# A Transition-Based Directed Acyclic Graph Parser for Universal Conceptual Cognitive Annotation

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# Linguistic Annotation Schemes

- Dependency grammar (Tesniére, 1959; Nivre, 2005):

  Purely syntactic analysis.

Semantic representation (Abend and Rappoport, 2017):

- Semantic dependencies (Oepen et al., 2015):

  Coupled with syntactic representation.

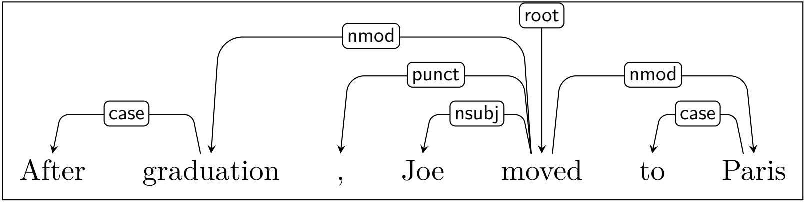
- AMR (Banarescu et al., 2013), UCCA (Abend and Rappoport, 2013):

  $\boxed{\text{...showered}} = \boxed{\text{...took a shower}}$

  $\boxed{\text{...'s war against crime}} = \boxed{\text{...fights crime}}$

# Dependency Parsing

- Graph representation of syntactic structure.
- Bilexical tree: edges are only between tokens.
- Fast and accurate parsers (e.g. *transition-based*).



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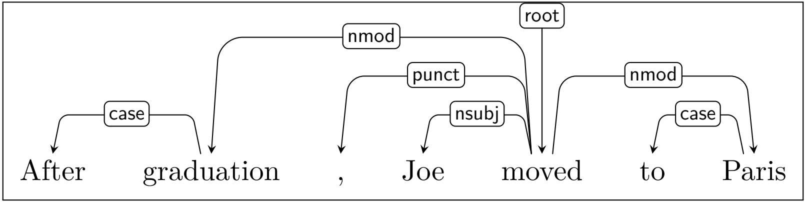
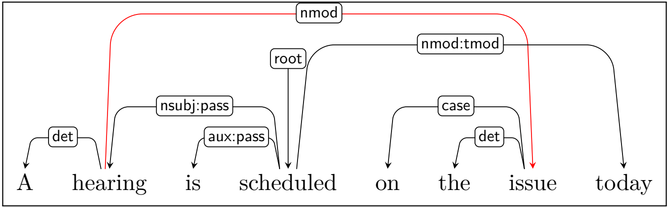
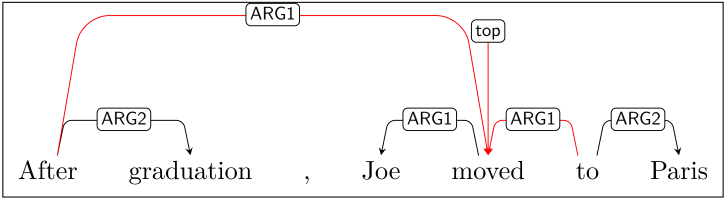



Non-projectivity (discontinuity) is a challenge (Nivre, 2009).



# Semantic Dependency Parsing

- Representation of predicate-argument relationships.
- Bilexical graph: allows reentrancy (and discontinuity).
- Various formalisms.




DELPH-IN MRS-derived bi-lexical dependencies (DM).

# Semantic Dependency Parsing

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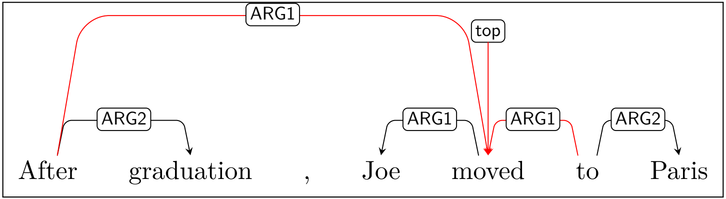


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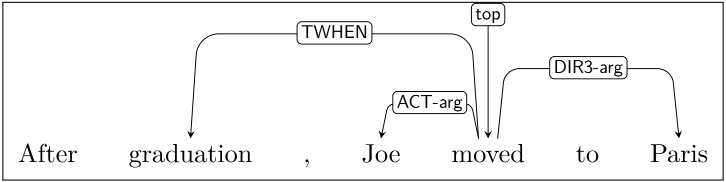
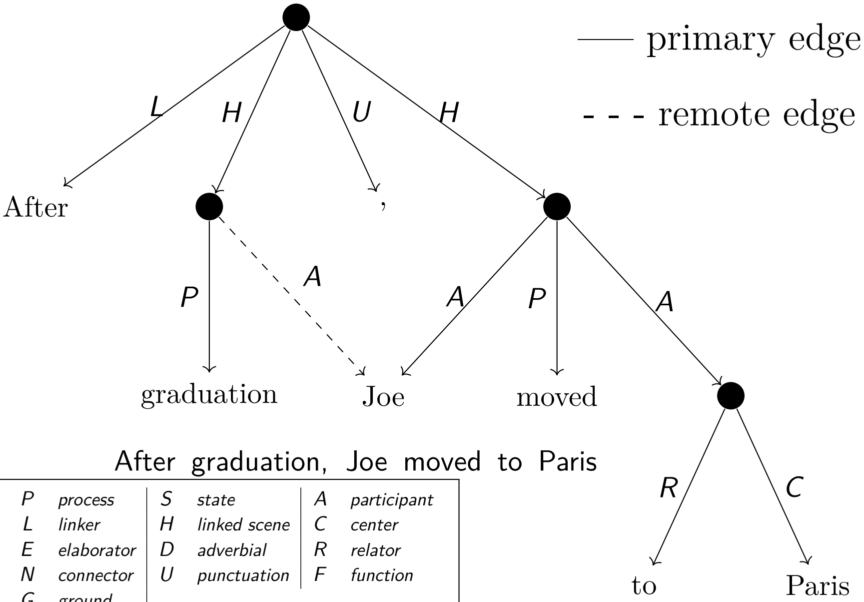



Prague Dependency Treebank tectogrammatical layer (PSD).

# Universal Conceptual Cognitive Annotation (UCCA)

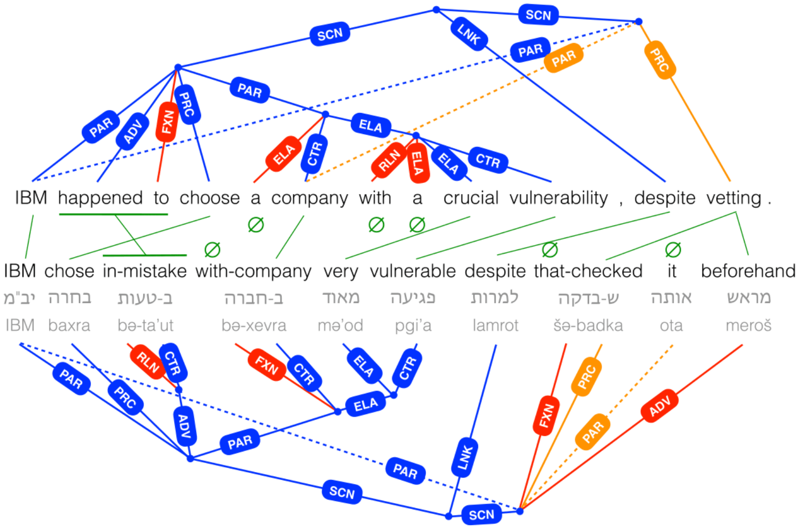



After graduation, Joe moved to Paris

| | | | | | |
|---|---|---|---|---|---|
| *P* | *process* | *S* | *state* | *A* | *participant* |
| *L* | *linker* | *H* | *linked scene* | *C* | *center* |
| *E* | *elaborator* | *D* | *adverbial* | *R* | *relator* |
| *N* | *connector* | *U* | *punctuation* | *F* | *function* |
| *G* | *ground* | | | | |

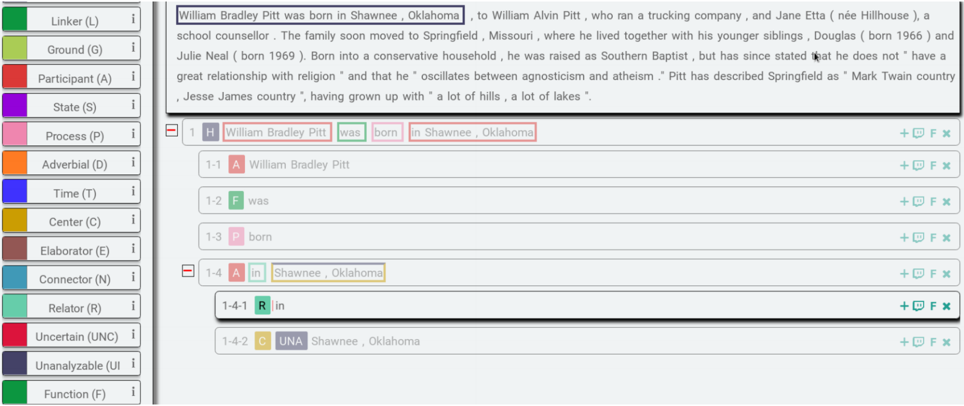
# The UCCA Semantic Representation Scheme

Cross-linguistically applicable (Abend and Rappoport, 2013).
Stable in translation (Sulem et al., 2015).



