Wrap-Up: Unsupervised Learning + Summary

LING 571 — Deep Processing Methods in NLP

December 4, 2019

Shane Steinert-Threlkeld

A Roadblock to Deep Processing

- Deep processing of natural language data helps with:
  - Information retrieval
  - QA
  - WSD
  - Conversational AI
  - …
- But….

Developing Deep Processing Systems

- Building a deep processing system requires lots of annotated data
  - For evaluation
  - For *training* an ML system

A roadblock

- The following are cheap:
  - Compute
  - Text [the web!]

- The following are expensive:
  - Human hours
    - Programmers
    - Data annotators

Un-/Semi-supervised Learning in NLP

Can we leverage the cheap resources?

Yann LeCun

https://twitter.com/rgblong/status/916062474545319938?lang=en

Main Idea

- Leverage the huge amounts of text to learn useful representations
- "Fine tune" on a much smaller amount of task-specific data
  - a.k.a. transfer learning

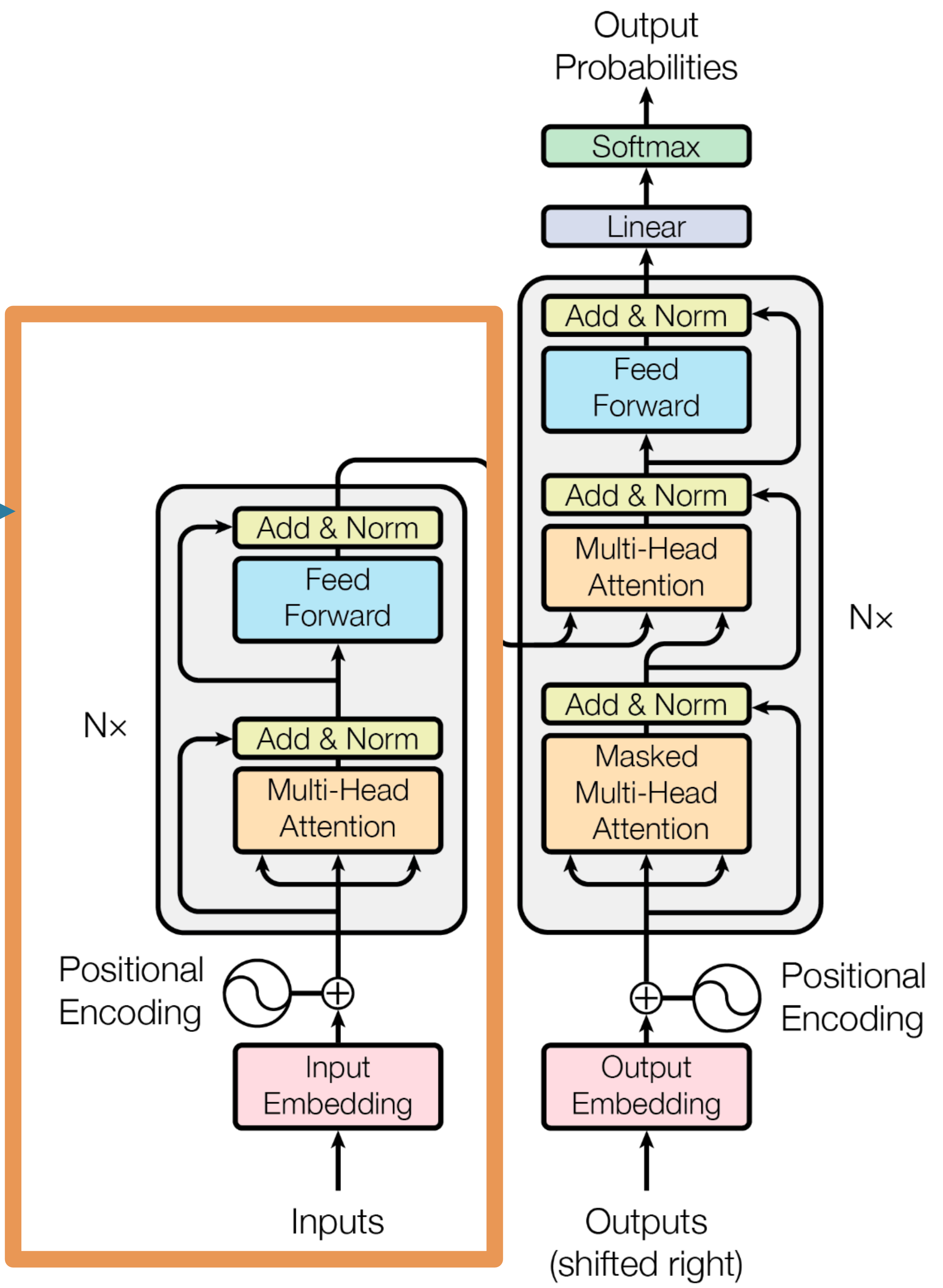
BERT

Bidirectional Encoder Representations from Transformers

Devlin et al 2018

Transformers [+ Encoder]

Encoder



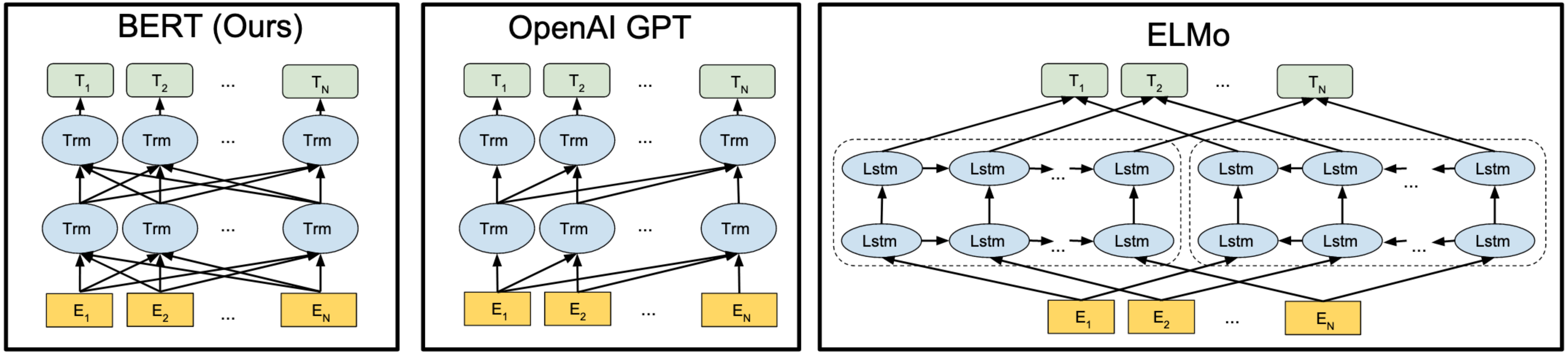
Vashwani et al 2017,
"Attention is All You Need"

