Top-down Tree Long Short-Term Memory Networks

Xingxing Zhang, Liang Lu, Mirella Lapata

School of Informatics, University of Edinburgh

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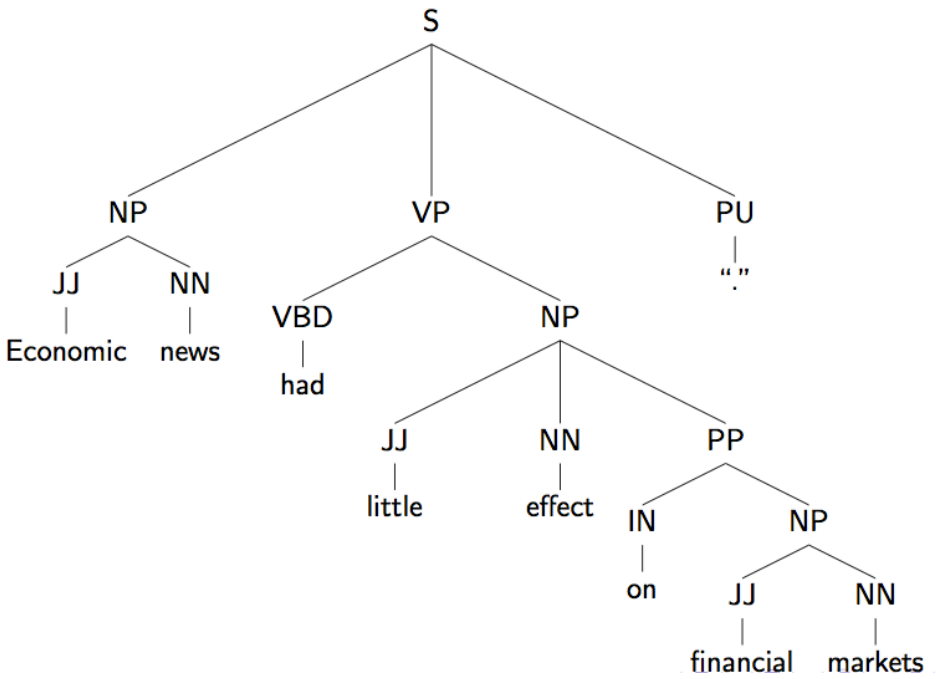
Sequential Language Models

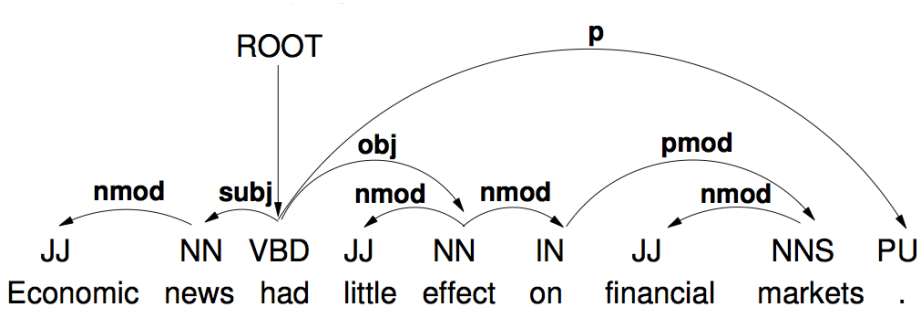
$$P(S = w_1, w_2, \ldots, w_n) = \prod_{i=1}^{n} P(w_i | w_{1:i-1}) \tag{1}$$

- State of the Art
  - based on Long Short Term Memory Network Language Model (Hochreiter and Schmidhuber, 1997; Sundermeyer et al., 2012)
  - **Billion word benchmark results** reported in Jozefowicz et al., (2016)

Models	PPL
KN5	67.6
LSTM	30.6
LSTM+CNN INPUTS	30.0

Will tree structures help LMs?





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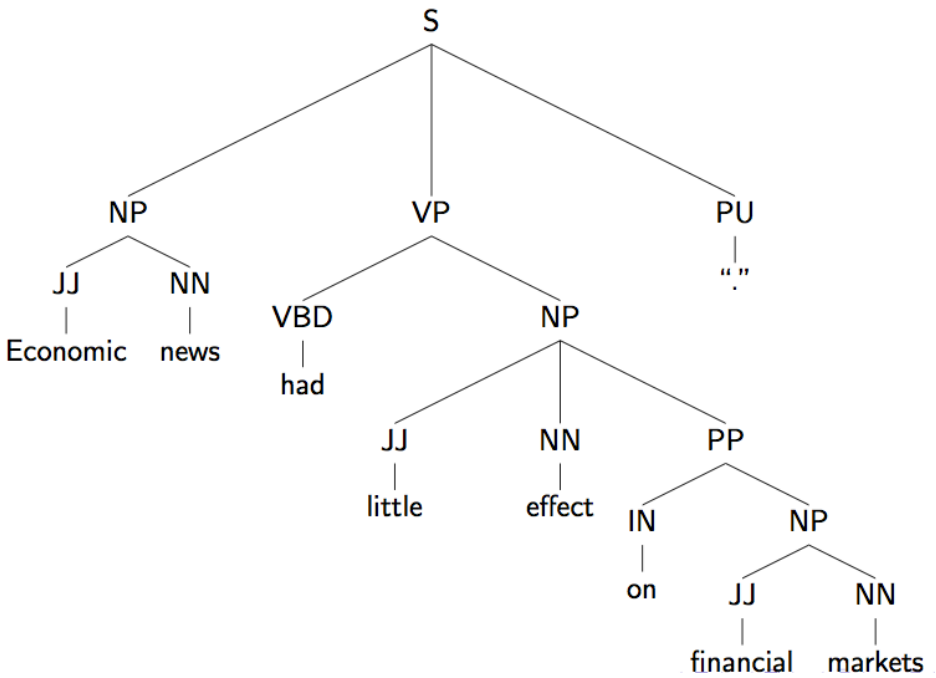
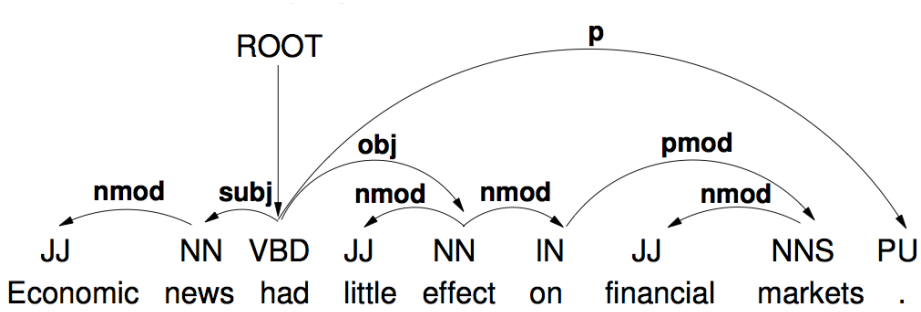
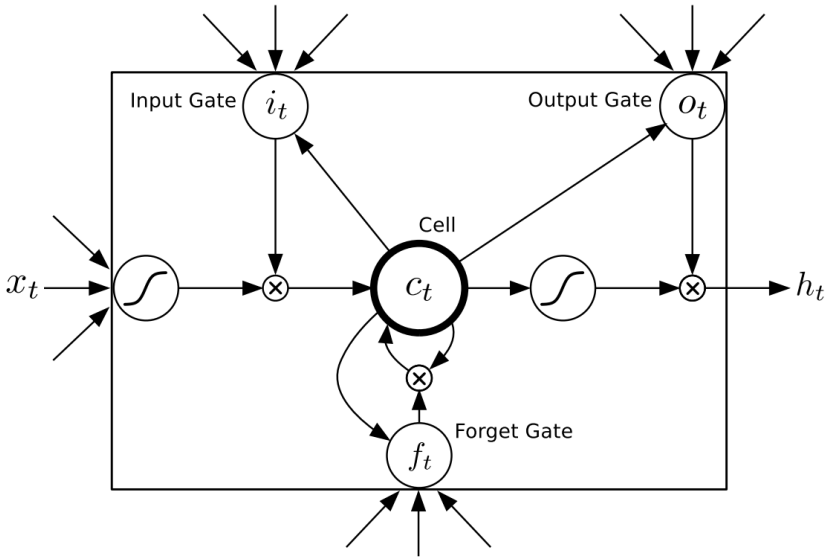
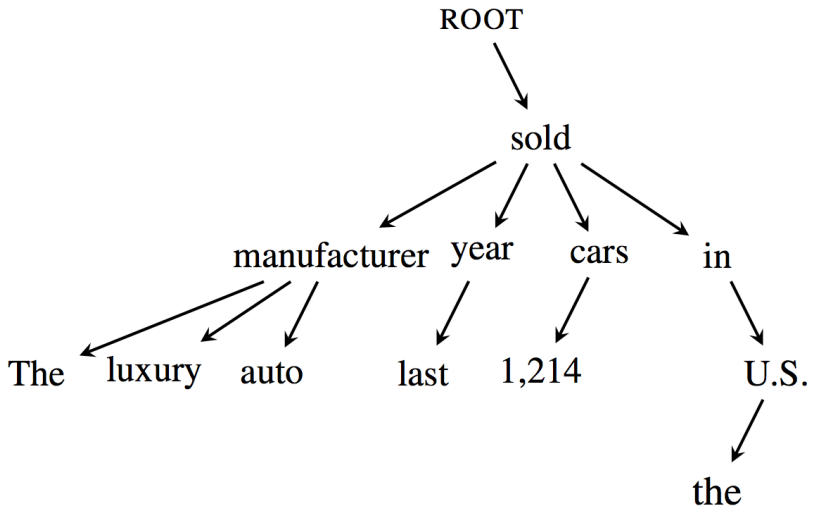




- Probably yes
  - LMs based on Constituency Parsing (Chelba and Jelinek, 2000; Roark, 2001; Charniak, 2001)
  - LMs based on Dependency Parsing (Shen et al., 2008; Zhang, 2009; Sennrich, 2015)

LSTMs + Dependency Trees = TreeLSTMs





- Why?
  - Sentence Length N v.s. Tree Height $log(N)$

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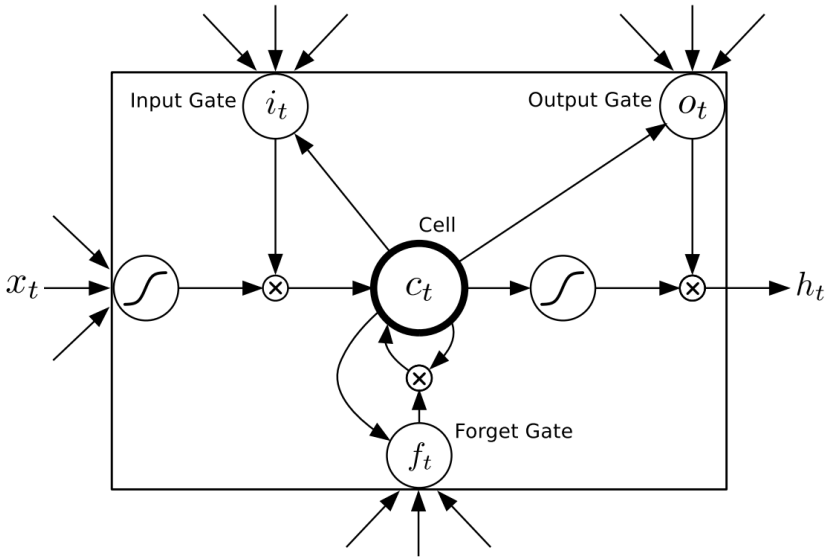

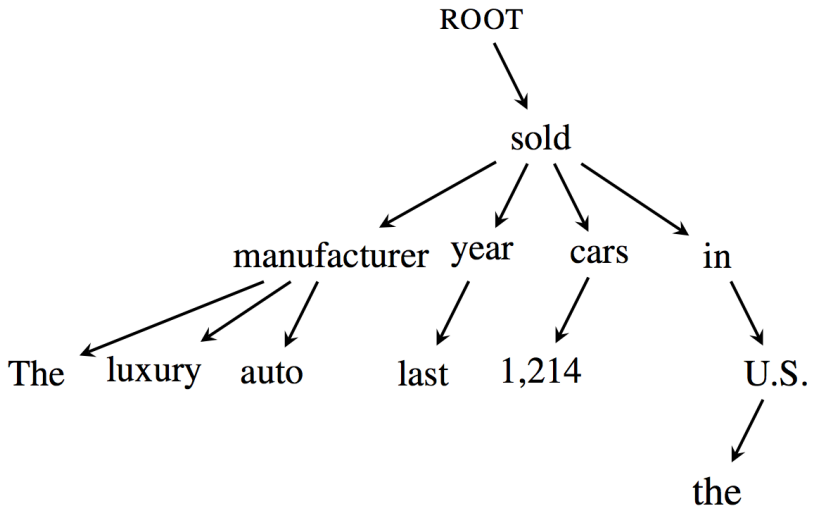

- Why?
  - Sentence Length N v.s. Tree Height $log(N)$
- How?
  - Top-down Generation
  - Breadth-first search
  - reminiscent of Eisner (1996)

Generation Process (Unlabeled Trees)

The luxury auto manufacturer last year sold 1,214 cars in the U.S.