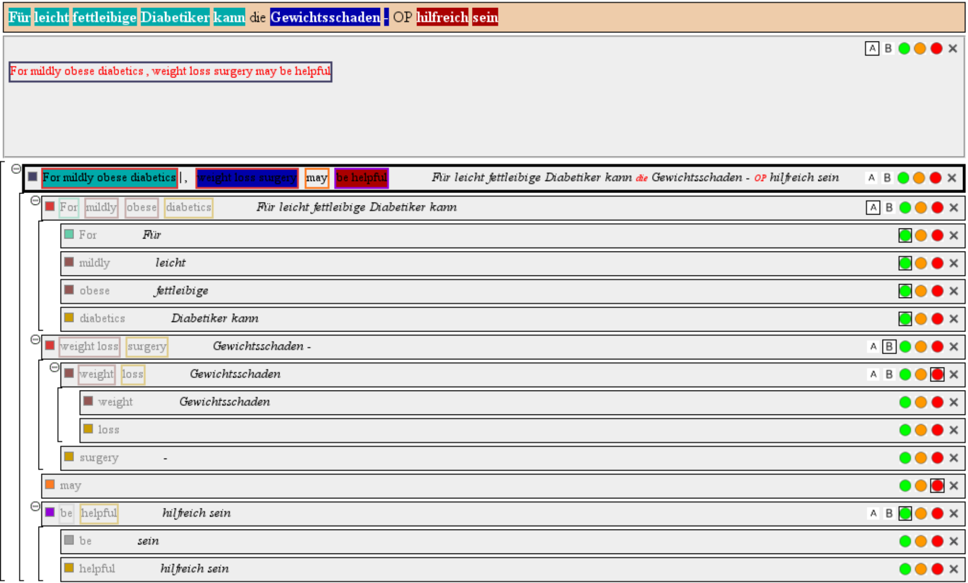
# UCCAApp

Rapid and intuitive annotation interface (Abend et al., 2017).
Usable by non-experts. `http://ucca-demo.cs.huji.ac.il`



# HUME

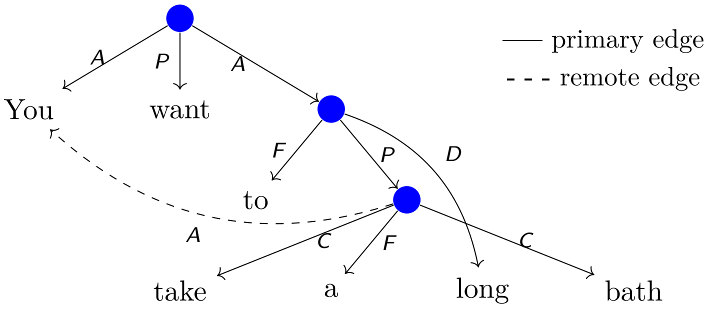
UCCA facilitates semantics-based human evaluation of machine translation (Birch et al., 2016). `http://ucca.cs.huji.ac.il/mteval`



# Graph Structure

UCCA forms a directed acyclic graph (DAG). Tokens are terminals.
Structural properties:

1. Non-terminal nodes

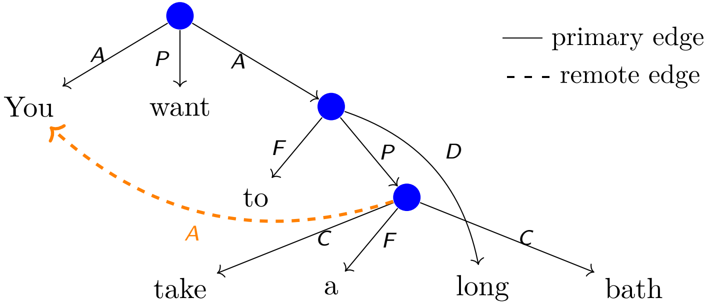



You want to take a long bath

# Graph Structure

UCCA forms a directed acyclic graph (DAG). Tokens are terminals.
Structural properties:

1. Non-terminal nodes
2. Reentrancy

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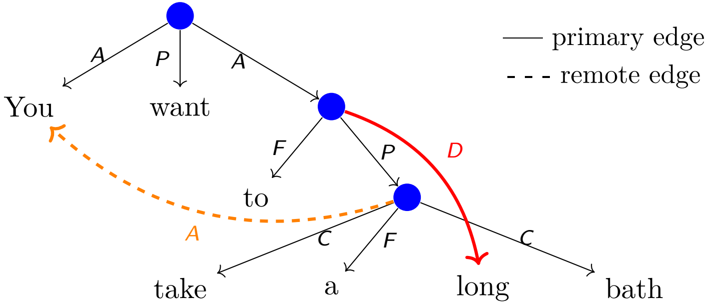
# Graph Structure

UCCA forms a directed acyclic graph (DAG). Tokens are terminals.
Structural properties:

1. Non-terminal nodes
2. Reentrancy
3. Discontinuity




You want to take a long bath

# Transition-Based Parsing

- Parse text $w_1 \ldots w_n$ to graph $G = (V, E, \ell)$ incrementally.
- Classifier determines transition to apply at each step.
- Trained by an oracle based on gold-standard graph.

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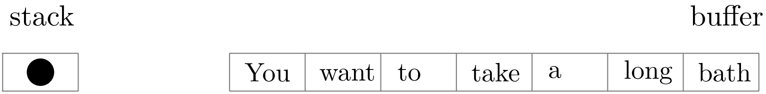
Initial state:



# Transition-Based Parsing

- Parse text $w_1 \dots w_n$ to graph $G = (V, E, \ell)$ incrementally.
- Classifier determines transition to apply at each step.
- Trained by an oracle based on gold-standard graph.

Initial state:

stack | buffer

| | | | | | | |
|---|---|---|---|---|---|---|
| You | want | to | take | a | long | bath |

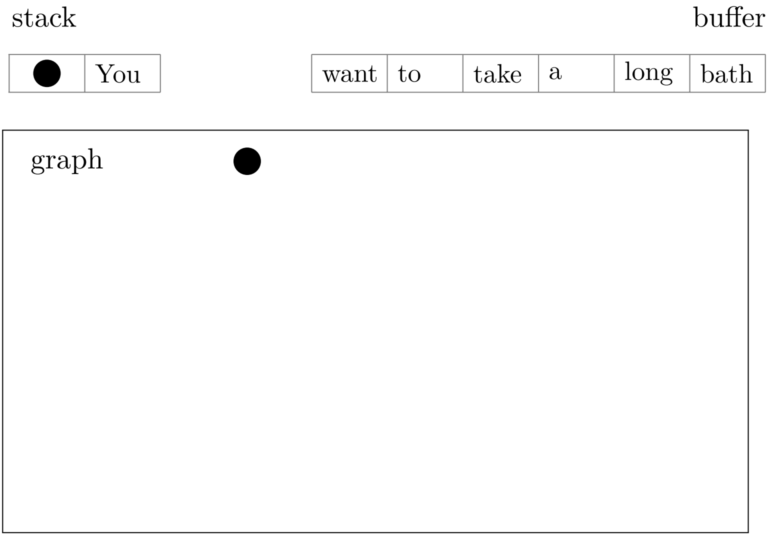
TUPA transitions:

$$\{\textsc{Shift}, \textsc{Reduce}, \textsc{Node}_X, \textsc{Left-Edge}_X, \textsc{Right-Edge}_X, \textsc{Left-Remote}_X, \textsc{Right-Remote}_X, \textsc{Swap}, \textsc{Finish}\}$$

Support non-terminal nodes, reentrancy and discontinuity.