The Annotated Transformer
The Illustrated Transformer

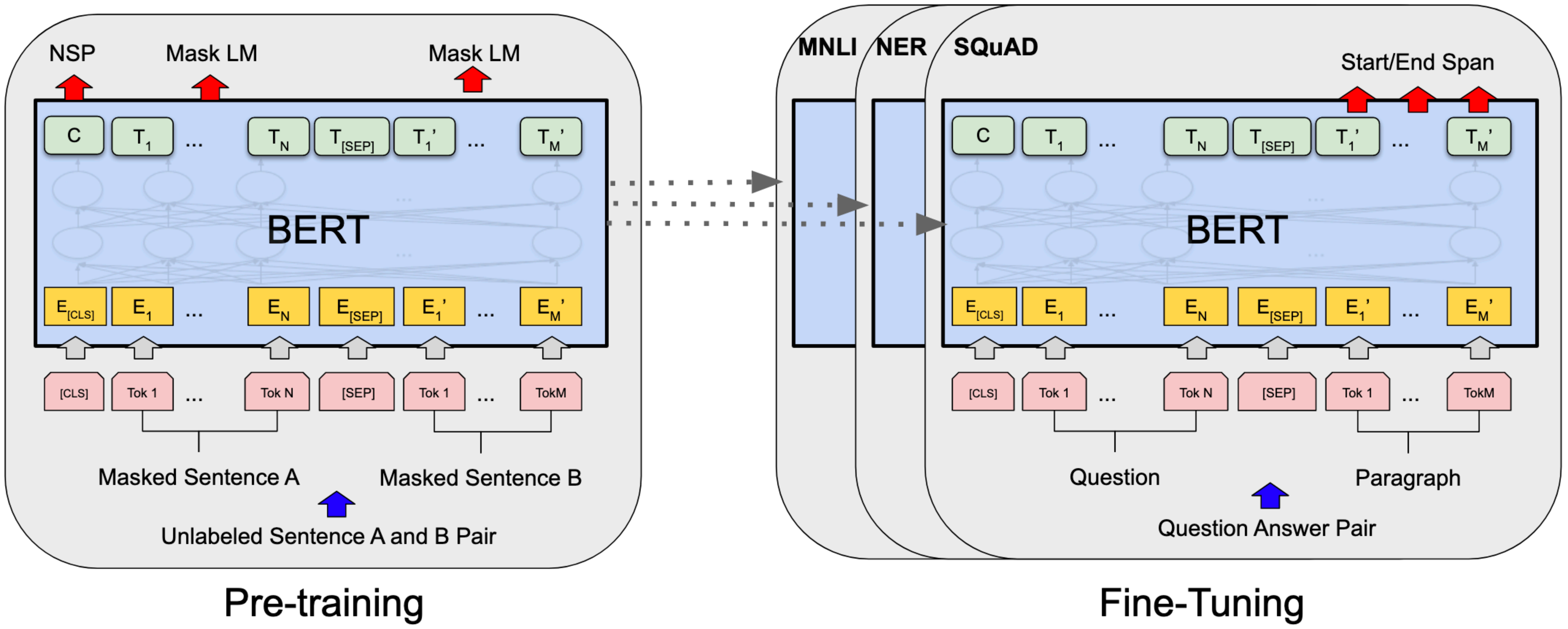
Bidirectional: Masked Language Modeling

- Main training task: *masked language modeling* (aka cloze task)
  - Raw text: “Seattle is the capital of Washington and is the home of UW.”
  - 15% of tokens are masked* (*some subtleties), e.g.:
  - Model input:
    - “Seattle is the [MASK] of Washington and [MASK] the home of UW.”
  - Task: predict the tokens in the [MASK] positions.
- [Also trained with Next Sentence Prediction: given two sentences, did the second follow the first in the text?]

Bidirectional



Fine Tuning



NSP
Mask LM
Mask LM
C
T1
...
TN
T[SEP]
T1'
...
TM'
BERT
E[CLS]
E1
...
EN
E[SEP]
E1'
...
EM'
[CLS]
Tok 1
...
Tok N
[SEP]
Tok 1
...
TokM
Masked Sentence A
Masked Sentence B
Unlabeled Sentence A and B Pair
Pre-training
MNLI
NER
SQuAD
Start/End Span
C
T1
...
TN
T[SEP]
T1'
...
TM'
BERT
E[CLS]
E1
...
EN
E[SEP]
E1'
...
EM'
[CLS]
Tok 1
...
Tok N
[SEP]
Tok 1
...
TokM
Question
Paragraph
Question Answer Pair
Fine-Tuning

Initial Results

System	MNLI-(m/mm)	QQP	QNLI	SST-2	CoLA	STS-B	MRPC	RTE	**Average**
	392k	363k	108k	67k	8.5k	5.7k	3.5k	2.5k	-
Pre-OpenAI SOTA	80.6/80.1	66.1	82.3	93.2	35.0	81.0	86.0	61.7	74.0
BiLSTM+ELMo+Attn	76.4/76.1	64.8	79.8	90.4	36.0	73.3	84.9	56.8	71.0
OpenAI GPT	82.1/81.4	70.3	87.4	91.3	45.4	80.0	82.3	56.0	75.1
$\text{BERT}_{\text{BASE}}$	84.6/83.4	71.2	90.5	93.5	52.1	85.8	88.9	66.4	79.6
$\text{BERT}_{\text{LARGE}}$	**86.7/85.9**	**72.1**	**92.7**	**94.9**	**60.5**	**86.5**	**89.3**	**70.1**	**82.1**

Major Application

Google

The Keyword　Latest Stories　Product Updates　Company News

SEARCH

Understanding searches better than ever before

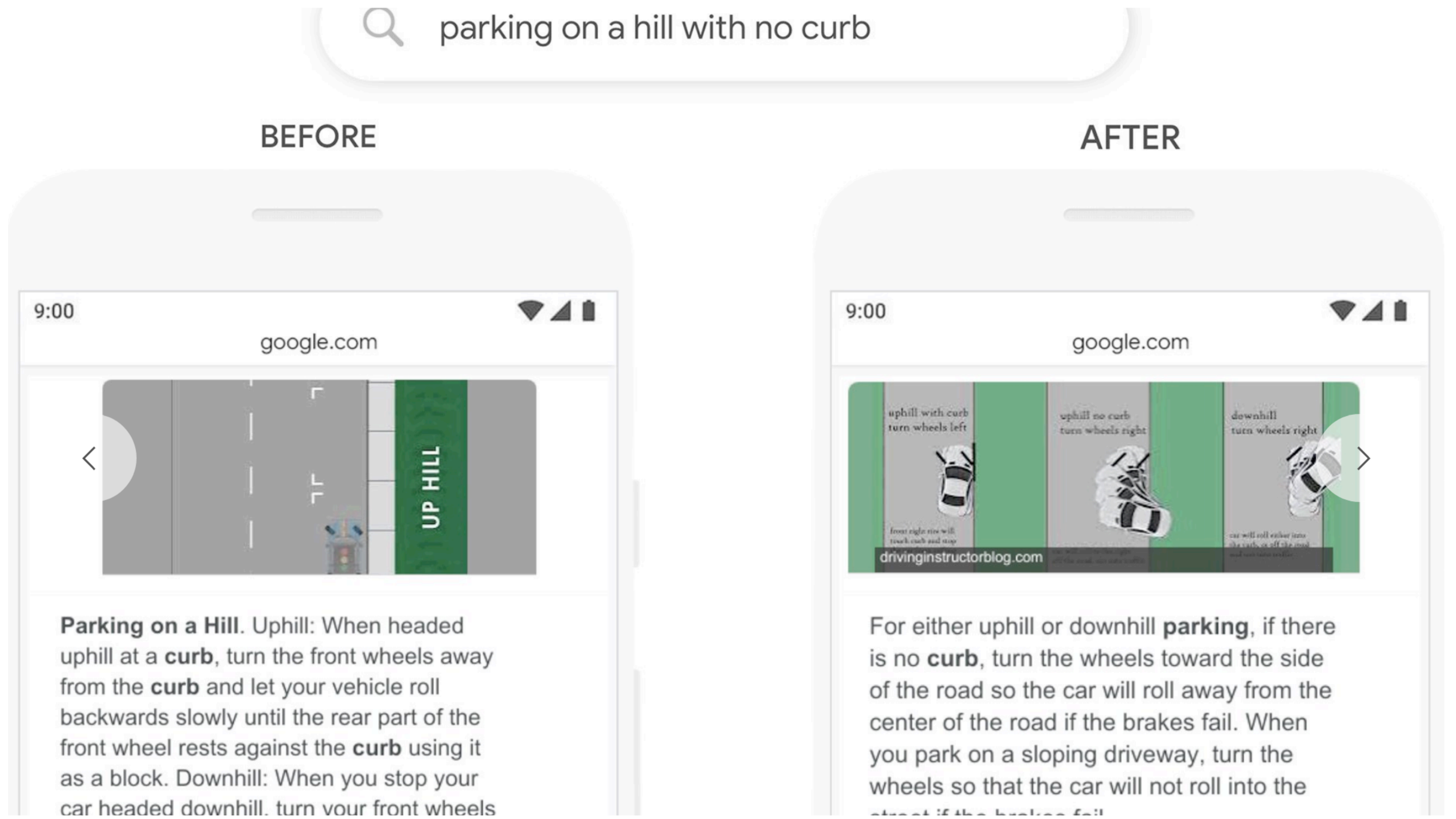
Pandu Nayak
Google Fellow and Vice President, Search

Published Oct 25, 2019

If there's one thing I've learned over the 15 years working on Google Search, it's that people's curiosity is endless. We see billions of searches every day, and 15 percent of those queries are ones we haven't seen before--so we've built ways to return results for queries we can't anticipate.

https://www.blog.google/products/search/search-language-understanding-bert/

Major Application



Does BERT implicitly perform deep processing?

WHAT DO YOU LEARN FROM CONTEXT? PROBING FOR SENTENCE STRUCTURE IN CONTEXTUALIZED WORD REPRESENTATIONS

Ian Tenney,[*1] Patrick Xia,[2] Berlin Chen,[3] Alex Wang,[4] Adam Poliak,[2]
R. Thomas McCoy,[2] Najoung Kim,[2] Benjamin Van Durme,[2] Samuel R. Bowman,[4]
Dipanjan Das,[1] and Ellie Pavlick[1,5]