ROOT

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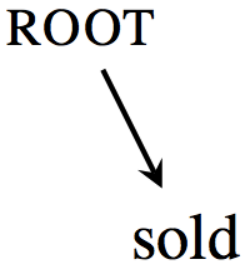

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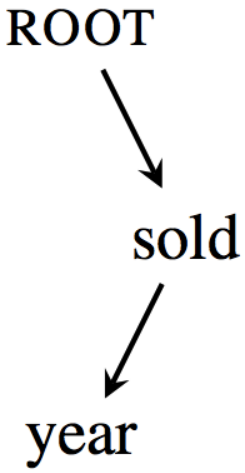

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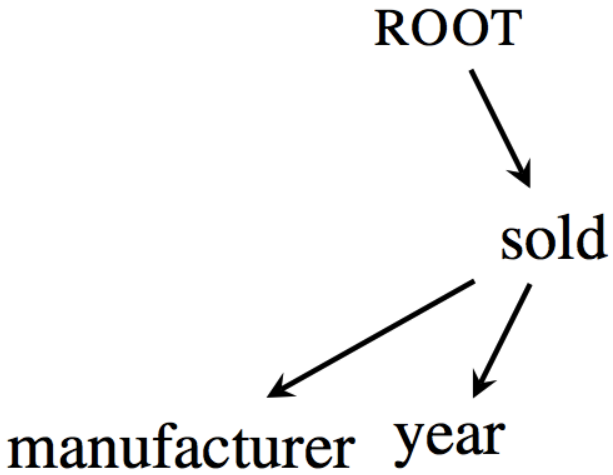

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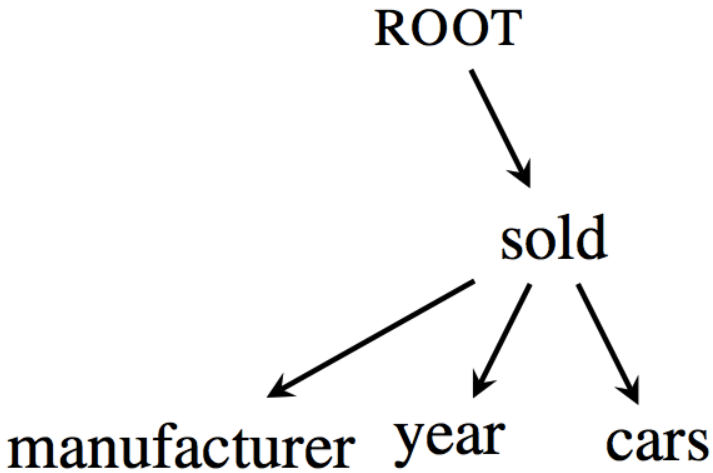

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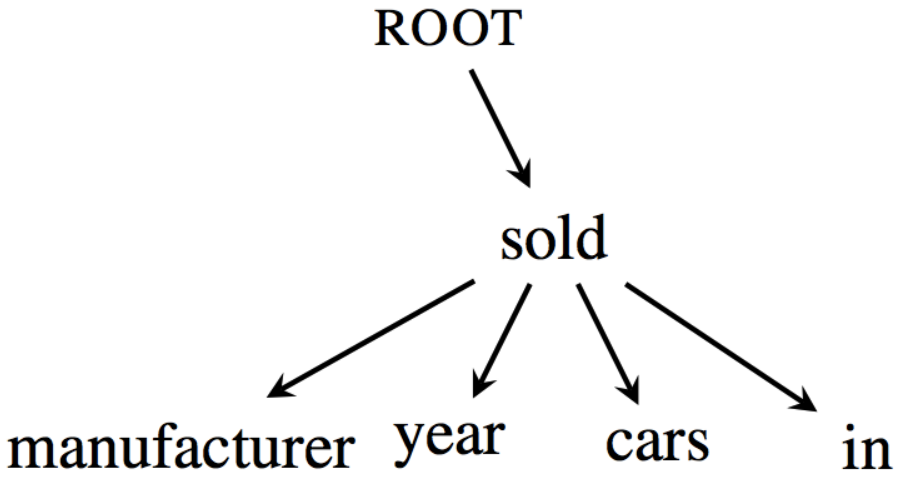

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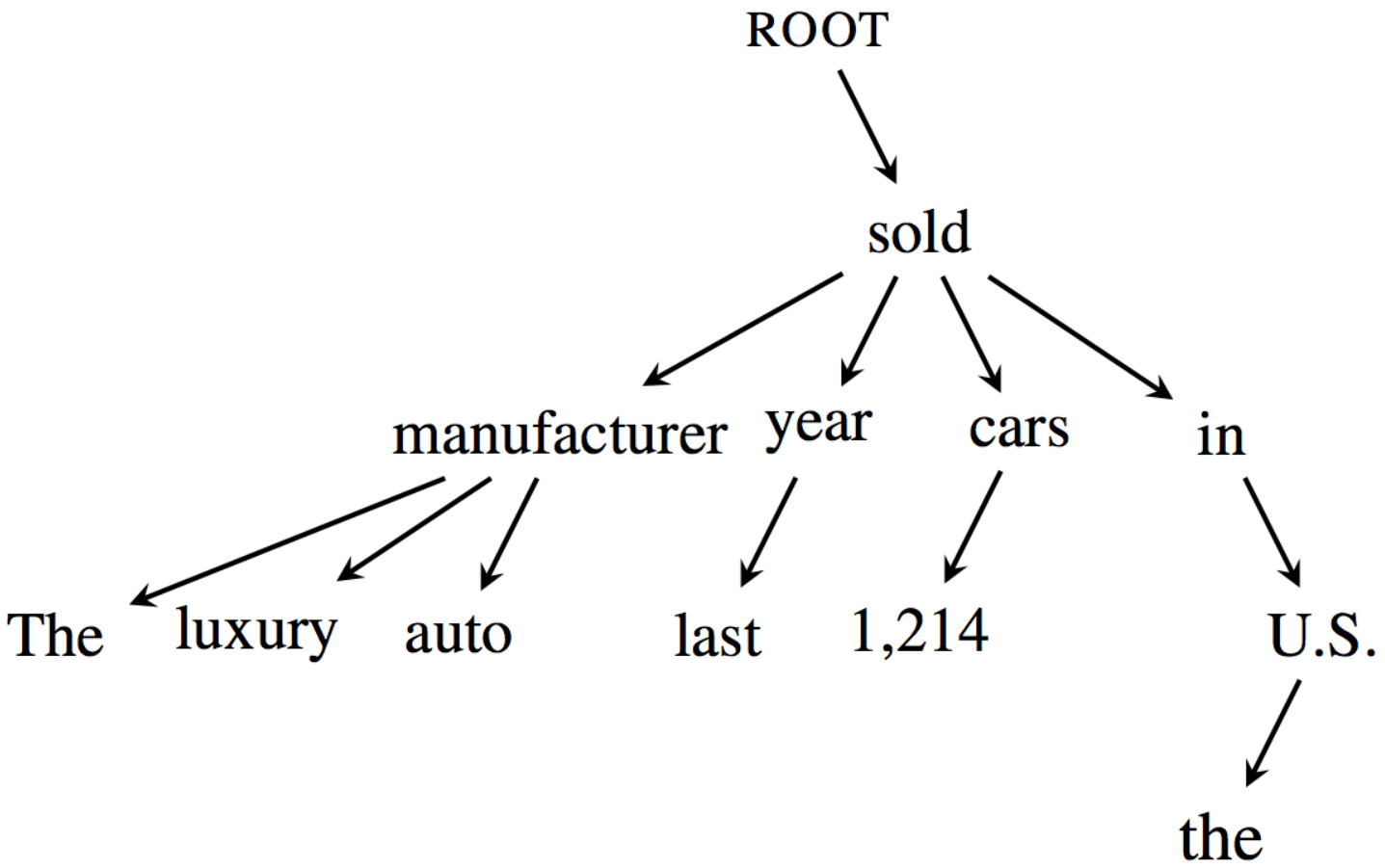


Tree LSTM

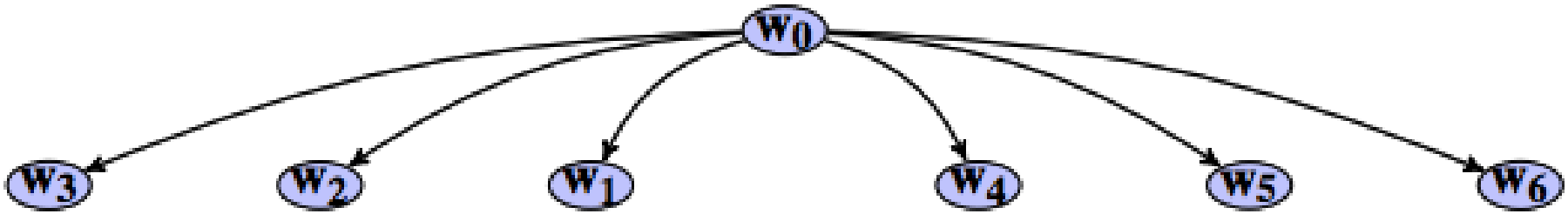
$$P(S) = \prod_{i=1}^{n} P(w_i | w_{1:i-1}) \tag{2}$$

$$\Downarrow$$

$$P(S|T) = \prod_{w \in \mathrm{BFS}(T) \setminus \mathrm{ROOT}} P(w|\mathcal{D}(w)) \tag{3}$$

- $\mathcal{D}(w)$ is the *Dependency Path* of w.
- $\mathcal{D}(w)$ is a generated sub-tree.
- Works on **projective** and **unlabeled** dependency trees.

Tree LSTM



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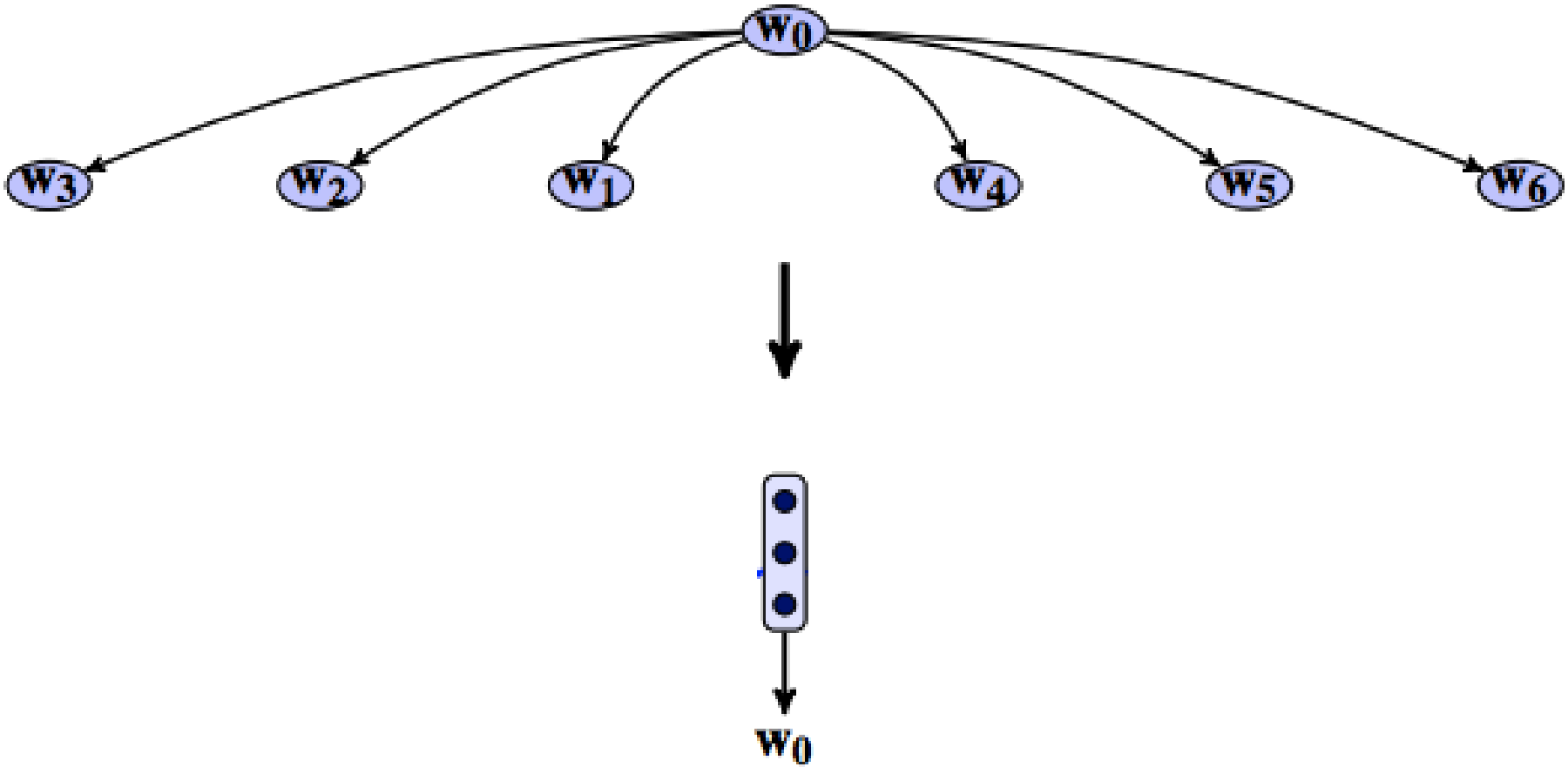

