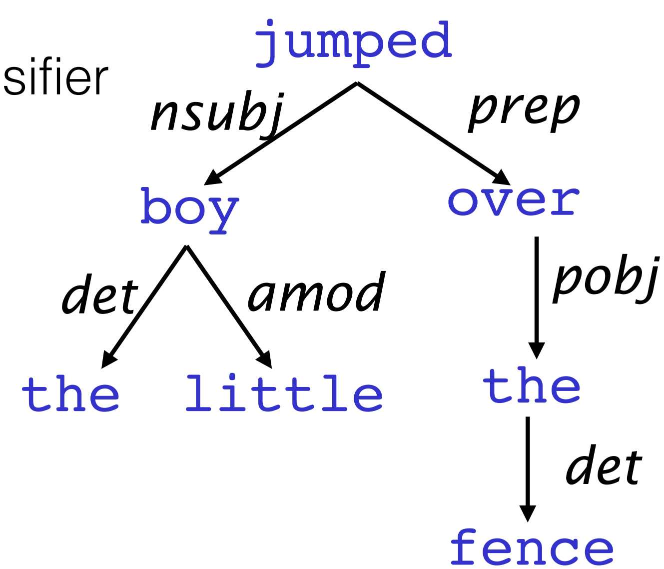
Let’s Parse

John saw Mary

He said that the boy who was wearing the blue shirt with the white pockets has left the building

Methods for Dependency Parsing

- Dynamic programming (CKY-style)
  - Similar to lexicalized PCFG: $O(n^5)$
  - Eisner (1996): $O(n^3)$
- Graph algorithms
  - McDonald et al. (2005): score edges independently using classifier and use maximum spanning tree
- Constraint satisfaction
  - Start with all edges, eliminate based on hard constraints
- "Deterministic parsing"
  - Left-to-right, each choice is done with a classifier



Making Decisions

What are the sources of information for dependency parsing?

1. Bilexical affinities
   – [issues → the] is plausible
2. Dependency distance
   – mostly with nearby words
3. Intervening material
   – Dependencies rarely span intervening verbs or punctuation
4. Valency of heads
   – How many dependents on which side are usual for a head?

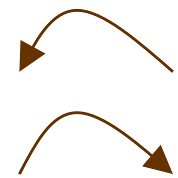
MaltParse (Nivre et al. 2008)

- Greedy transition-based parser
- Each decision: how to attach each word as we encounter it
  - If you are familiar: like shift-reduce parser
- Select each action with a classifier
- The parser has:
  - a stack σ, written with the top to the right
    - which starts with the ROOT symbol
  - a buffer β, written with the top to the left
    - which starts with the input sentence
  - a set of dependency arcs A
    - which starts off empty
  - a set of actions

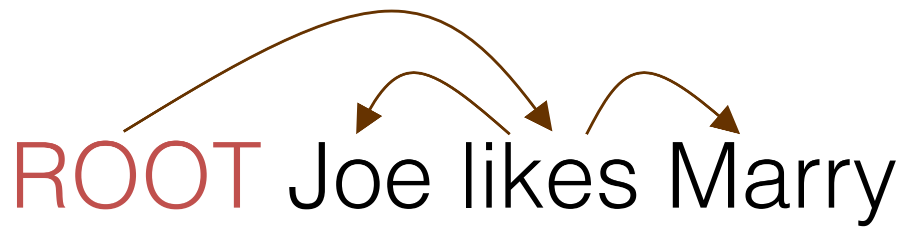
Arc-standard Dependency Parsing

Start: σ = [ROOT], $\beta = w_1, \ldots, w_n$, $A = \varnothing$

- Shift $\quad \sigma, w_i|\beta, A \rightarrow \sigma|w_i, \beta, A$
- Left-Arc$_r$ $\quad \sigma|w_i, w_j|\beta, A \rightarrow \sigma, w_j|\beta, A \cup \{r(w_j,w_i)\}$
- Right-Arc$_r$ $\quad \sigma|w_i, w_j|\beta, A \rightarrow \sigma, w_i|\beta, A \cup \{r(w_i,w_j)\}$