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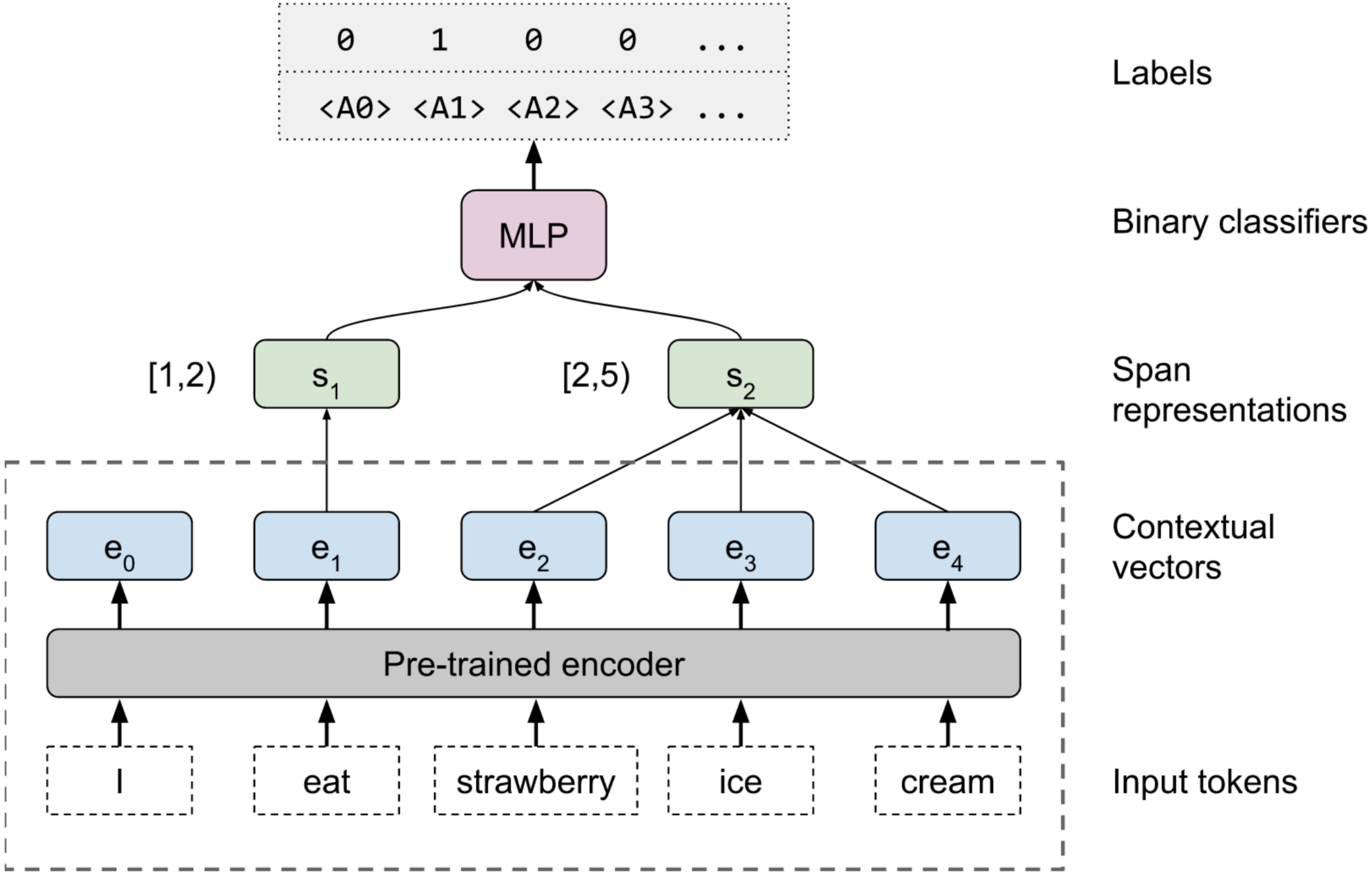
Tenney et al 2019

ABSTRACT

Contextualized representation models such as ELMo (Peters et al., 2018a) and BERT (Devlin et al., 2018) have recently achieved state-of-the-art results on a diverse array of downstream NLP tasks. Building on recent token-level probing work, we introduce a novel *edge probing* task design and construct a broad suite of sub-sentence tasks derived from the traditional structured NLP pipeline. We probe word-level contextual representations from four recent models and investigate how they encode sentence structure across a range of syntactic, semantic, local, and long-range phenomena. We find that existing models trained on language modeling and translation produce strong representations for syntactic phenomena, but only offer comparably small improvements on semantic tasks over a non-contextual baseline.

Edge Probing Set-up



Results

	CoVe			ELMo			GPT		
	Lex.	Full	Abs. Δ	Lex.	Full	Abs. Δ	Lex.	`cat`	`mix`
Part-of-Speech	85.7	94.0	8.4	90.4	**96.7**	6.3	88.2	94.9	95.0
Constituents	56.1	81.6	25.4	69.1	**84.6**	15.4	65.1	81.3	**84.6**
Dependencies	75.0	83.6	8.6	80.4	**93.9**	13.6	77.7	92.1	**94.1**
Entities	88.4	90.3	1.9	92.0	**95.6**	3.5	88.6	92.9	92.5
SRL (all)	59.7	80.4	20.7	74.1	**90.1**	16.0	67.7	86.0	89.7
Core roles	*56.2*	*81.0*	*24.7*	*73.6*	***92.6***	*19.0*	*65.1*	*88.0*	*92.0*
Non-core roles	*67.7*	*78.8*	*11.1*	*75.4*	***84.1***	*8.8*	*73.9*	*81.3*	***84.1***
OntoNotes coref.	72.9	79.2	6.3	75.3	84.0	8.7	71.8	83.6	**86.3**
SPR1	73.7	77.1	3.4	80.1	**84.8**	4.7	79.2	83.5	83.1
SPR2	76.6	80.2	3.6	82.1	83.1	1.0	82.2	**83.8**	**83.5**
Winograd coref.	52.1	**54.3**	2.2	**54.3**	**53.5**	-0.8	51.7	52.6	**53.8**
Rel. (SemEval)	51.0	60.6	9.6	55.7	77.8	22.1	58.2	**81.3**	**81.0**
Macro Average	69.1	78.1	9.0	75.4	**84.4**	9.1	73.0	83.2	**84.4**

	BERT-base				BERT-large				
	F1 Score			Abs. Δ	F1 Score			Abs. Δ	
	Lex.	`cat`	`mix`	ELMo	Lex.	`cat`	`mix`	(base)	ELMo
Part-of-Speech	88.4	**97.0**	96.7	0.0	88.1	96.5	**96.9**	0.2	0.2
Constituents	68.4	83.7	86.7	2.1	69.0	80.1	**87.0**	0.4	2.5
Dependencies	80.1	93.0	95.1	1.1	80.2	91.5	**95.4**	0.3	1.4
Entities	90.9	96.1	96.2	0.6	91.8	96.2	**96.5**	0.3	0.9
SRL (all)	75.4	89.4	91.3	1.2	76.5	88.2	**92.3**	1.0	2.2
Core roles	*74.9*	*91.4*	*93.6*	*1.0*	*76.3*	*89.9*	***94.6***	*1.0*	*2.0*
Non-core roles	*76.4*	*84.7*	*85.9*	*1.8*	*76.9*	*84.1*	***86.9***	*1.0*	*2.8*
OntoNotes coref.	74.9	88.7	90.2	6.3	75.7	89.6	**91.4**	1.2	7.4
SPR1	79.2	84.7	**86.1**	1.3	79.6	85.1	**85.8**	-0.3	1.0
SPR2	81.7	83.0	**83.8**	0.7	81.6	83.2	**84.1**	0.3	1.0
Winograd coref.	54.3	53.6	54.9	1.4	53.0	53.8	**61.4**	6.5	7.8
Rel. (SemEval)	57.4	78.3	82.0	4.2	56.2	77.6	**82.4**	0.5	4.6
Macro Average	75.1	84.8	86.3	1.9	75.2	84.2	**87.3**	1.0	2.9

Conclusion

- "in general, contextualized embeddings improve over their non-contextualized counterparts largely on syntactic tasks(e.g. constituent labeling) in comparison to semantic tasks (e.g. coreference), suggesting that these embeddings encode syntax more so than higher-level semantics"

BERT Rediscovers the Classical NLP Pipeline

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Abstract

Pre-trained text encoders have rapidly advanced the state of the art on many NLP tasks. We focus on one such model, BERT, and aim to quantify where linguistic information is captured within the network. We find that the model represents the steps of the traditional NLP pipeline in an interpretable and localizable way, and that the regions responsible for each step appear in the expected sequence: POS tagging, parsing, NER, semantic roles, then coreference. Qualitative analysis reveals that the model can and often does adjust this pipeline dynamically, revising lower-level decisions on the basis of disambiguating information from higher-level representations.