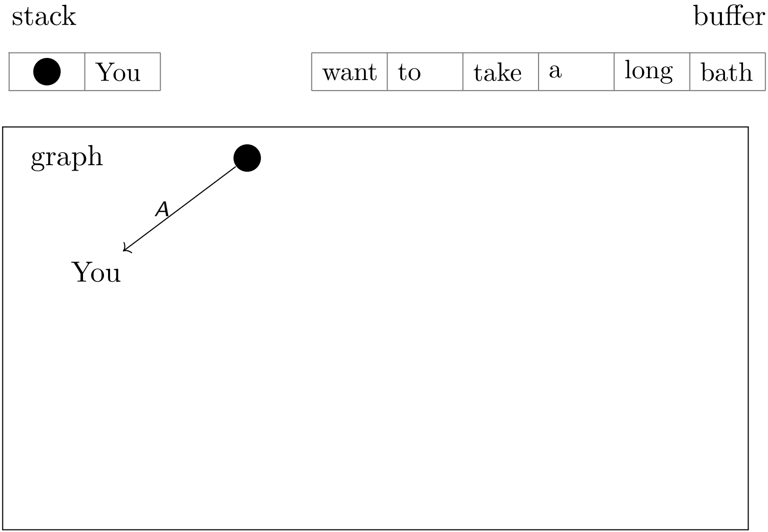
# Transition-Based UCCA Parsing

⇒ SHIFT



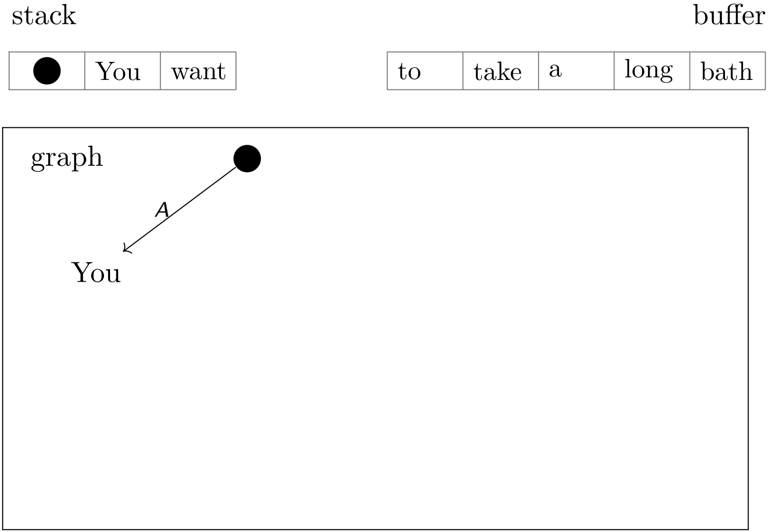
# Transition-Based UCCA Parsing

$\Rightarrow$ Right-Edge$_{\text{A}}$



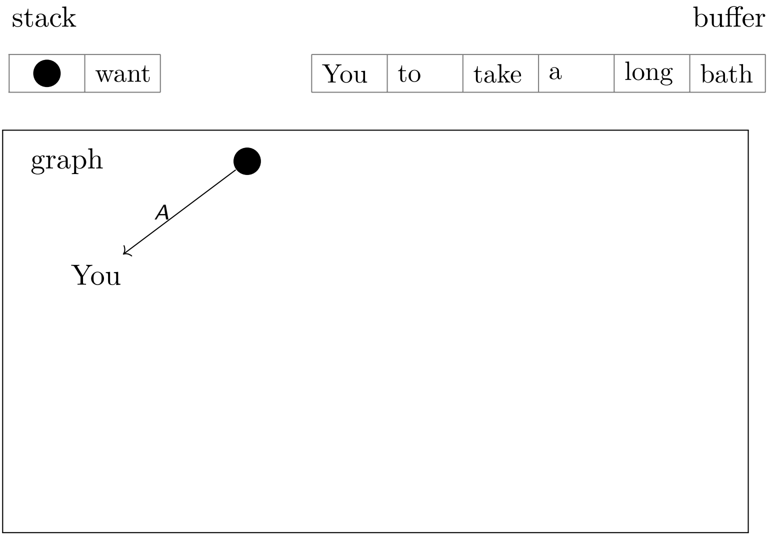
# Transition-Based UCCA Parsing

⇒ SHIFT



# Transition-Based UCCA Parsing

⇒ Swap



# Transition-Based UCCA Parsing

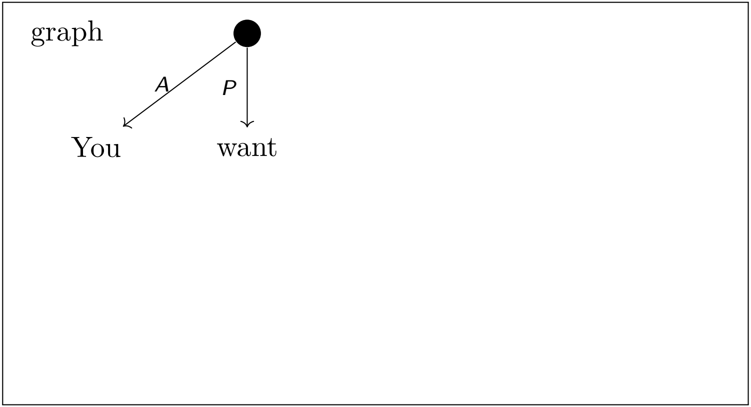
⇒ Right-Edge$_P$

stack

| | |
|---|---|
| ● | want |

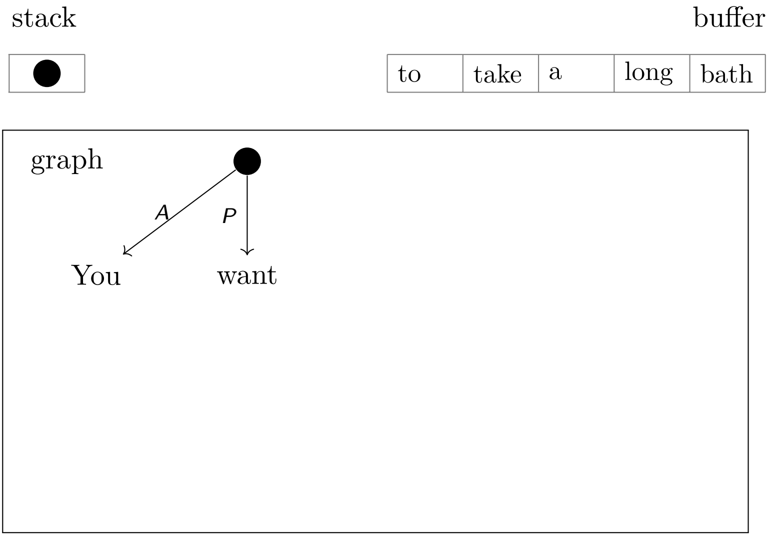
buffer

| | | | | | |
|---|---|---|---|---|---|
| You | to | take | a | long | bath |



# Transition-Based UCCA Parsing

⇒ Reduce



# Transition-Based UCCA Parsing

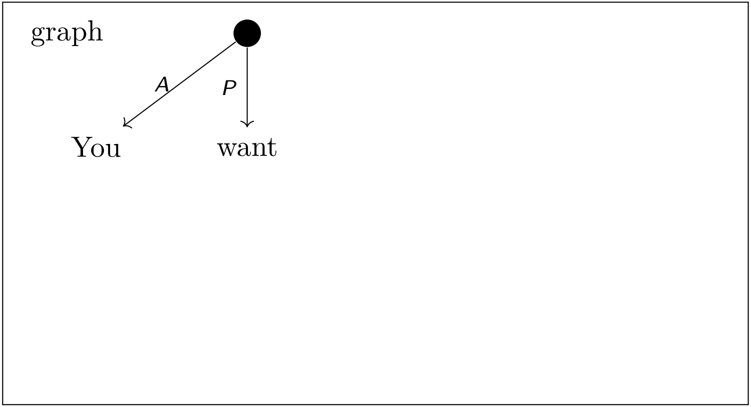
⇒ Shift

stack

| | |
|---|---|
| ● | You |

buffer

| | | | | |
|---|---|---|---|---|
| to | take | a | long | bath |



# Transition-Based UCCA Parsing

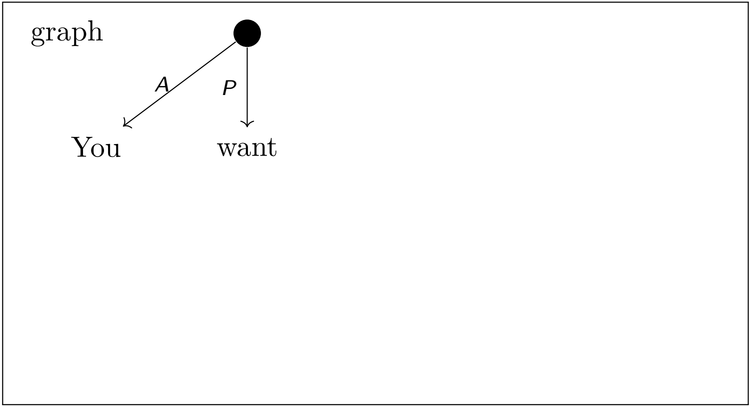
⇒ SHIFT

stack

| | | |
|---|---|---|
| ● | You | to |

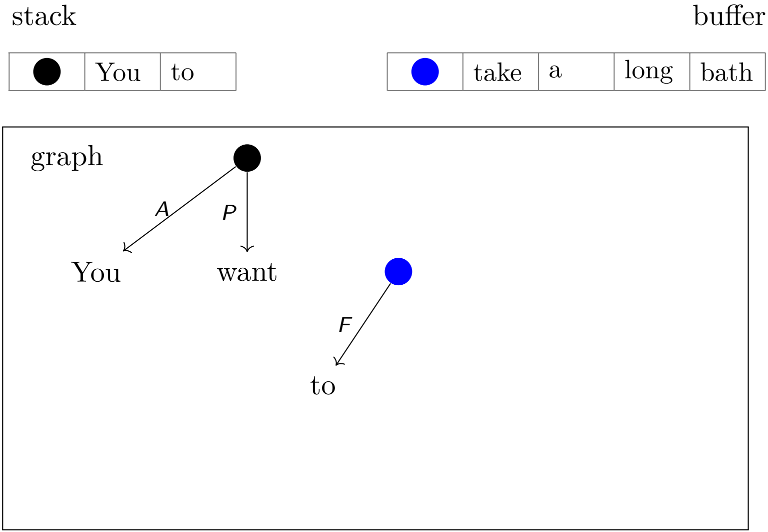
buffer

| | | | |
|---|---|---|---|
| take | a | long | bath |



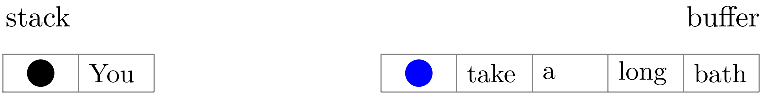
# Transition-Based UCCA Parsing

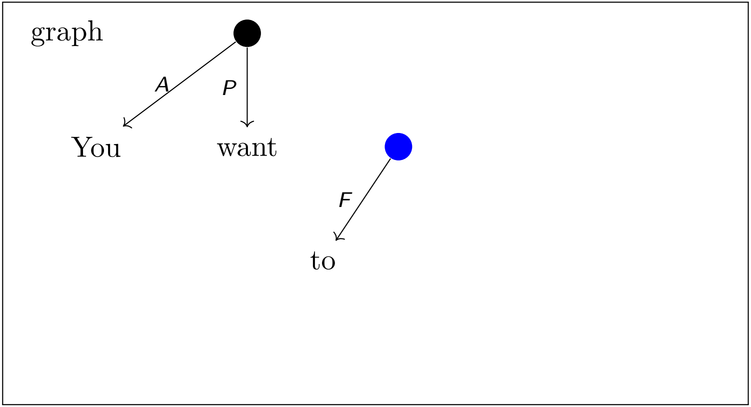
$\Rightarrow$ $\textsc{Node}_{\mathrm{F}}$