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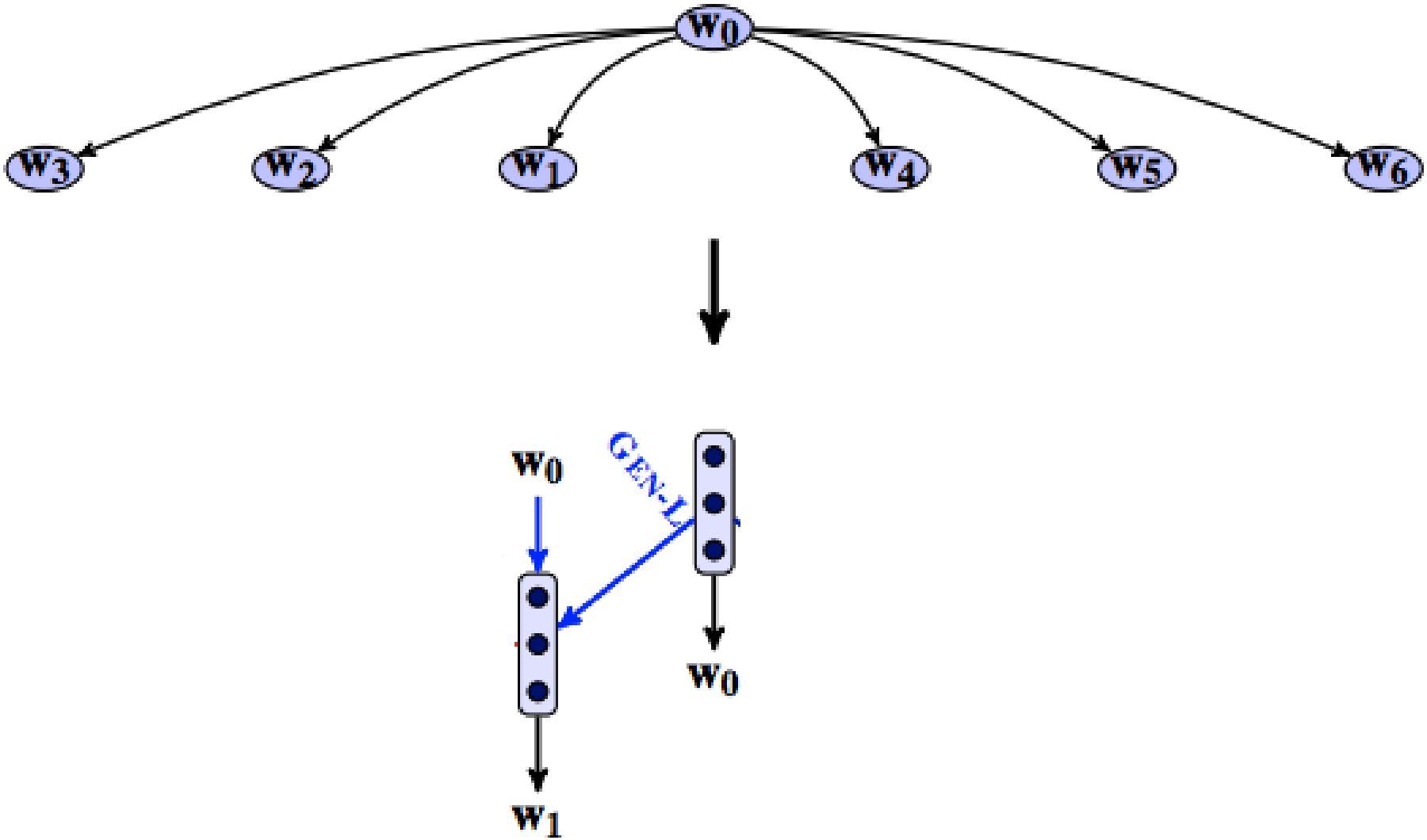

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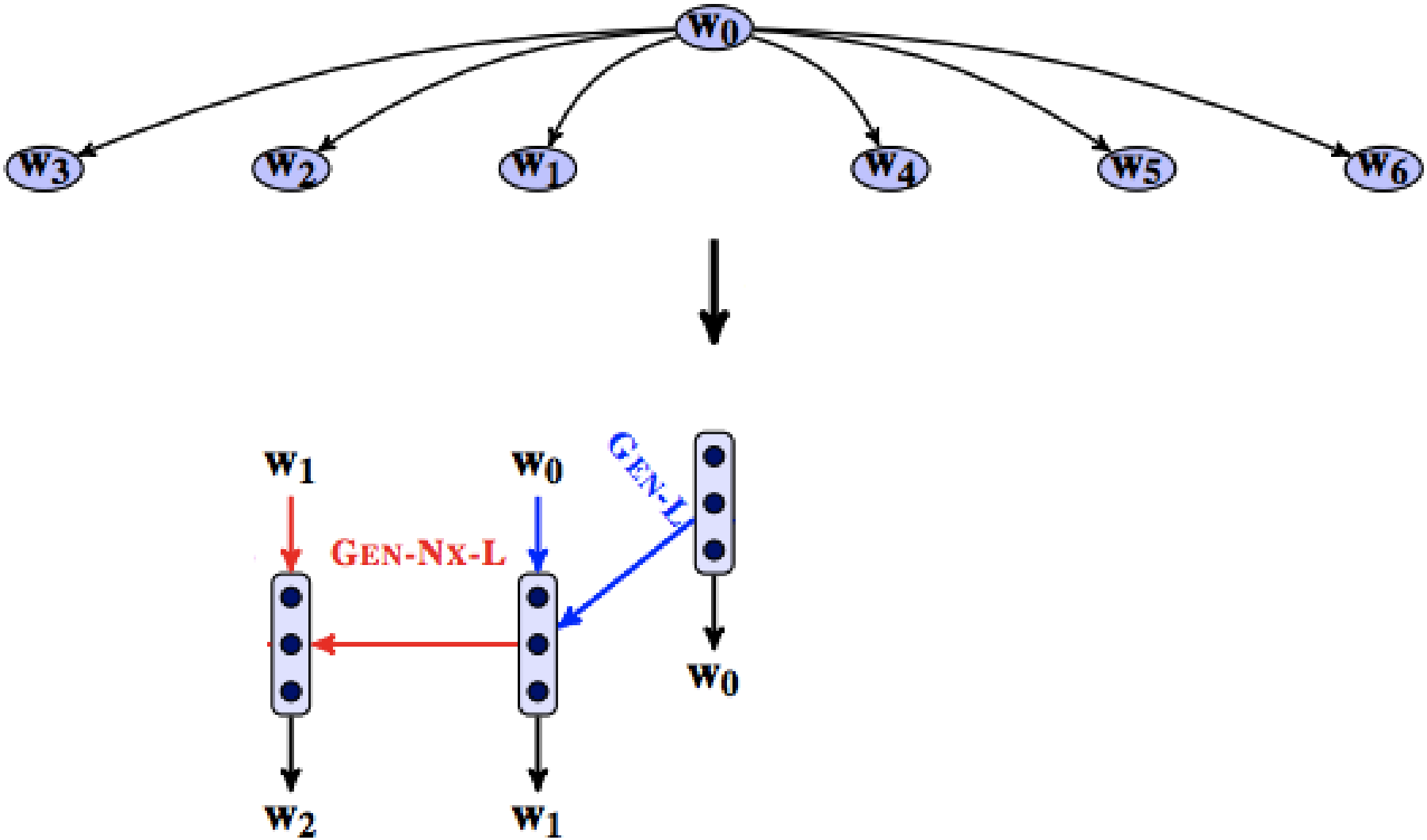

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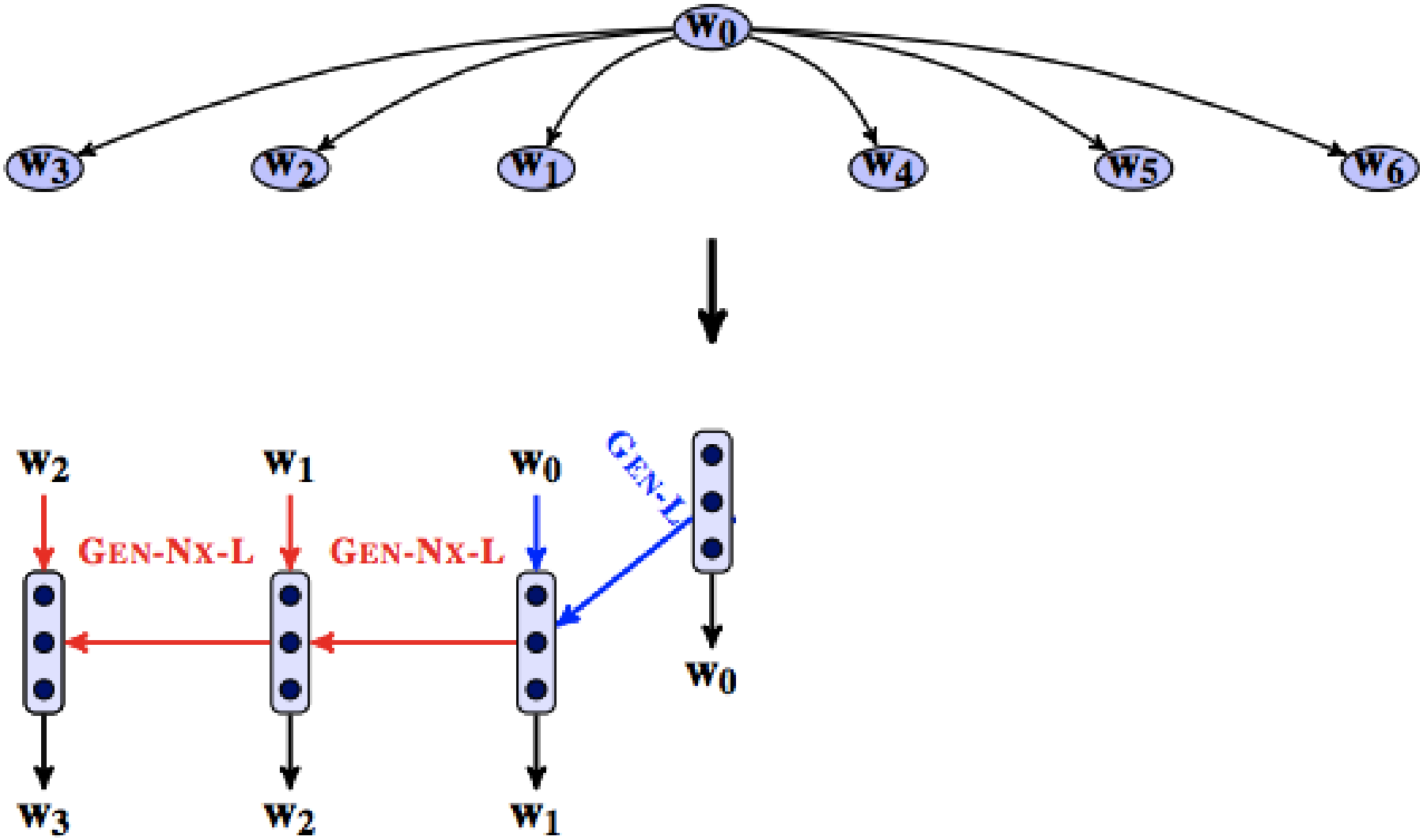