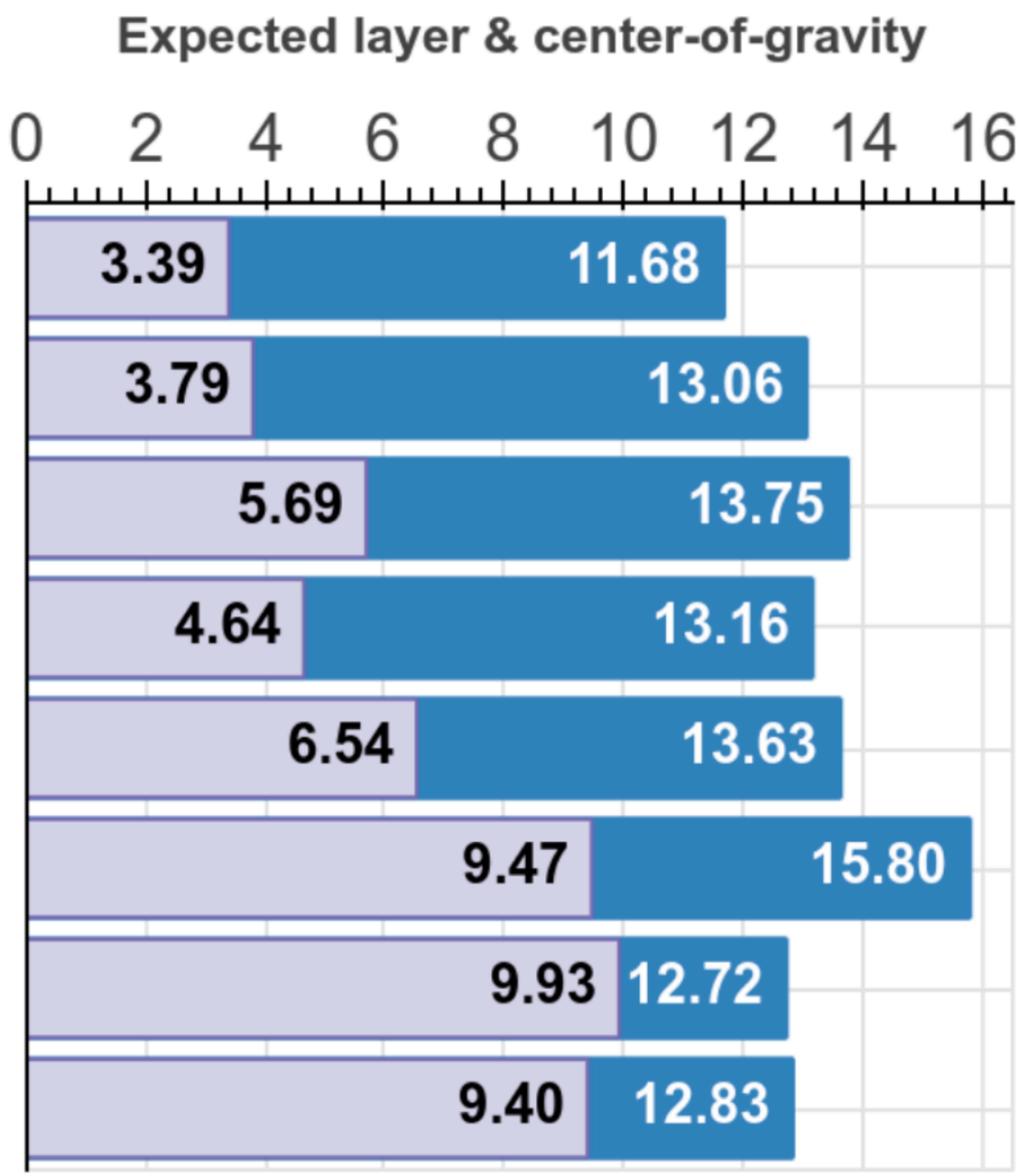
of the network directly, to assess whether there exist localizable regions associated with distinct types of linguistic decisions. Such work has produced evidence that deep language models can encode a range of syntactic and semantic information (e.g. Shi et al., 2016; Belinkov, 2018; Tenney et al., 2019), and that more complex structures are represented hierarchically in the higher layers of the model (Peters et al., 2018b; Blevins et al., 2018).

We build on this latter line of work, focusing on the BERT model (Devlin et al., 2019), and use a suite of probing tasks (Tenney et al., 2019) derived from the traditional NLP pipeline to quantify where specific types of linguistic information are

Tenney et al 2019

F1 Scores

	ℓ=0	ℓ=24
POS	88.5	96.7
Consts.	73.6	87.0
Deps.	85.6	95.5
Entities	90.6	96.1
SRL	81.3	91.4
Coref.	80.5	91.9
SPR	77.7	83.7
Relations	60.7	84.2



A Structural Probe for Finding Syntax in Word Representations

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Abstract

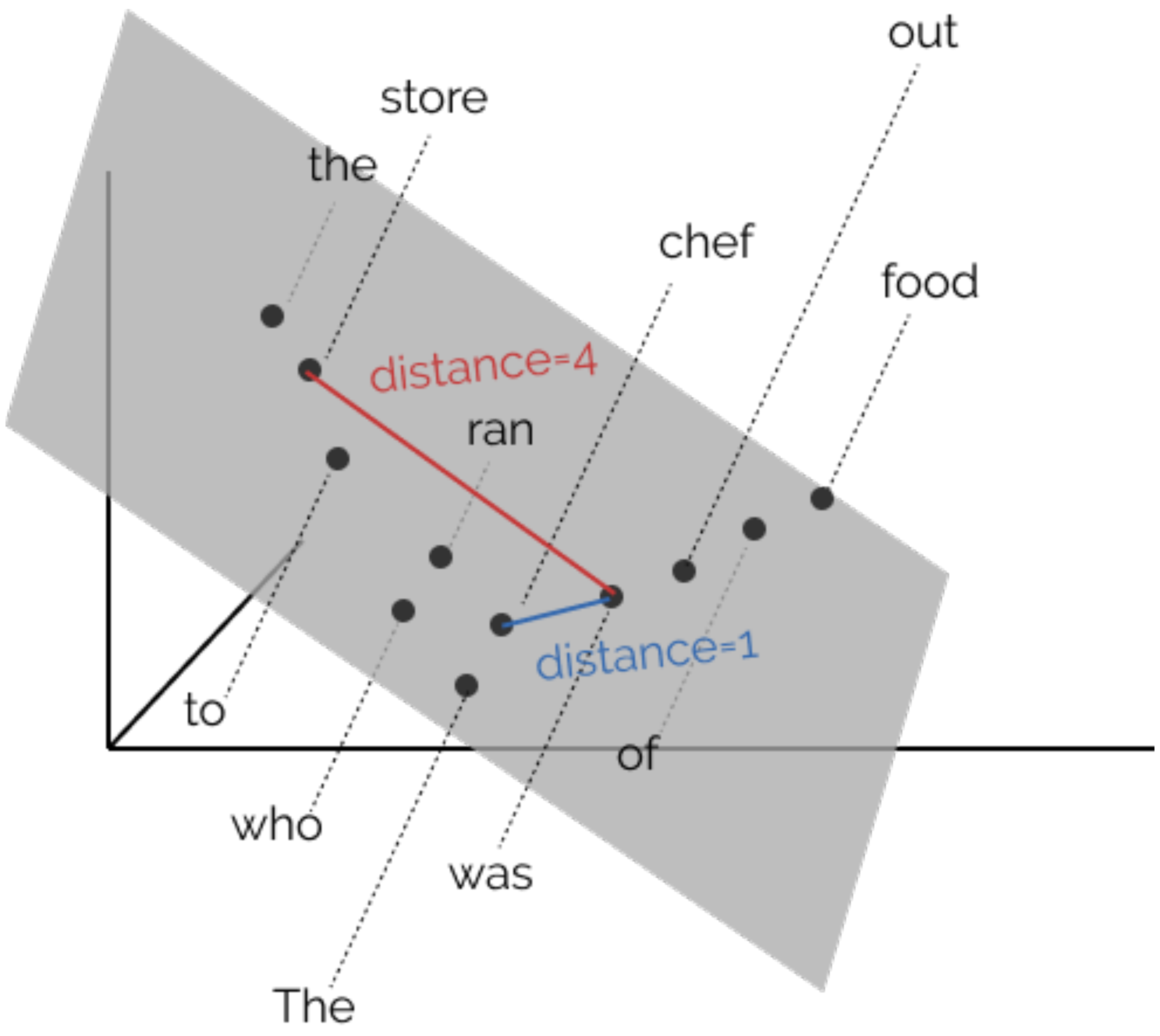
Recent work has improved our ability to detect linguistic knowledge in word representations. However, current methods for detecting syntactic knowledge do not test whether syntax trees are represented in their entirety. In this work, we propose a *structural probe*, which evaluates whether syntax trees are embedded in a linear transformation of a neural network's word representation space. The probe identifies a linear transformation under which squared L2 distance encodes the distance between words in the parse tree, and one in which squared L2 norm encodes depth in the parse tree. Using our probe, we show

In this work, we propose a *structural probe*, a simple model which tests whether syntax trees are consistently embedded in a linear transformation of a neural network's word representation space. Tree structure is embedded if the transformed space has the property that squared L2 distance between two words' vectors corresponds to the number of edges between the words in the parse tree. To reconstruct edge directions, we hypothesize a linear transformation under which the squared L2 norm corresponds to the depth of the word in the parse tree. Our probe uses supervision to find the transformations under which these properties are best approximated for each model. If such transfor-

Hewitt and Manning 2019
blog post

“The chef who ran to the store was out of food.”

“The chef who ran to the store was out of food.”