# Transition-Based UCCA Parsing

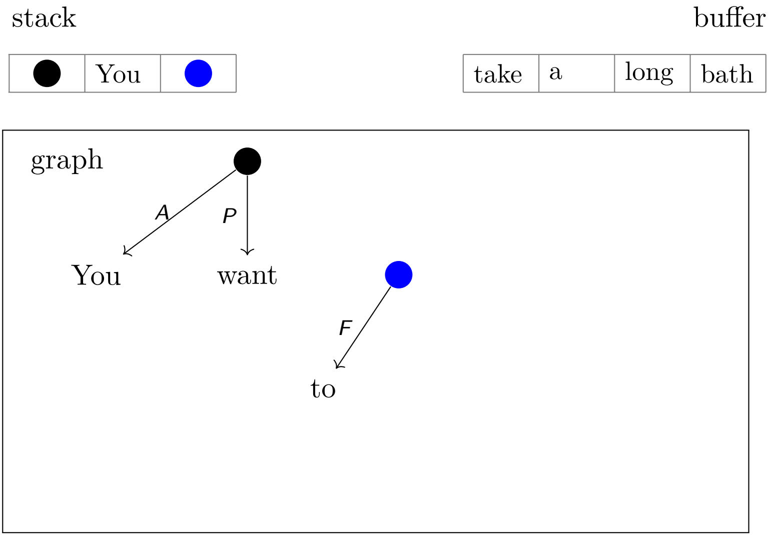
⇒ Reduce



# Transition-Based UCCA Parsing

⇒ Shift



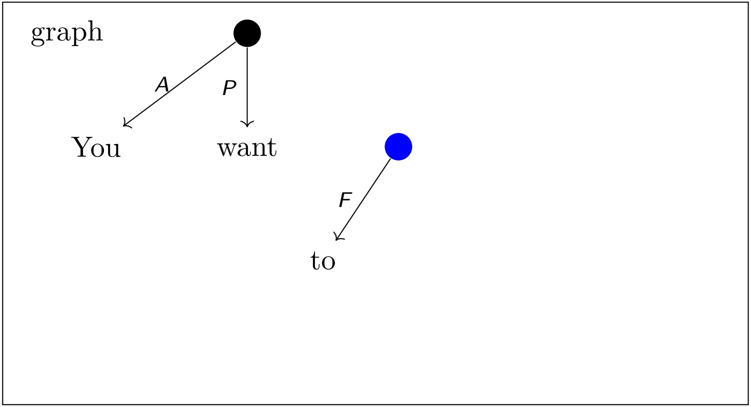
# Transition-Based UCCA Parsing

$\Rightarrow$ SHIFT

stack | buffer

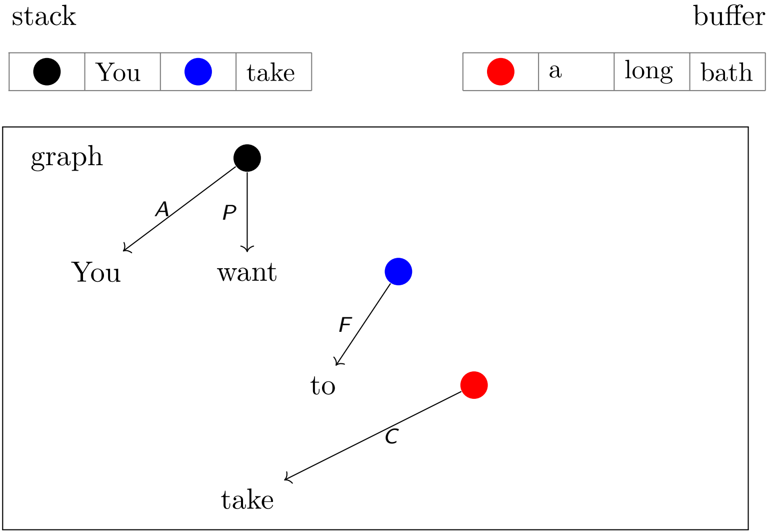
| | | | |
|---|---|---|---|
| ● | You | ● | take |

