# L95: Natural Language Syntax and Parsing
# 6) N-best Parsing

Paula Buttery

Dept of Computer Science & Technology, University of Cambridge

# Reminder...

We have looked at the following algorithms:

- CKY
- Shift-Reduce
- A*

But so far we have discussed finding the best parse... **what if we want to find the n-best parses?**

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | | | |
| 1 | | | |
| 2 | | | |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
&\quad VP \rightarrow VM\ VV\ 0.9 \\
&\quad VP \rightarrow VV\ NP\ 0.1 \\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
&\quad VM \rightarrow can\ 1.0 \\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | | |
| 1 | | | |
| 2 | | | |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
&\quad VP \rightarrow VM\ VV\ 0.9 \\
&\quad VP \rightarrow VV\ NP\ 0.1 \\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
&\quad VM \rightarrow can\ 1.0 \\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | | |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | |
| 2 | | | |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
& \quad VP \rightarrow VM\ VV\ 0.9 \\
& \quad VP \rightarrow VV\ NP\ 0.1 \\
& \quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
& \quad VM \rightarrow can\ 1.0 \\
& \quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | |
| 2 | | | |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
&\quad VP \rightarrow VM\ VV\ 0.9 \\
&\quad VP \rightarrow VV\ NP\ 0.1 \\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
&\quad VM \rightarrow can\ 1.0 \\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{array}{lcl}
\mathcal{N} & = & \{S, NP, VP, VV, VM\} \\
\Sigma & = & \{can, fish, they\} \\
S & = & S \\
\mathcal{P} & = & \{S \rightarrow NP\ VP\ 1.0 \\
 & & VP \rightarrow VM\ VV\ 0.9 \\
 & & VP \rightarrow VV\ NP\ 0.1 \\
 & & VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
 & & VM \rightarrow can\ 1.0 \\
 & & NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{array}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | $VP^{0.2*0.5*0.1=0.01}_{1\rightarrow([1,2]_{VV},[2,3]_{NP})}$ $VP^{1.0*0.8*0.9=0.72}_{2\rightarrow([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
& \quad VP \rightarrow VM\ VV\ 0.9 \\
& \quad VP \rightarrow VV\ NP\ 0.1 \\
& \quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
& \quad VM \rightarrow can\ 1.0 \\
& \quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | $VP^{1.0*0.8*0.9=0.72}_{([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
&\quad VP \rightarrow VM\ VV\ 0.9 \\
&\quad VP \rightarrow VV\ NP\ 0.1 \\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
&\quad VM \rightarrow can\ 1.0 \\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# Recall that full CKY is **optimal** and **exhaustive**

- For the best parse we keep the most probable partial derivation for every non-terminal at each cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | $S^{0.5*1.0*0.8*0.9*1.0=0.36}_{([0,1]_{NP},[1,3]_{VP})}$ |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | $VP^{1.0*0.8*0.9=0.72}_{([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\}\\
\Sigma &= \{can, fish, they\}\\
S &= S\\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0\\
&\quad VP \rightarrow VM\ VV\ 0.9\\
&\quad VP \rightarrow VV\ NP\ 0.1\\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8\\
&\quad VM \rightarrow can\ 1.0\\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

# For n-best in CKY **discard** based on **beam**

An example beam strategy:

- Discard partial derivations based on a score rather than their non-terminal type
- Discard all partial derivations whose score is less than $\alpha$ times the maximum score for that cell
- Typical value for $\alpha$ is 0.0001
- Strategy can cause some loss of accuracy