Finish: $\beta = \varnothing$



Arc-standard Dependency Parsing

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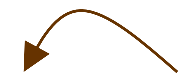
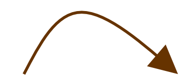
- Left-Arc$_r$ $\quad \sigma|w_i,\ w_j|\beta,\ A \ \rightarrow\ \sigma,\ w_j|\beta,\ A \cup \{r(w_j,w_i)\}$ 
- Right-Arc$_r$ $\quad \sigma|w_i,\ w_j|\beta,\ A \ \rightarrow\ \sigma,\ w_i|\beta,\ A \cup \{r(w_i,w_j)\}$ 

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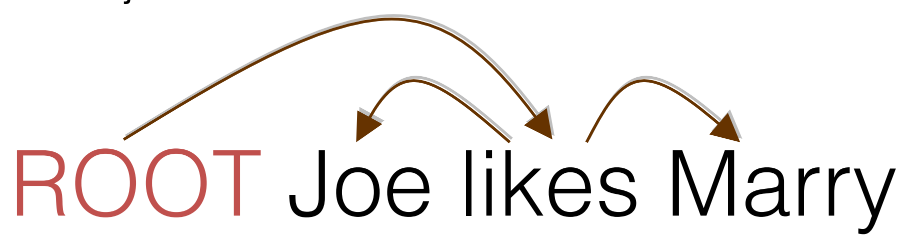

	[ROOT]	[Joe, likes, marry]	$\varnothing$
Shift	[ROOT, Joe]	[likes, marry]	$\varnothing$
Left-Arc	[ROOT]	[likes, marry]	{(likes,Joe)} = A_1
Shift	[ROOT, likes]	[marry]	A_1
Right-Arc	[ROOT]	[likes]	$A_1 \cup$ {(likes,Marry)} = A_2
Right-Arc	[]	[ROOT]	$A_2 \cup$ {(ROOT, likes)} = A_3
Shift	[ROOT]	[]	A_3

Arc-standard Dependency Parsing

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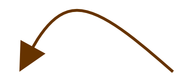
- Left-Arc$_r$ $\sigma|w_i, w_j|\beta, A \rightarrow \sigma, w_j|\beta, A \cup \{r(w_j,w_i)\}$ 
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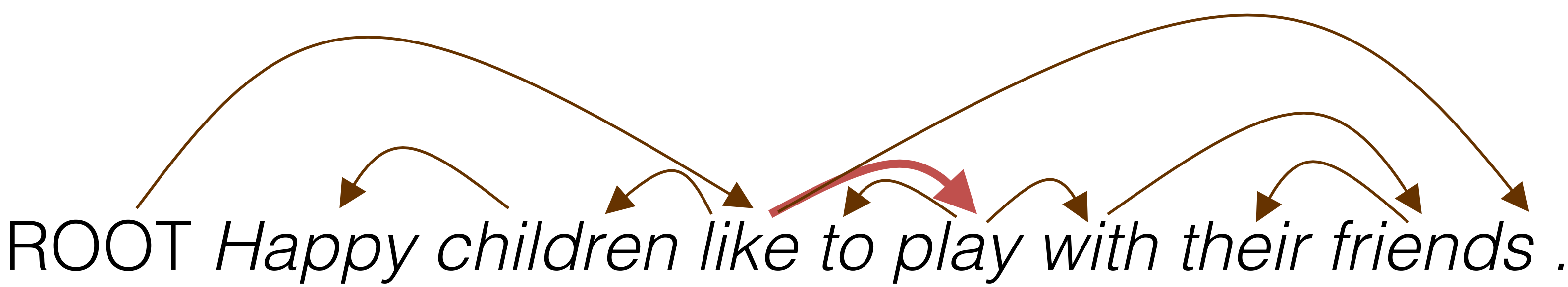
Finish: $\beta = \varnothing$