| | | |
|---|---|---|
| a | long | bath |



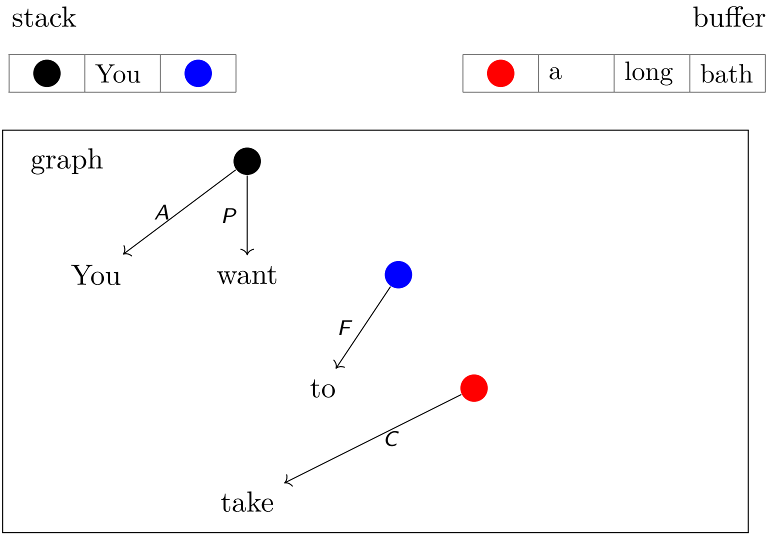
# Transition-Based UCCA Parsing

$\Rightarrow$ $\textsc{Node}_{C}$



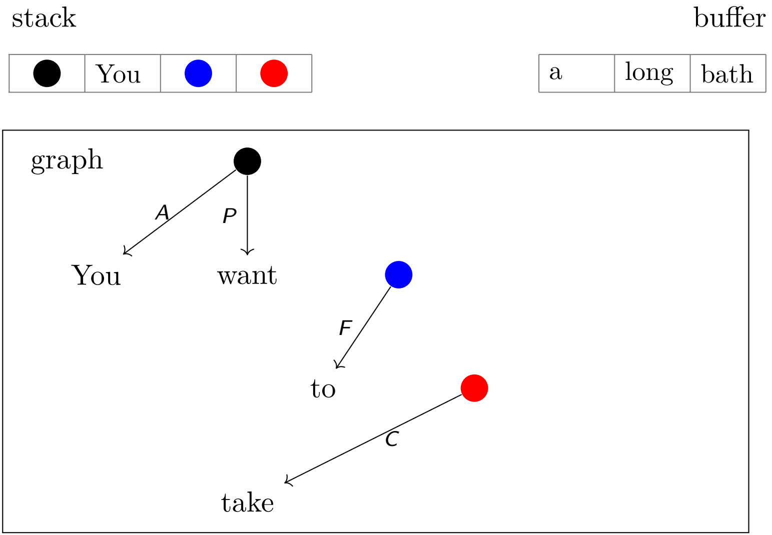
# Transition-Based UCCA Parsing

⇒ Reduce



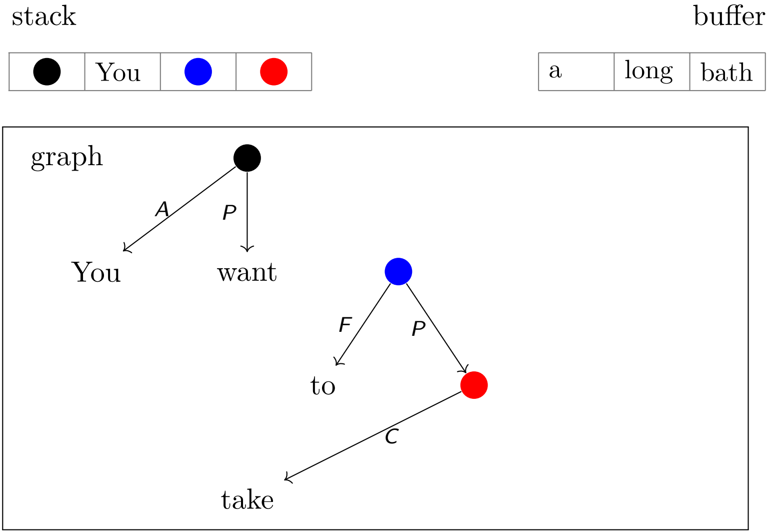
# Transition-Based UCCA Parsing

⇒ SHIFT



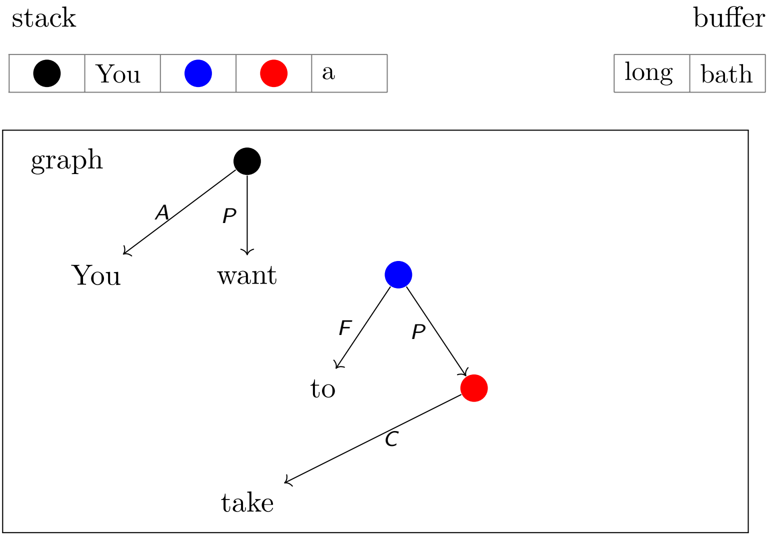
# Transition-Based UCCA Parsing

⇒ RIGHT-EDGE$_P$



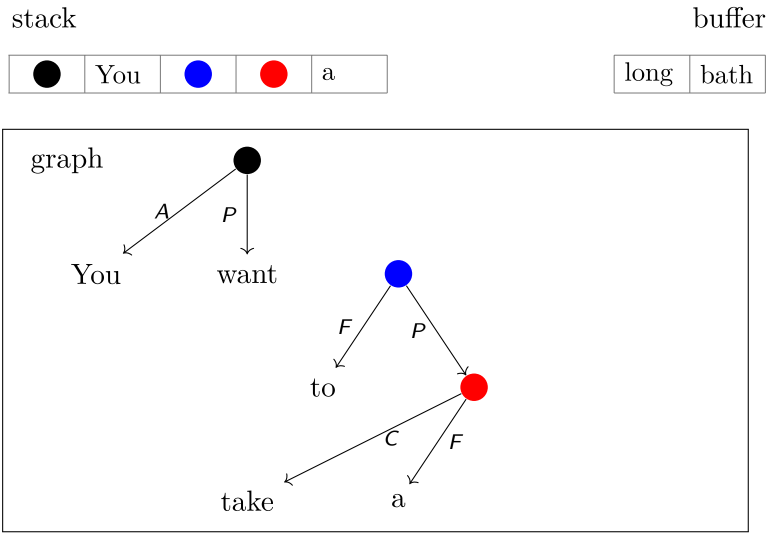
# Transition-Based UCCA Parsing

⇒ Shift



# Transition-Based UCCA Parsing

⇒ RIGHT-EDGE$_F$



# Transition-Based UCCA Parsing

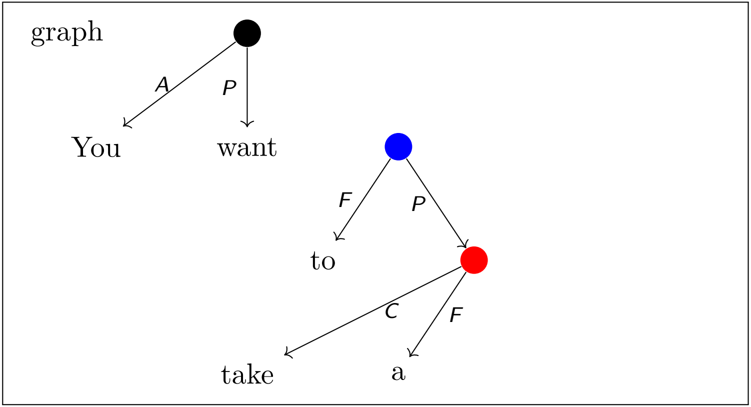
⇒ REDUCE

stack

| | | | |
|---|---|---|---|
| ● | You | ● | ● |

buffer

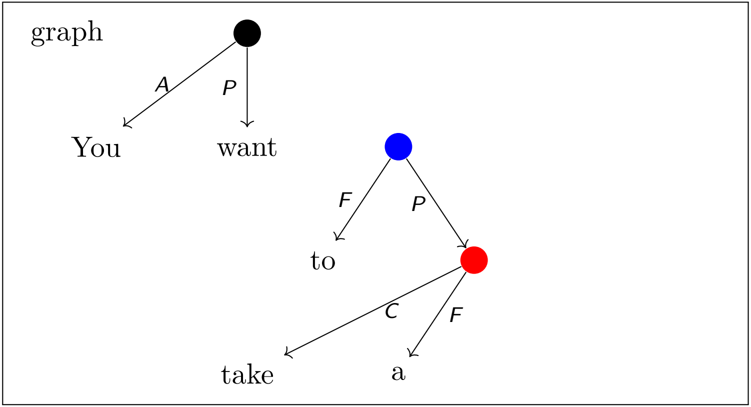
| | |
|---|---|
| long | bath |



# Transition-Based UCCA Parsing

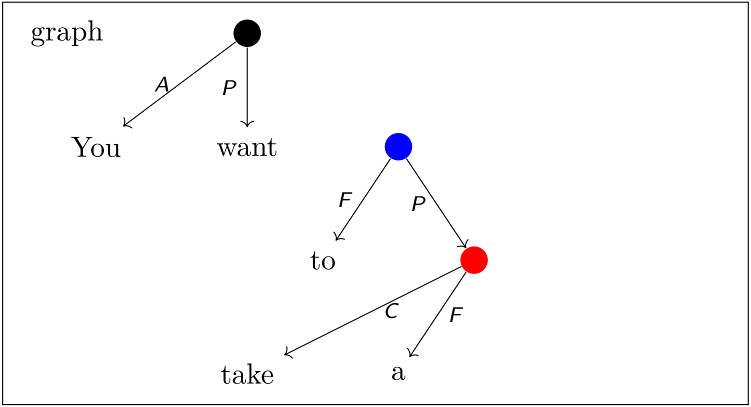
⇒ Shift

| stack | | | | | | buffer |
|---|---|---|---|---|---|---|
| ● | You | ● | ● | long | | bath |