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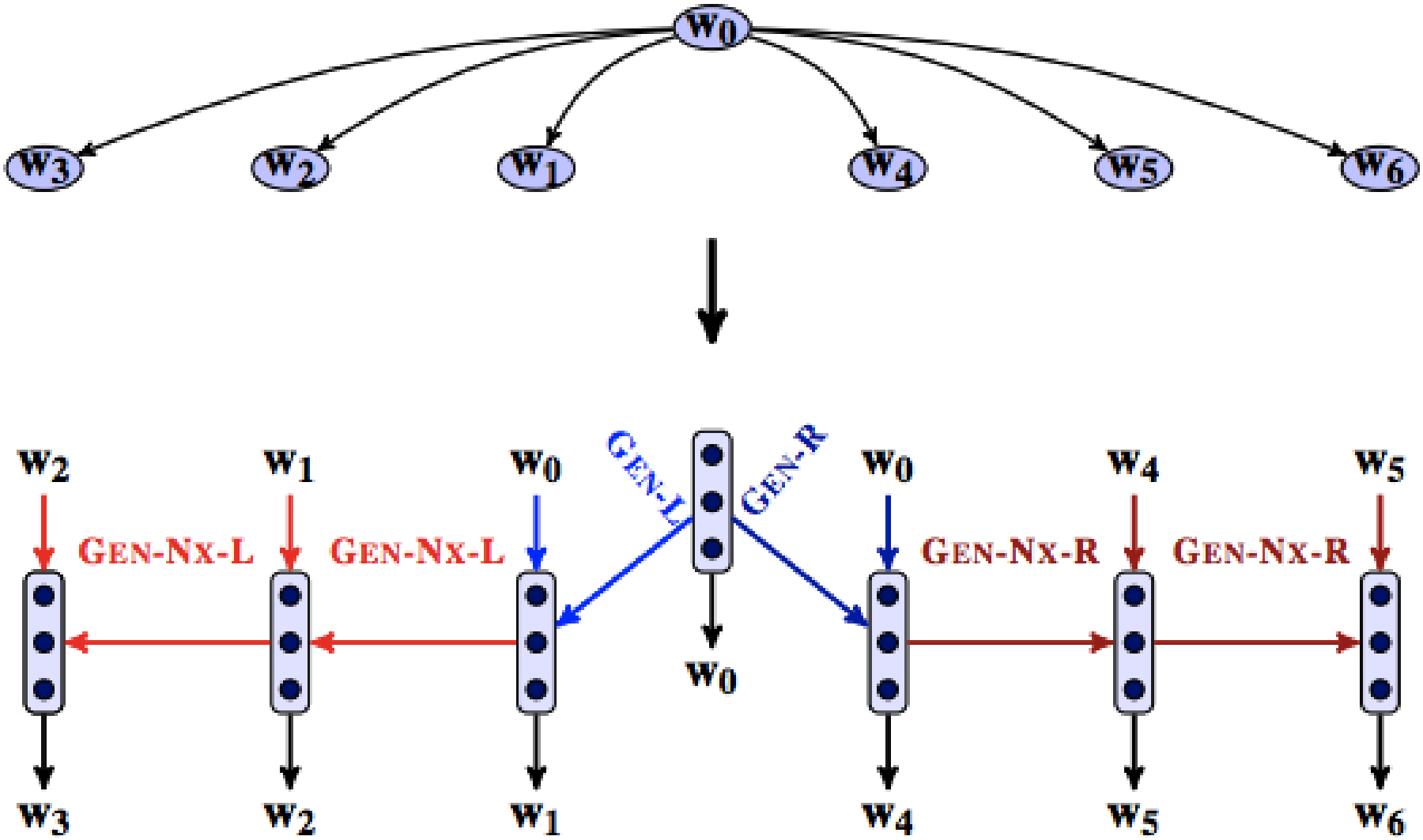
w0
w3
w2
w1
w4
w5
w6
w2
w1
w0
GEN-L
GEN-R
w0
w4
w5
GEN-NX-L
GEN-NX-L
GEN-NX-R
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w0
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w2
w1
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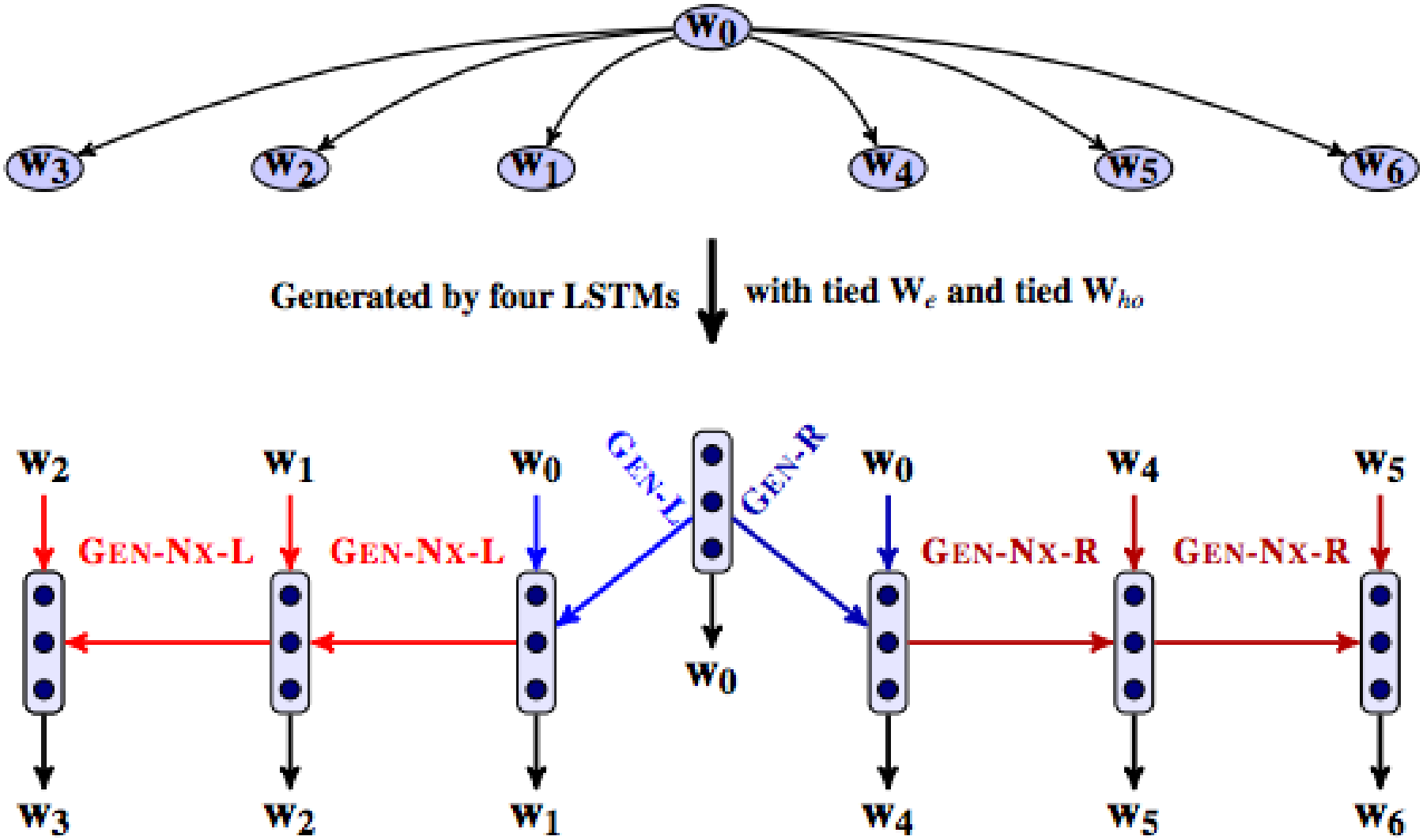
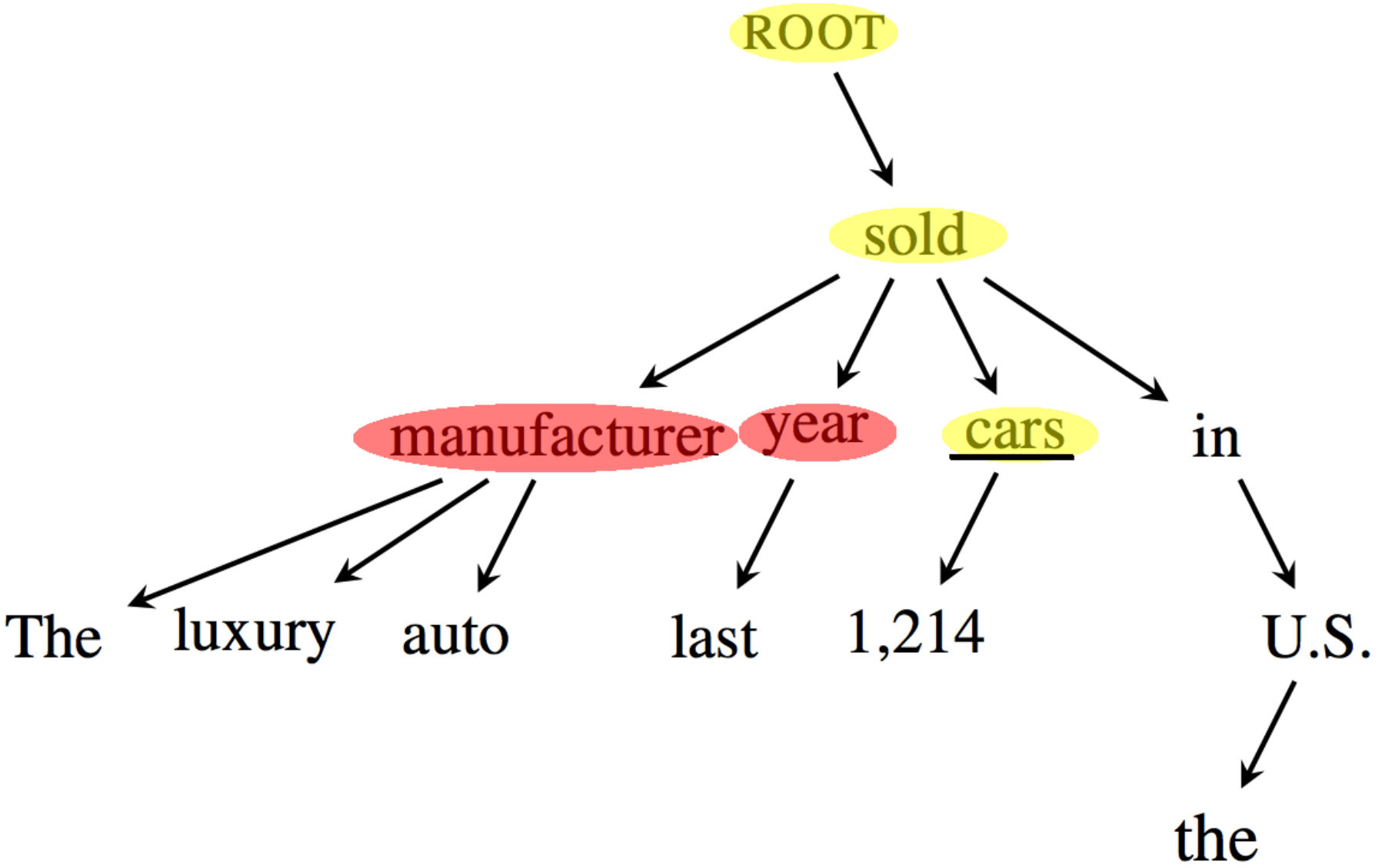
w6