# For n-best in CKY **discard** based on **beam**

- Can discard partial derivations when probability is $\leq \alpha$ times the maximum score for that cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | $S^{0.5*0.2*0.5*0.1*1.0=0.005}_{([0,1]_{NP},[1,3]_{VP})}$ $S^{0.5*1.0*0.8*0.9*1.0=0.36}_{([0,1]_{NP},[1,3]_{VP})}$ |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | $VP^{0.2*0.5*0.1=0.01}_{1\rightarrow([1,2]_{VV},[2,3]_{NP})}$ $VP^{1.0*0.8*0.9=0.72}_{2\rightarrow([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$\mathcal{N} = \{S, NP, VP, VV, VM\}$$
$$\Sigma = \{can, fish, they\}$$
$$S = S$$
$$\mathcal{P} = \{S \rightarrow NP\ VP\ 1.0$$
$$VP \rightarrow VM\ VV\ 0.9$$
$$VP \rightarrow VV\ NP\ 0.1$$
$$VV \rightarrow can\ 0.2 \mid fish\ 0.8$$
$$VM \rightarrow can\ 1.0$$
$$NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}$$

$\alpha = 0.0001$

# For n-best in CKY **discard** based on **beam**

- Can discard partial derivations when probability is $\leq \alpha$ times the maximum score for that cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | $S^{0.5*1.0*0.8*0.9*1.0=0.36}_{([0,1]_{NP},[1,3]_{VP})}$ |
| 1 | | $VV^{0.2}_{(can)}$ $VM^{1.0}_{(can)}$ | $VP^{0.2*0.5*0.1=0.01}_{1\rightarrow([1,2]_{VV},[2,3]_{NP})}$ $VP^{1.0*0.8*0.9=0.72}_{2\rightarrow([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
& \quad VP \rightarrow VM\ VV\ 0.9 \\
& \quad VP \rightarrow VV\ NP\ 0.1 \\
& \quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
& \quad VM \rightarrow can\ 1.0 \\
& \quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

$\alpha = 0.05$

# For n-best in CKY **discard** based on **beam**

- Can discard partial derivations when probability is $\leq \alpha$ times the maximum score for that cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | $S^{0.5*1.0*0.8*0.9*1.0=0.36}_{([0,1]_{NP},[1,3]_{VP})}$ |
| 1 | | $VM^{1.0}_{(can)}$ | $VP^{1.0*0.8*0.9=0.72}_{([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
&\quad VP \rightarrow VM\ VV\ 0.9 \\
&\quad VP \rightarrow VV\ NP\ 0.1 \\
&\quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
&\quad VM \rightarrow can\ 1.0 \\
&\quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

$\alpha = 0.2$

# For n-best in CKY **discard** based on **beam**

- Can discard partial derivations when probability is $\leq \alpha$ times the maximum score for that cell

| | 1 | 2 | 3 |
|---|---|---|---|
| 0 | $NP^{0.5}_{(they)}$ | . | $S^{0.5*1.0*0.8*0.9*1.0=0.36}_{([0,1]_{NP},[1,3]_{VP})}$ |
| 1 | | $VM^{1.0}_{(can)}$ | $VP^{1.0*0.8*0.9=0.72}_{([1,2]_{VM},[2,3]_{VV})}$ |
| 2 | | | $VV^{0.8}_{(fish)}$ $NP^{0.5}_{(fish)}$ |
| | *they* | *can* | *fish* |

$$
\begin{aligned}
\mathcal{N} &= \{S, NP, VP, VV, VM\} \\
\Sigma &= \{can, fish, they\} \\
S &= S \\
\mathcal{P} &= \{S \rightarrow NP\ VP\ 1.0 \\
& \quad VP \rightarrow VM\ VV\ 0.9 \\
& \quad VP \rightarrow VV\ NP\ 0.1 \\
& \quad VV \rightarrow can\ 0.2 \mid fish\ 0.8 \\
& \quad VM \rightarrow can\ 1.0 \\
& \quad NP \rightarrow they\ 0.5 \mid fish\ 0.5\ \}
\end{aligned}
$$

Question: in what scenario is the best-parse lost when using a beam?