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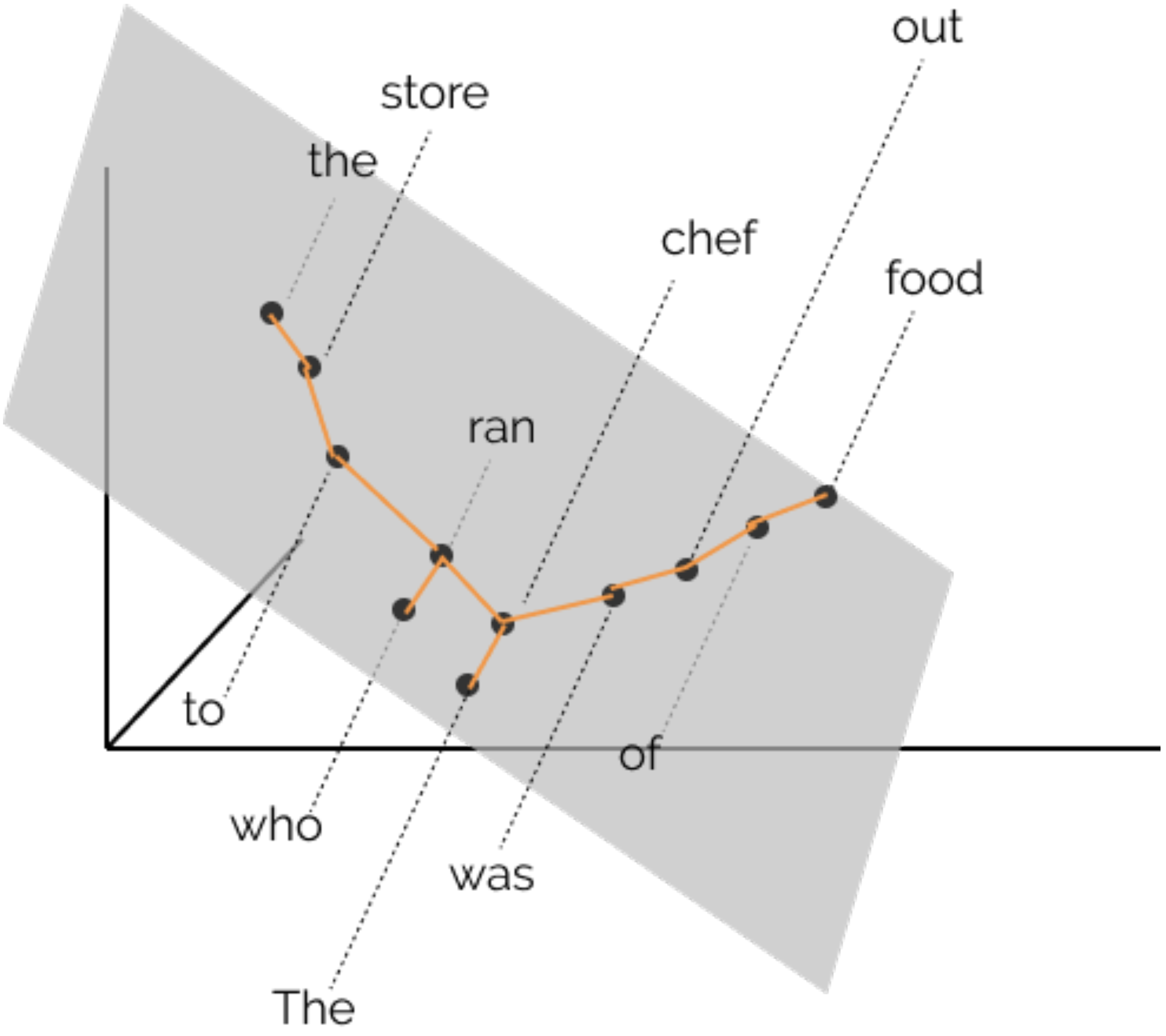
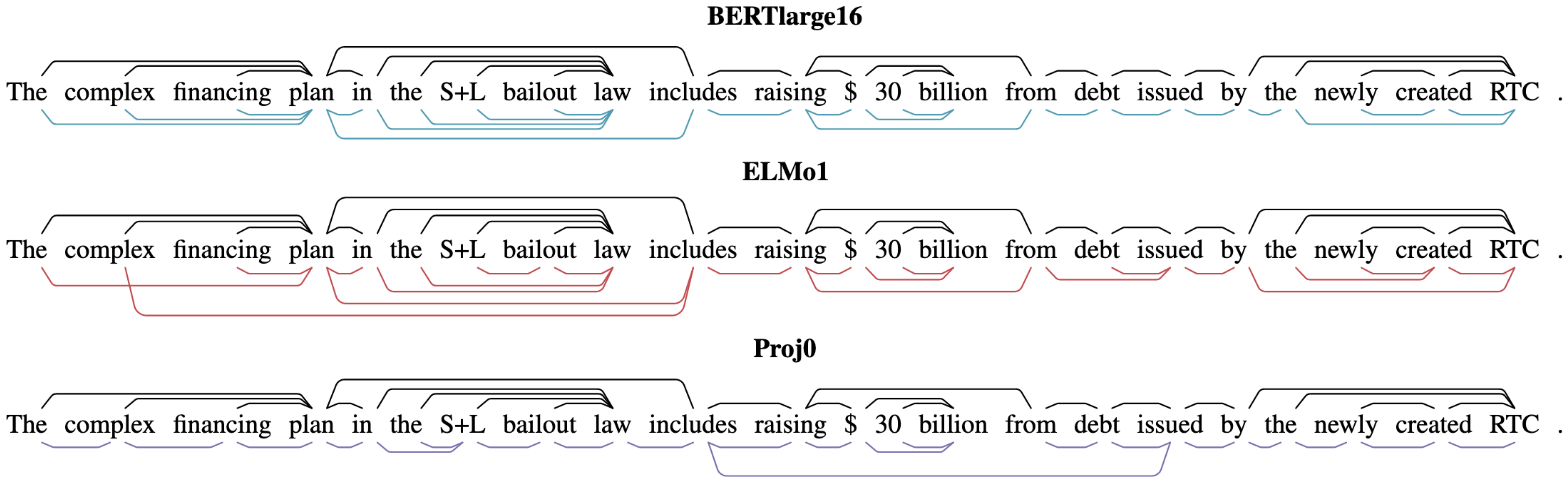


Results

Method	Distance		Depth	
	UUAS	DSpr.	Root%	NSpr.
LINEAR	48.9	0.58	2.9	0.27
ELMO0	26.8	0.44	54.3	0.56
DECAY0	51.7	0.61	54.3	0.56
PROJ0	59.8	0.73	64.4	0.75
ELMO1	77.0	0.83	86.5	0.87
BERTBASE7	79.8	0.85	88.0	0.87
BERTLARGE15	**82.5**	0.86	89.4	0.88
BERTLARGE16	81.7	**0.87**	**90.1**	**0.89**

[SOTA: directed UAS >97%]

Examples



Black = gold parse.

Model parses: Maximum Spanning Tree from distances in transformed space.

Right for the Wrong Reasons: Diagnosing Syntactic Heuristics in Natural Language Inference

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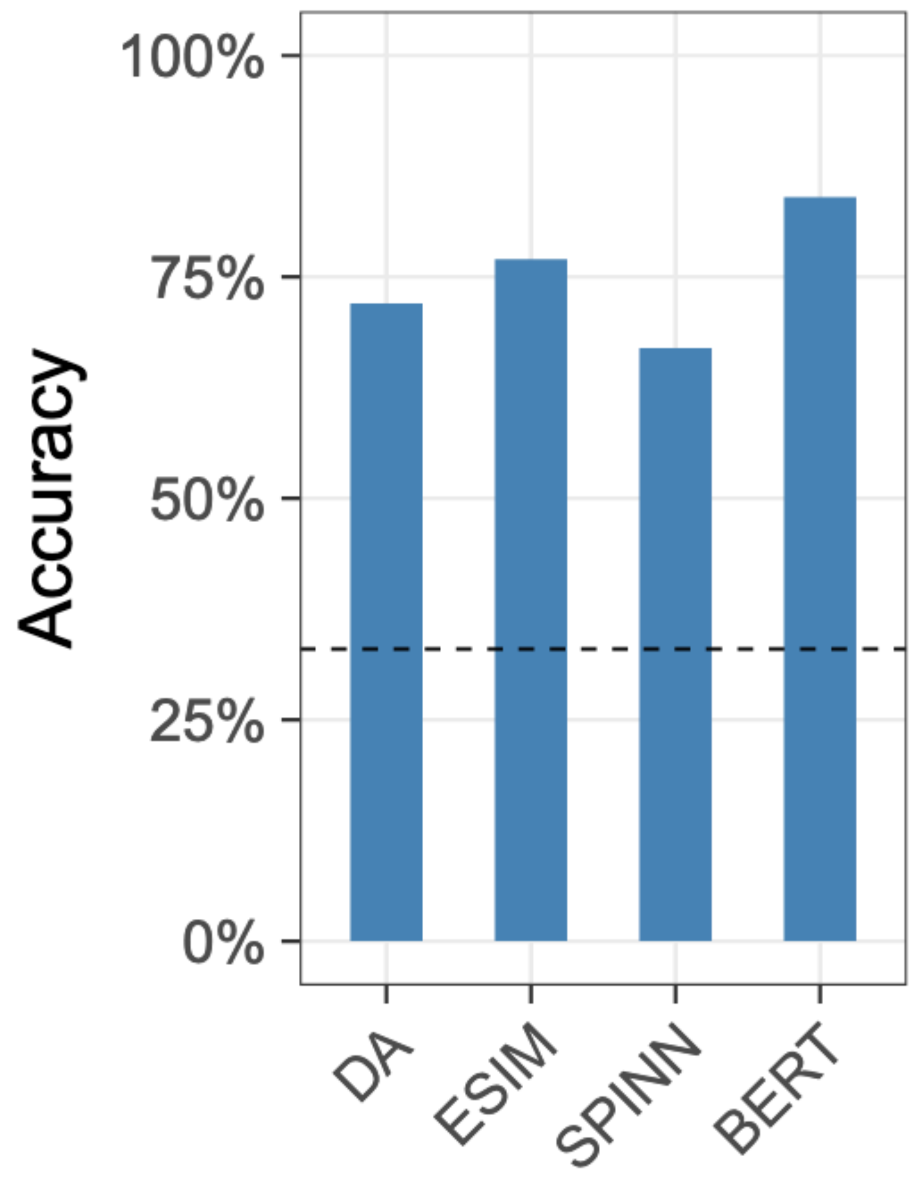
McCoy et al 2019