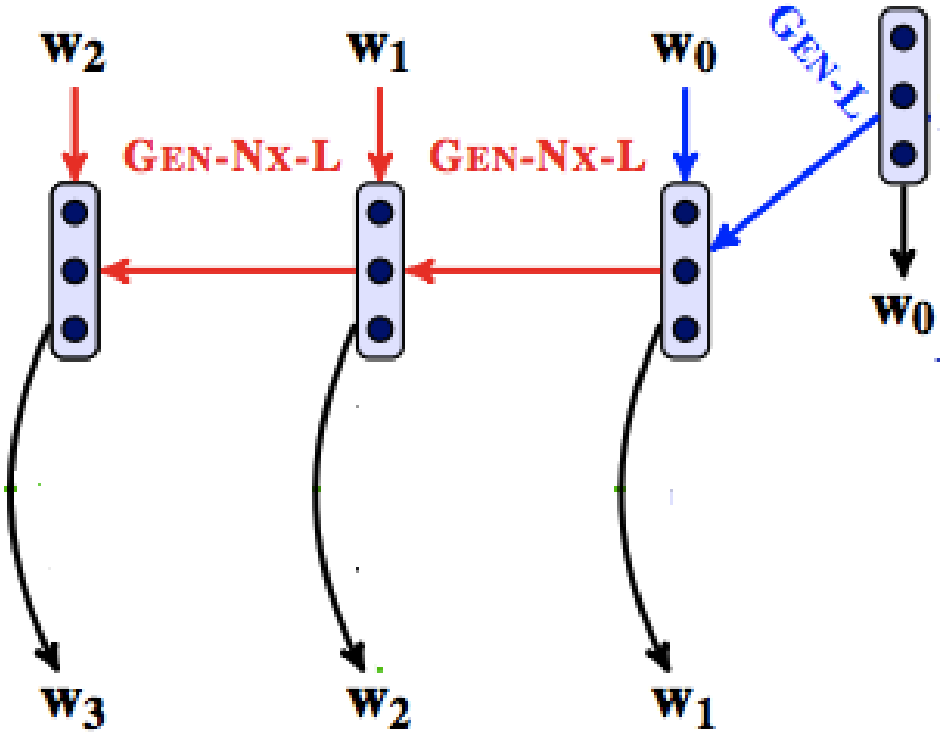
Tree LSTM


w0
w3
w2
w1
w4
w5
w6
Generated by four LSTMs
with tied W_e and tied W_{ho}
w2
w1
w0
Gen-L
Gen-R
w0
w4
w5
Gen-Nx-L
Gen-Nx-L
Gen-Nx-R
Gen-Nx-R
w0
w3
w2
w1
w4
w5
w6

One Limitation of Tree LSTM



Left Dependent Tree LSTM



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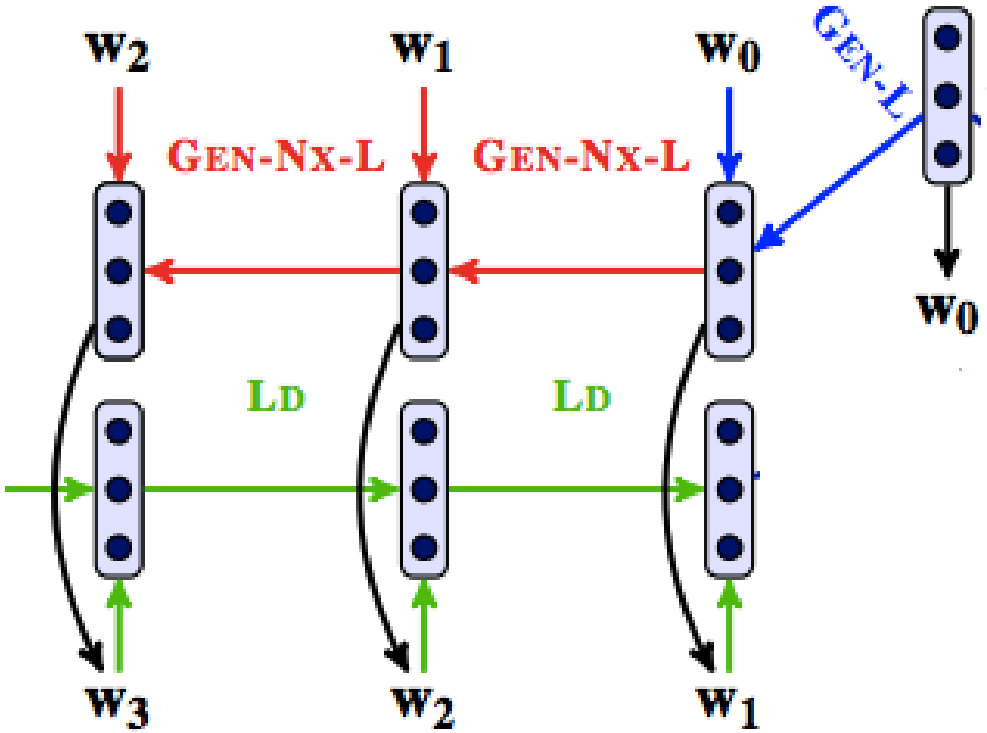

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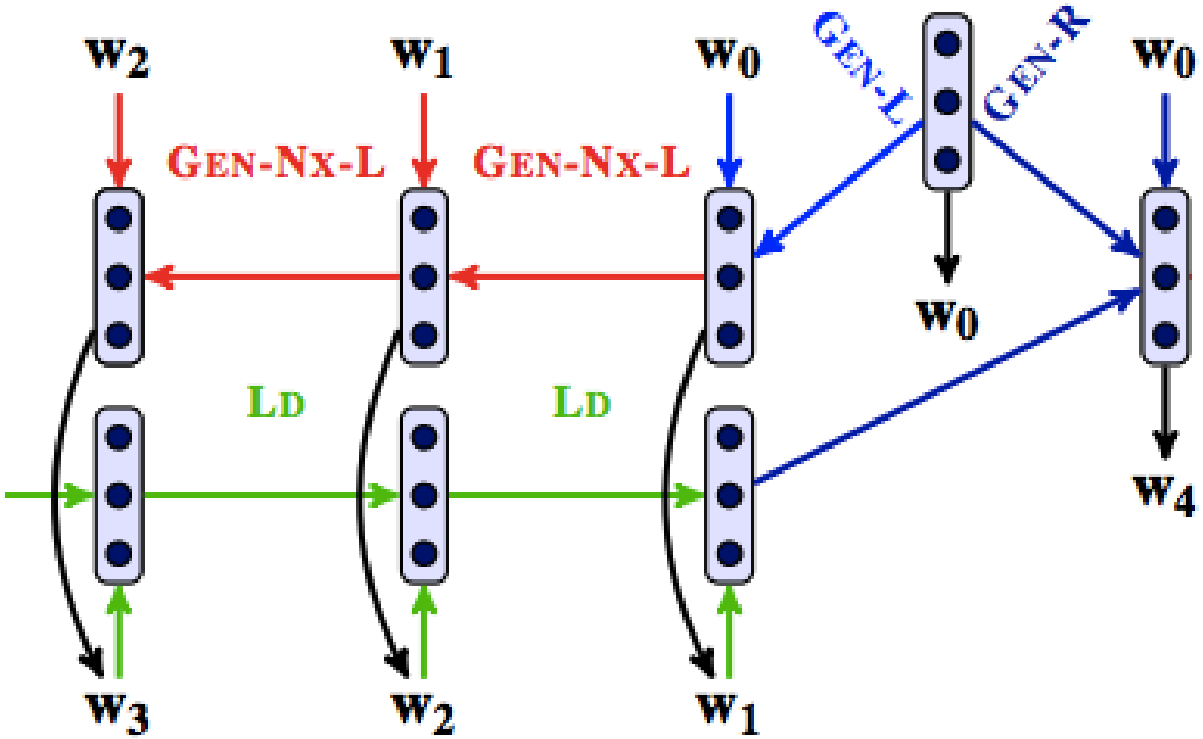

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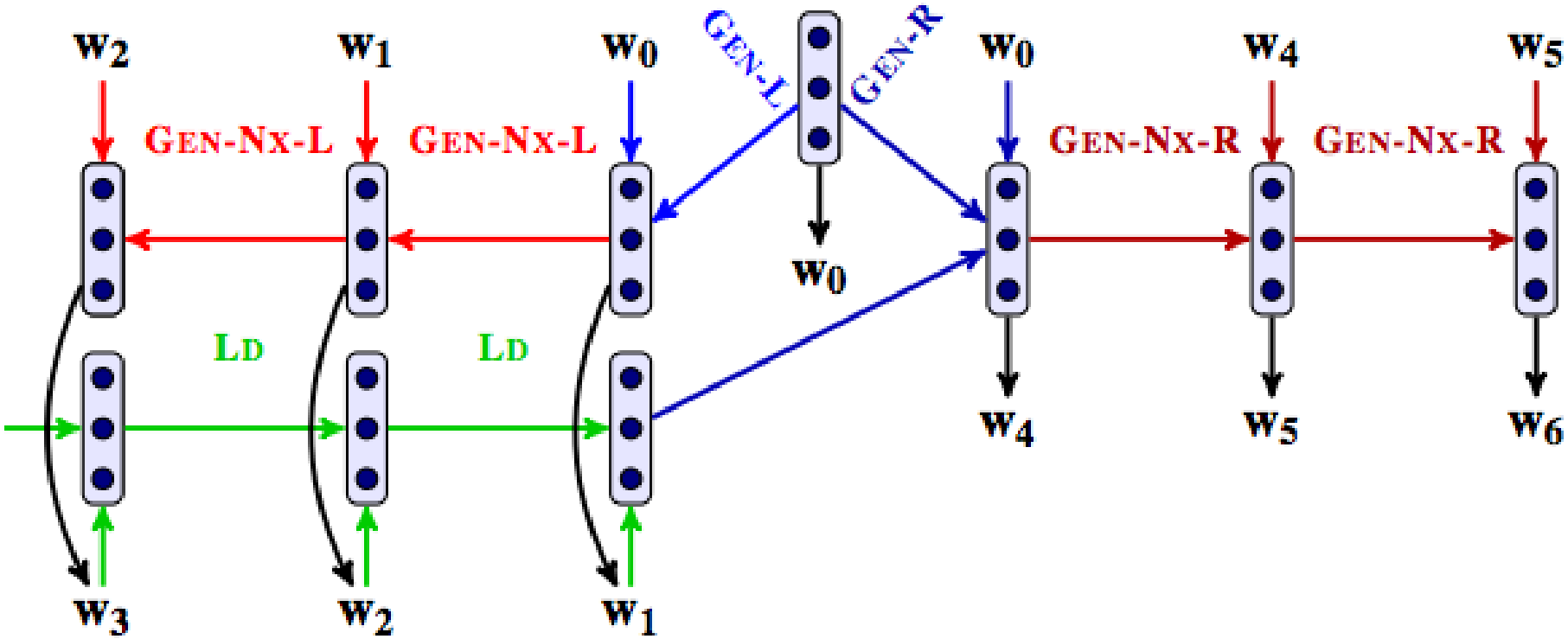
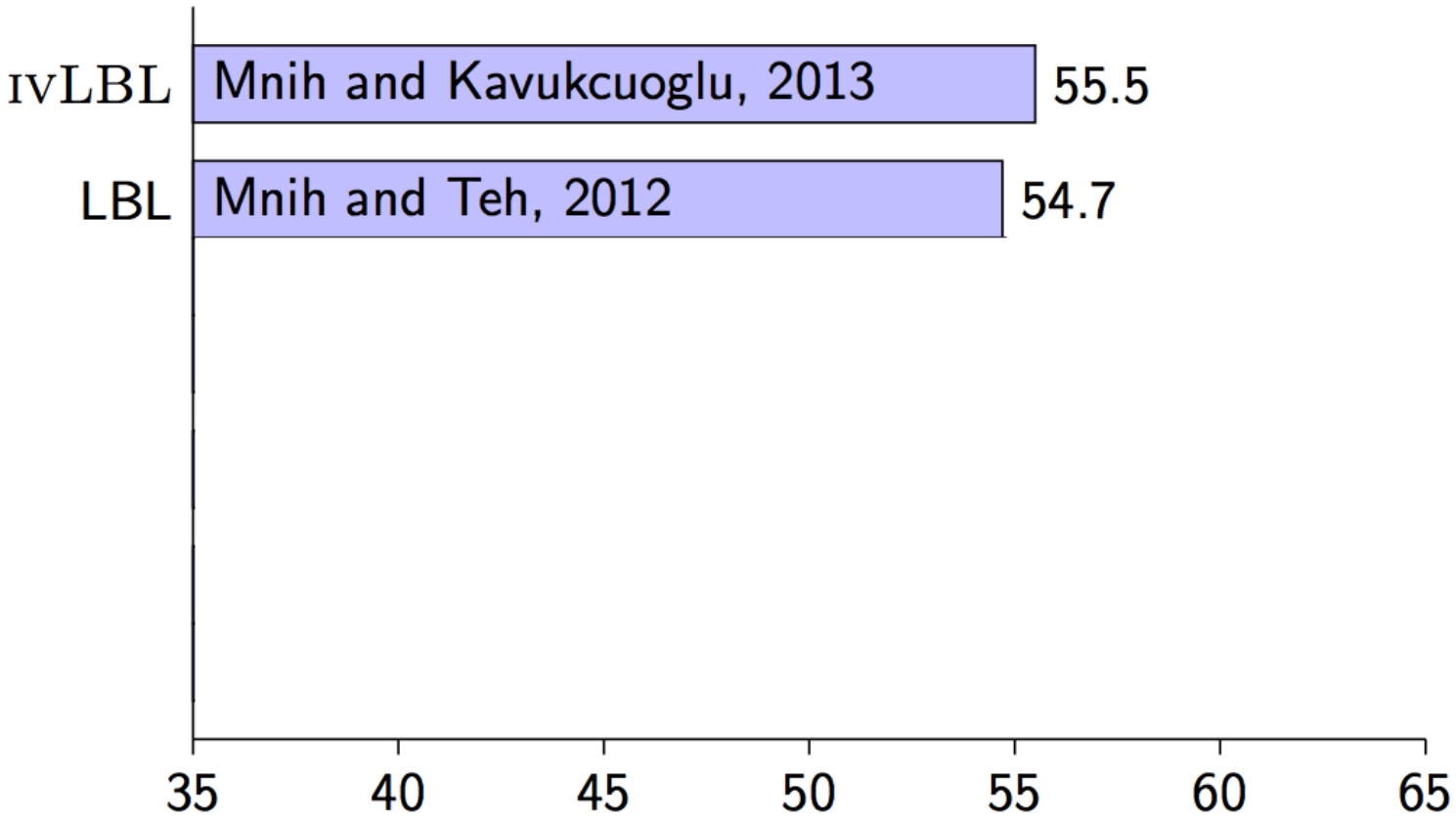