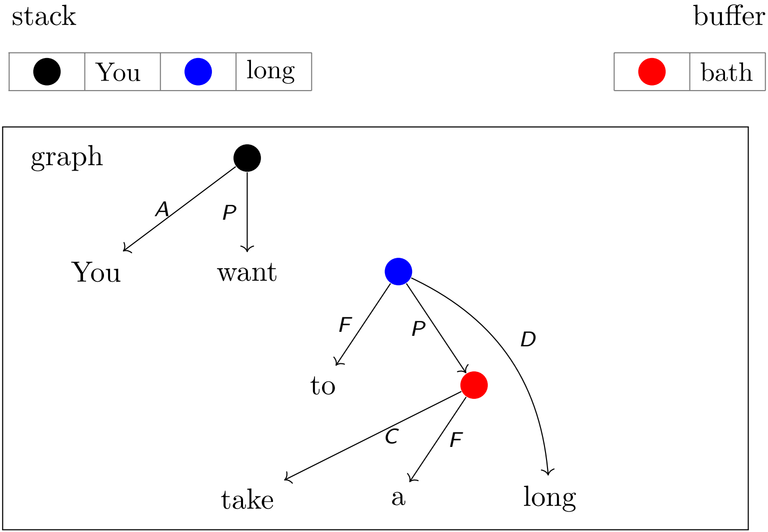
# Transition-Based UCCA Parsing

⇒ SWAP

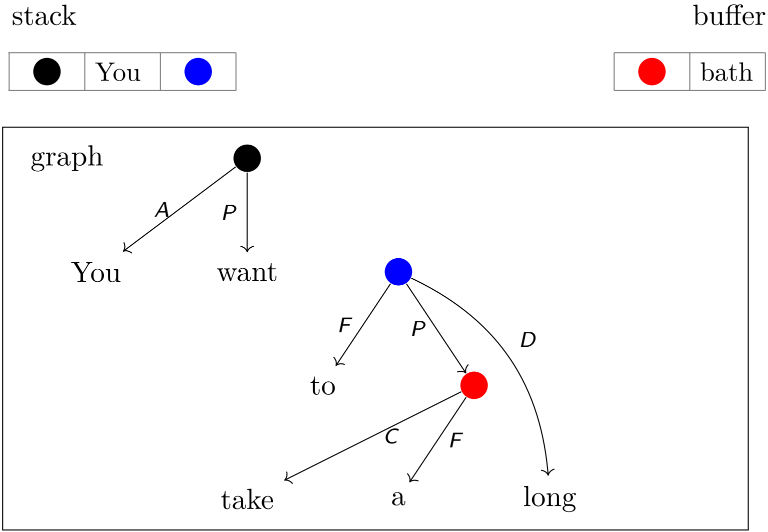
# Transition-Based UCCA Parsing

$\Rightarrow$ Right-Edge$_{D}$



# Transition-Based UCCA Parsing

⇒ Reduce

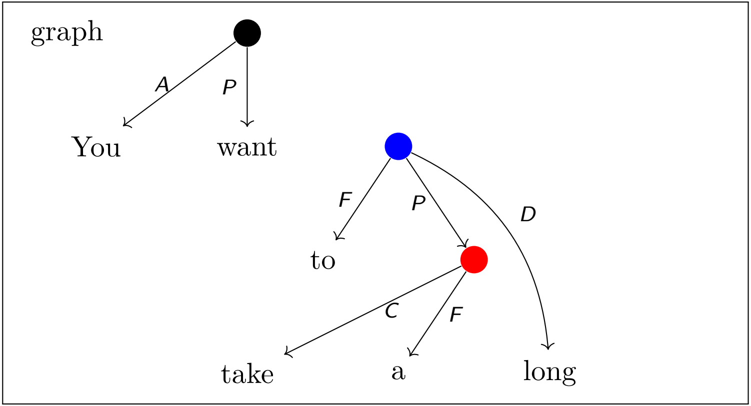


# Transition-Based UCCA Parsing

$\Rightarrow$ Swap

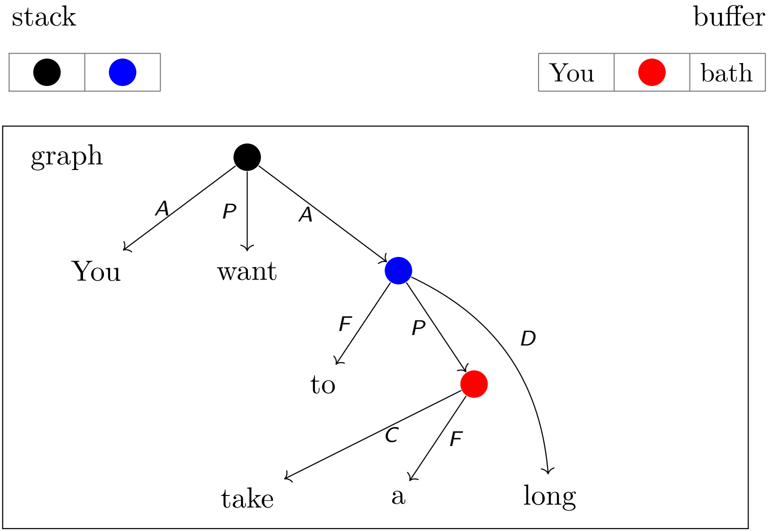
stack

buffer

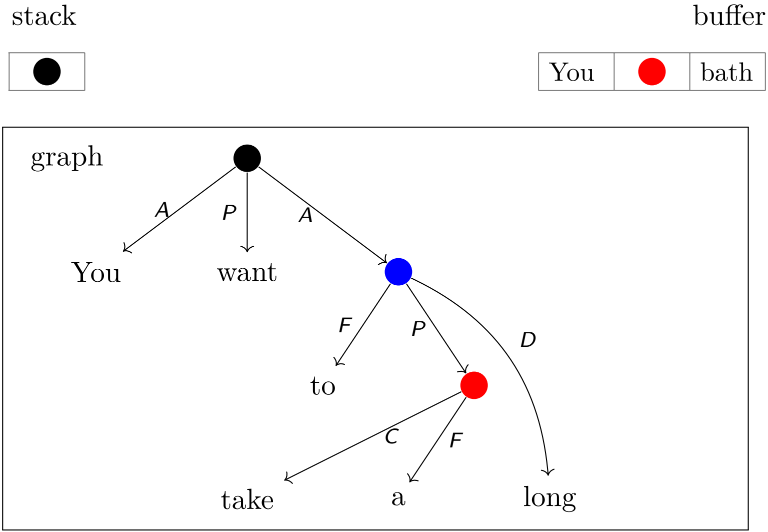
# Transition-Based UCCA Parsing

⇒ $\textsc{Right-Edge}_{\mathrm{A}}$



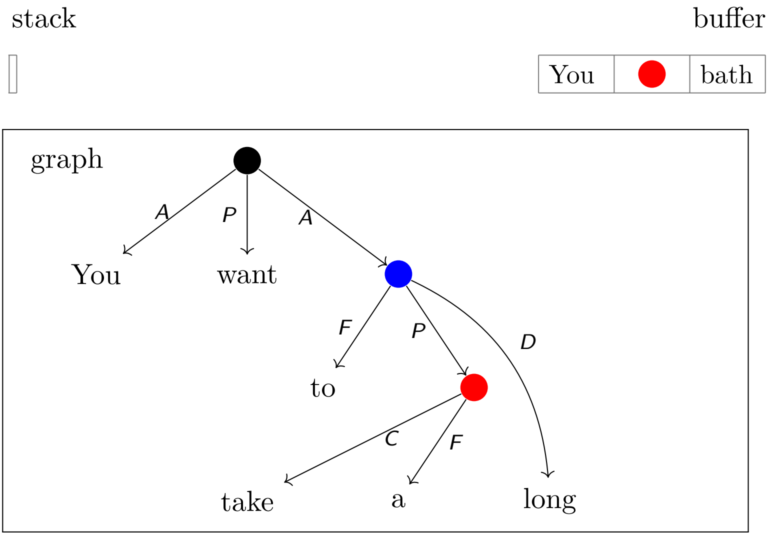
# Transition-Based UCCA Parsing

⇒ REDUCE



# Transition-Based UCCA Parsing

⇒ Reduce



# Transition-Based UCCA Parsing

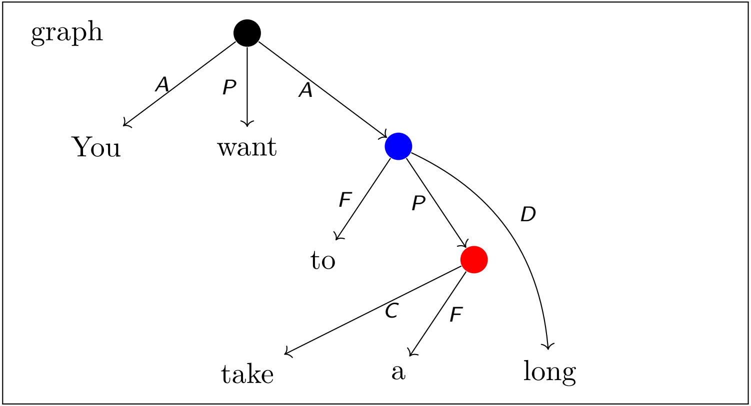
⇒ SHIFT

stack

| |
|---|
| You |

buffer

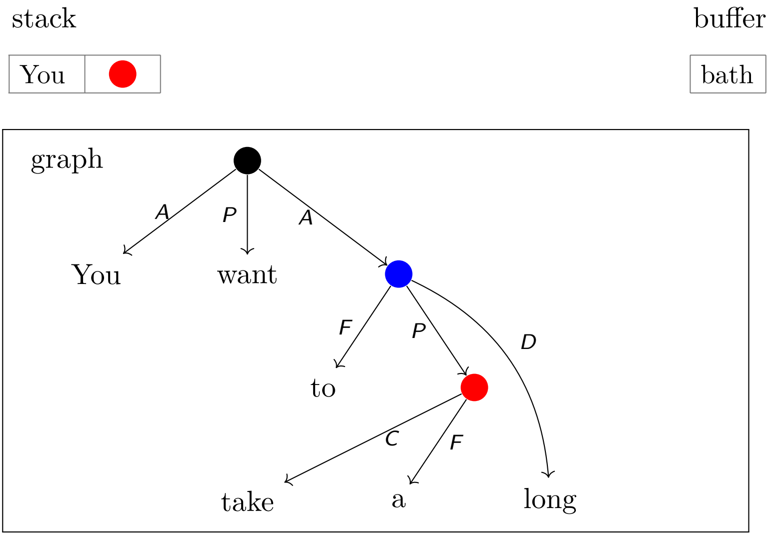
| | |
|---|---|
| | bath |



# Transition-Based UCCA Parsing

⇒ SHIFT

stack | buffer



# Transition-Based UCCA Parsing

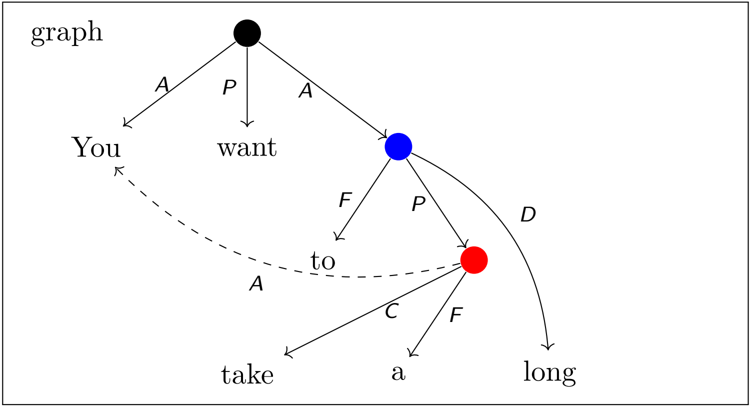
$\Rightarrow$ LEFT-REMOTE$_A$

stack

| You | ● |
|---|---|

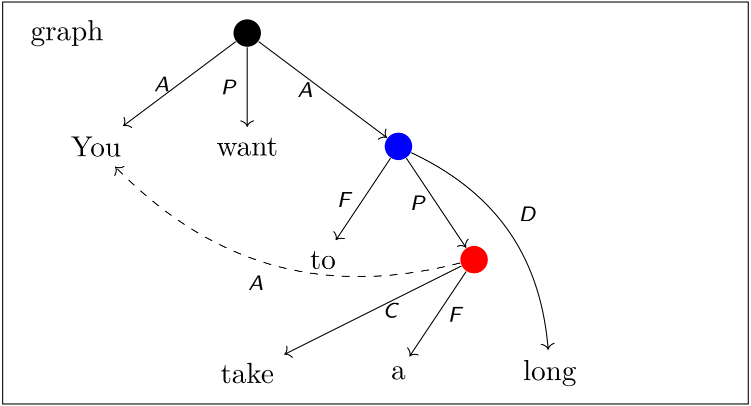
buffer

| bath |
|---|



# Transition-Based UCCA Parsing

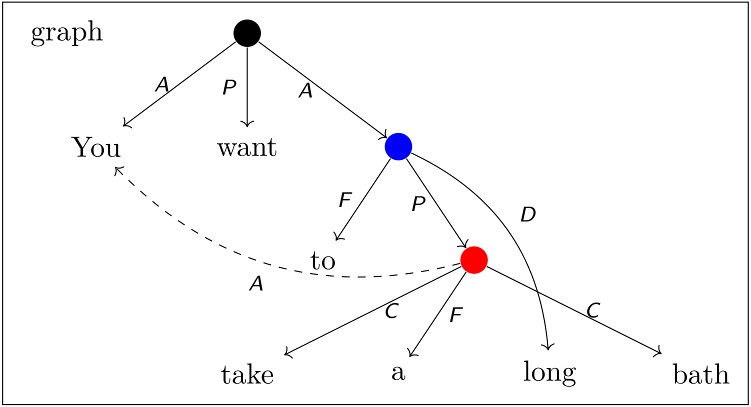
$\Rightarrow$ SHIFT

# Transition-Based UCCA Parsing

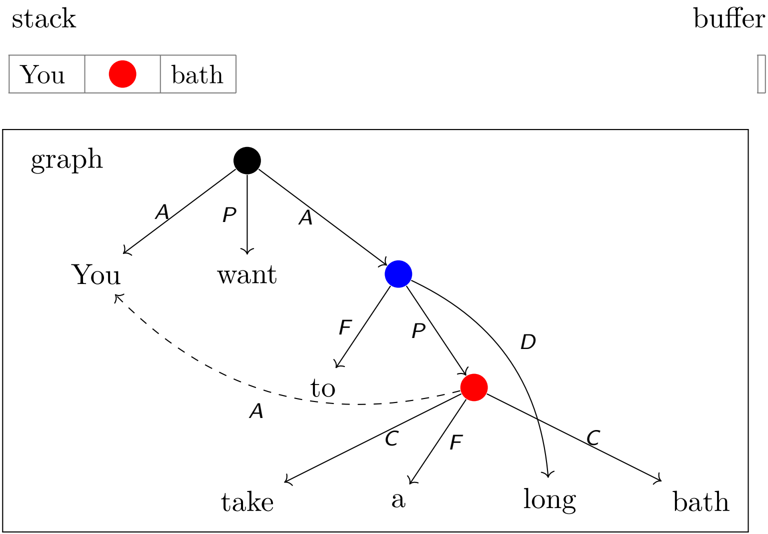
$\Rightarrow$ RIGHT-EDGE$_C$

stack buffer

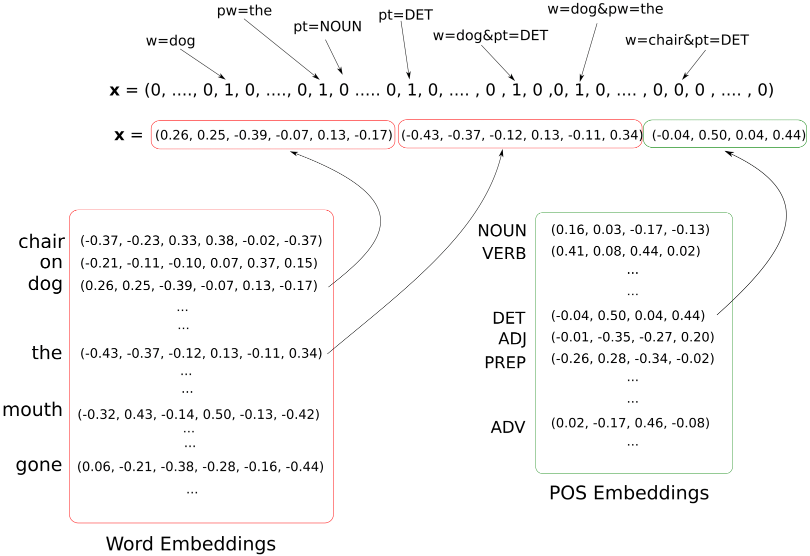
# Transition-Based UCCA Parsing

$\Rightarrow$ Finish



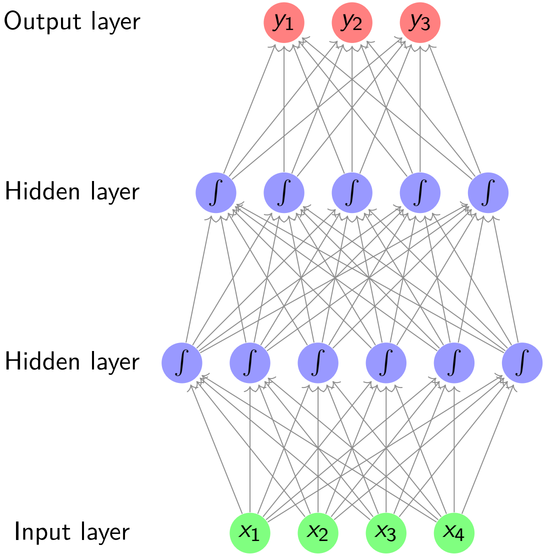
# Word Embeddings

Represent discrete features by dense vectors (Goldberg, 2016).



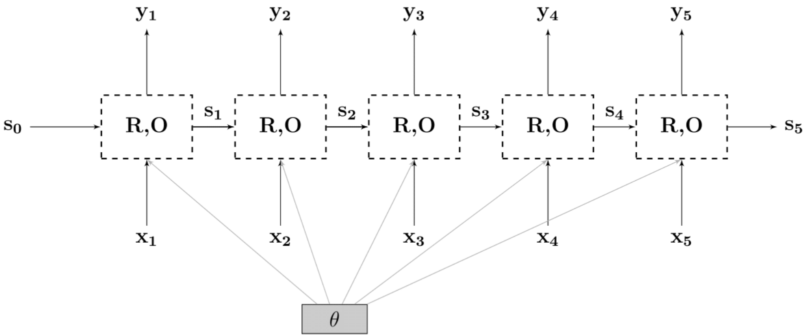