Arc-eager Dependency Parsing

Start: $\sigma = [\text{ROOT}], \beta = w_1, \ldots, w_n, A = \varnothing$

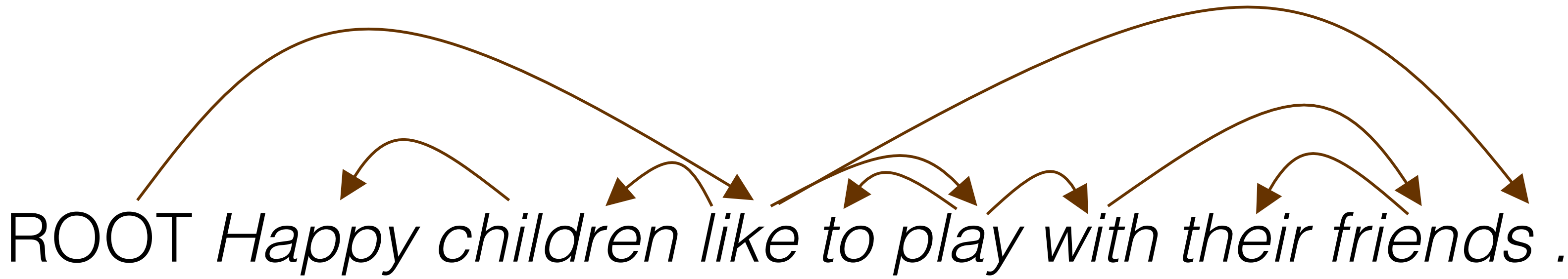
- Left-Arc$_r$ $\quad \sigma|w_i, w_j|\beta, A \rightarrow \sigma, w_j|\beta, A \cup \{r(w_j, w_i)\}$
  - Precondition: $r'(w_k, w_i) \notin A$, $w_i \neq \text{ROOT}$
- Right-Arc$_r$ $\quad \sigma|w_i, w_j|\beta, A \rightarrow \sigma|w_i|w_j, \beta, A \cup \{r(w_i, w_j)\}$
- Reduce $\quad \sigma|w_i, \beta, A \rightarrow \sigma, \beta, A$
  - Precondition: $r'(w_k, w_i) \in A$
- Shift $\quad \sigma, w_i|\beta, A \rightarrow \sigma|w_i, \beta, A$

Finish: $\beta = \varnothing$

This is the common "arc-eager" variant: a head can immediately take a right dependent, before *its* dependents are found

Arc-eager

1. Left-Arc$_r$ $\sigma|w_i,\ w_j|\beta,\ A \rightarrow \sigma,\ w_j|\beta,\ A \cup \{r(w_j,w_i)\}$
   Precondition: $r'(w_k,\ w_i) \notin A,\ w_i \neq$ ROOT
2. Right-Arc$_r$ $\sigma|wi,\ w_j|\beta,\ A \rightarrow \sigma|w_i|w_j,\ \beta,\ A \cup \{r(w_i,w_j)\}$
3. Reduce $\sigma|w_i,\ \beta,\ A \rightarrow \sigma,\ \beta,\ A$
   Precondition: $r'(w_k,\ w_i) \in A$
4. Shift $\sigma,\ w_i|\beta,\ A \rightarrow \sigma|w_i,\ \beta,\ A$