Experiments

MSR Sentence Completion Challenge

1) I have seen it on him , and could _____ to it.
a) write b) migrate c) climb d) swear e) contribute

- Training set: 49 million words (around 2 million sentences)
- development set: 4000 sentences
- test set: 1040 completion questions.


IVLBL
Mnih and Kavukcuoglu, 2013
55.5
LBL
Mnih and Teh, 2012
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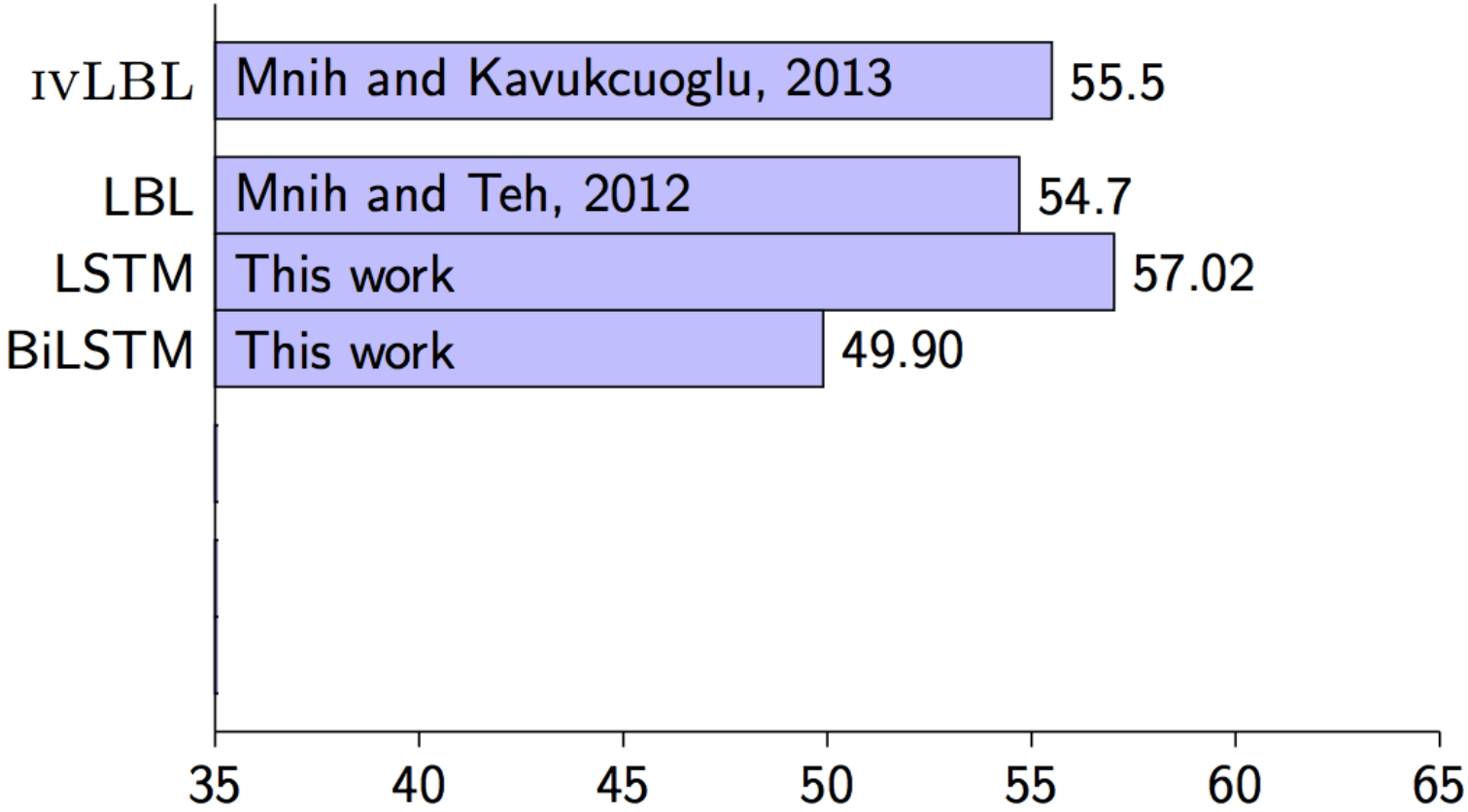
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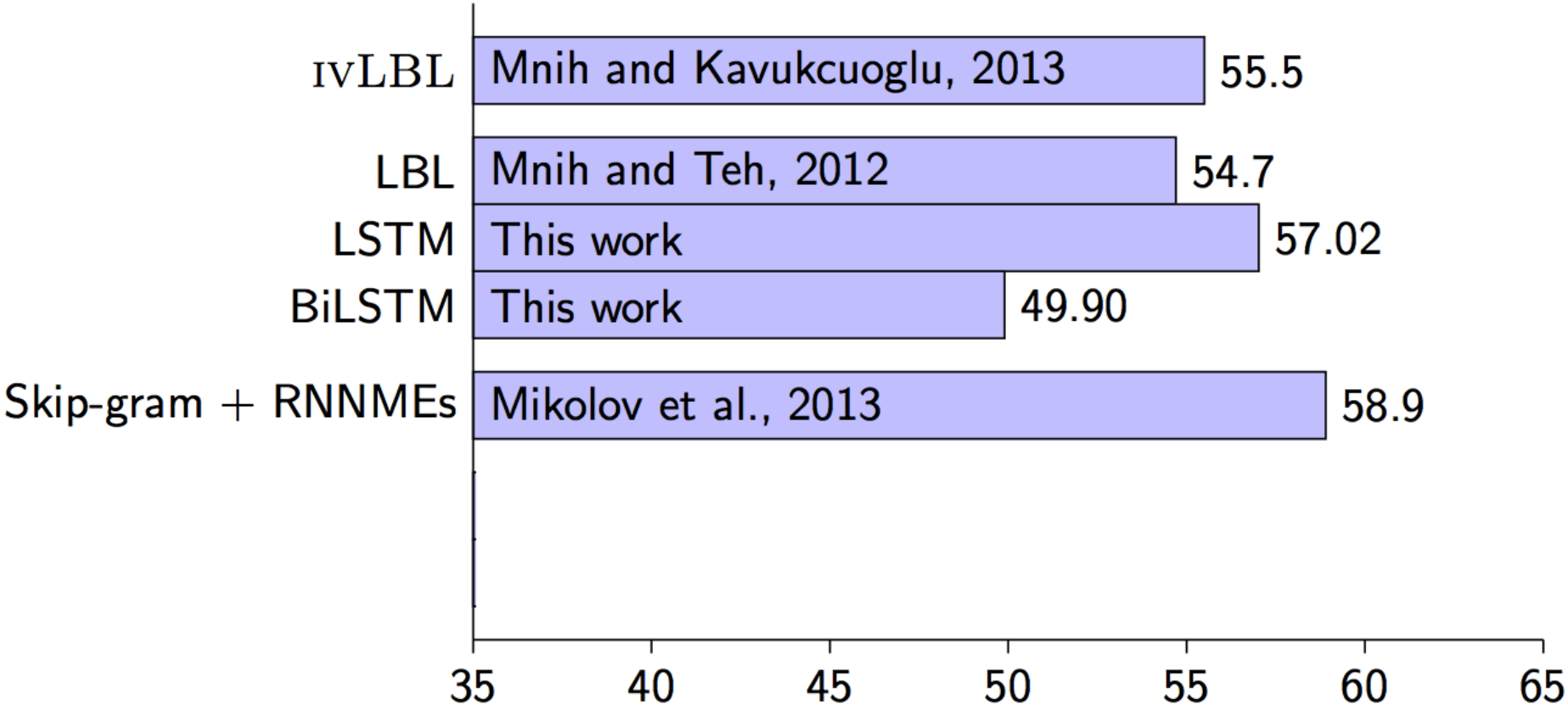
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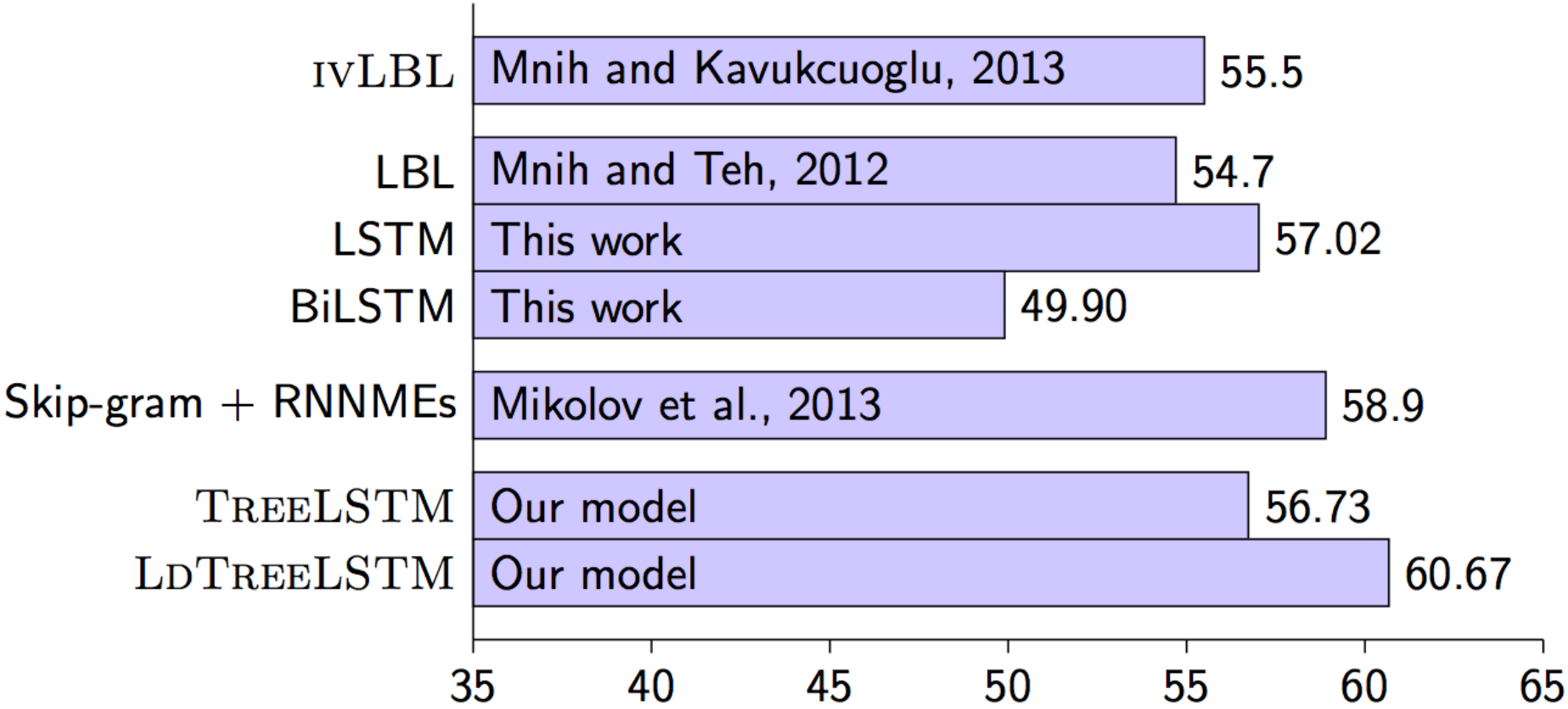
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TreeLSTM
Our model
56.73
LdTreeLSTM
Our model
60.67
35
40
45
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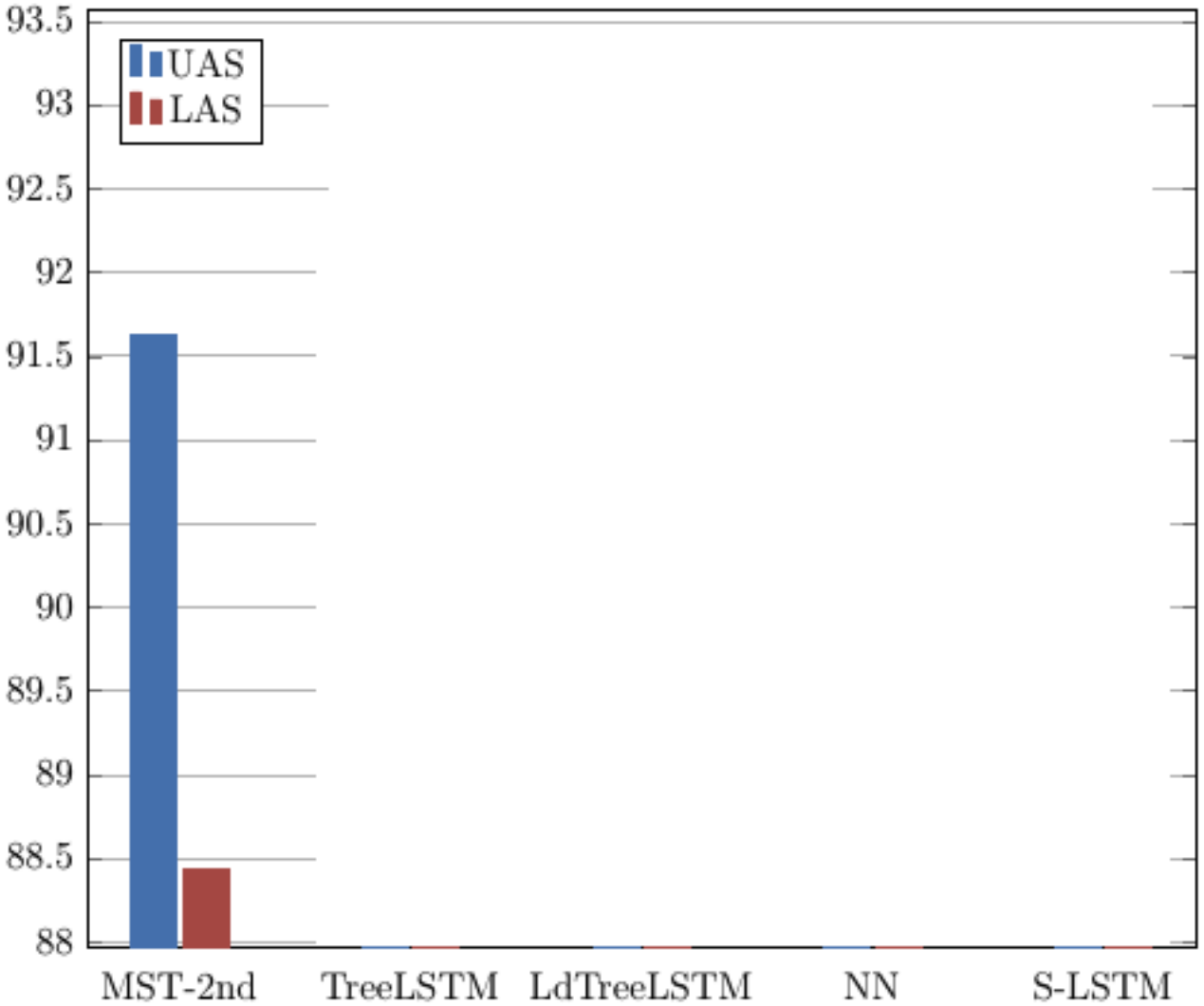
65