# Feed-Forward Neural Network (MLP)

Learns representation and classification by optimizing weights.



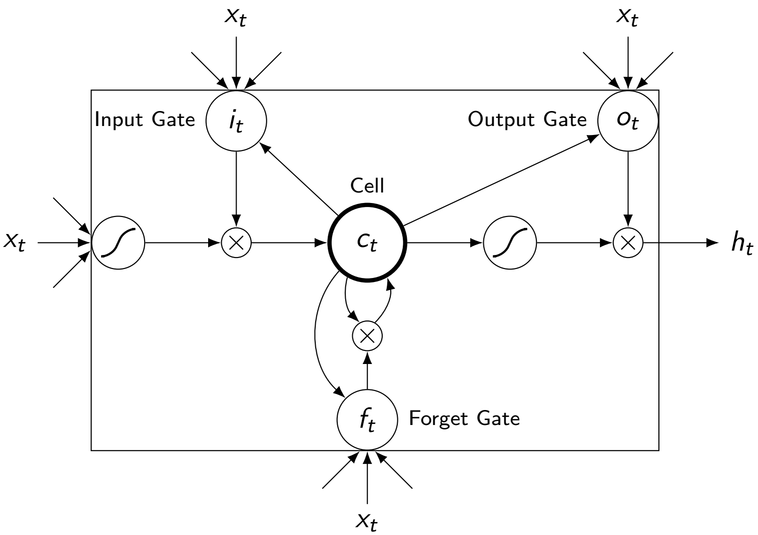
# Recurrent Neural Network (RNN)

Applied to sequences, updates state given input and previous state.



# Long Short-Term Memory (LSTM)

Memory cell to avoid vanishing gradients in RNNs.



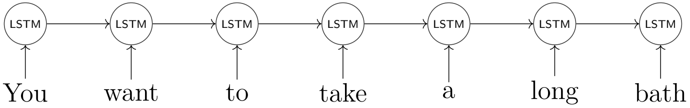
# TUPA Model

Greedy parsing, experimenting with three classifiers:

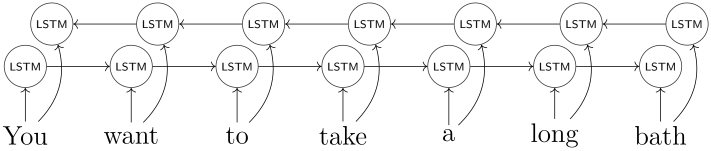
| | |
|---|---|
| **Sparse** | Perceptron with sparse features. |
| **MLP** | Embeddings + feedforward NN classifier. |
| **BiLSTM** | Embeddings + deep bidirectional LSTM + MLP. |

Features: words, POS, syntactic dependencies, existing edge labels from the stack and buffer + parents, children, grandchildren; ordinal features (height, number of parents and children)

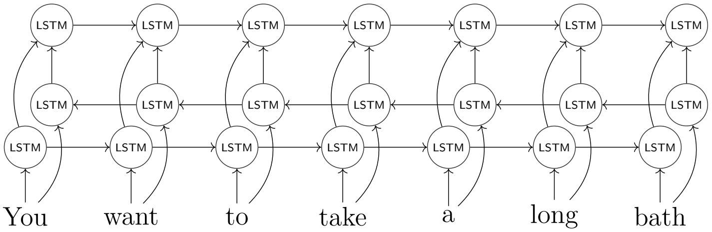
# BiLSTM


LSTM
LSTM
LSTM
LSTM
LSTM
LSTM
LSTM
You
want
to
take
a
long
bath

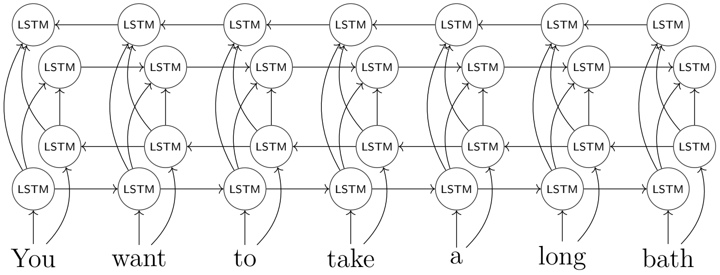
# BiLSTM

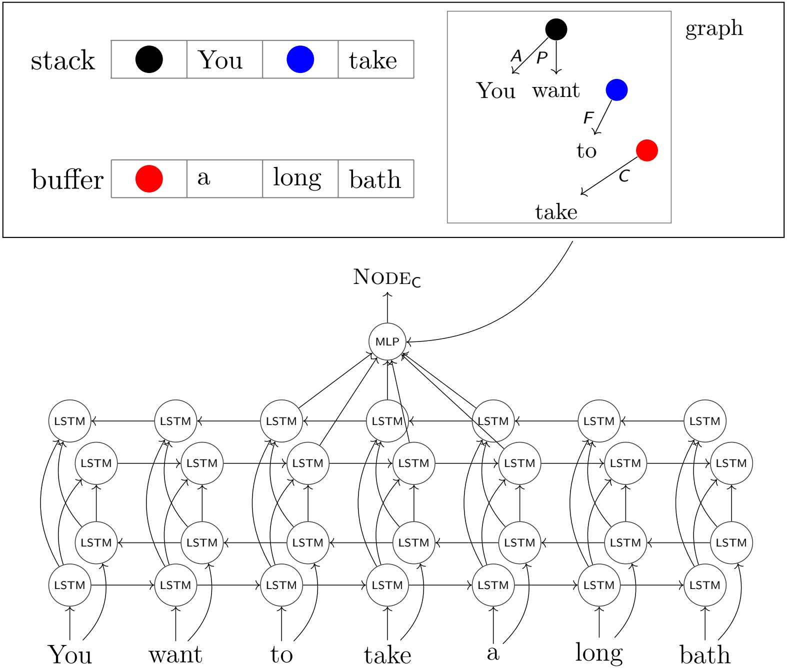

LSTM LSTM LSTM LSTM LSTM LSTM LSTM
LSTM LSTM LSTM LSTM LSTM LSTM LSTM
You want to take a long bath

# BiLSTM



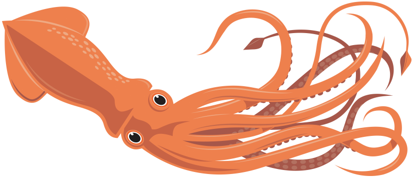
# BiLSTM




stack
You
take
buffer
a
long
bath
graph
A
P
You
want
F
to
C
take
NODE_C
MLP
LSTM
You
want
to
take
a
long
bath

# Experimental Setup

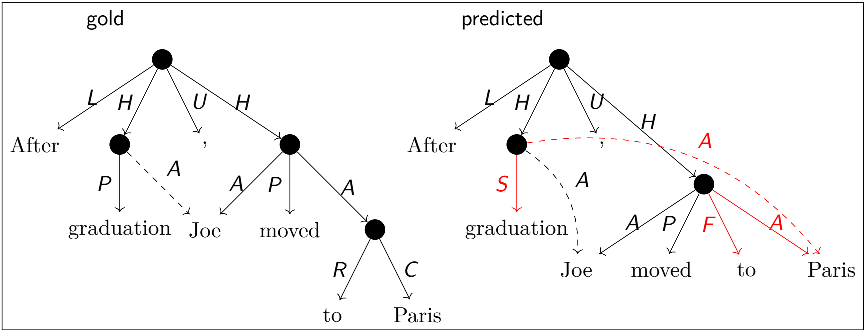
- UCCA Wikipedia corpus ($\overset{\text{train}}{4268} + \overset{\text{dev}}{454} + \overset{\text{test}}{503}$ sentences).
- Out-of-domain: English part of English-French parallel corpus, *Twenty Thousand Leagues Under the Sea* (506 sentences).