Arc-eager

1. Left-Arc$_r$ $\sigma|w_i,\ w_j|\beta,\ A \rightarrow \sigma,\ w_j|\beta,\ A \cup \{r(w_j, w_i)\}$
   Precondition: $r'(w_k, w_i) \notin A,\ w_i \neq ROOT$
2. Right-Arc$_r$ $\sigma|wi,\ w_j|\beta,\ A \rightarrow \sigma|w_i|w_j,\ \beta,\ A \cup \{r(w_i, w_j)\}$
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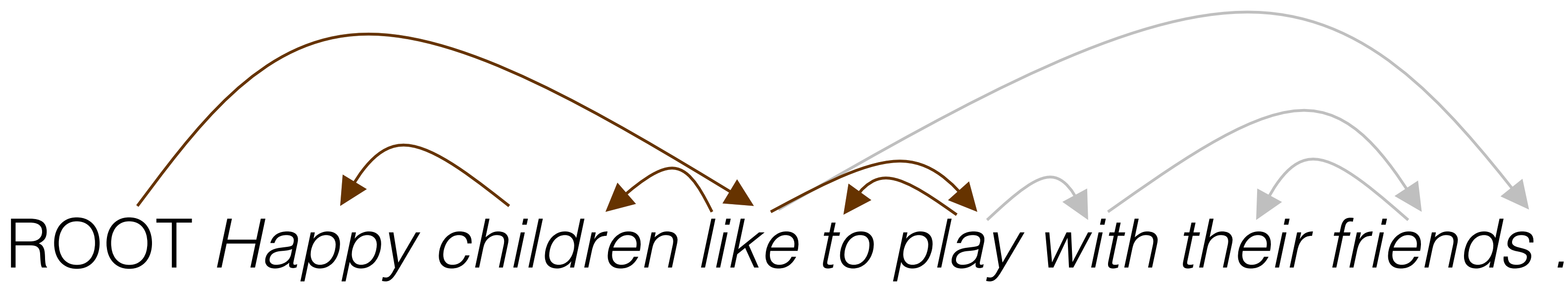

	[ROOT]	[Happy, children, …]	∅
Shift	[ROOT, Happy]	[children, like, …]	∅
LA$_{amod}$	[ROOT]	[children, like, …]	{amod(children, happy)} = A_1
Shift	[ROOT, children]	[like, to, …]	A_1
LA$_{nsubj}$	[ROOT]	[like, to, …]	$A_1 \cup$ {nsubj(like, children)} = A_2
RA$_{root}$	[ROOT, like]	[to, play, …]	$A_2 \cup${root(ROOT, like) = A_3
Shift	[ROOT, like, to]	[play, with, …]	A_3
LA$_{aux}$	[ROOT, like]	[play, with, …]	$A_3 \cup${aux(play, to) = A_4
RA$_{xcomp}$	[ROOT, like, play]	[with their, …]	$A_4 \cup${xcomp(like, play) = A_5

Arg-eager

1. Left-Arc$_r$ $\sigma|w_i,\ w_j|\beta,\ A \rightarrow \sigma,\ w_j|\beta,\ A \cup \{r(w_j, w_i)\}$
   Precondition: $r'(w_k, w_i) \notin A,\ w_i \neq \text{ROOT}$
2. Right-Arc$_r$ $\sigma|wi,\ w_j|\beta,\ A \rightarrow \sigma|w_i|w_j,\ \beta,\ A \cup \{r(w_i, w_j)\}$
3. Reduce $\sigma|w_i,\ \beta,\ A \rightarrow \sigma,\ \beta,\ A$
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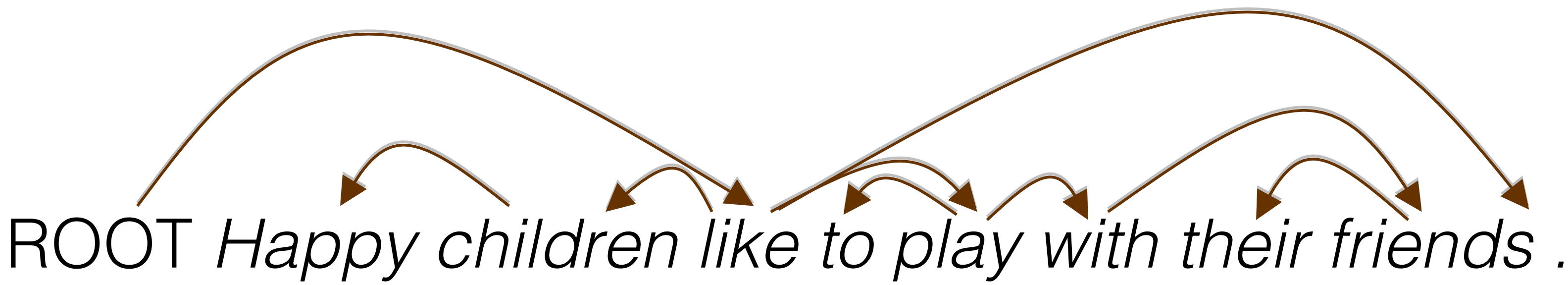
4. Shift $\sigma,\ w_i|\beta,\ A \rightarrow \sigma|w_i,\ \beta,\ A$



