

EDAN20

Language Technology

<http://cs.lth.se/edan20/>
Chapter 13: Dependency Parsing

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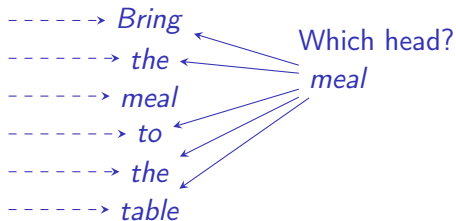
September 27, 2018



Parsing Dependencies

Generate all the pairs:

Which sentence root?



Talbanken: An Annotated Corpus of Swedish

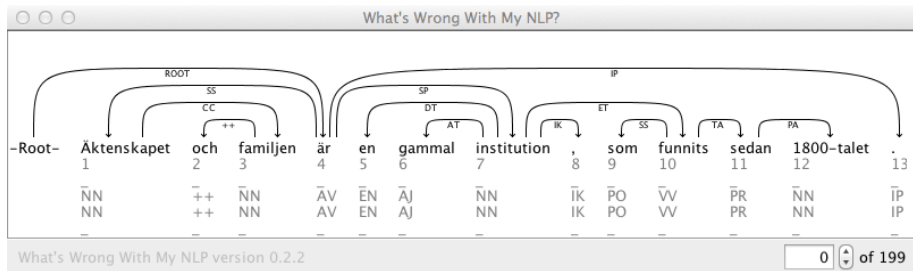
| | | | | | | | |
|----|-------------|---|----|----|---|----|------|
| 1 | Äktenskapet | — | NN | NN | — | 4 | SS |
| 2 | och | — | ++ | ++ | — | 3 | ++ |
| 3 | familjen | — | NN | NN | — | 1 | CC |
| 4 | är | — | AV | AV | — | 0 | ROOT |
| 5 | en | — | EN | EN | — | 7 | DT |
| 6 | gammal | — | AJ | AJ | — | 7 | AT |
| 7 | institution | — | NN | NN | — | 4 | SP |
| 8 | , | — | IK | IK | — | 7 | IK |
| 9 | som | — | PO | PO | — | 10 | SS |
| 10 | funnits | — | VV | VV | — | 7 | ET |
| 11 | sedan | — | PR | PR | — | 10 | TA |
| 12 | 1800-talet | — | NN | NN | — | 11 | PA |
| 13 | . | — | IP | IP | — | 4 | IP |



Visualizing the Graph

Using *What's Wrong With My NLP*

(<https://code.google.com/p/whatswrong/>):



Parser Input

The words and their parts of speech obtained from an earlier step.

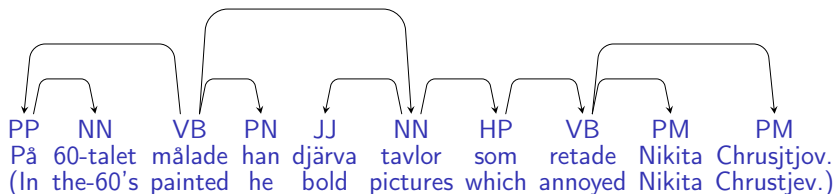
| | | | | | |
|----|-------------|---|----|----|---|
| 1 | Äktenskapet | — | NN | NN | — |
| 2 | och | — | ++ | ++ | — |
| 3 | familjen | — | NN | NN | — |
| 4 | är | — | AV | AV | — |
| 5 | en | — | EN | EN | — |
| 6 | gammal | — | AJ | AJ | — |
| 7 | institution | — | NN | NN | — |
| 8 | , | — | IK | IK | — |
| 9 | som | — | PO | PO | — |
| 10 | funnits | — | VV | VV | — |
| 11 | sedan | — | PR | PR | — |
| 12 | 1800-talet | — | NN | NN | — |
| 13 | . | — | IP | IP | — |



Nivre's Parser

Joakim Nivre designed an efficient dependency parser extending the shift-reduce algorithm.

He started with Swedish and has reported the best results for this language and many others.



His team obtained the best results in the CoNLL 2007 shared task on dependency parsing.