Main Idea

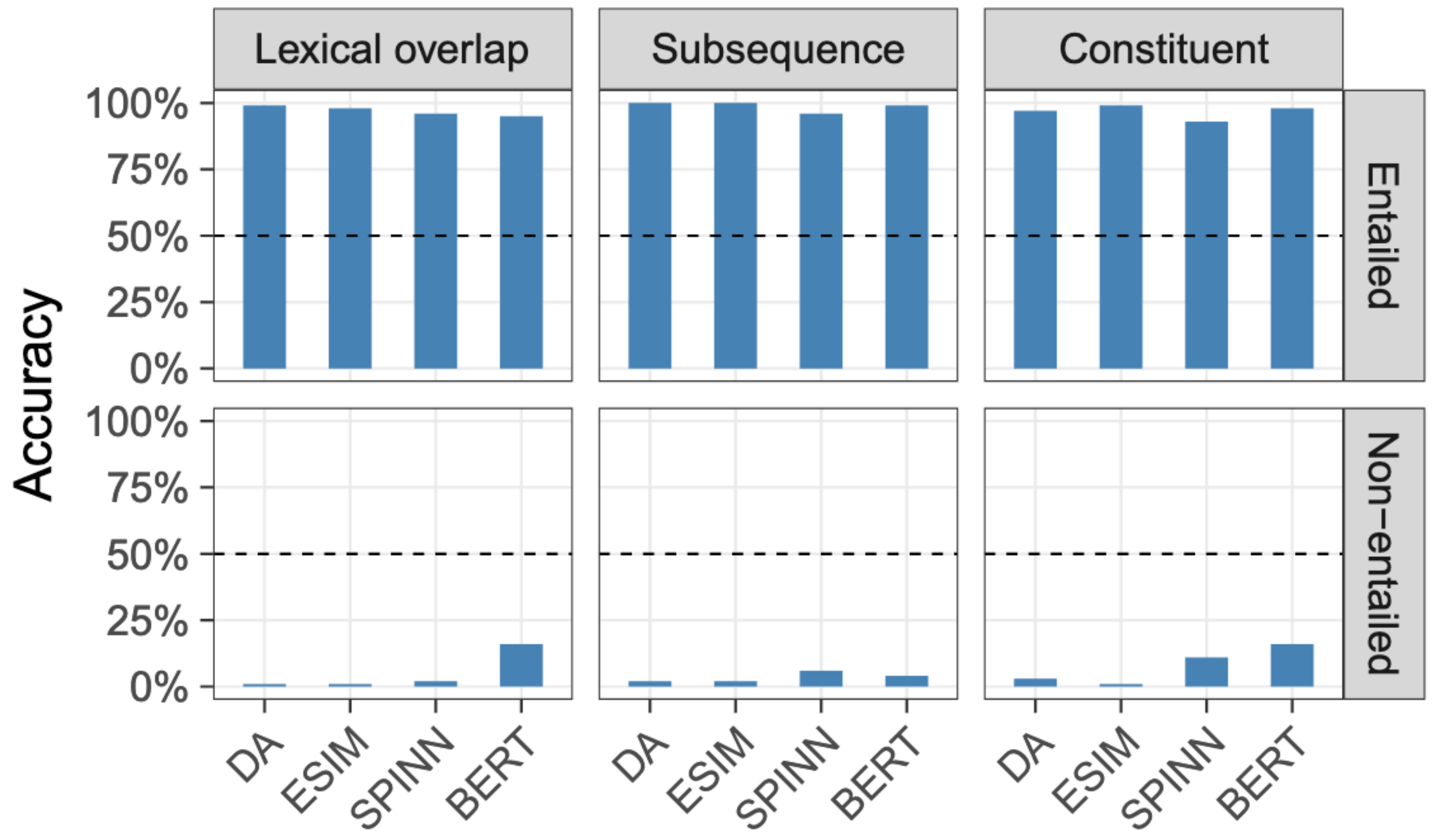
- BERT et al do really well on natural language understanding tasks like NLI (natural language inference)
- Do they do so “for the right reasons”?
- In other words:
  - Or does solving the existing datasets mean they’ve solved the task?
  - Or can success reflect other features than deep language understanding?

Heuristic	Premise	Hypothesis	Label
Lexical overlap heuristic	The banker near the judge saw the actor.	The banker saw the actor.	E
	The lawyer was advised by the actor.	The actor advised the lawyer.	E
	The doctors visited the lawyer.	The lawyer visited the doctors.	N
	The judge by the actor stopped the banker.	The banker stopped the actor.	N
Subsequence heuristic	The artist and the student called the judge.	The student called the judge.	E
	Angry tourists helped the lawyer.	Tourists helped the lawyer.	E
	The judges heard the actors resigned.	The judges heard the actors.	N
	The senator near the lawyer danced.	The lawyer danced.	N
Constituent heuristic	Before the actor slept, the senator ran.	The actor slept.	E
	The lawyer knew that the judges shouted.	The judges shouted.	E
	If the actor slept, the judge saw the artist.	The actor slept.	N
	The lawyers resigned, or the artist slept.	The artist slept.	N

Results



(a)



(b)

(performance improves if fine-tuned on this challenge set)

Summary

- Pre-trained encoders are very powerful
- Transfer learning from them often leads to very strong performance on NLP tasks
- Why?
    - Some evidence of *some* internal deep processing (esp. syntax)
    - Very clever exploitation of spurious correlations in the data

Course Recap / Highlights

Wrapping Up

Deep Processing

- Building of deep linguistic structures for NLP
  - Syntax
  - Semantics
  - Pragmatics

- Used and useful in many applications, e.g.
  - IR/QA/search
  - Conversational AI

Syntax

- Constituency Parsing
  - (P)CFGs
  - Grammar induction
- Dependency Parsing
  - Transition vs. MST based parsers

CKY Parsing Example

$\mathscr{L}_1$ Grammar

S → NP VP
S → X1 VP
X1 → Aux NP
S → book | include | prefer
S → Verb NP
S → X2 PP
S → Verb PP
S → VP PP

NP → I | she | me
NP → TWA | Houston
NP → Det Nominal

Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP

VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP

PP → Preposition NP

NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]		
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]		
		Det [2,3]	**NP** [2,4]		
			Noun, Nom [3,4]		
				Prep [4,5]	

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

I prefer a flight on TWA

0 1 2 3 4 5 6

$\mathscr{L}_1$ Grammar

S → *NP VP*
S → *X1 VP*
X1 → *Aux NP*
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S → *X2 PP*
S → *Verb PP*
S → *VP PP*

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	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]		
		Det [2,3]	NP [2,4]		
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I *prefer* *a* *flight* *on* *TWA*

0 1 2 3 4 5 6

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]		
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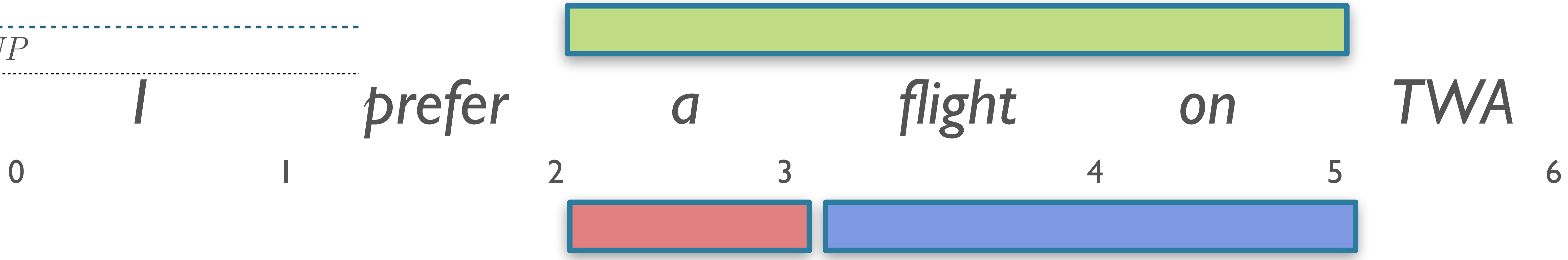

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Verb → book | include | prefer