Dependency Parsing Reranking

- Rerank 2nd Order MSTParser (McDonald and Pereira, 2006)
- We train TreeLSTM and LdTreeLSTM as language models.
- We only use words as input features; POS tags, dependency labels or composition features are not used.

Dependency Parsing Reranking



NN: Chen & Manning, 2014; S-LSTM: Dyer et al., 2015

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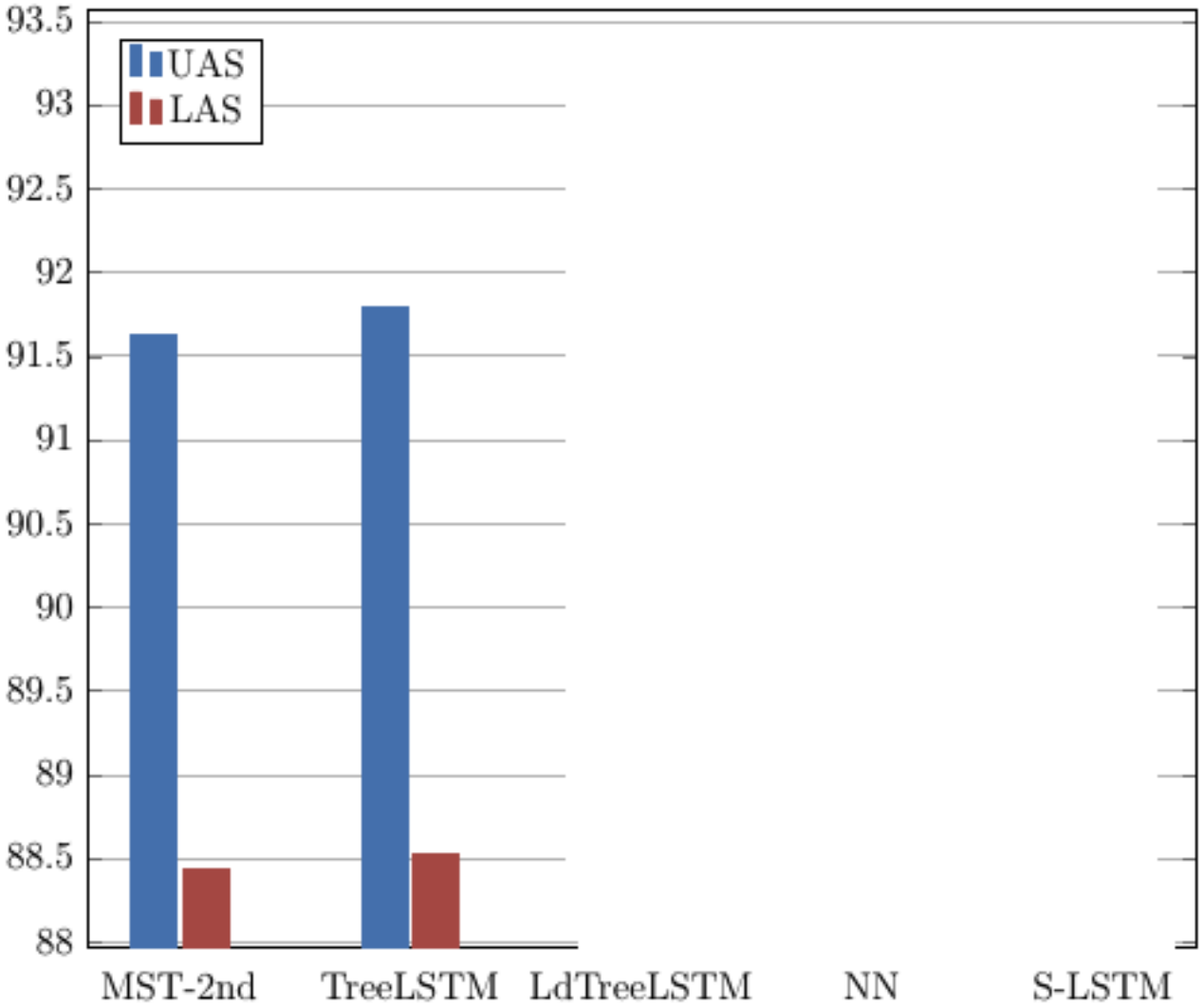

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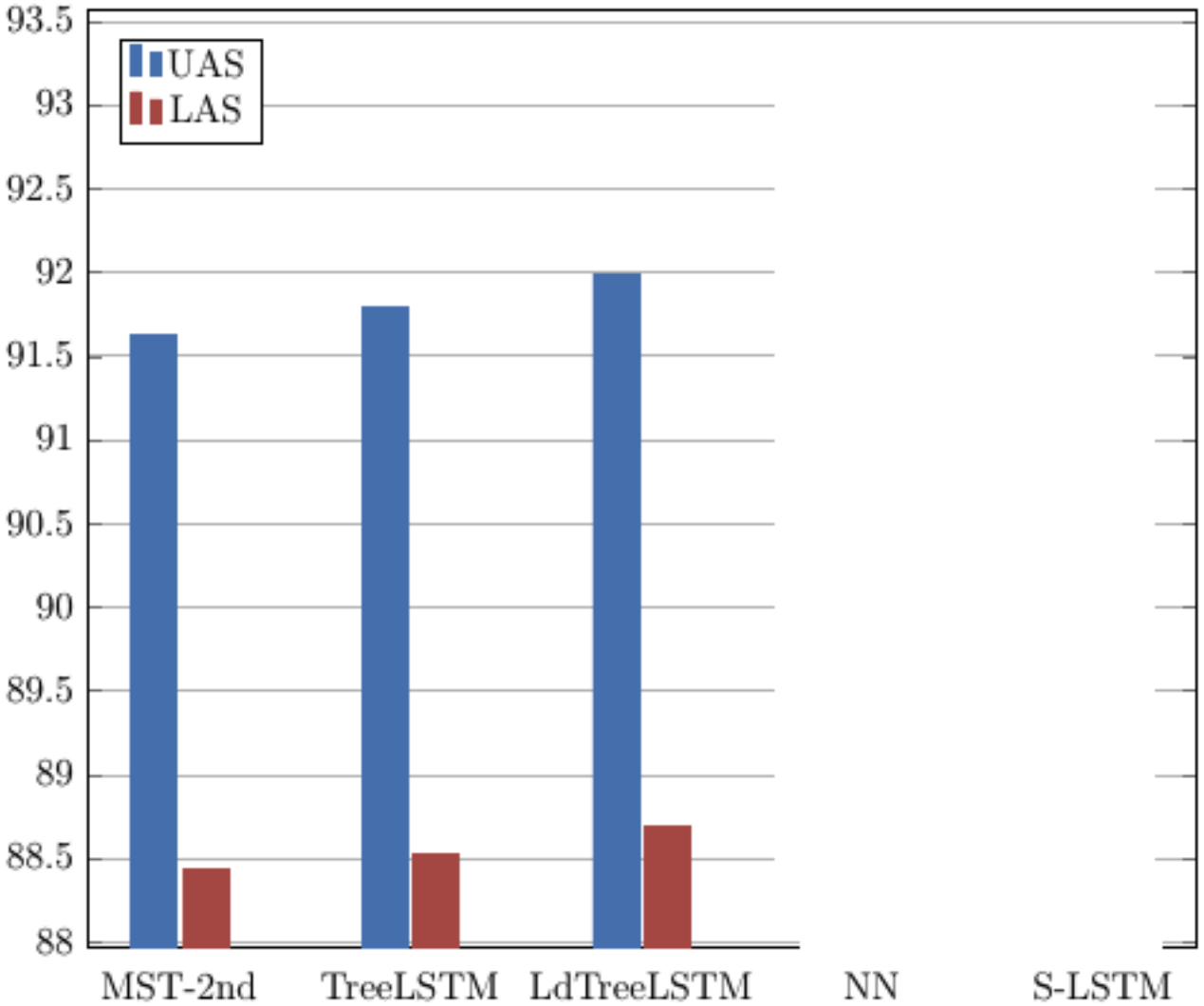