RA$_{xcomp}$	[ROOT, like, play]	[with their, …]	$A_4 \cup \{$xcomp(like, play) = A_5
RA$_{prep}$	[ROOT, like, play, with]	[their, friends, …]	$A_5 \cup \{$prep(play, with) = A_6
Shift	[ROOT, like, play, with, their]	[friends, .]	A_6
LA$_{poss}$	[ROOT, like, play, with]	[friends, .]	$A_6 \cup \{$poss(friends, their) = A_7
RA$_{pobj}$	[ROOT, like, play, with, friends]	[.]	$A_7 \cup \{$pobj(with, friends) = A_8
Reduce	[ROOT, like, play, with]	[.]	A_8
Reduce	[ROOT, like, play]	[.]	A_8
Reduce	[ROOT, like]	[.]	A_8
RA$_{punc}$	[ROOT, like, .]	[]	$A_8 \cup \{$punc(like, .) = A_9

You terminate as soon as the buffer is empty. Dependencies = A_9

MaltParser (Nivre et al. 2008)

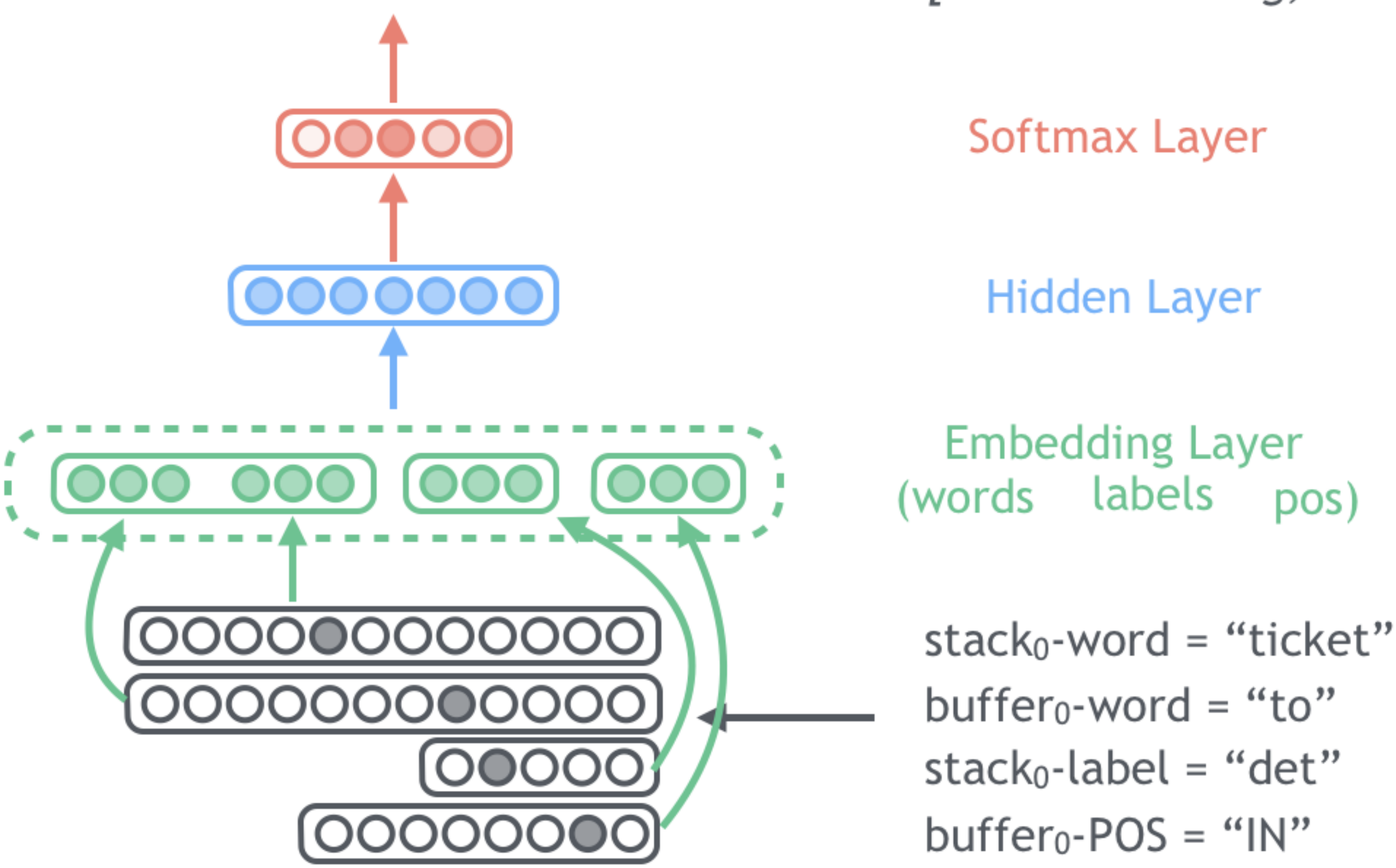
- Selecting the next action:
  - Discriminative classifier (SVM, MaxEnt, etc.)
  - Untyped choices: 4
  - Typed choices: |R| * 2 + 2
- Features: POS tags, word in stack, word in buffer, etc.
- Greedy → no search
  - But can easily do beam search
- Close to state of the art
- Linear time parser → **very fast!**