I prefer a flight on TWA

0 1 2 3 4 5 6

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NP → *I* | *she* | *me*
NP → *TWA* | *Houston*
NP → *Det Nominal*

Nominal → *book* | *flight* | *meal* | *money*
Nominal → *Nominal Noun*
Nominal → *Nominal PP*

VP → *book* | *include* | *prefer*
VP → *Verb NP*
VP → *X2 PP*
X2 → *Verb NP*
VP → *Verb PP*
VP → *VP PP*

PP → *Preposition NP*

NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]		
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

Lexicon

Det → *that* | *this* | *a*
Noun → *book* | *flight* | *meal* | *money*
Pronoun → *I* | *she* | *me*
Proper-Noun → *Houston* | *TWA*
Aux → *does*
Preposition → *from* | *to* | *on* | *near* | *through*
Verb → *book* | *include* | *prefer*

I *prefer* *a* *flight* *on* *TWA*

0 1 2 3 4 5 6

$\mathscr{L}_1$ Grammar

S → *NP VP*
S → *X1 VP*
X1 → *Aux NP*
S → *book* | *include* | *prefer*
S → *Verb NP*
S → *X2 PP*
S → *Verb PP*
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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]		
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

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S → X1 VP
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S → book | include | prefer
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NP → I | she | me
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NP → Det Nominal

Nominal → book | flight | meal | money
Nominal → Nominal Noun
Nominal → Nominal PP

VP → book | include | prefer
VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
VP → VP PP

PP → Preposition NP

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

Lexicon

Det → that | this | a
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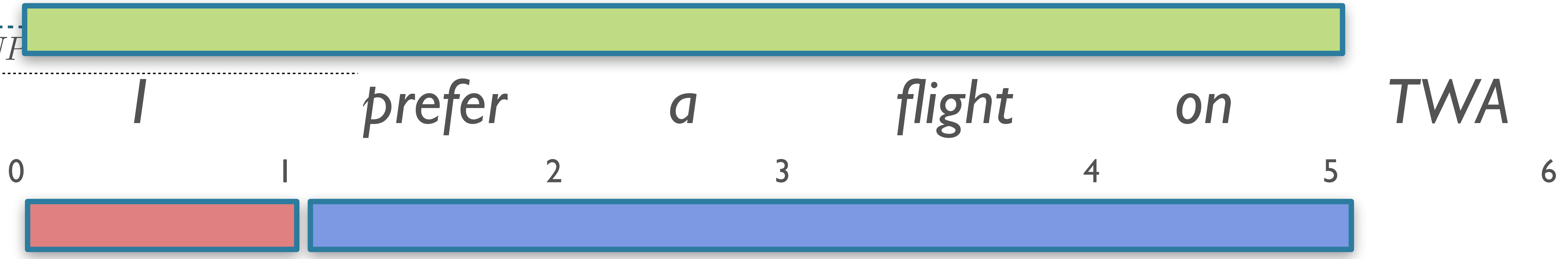
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer



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VP → Verb NP
VP → X2 PP
X2 → Verb NP
VP → Verb PP
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PP → Preposition NP

NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

I prefer a flight on TWA

0 1 2 3 4 5 6

NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

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X2 → Verb NP
VP → Verb PP
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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	

Lexicon

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Preposition → from | to | on | near | through
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Nominal → *Nominal Noun*
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X2 → *Verb NP*
VP → *Verb PP*
VP → *VP PP*

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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	
					NNP, NP [5,6]

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Pronoun → *I* | *she* | *me*
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0 1 2 3 4 5 6

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Nominal → Nominal PP

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X2 → Verb NP
VP → Verb PP
VP → VP PP

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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	
				Prep [4,5]	**PP** [4,6]
					NNP, NP [5,6]

Lexicon

Det → that | this | a
Noun → book | flight | meal | money
Pronoun → I | she | me
Proper-Noun → Houston | TWA
Aux → does
Preposition → from | to | on | near | through
Verb → book | include | prefer

0 I 1 prefer 2 a 3 flight 4 on 5 TWA 6

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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

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I prefer a flight on TWA

0 1 2 3 4 5 6

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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	
			Noun, Nom [3,4]	[3,5]	**Nom** [3,6]
				Prep [4,5]	**PP** [4,6]
					NNP, NP [5,6]

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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	**NP** [2,6]
			Noun, Nom [3,4]	[3,5]	**Nom** [3,6]
				Prep [4,5]	**PP** [4,6]
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I *prefer* *a* *flight* *on* *TWA*

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NP, Pronoun [0,1]	**S** [0,2]	[0,3]	**S** [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	**VP, X2, S** [1,4]	[1,5]	
		Det [2,3]	**NP** [2,4]	[2,5]	**NP** [2,6]
			Noun, Nom [3,4]	[3,5]	**Nom** [3,6]
				Prep [4,5]	**PP** [4,6]
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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	[1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
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	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
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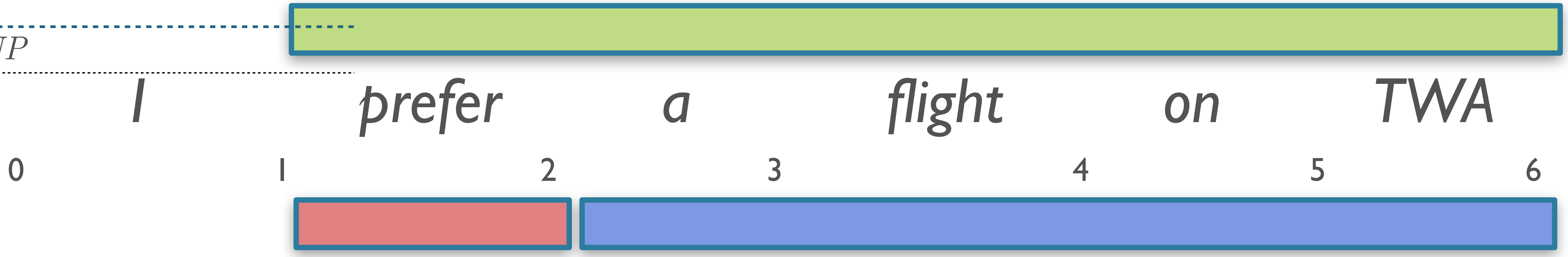

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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2 [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
					NNP, NP [5,6]

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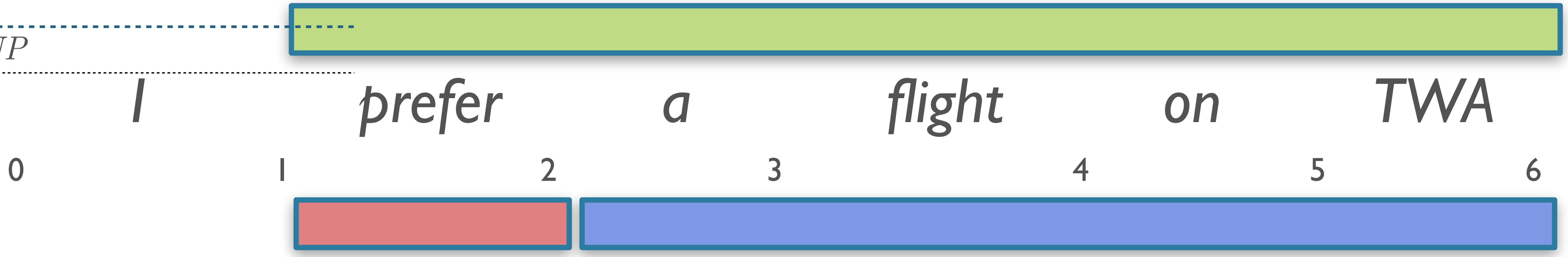

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NP, Pronoun [0,1]	S [0,2]	[0,3]	S [0,4]	[0,5]	
	Verb, VP, S [1,2]	[1,3]	VP, X2, S [1,4]	[1,5]	VP, X2, S [1,6]
		Det [2,3]	NP [2,4]	[2,5]	NP [2,6]
			Noun, Nom [3,4]	[3,5]	Nom [3,6]
				Prep [4,5]	PP [4,6]
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Lexicon

Det → *that* | *this* | *a*
Noun → *book* | *flight* | *meal* | *money*
Pronoun → *I* | *she* | *me*
Proper-Noun → *Houston* | *TWA*
Aux → *does*
Preposition → *from* | *to* | *on* | *near* | *through*
Verb → *book* | *include* | *prefer*

I prefer a flight on TWA

0 1 2 3 4 5 6

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S → book / include / prefer
S → Verb NP
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S → Verb PP
S → VP PP

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NP → Det Nominal

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0 *I* 1 *prefer* 2 *a* 3 *flight* 4 *on* 5 *TWA* 6