The Parser (Arc-Eager)

The first step is a POS tagging

The parser applies a variation/extension of the shift-reduce algorithm since dependency grammars have no nonterminal symbols

The transitions are:

1. **Shift**, pushes the input token onto the stack
2. **Right arc**, adds an arc from the token on top of the stack to the next input token and pushes the input token onto the stack.
3. **Reduce**, pops the token on the top of the stack
4. **Left arc**, adds an arc from the next input token to the token on the top of the stack and pops it.



Transitions' Definition

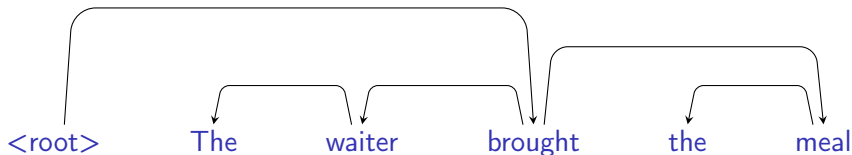
| Actions | Parser states | Conditions |
|----------------|--|------------------------------|
| Initialization | $\langle nil, W, \emptyset \rangle$ | |
| Termination | $\langle S, [], A \rangle$ | |
| Shift | $\langle S, [n I], A \rangle \rightarrow \langle [S n], I, A \rangle$ | |
| Reduce | $\langle [S n], I, A \rangle \rightarrow \langle S, I, A \rangle$ | $\exists n'(n', n) \in A$ |
| Left-arc | $\langle [S n], [n' I], A \rangle \rightarrow \langle S, [n' I], A \cup \{(n \leftarrow n')\} \rangle$ | $\nexists n''(n'', n) \in A$ |
| Right-arc | $\langle [S n], [n' I], A \rangle \rightarrow \langle [S n, n'], I, A \cup \{(n \rightarrow n')\} \rangle$ | |

- 1 The first condition $\exists n'(n', n) \in A$, where n' is the head and n , the dependent, is to ensure that the graph is connected.
- 2 The second condition $\nexists n''(n'', n) \in A$, where n'' is the head and n , the dependent, is to enforce a unique head.



Nivre's Parser in Action

Input W = The waiter brought the meal.
The graph is:



{the \leftarrow waiter, waiter \leftarrow brought, ROOT \rightarrow brought, the \leftarrow meal,
brought \rightarrow meal},

Let us apply the sequence:

[sh, sh, la, sh, la, ra, sh, la, ra]



Nivre's Parser in Action

[sh, sh, la, sh, la, ra, sh, la, ra]

| Trans. | Stack | Queue | Graph |
|--------|------------------|---|----------------------------------|
| start | \emptyset | [ROOT, the, waiter, brought, the, meal] | {} |
| sh | | | |
| | [ROOT] | [the, waiter, brought, the, meal] | {} |
| sh | | | |
| | [the ROOT] | [waiter, brought, the, meal] | {} |
| la | | | |
| | [ROOT] | [waiter, brought, the, meal] | {the ← waiter} |
| sh | | | |
| | [waiter ROOT] | [brought, the, meal] | {the ← waiter} |
| la | | | |
| | [ROOT] | [brought, the, meal] | {the ← waiter, waiter ← brought} |



Nivre's Parser in Action (II)

[sh, sh, la, sh, la, ra, sh, la, ra]

| Trans. | Stack | Queue | Graph |
|--------|---------------------------|-------------|---|
| ra | | | |
| | [brought ROOT] | [the, meal] | {the \leftarrow waiter, waiter \leftarrow brought, ROOT \rightarrow brought} |
| sh | | | |
| | [the brought ROOT] | [meal] | {the \leftarrow waiter, waiter \leftarrow brought, ROOT \rightarrow brought} |
| la | | | |
| | [brought ROOT] | [meal] | {the \leftarrow waiter, waiter \leftarrow brought, ROOT \rightarrow brought, the \leftarrow meal} |
| ra | | | |
| end | [meal brought ROOT] | [] | {the \leftarrow waiter, waiter \leftarrow brought, ROOT \rightarrow brought, the \leftarrow meal, brought \rightarrow meal} |