# For n-best in CKY **discard** based on **beam**

- Can apply beam dynamically at each cell
- To find n-best, select $n$ most probable $S$ parses from top right cell

- Alternatively, exploit fact that **2nd best parse will differ from best parse by just 1 of its parsing decisions**
- for nth-best parse all but one of its decisions will be involved in one of the 2nd through the (n -1)th-best parses.
- So first find the best parse, then find the second-best parse, then the third-best, and so on...
- Practically, at each cell keep an **ordered list of n-best partial derivations, combine with n-best lists for adjacent partial derivations until you have exactly n** to store in the new cell

# **Coarse-to-fine** n-best strategies, Charniak

Charniak parser adopts a **coarse-to-fine** parsing strategy:

1. produce a parse forest using simple version of the grammar
   i.e. find possible parses using coarse-grained non-terminals, e.g. $VP$
2. refine most promising of coarse-grained parses using complex grammar
   i.e with feature-based, lexicalised non-terminals, e.g. $VP[buys/VBZ]$

# **Coarse-to-fine** n-best strategies, Charniak

- **Coarse-grained step** can be **efficiently parsed** using e.g. CKY
- But the simple grammar **ignores contextual features** so best parse might not be accurate
- **Output a pruned packed parse** forest for the parses generated by the simple grammar (using a beam threshold)
- **Evaluate remaining parses with complex grammar** (i.e. each coarse-grained state is split into several fine-grained states)
- To create **n-best parses** fine-grained step keeps the n-best possibilities at each cell

# **Discriminative reranking** is used to recover best parse

- Use parser to produce n-best list of parses
- Define an **initial ranking** of these parses based on original parse score
- Use **second model** (e.g. max-ent) to **improve the initial ranking** (using additional features)

- Collins re-ranking: `http://www.aclweb.org/anthology/J05-1003`
- Charniak re-ranking: `https://dl.acm.org/citation.cfm?id=1219862`
- Provides small improvements PARSEVAL metrics on Penn Treebank

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | | |

b a c d f e

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

b a c d f e

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | | |

b a c d f e

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

b a c d f e

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | | |

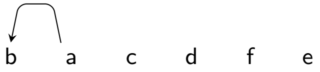
b a c d f e

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |

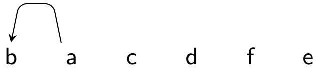


# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

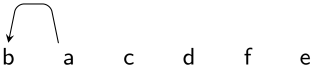
| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | | |



# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

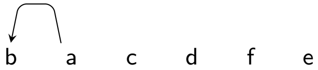



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack



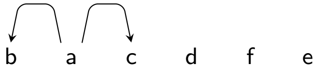

| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

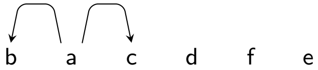
| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |



# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

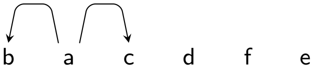



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

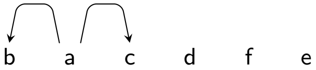



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

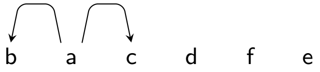



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

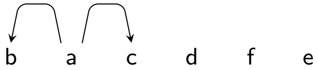



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

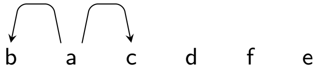



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

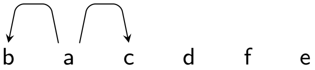
- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack




| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

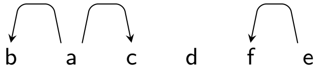



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

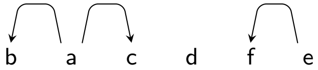



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

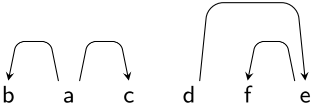



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

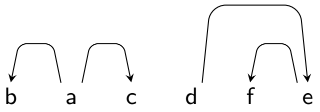



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | RIGHT-ARC | $d \rightarrow e$ |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

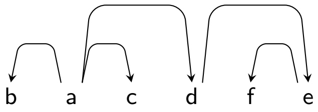



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | RIGHT-ARC | $d \rightarrow e$ |
| ad | | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

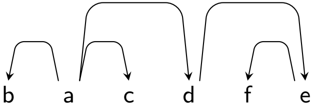



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | RIGHT-ARC | $d \rightarrow e$ |
| ad | | RIGHT-ARC | $a \rightarrow d$ |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack