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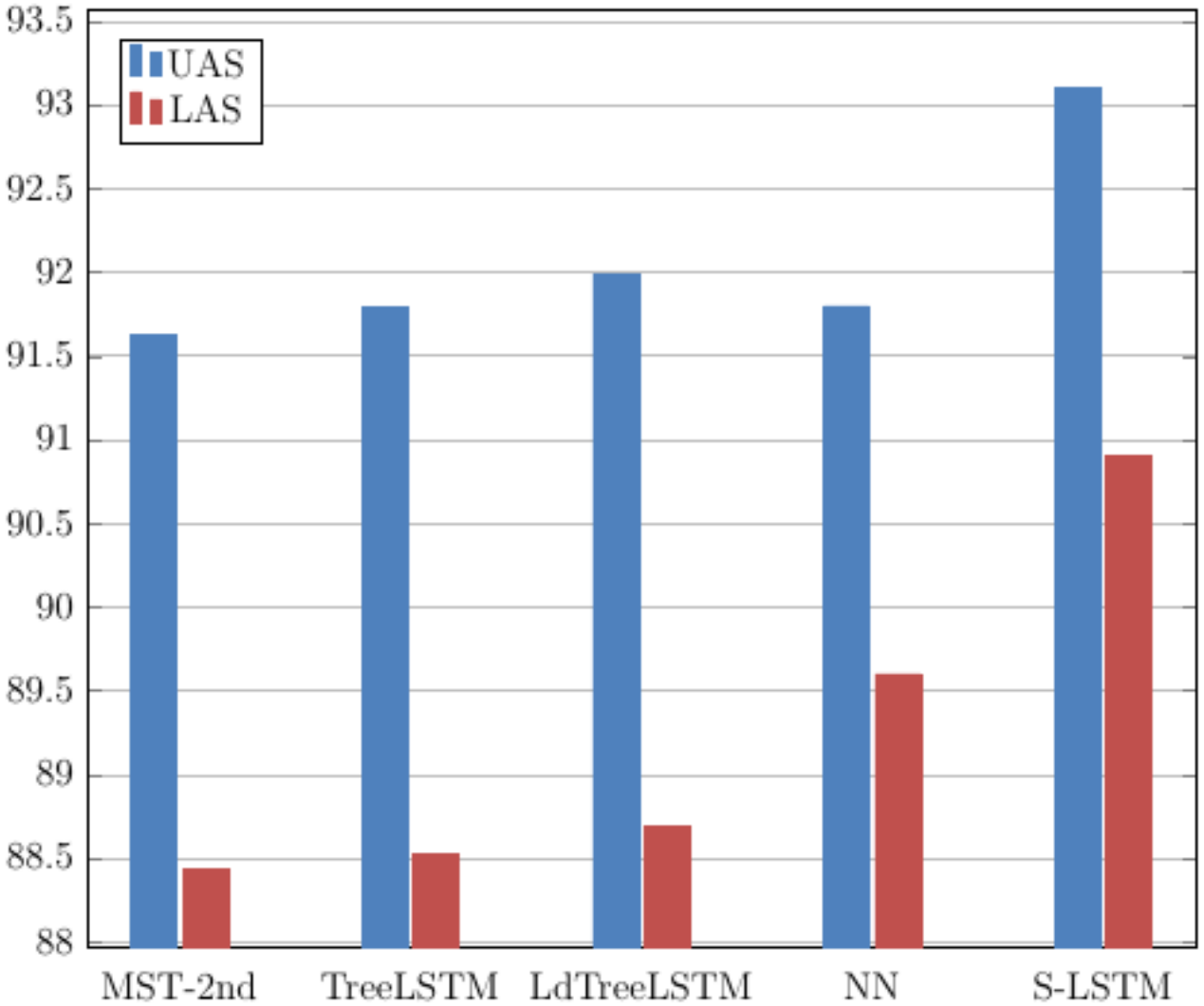

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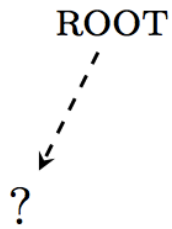

Four binary classifiers:

- Add Left? No!

Features: hidden states and word embeddings

Classifiers	Accuracies
Add-Left	94.3
Add-Right	92.6
Add-Nx-Left	93.4
Add-Nx-Right	96.0

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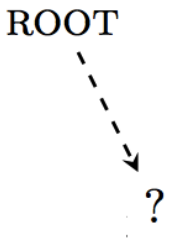

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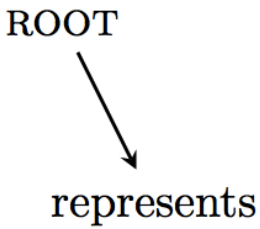

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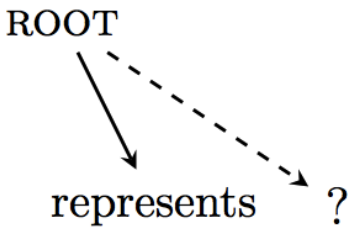

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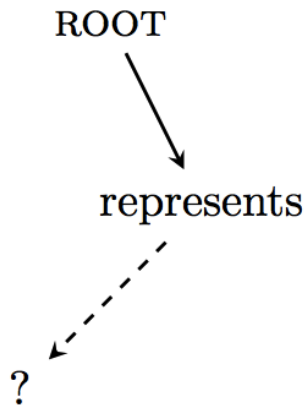

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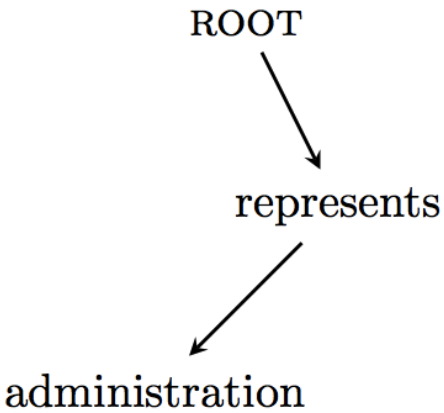

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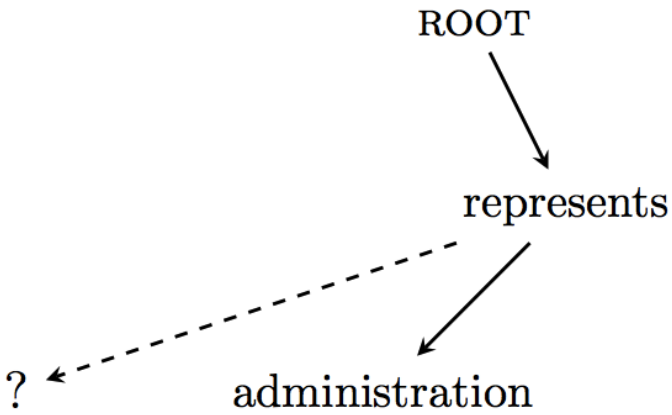

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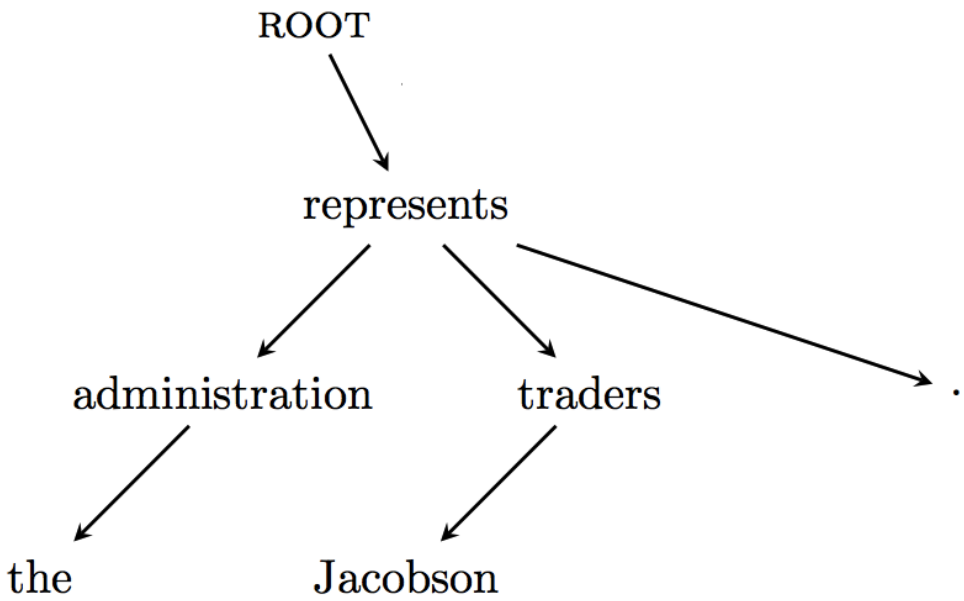

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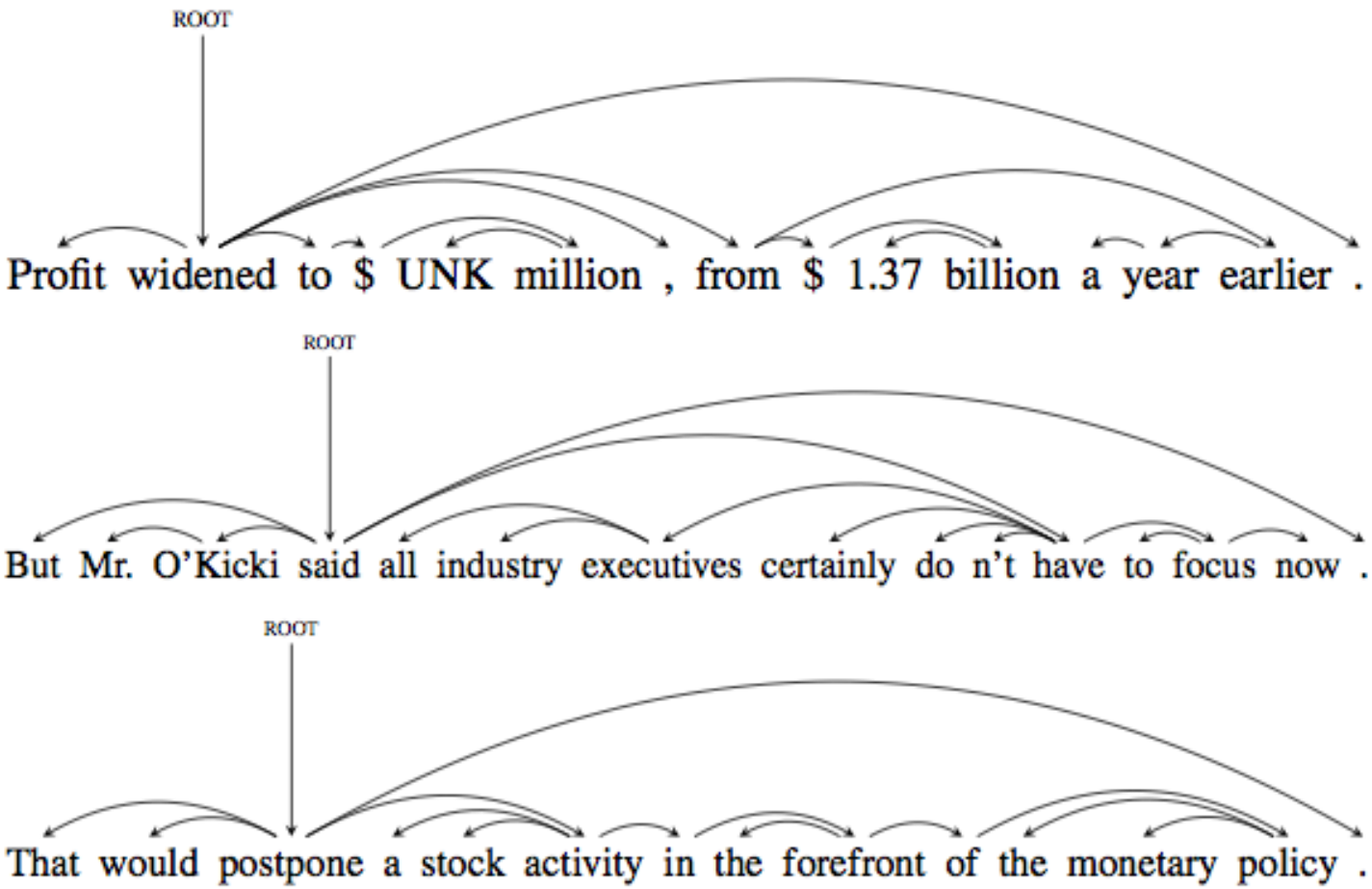

Conclusions

- Syntax can help language modeling.
- Predicting tree structures with Neural Networks is possible.
- Next Steps:
  - Sequence to Tree Models
  - Tree to Tree Models
- code available:
  `https://github.com/XingxingZhang/td-treelstm`

Thanks & Questions?