Nivre's Parser in Python: Shift and Reduce

We use a stack, a queue, and a partial graph that contains all the arcs.

```
def shift(stack, queue, graph):  
    stack = [queue[0]] + stack  
    queue = queue[1:]  
    return stack, queue, graph  
  
def reduce(stack, queue, graph):  
    return stack[1:], queue, graph
```



Nivre's Parser in Python: Left-Arc

The partial graph is a dictionary of dictionaries with the heads and the functions (deprels): `graph['heads']` and `graph['deprels']`

The `deprel` argument is either to assign a function or to read it from the manually-annotated corpus.

```
def left_arc(stack, queue, graph, deprel=False):  
    graph['heads'][stack[0]['id']] = queue[0]['id']  
    if deprel:  
        graph['deprels'][stack[0]['id']] = deprel  
    else:  
        graph['deprels'][stack[0]['id']] = stack[0]['deprel']  
    return reduce(stack, queue, graph)
```



Nivre's Parser in Prolog: Left-Arc

```
% shift_reduce(+Sentence, -Graph)
shift_reduce(Sentence, Graph) :-
    shift_reduce(Sentence, [], [], Graph).

% shift_reduce(+Words, +Stack, +CurGraph, -FinGraph)
shift_reduce([], _, Graph, Graph).
shift_reduce(Words, Stack, Graph, FinalGraph) :-
    left_arc(Words, Stack, NewStack, Graph, NewGraph),
    write('left arc'), nl,
    shift_reduce(Words, NewStack, NewGraph, FinalGraph).
```



Nivre's Parser in Prolog: Left-Arc (II)

```
% left_arc(+WordList, +Stack, -NewStack, +Graph, -NewGraph)
```

```
left_arc([w(First, PosF) | _], [w(Top, PosT) | Stack],  
        Stack, Graph, [d(w(First, PosF),  
        w(Top, PosT), Function) | Graph]) :-  
    word(First, FirstPOS),  
    word(Top, TopPOS),  
    drule(FirstPOS, TopPOS, Function, left),  
    \+ member(d(_, w(Top, PosT), _), Graph).
```



Gold Standard Parsing

Nivre's parser uses a sequence of actions taken in the set $\{la, ra, re, sh\}$.

We have:

- A sequence of actions creates a dependency graph
- Given a projective dependency graph, we can find an action sequence creating this graph. This is gold standard parsing.

Let TOP be the top of the stack and $FIRST$, the first token of the input list, and A the dependency graph.

- 1 if $arc(TOP, FIRST) \in A$, then right-arc;
- 2 else if $arc(FIRST, TOP) \in A$, then left-arc;
- 3 else if $\exists k \in Stack, arc(FIRST, k) \in A$ or $arc(k, FIRST) \in A$, then reduce;
- 4 else shift.



Parsing a Sentence

When parsing an unknown sentence, we do not know the dependencies yet. The parser will use a “guide” to tell which transition to apply in the set $\{la, ra, re, sh\}$.

The parser will extract a context from its current state, for instance the part of speech of the top of the stack and the first in the queue, and will ask the guide.

D-rules are a simply way to implement this



Dependency Rules

D-rules are possible relations between a head and a dependent.
They involve part-of-speech, mostly, and words

- | | |
|-----------------------------------|-----------------------------------|
| 1. determiner \leftarrow noun. | 4. noun \leftarrow verb. |
| 2. adjective \leftarrow noun. | 5. preposition \leftarrow verb. |
| 3. preposition \leftarrow noun. | 6. verb \leftarrow root. |

$$\left[\begin{array}{l} \textit{category} : \textit{noun} \\ \textit{number} : N \\ \textit{person} : P \\ \textit{case} : \textit{nominative} \end{array} \right] \leftarrow \left[\begin{array}{l} \textit{category} : \textit{verb} \\ \textit{number} : N \\ \textit{person} : P \end{array} \right]$$



Parsing Dependency Rules in Prolog

```
%drule(Head, Dependent, Function).
```

```
drule(noun, determiner, determinative).
```

```
drule(noun, adjective, attribute).
```

```
drule(verb, noun, subject).
```

```
drule(verb, noun, object).
```

D-Rules may also include a direction, for instance a determiner is always to the left

```
%drule(Head, Dependent, Function, Direction).
```