# Evaluation

Comparing graphs over the same sequence of tokens,

- Match edges by their terminal yield and label.
- Calculate labeled precision, recall and F1 scores.
- Separate primary and remote edges.




Primary:

| LP | LR | LF |
|---|---|---|
| $\frac{6}{9} = 67\%$ | $\frac{6}{10} = 60\%$ | $64\%$ |

Remote:

| LP | LR | LF |
|---|---|---|
| $\frac{1}{2} = 50\%$ | $\frac{1}{1} = 100\%$ | $67\%$ |

# Results

| | Primary | | | Remote | | |
|---|---|---|---|---|---|---|
| | **LP** | **LR** | **LF** | **LP** | **LR** | **LF** |
| Sparse | 64.5 | 63.7 | 64.1 | 19.8 | 13.4 | 16 |
| MLP | 65.2 | 64.6 | 64.9 | 23.7 | 13.2 | 16.9 |
| BiLSTM | 74.4 | 72.7 | **73.5** | 47.4 | 51.6 | **49.4** |

Results on the Wiki test set.

# Results

| | Primary | | | Remote | | |
|---|---|---|---|---|---|---|
| | **LP** | **LR** | **LF** | **LP** | **LR** | **LF** |
| Sparse | 64.5 | 63.7 | 64.1 | 19.8 | 13.4 | 16 |
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| BiLSTM | 74.4 | 72.7 | **73.5** | 47.4 | 51.6 | **49.4** |

Results on the Wiki test set.

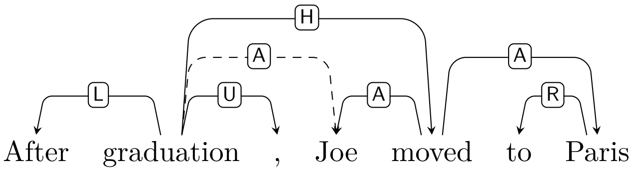
| | Primary | | | Remote | | |
|---|---|---|---|---|---|---|
| | **LP** | **LR** | **LF** | **LP** | **LR** | **LF** |
| Sparse | 59.6 | 59.9 | 59.8 | 22.2 | 7.7 | 11.5 |
| MLP | 62.3 | 62.6 | 62.5 | 20.9 | 6.3 | 9.7 |
| BiLSTM | 68.7 | 68.5 | **68.6** | 38.6 | 18.8 | **25.3** |

Results on the 20K Leagues out-of-domain set.

# Bilexical Graph Approximation

No existing UCCA parsers ⇒ compare to bilexical parsers:

1. Convert UCCA to bilexical dependencies.
2. Train bilexical parsers and apply to test sentences.
3. Reconstruct UCCA graphs and compare with gold standard.




Bilexical DAG approximation.

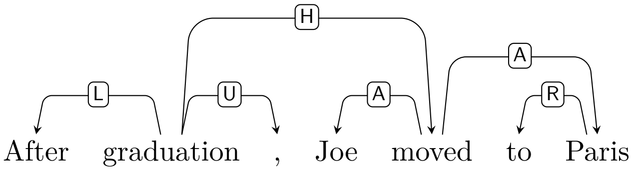
# Baselines

Bilexical DAG parsers:

- DAGParser (Ribeyre et al., 2014): transition-based.
- TurboParser (Almeida and Martins, 2015): graph-based.

Tree parsers (all transition-based):

- MaltParser (Nivre et al., 2007): bilexical tree parser.
- LSTM Parser (Dyer et al., 2015): bilexical tree parser.
- UPARSE (Maier, 2015): allows non-terminals, discontinuity.




Bilexical tree approximation.

Conversion to trees is just removing remote edges.

# Results

$\text{TUPA}_{\text{BiLSTM}}$ obtains the highest F-scores in all metrics:

| | Primary | | | Remote | | |
|---|---|---|---|---|---|---|
| | **LP** | **LR** | **LF** | **LP** | **LR** | **LF** |
| $\text{TUPA}_{\text{Sparse}}$ | 64.5 | 63.7 | 64.1 | 19.8 | 13.4 | 16 |
| $\text{TUPA}_{\text{MLP}}$ | 65.2 | 64.6 | 64.9 | 23.7 | 13.2 | 16.9 |
| $\text{TUPA}_{\text{BiLSTM}}$ | 74.4 | 72.7 | **73.5** | 47.4 | 51.6 | **49.4** |
| Bilexical DAG | | | (91) | | | (58.3) |
| DAGParser | 61.8 | 55.8 | 58.6 | 9.5 | 0.5 | 1 |
| TurboParser | 57.7 | 46 | 51.2 | 77.8 | 1.8 | 3.7 |
| Bilexical tree | | | (91) | | | – |
| MaltParser | 62.8 | 57.7 | 60.2 | – | – | – |
| LSTM Parser | 73.2 | 66.9 | 69.9 | – | – | – |
| Tree | | | (100) | | | – |
| UPARSE | 60.9 | 61.2 | 61.1 | – | – | – |

Results on the Wiki test set.

# Results

Similar on out-of-domain test set:

| | Primary | | | Remote | | |
|---|---|---|---|---|---|---|
| | **LP** | **LR** | **LF** | **LP** | **LR** | **LF** |
| $\text{TUPA}_{\text{Sparse}}$ | 59.6 | 59.9 | 59.8 | 22.2 | 7.7 | 11.5 |
| $\text{TUPA}_{\text{MLP}}$ | 62.3 | 62.6 | 62.5 | 20.9 | 6.3 | 9.7 |
| $\text{TUPA}_{\text{BiLSTM}}$ | 68.7 | 68.5 | **68.6** | 38.6 | 18.8 | **25.3** |
| Bilexical DAG | | | (91.3) | | | (43.4) |
| DAGParser | 56.4 | 50.6 | 53.4 | – | 0 | 0 |
| TurboParser | 50.3 | 37.7 | 43.1 | 100 | 0.4 | 0.8 |
| Bilexical tree | | | (91.3) | | | – |
| MaltParser | 57.8 | 53 | 55.3 | – | – | – |
| LSTM Parser | 66.1 | 61.1 | 63.5 | – | – | – |
| Tree | | | (100) | | | – |
| UPARSE | 52.7 | 52.8 | 52.8 | – | – | – |

Results on the 20K Leagues out-of-domain set.

# Conclusion

- UCCA's semantic distinctions require a graph structure including challenging structural properties.
- TUPA is a transition-based parser suitable for UCCA, achieving high accuracy with BiLSTM model.
- Outperforms conversion-based parsing with a variety of strong bilexical DAG and tree baselines.

Corpora: `http://www.cs.huji.ac.il/~oabend/ucca.html`
Code: `https://github.com/danielhers/tupa`
Demo: `https://rebrand.ly/tupa`

# Future Work

- Beam search, training with exploration.
- More languages (German corpus construction is underway).
- Parsing other schemes, such as AMR.
- Different target representations for conversion.
- Application to text simplification and other tasks.

Thank you

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# UCCA Corpora

| | Wiki | | | 20K |
|---|---|---|---|---|
| | Train | Dev | Test | Leagues |
| # passages | 300 | 34 | 33 | 154 |
| # sentences | 4268 | 454 | 503 | 506 |
| # nodes | 298,993 | 33,704 | 35,718 | 29,315 |
| % terminal | 42.96 | 43.54 | 42.87 | 42.09 |
| % non-term. | 58.33 | 57.60 | 58.35 | 60.01 |
| % **discont.** | **0.54** | **0.53** | **0.44** | **0.81** |
| % **reentrant** | **2.38** | **1.88** | **2.15** | **2.03** |
| # edges | 287,914 | 32,460 | 34,336 | 27,749 |
| % primary | 98.25 | 98.75 | 98.74 | 97.73 |
| % remote | 1.75 | 1.25 | 1.26 | 2.27 |
| Average per non-terminal node | | | | |
| # children | 1.67 | 1.68 | 1.66 | 1.61 |

Corpus statistics.

# Evaluation

*Mutual edges* between predicted graph $G_p = (V_p, E_p, \ell_p)$ and gold graph $G_g = (V_g, E_g, \ell_g)$, both over terminals $W = \{w_1, \ldots, w_n\}$:

$$M(G_p, G_g) = \left\{(e_1, e_2) \in E_p \times E_g \;\middle|\; y(e_1) = y(e_2) \wedge \ell_p(e_1) = \ell_g(e_2)\right\}$$

The yield $y(e) \subseteq W$ of an edge $e = (u, v)$ in either graph is the set of terminals in $W$ that are descendants of $v$. $\ell$ is the edge label.

Labeled precision, recall and F-score are then defined as:

$$\mathrm{LP} = \frac{|M(G_p, G_g)|}{|E_p|}, \quad \mathrm{LR} = \frac{|M(G_p, G_g)|}{|E_g|},$$

$$\mathrm{LF} = \frac{2 \cdot \mathrm{LP} \cdot \mathrm{LR}}{\mathrm{LP} + \mathrm{LR}}.$$

Two variants: one for primary edges, and another for remote edges.