Parsing with Neural Networks Chen and Manning (2014)

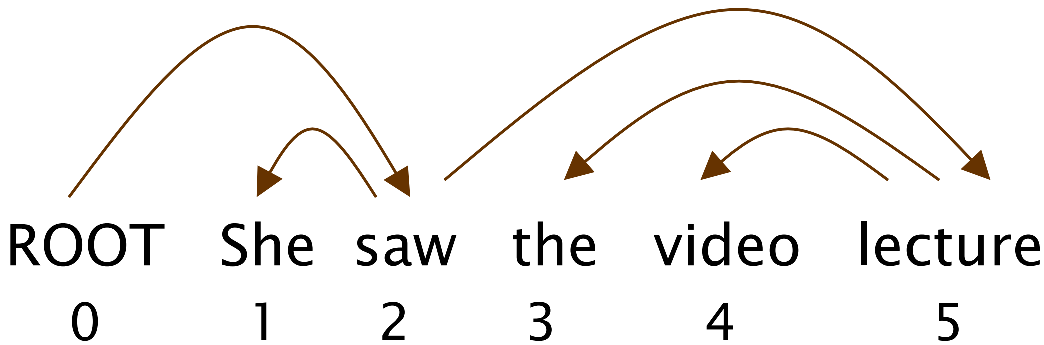
- Arc-standard Transitions
  - Shift
  - Left-Arc$_r$
  - Right-Arc$_r$
- Selecting the next actions:
  - Untyped choices: 3
  - Typed choices: |R| * 2 + 1
  - Neural network classifier
- With a few training and model improvements gives SOTA results

Parsing with Neural Networks
Chen and Manning (2014)

[Chen & Manning, 2014]



Evaluation



$$Acc = \frac{\#\ \text{correct deps}}{\#\ \text{of deps}}$$

UAS = 4 / 5 = 80%

LAS = 2 / 5 = 40%

Gold

1	2	She	nsubj
2	0	saw	root
3	5	the	det
4	5	video	nn
5	2	lecture	dobj

Parsed

1	2	She	nsubj
2	0	saw	root
3	4	the	det
4	5	video	nsubj
5	2	lecture	ccomp

Projectivity

- Dependencies from CFG trees with head rules must be projective
  - Crossing arcs are not allowed
- But: theory allows to account for displaced constituents → non-projective structures

Projectivity

- Arc-eager transition system:
  - Can’t handle non-projectivity
- Possible directions:
  - Give up!
  - Post-processing
  - Add new transition types
  - Switch to a different algorithm
    - Graph-based parsers (e.g., MSTParser)