Tracing Nivre's Parser in Python

| | | | | | | | | | |
|---|--------|---|----|----|---|---|------|---|---|
| 1 | Jag | — | PO | PO | — | 2 | SS | — | — |
| 2 | tycker | — | VV | VV | — | 0 | ROOT | — | — |
| 3 | det | — | PO | PO | — | 2 | OO | — | — |
| 4 | inte | — | AB | AB | — | 2 | NA | — | — |
| 5 | . | — | IP | IP | — | 2 | IP | — | — |

Transitions:

```
['sh', 'sh', 'la.SS', 'ra.ROOT', 'ra.OO', 're', 'ra.NA',
 're', 'ra.IP']
```

Parser state:

```
{'heads': {'4': '2', '5': '2', '3': '2', '2': '0', '1': '2',
 '0': '0'},
 'deprels': {'4': 'NA', '5': 'IP', '3': 'OO', '2': 'ROOT', '1':
 'SS', '0': 'ROOT'}}
```



Tracing Nivre's Parser (Prolog)

```
shift_reduce([w(the, 1), w(waiter, 2), w(brought, 3),  
w(the, 4), w(meal, 5)], G).
```

```
shift
```

```
left arc
```

```
shift
```

```
left arc
```

```
shift
```

```
shift
```

```
left arc
```

```
right arc
```

```
G = [d(w(brought, 3), w(meal, 5), object),  
d(w(meal, 5), w(the, 4), determinative),  
d(w(brought, 3), w(waiter, 2), subject),  
d(w(waiter, 2), w(the, 1), determinative)]
```



Using Features

D-rules consider a limited context: the part of speech of the top of the stack and the first in the queue

We can extend the context:

- Extracts more features (attributes), for instance two words in the stack, three words in the queue
- Use them as input to a four-class classifier and determine the next action



Training a Classifier

Gold standard parsing of a manually annotated corpus produces training data

| Stack | Queue | Stack | Queue | Trans. |
|--------------|--------------|--------------|--|--------|
| POS(T_0) | POS(Q_0) | POS(T_0) | POS(T_{-1}) POS(Q_0) POS(Q_{+1}) | |
| nil | ROOT | nil | nil ROOT DT | sh |
| ROOT | DT | ROOT | nil DT NN | sh |
| DT | NN | DT | ROOT NN VBD | la |
| ROOT | NN | ROOT | nil NN VBD | sh |
| NN | VBD | NN | ROOT VBD DT | la |
| ROOT | VBD | ROOT | nil VBD DT | ra |
| VBD | DT | VBD | ROOT DT NN | sh |
| DT | NN | DT | VBD NN nil | la |
| VBD | NN | VBD | ROOT NN nil | ra |

Using Talbanken and CoNLL 2006 data, you can train decision trees and implement a parser.



Feature Vectors

You extract one feature (attribute) vector for each parsing action.

The most elementary feature vector consists of two parameters: POS_TOP, POS_FIRST

Nivre et al. (2006) used from 16 to 30 parameters and support vector machines.

As machine-learning algorithm, you can use decision trees, perceptron, logistic regression, or support vector machines.



Finding Dependencies using Constraints

| Parts of speech | Possible governors | Possible functions |
|-----------------|--------------------|--------------------|
| Determiner | noun | det |
| Noun | verb | object, iobject |
| Noun | prep | pcomp |
| Verb | root | root |
| Prep | verb, noun | mod, loc |



Tagging

| | | | | | | |
|-----------------------|--------------|------------------|-------------------------------------|------------------|------------------|-------------------------------------|
| Words | <i>Bring</i> | <i>the</i> | <i>meal</i> | <i>to</i> | <i>the</i> | <i>table</i> |
| Position | 1 | 2 | 3 | 4 | 5 | 6 |
| Part of speech | verb | det | noun | prep | det | noun |
| Possible tags | nil, root | 3, det 6, det | 4, pcomp 1, object 1, iobject | 3, mod 1, loc | 3, det 6, det | 4, pcomp 1, object 1, iobject |

A second step applies and propagates constraint rules.