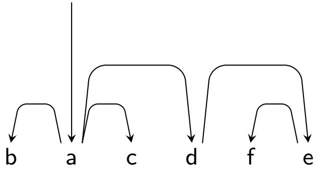



| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | RIGHT-ARC | $d \rightarrow e$ |
| ad | | RIGHT-ARC | $a \rightarrow d$ |
| a | | | |

# Reminder: the shift-reduce dependency parser

Example of shift-reduce parse for the string *bacdfe*

- Actions selected from a classifier based on the features of the configuration of items on the buffer and stack




| STACK | BUFFER | ACTION | RECORD |
|---|---|---|---|
| | bacdfe | SHIFT | |
| b | acdfe | SHIFT | |
| ba | cdfe | LEFT-ARC | $a \rightarrow b$ |
| a | cdfe | SHIFT | |
| ac | dfe | RIGHT-ARC | $a \rightarrow c$ |
| a | dfe | SHIFT | |
| ad | fe | SHIFT | |
| adf | e | SHIFT | |
| adfe | | LEFT-ARC | $e \rightarrow f$ |
| ade | | RIGHT-ARC | $d \rightarrow e$ |
| ad | | RIGHT-ARC | $a \rightarrow d$ |
| a | | TERMINATE | $root \rightarrow a$ |

# The shift-reduce parser is **greedy**

- Shift-reduce parser makes a single pass through the sentence making greedy decisions
- Makes the algorithm very efficient, $O(n)$ for sentence length $n$
- Stuck with early decisions no matter how much later evidence contradicts them

# Retrieve n-best shift-reduce parses using **agenda**

- To get the n-best parses we need to systematically explore and **score alternative action sequences**
- This gives rise to an exponential number of of potential sequences
- Solution is to score and filter possible sequences to within a **fixed beam size**

- Use an **agenda** to store possible buffer/stack configurations along with a score of the actions that let to that configuration
- **Apply all actions** to top item on the agenda and then score the resulting configurations
- Add new configurations to the agenda until the beam is full and then **replace lowest scoring items** with higher scoring ones
- Continue as long as non-terminating configurations exist on the agenda (guarantees best parse will be found)

# Retrieve n-best shift-reduce parses using **agenda**

- To get the n-best parses we need to systematically explore and **score alternative action sequences**
- This gives rise to an exponential number of of potential sequences
- Solution is to score and filter possible sequences to within a **fixed beam size**

- Use an **agenda** to store possible buffer/stack configurations along with a score of the actions that let to that configuration
- **Apply all actions** to top item on the agenda and then score the resulting configurations
- Add new configurations to the agenda until the beam is full and then **replace lowest scoring items** with higher scoring ones
- Continue as long as non-terminating configurations exist on the agenda (guarantees best parse will be found)

# Score reflects **action-sequences** rather than actions

- In the **greedy algorithm** the classifier acted as an **oracle** — **actions are scored**
- With the **beam search** we want to score action sequences — **action sequences are scored**

- Notice that **beam** here is constrained by the size of the agenda

# N-best dependency parse algorithm

```
function DependencyBeamParse(words, width) returns dependency tree

  state ← {[root], [words], [], 0.0}     ;initial configuration
  agenda ← ⟨state⟩;        initial agenda

  while agenda contains non-final states
    newagenda ← ⟨⟩
    for each state ∈ agenda do
       for all {t | t ∈ ValidOperators(state)} do
         child ← Apply(t, state)
         newagenda ← AddToBeam(child, newagenda, width)
    agenda ← newagenda
  return BestOf(agenda)

function AddToBeam(state, agenda, width) returns updated agenda

  if Length(agenda) < width then
     agenda ← Insert(state, agenda)
  else if Score(state) > Score(WorstOf(agenda))
     agenda ← Remove(WorstOf(agenda))
     agenda ← Insert(state, agenda)
  return agenda
```

Psuedo code from Jurafsky and Martin version 3 n-best shift-reduce parser example in class

# Next time

- Lexicalised PCFGs
- More on features and training...