Rules for English describe: projectivity – links must not cross –, function uniqueness – there is only one subject, one object, one indirect object –, topology



Constraints

- A determiner has its head to its right-hand side
- A subject has its head to its right-hand side when the verb is at the active form
- An object and an indirect object have their head to their left-hand side (active form)
- A prepositional complement has its head to its left-hand side

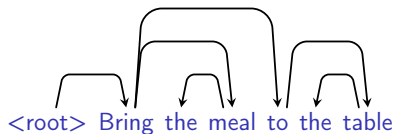
| Words | <i>Bring</i> | <i>the</i> | <i>meal</i> | <i>to</i> | <i>the</i> | <i>table</i> |
|----------------|--------------|------------|-------------------------|------------------|------------|--------------|
| Position | 1 | 2 | 3 | 4 | 5 | 6 |
| Part of speech | verb | det | noun | prep | det | noun |
| Possible tags | nil, root | 3, det | 1, iobject 1, object | 3, mod 1, loc | 6, det | 4, pcomp |



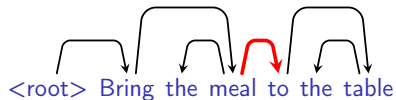
Evaluation of Dependency Parsing

Dependency parsing: The error count is the number of words that are assigned a wrong head, here 1/6.

Reference



Output



Parser Variant: Arc-Standard

Nivre's parser has two variants in addition to arc-eager: arc-standard (Yamada and Matsumoto) and swap

The first step is a POS tagging

The transitions are:

1. **Shift**, pushes the input token onto the stack
2. **Right arc**, adds an arc from the second token in the stack to the top of the stack and pops it.
3. **Left arc**, adds an arc from the top of the stack to the second in the stack and removes the second in the stack.



Transitions' Definition of Arc-Standard

| Actions | Parser states | Conditions |
|----------------|---|---------------|
| Initialization | $\langle nil, W, \emptyset \rangle$ | |
| Termination | $\langle [ROOT], [], A \rangle$ | |
| Shift | $\langle S, [n I], A \rangle \rightarrow \langle [S n], I, A \rangle$ | |
| Left-arc | $\langle [S n, n'], I, A \rangle \rightarrow \langle [S n'], I, A \cup \{(n \leftarrow n')\} \rangle$ | $n \neq ROOT$ |
| Right-arc | $\langle [S n, n'], I, A \rangle \rightarrow \langle [S n], I, A \cup \{(n \rightarrow n')\} \rangle$ | |



Arc Standard Parser in Action (I)

| Trans. | Stack | Queue | Graph |
|--------|---------------------------|------------------------------------|--------------|
| start | [ROOT] | [I, booked, a, ticket, to, Google] | {} |
| sh | | | |
| | [I ROOT] | [booked, a, ticket, to, Google] | {} |
| sh | | | |
| | [booked I ROOT] | [a, ticket, to, Google] | {} |
| la | | | |
| | [booked ROOT] | [a, ticket, to, Google] | {I ← booked} |
| sh | | | |
| | [a booked ROOT] | [ticket, to, Google] | {I ← booked} |



Arc Standard Parser in Action (II)

| Trans. | Stack | Queue | Graph |
|--------|--|--------------|--|
| sh | | | |
| | $\begin{bmatrix} \text{ticket} \\ a \\ \text{booked} \\ \text{ROOT} \end{bmatrix}$ | [to, Google] | {I \leftarrow booked} |
| la | | | |
| | $\begin{bmatrix} \text{ticket} \\ \text{booked} \\ \text{ROOT} \end{bmatrix}$ | [to, Google] | {I \leftarrow booked, a \leftarrow ticket} |
| sh | | | |
| | $\begin{bmatrix} \text{to} \\ \text{ticket} \\ \text{booked} \\ \text{ROOT} \end{bmatrix}$ | [Google] | {I \leftarrow booked, a \leftarrow ticket} |



Arc Standard Parser in Action (III)

| Trans. | Stack | Queue | Graph |
|--------|---|-------|---|
| sh | | | |
| | <div>Google</div> <div>to</div> <div>ticket</div> <div>booked</div> <div>ROOT</div> | [] | {l ← booked, a ← ticket} |
| ra | | | |
| | <div>to</div> <div>ticket</div> <div>booked</div> <div>ROOT</div> | [] | {l ← booked, a ← ticket, to → Google} |
| ra | | | |
| | <div>ticket</div> <div>booked</div> <div>ROOT</div> | [] | {l ← booked, a ← ticket, to → Google, ticket → to} |



Arc Standard Parser in Action (IV)

| Trans. | Stack | Queue | Graph |
|--------|------------------------------|---------------|--|
| ra | | | |
| | <div>[booked ROOT]</div> | <div>[]</div> | <div>{l ← booked, a ← ticket, to → Google, ticket → to, booked → ticket}</div> |



Transitions' Definition of Swap

The Swap variant enables the parser to parse nonprojective sentences

| Actions | Parser states | Conditions |
|----------------|---|--------------------------------------|
| Initialization | $\langle nil, W, \emptyset \rangle$ | |
| Termination | $\langle [ROOT], [], A \rangle$ | |
| Shift | $\langle S, [n I], A \rangle \rightarrow \langle [S n], I, A \rangle$ | |
| Left-arc | $\langle [S n, n'], I, A \rangle \rightarrow \langle [S n'], I, A \cup \{(n \leftarrow n')\} \rangle$ | $n \neq ROOT$ |
| Right-arc | $\langle [S n, n'], I, A \rangle \rightarrow \langle [S n], I, A \cup \{(n \rightarrow n')\} \rangle$ | |
| Swap | $\langle [S n, n'], I, A \rangle \rightarrow \langle [S n'], [n I], A \rangle$ | $n \neq ROOT$ and $inx(n) < inx(n')$ |



Application: Dependency Parsing for Knowledge Extraction

IBM Watson, the question-answering system, uses dependency parsing to

- Analyze questions and
- Extract knowledge from text.

Given the question:

POETS & POETRY: He was a bank clerk in the Yukon before he published "Songs of a Sourdough" in 1907

Watson extracts:

`authorOf(he, 'Songs of a Sourdough')`

A predicate–argument structure representation would be:

`published(he, 'Songs of a Sourdough')`



IBM Watson: Parsing the Question

Watson parses the question in the form of dependencies.

- In the CoNLL format:

| Inx | Form | Lemma | POS | Head | Funct. |
|-----|----------------------|----------------------|---------|------|---------|
| 1 | he | he | pronoun | 2 | subject |
| 2 | published | publish | verb | 0 | root |
| 3 | Songs of a Sourdough | Songs of a Sourdough | noun | 2 | object |

- In the Watson format:

```
lemma(1, "he").                partOfSpeech(1,pronoun).
lemma(2, "publish").            partOfSpeech(2,verb).
lemma(3, "Songs of a Sourdough"). partOfSpeech(3,noun).

subject(2,1).
object(2,3).
```



IBM Watson: Inferences

Watson uses Prolog rules to detect author/composition relationships:

```
authorOf(Author,Composition) :-  
    createVerb(Verb),  
    subject(Verb,Author),  
    author(Author),  
    object(Verb,Composition),  
    composition(Composition).
```

```
createVerb(Verb) :-  
    partOfSpeech(Verb,verb),  
    lemma(Verb,VerbLemma),  
    member(VerbLemma, ["write", "publish",...]).
```

Eventually, the question is reduced to:

```
authorOf(he, 'Songs of a Sourdough')
```



IBM Watson: Evidence from Text

Watson parses large volumes of text, for instance Wikipedia and the *New York Times*.

From the excerpt:

Songs of a Sourdough by Robert W. Service

Watson extracts:

```
authorOf('Robert W. Service', 'Songs of a Sourdough')
```

The classical predicate–argument structure representation of the same phrase is:

```
by('Songs of a Sourdough', 'Robert W. Service')
```



IBM Watson: Matching Evidences

The relation is extracted from text using the rule:

```
authorOf(Author,Composition) :-  
    composition(Composition),  
    argument(Composition,Preposition),  
    lemma(Preposition, "by"),  
    objectOfPreposition(Preposition,Author),  
    author(Author).
```

Leading to:

```
authorOf('Robert W. Service', 'Songs of a Sourdough')
```

This predicate–argument structure can be compared to:

```
authorOf(he, 'Songs of a Sourdough')
```

Or unified with:

```
authorOf(X, 'Songs of a Sourdough')
```