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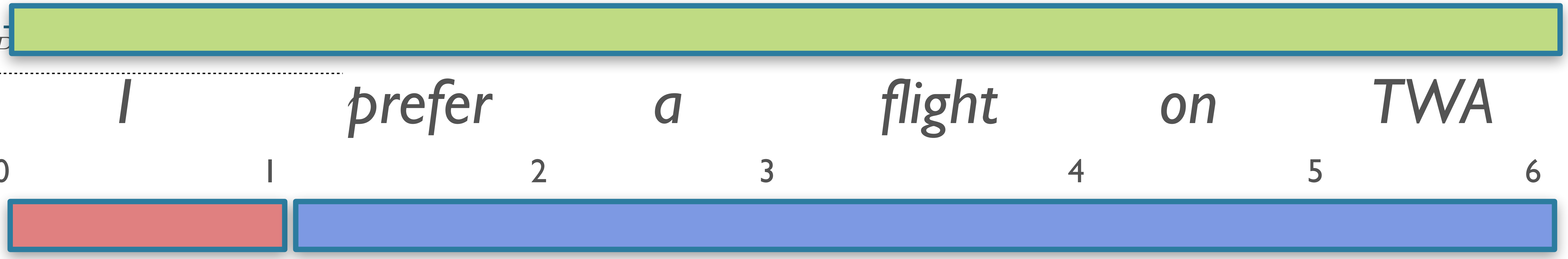

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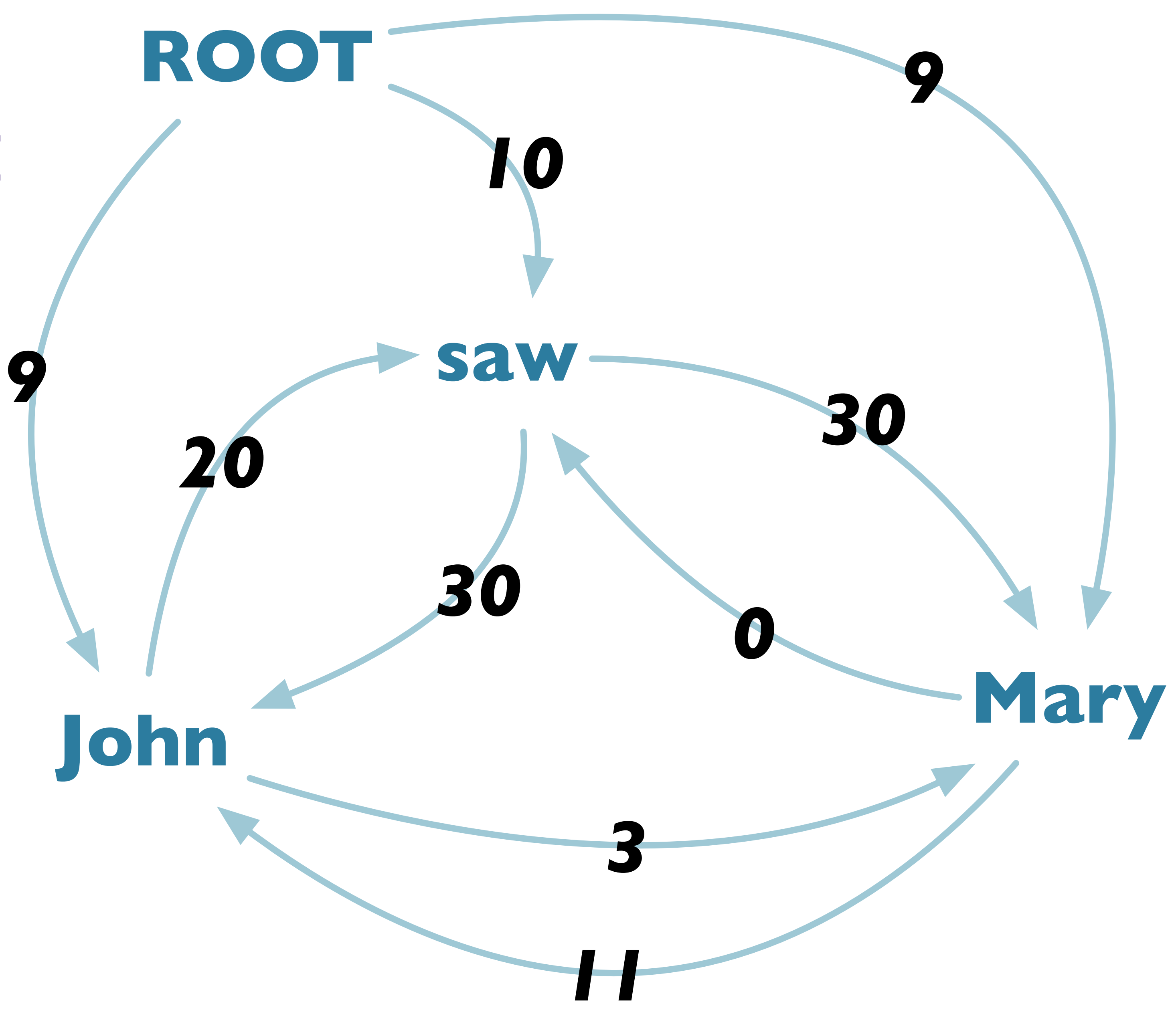
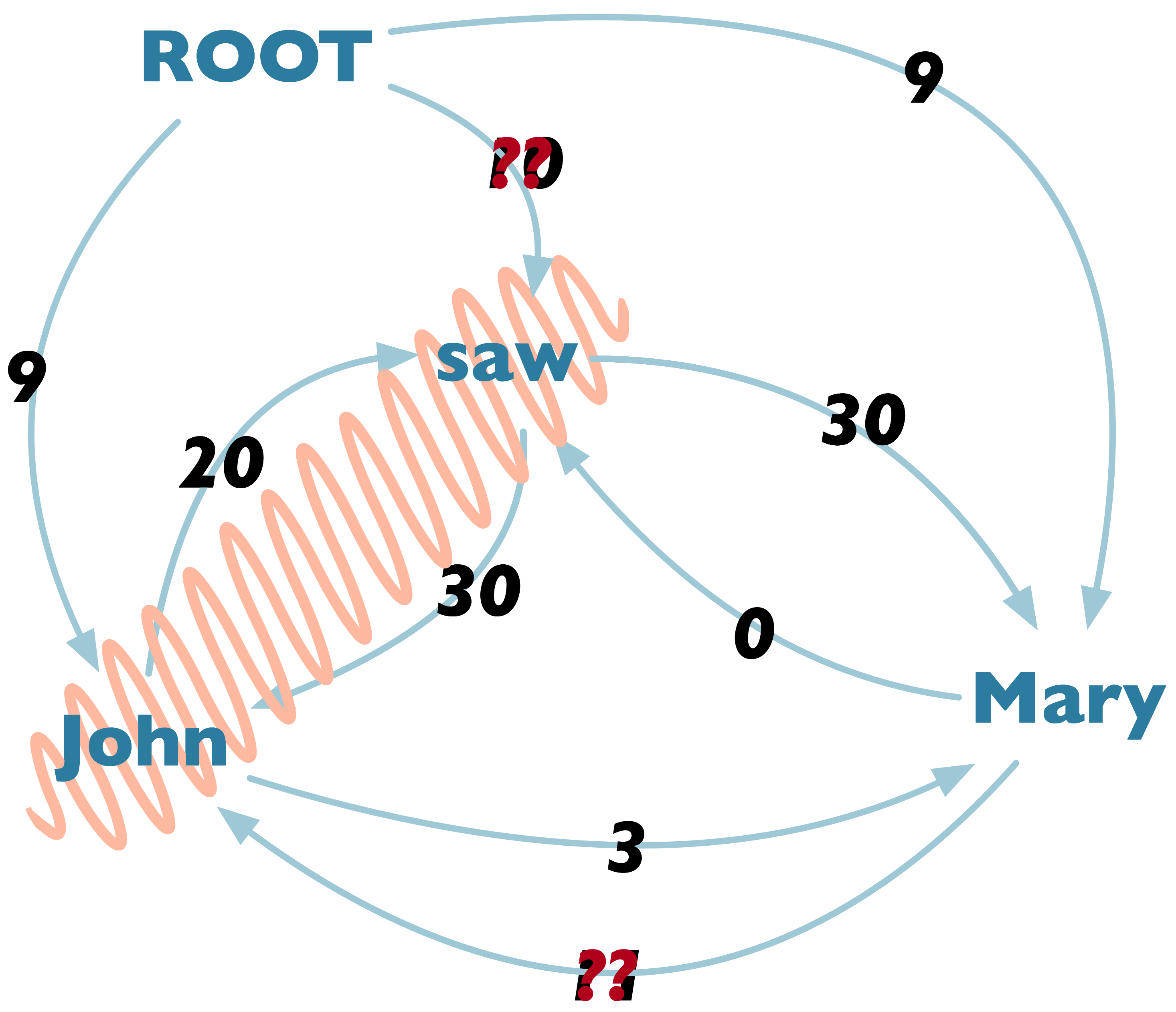
Maximum Spanning Tree

- McDonald et al, 2005 use variant of Chu-Liu-Edmonds algorithm for MST (CLE)
- Sketch of algorithm:
  - For each node, greedily select incoming arc with max weight
  - If the resulting set of arcs forms a tree, this is the MST.
  - If not, there must be a cycle.
    - “Contract” the cycle: Treat it as a single vertex
    - Recalculate weights into/out of the new vertex
    - Recursively do MST algorithm on resulting graph
- Running time: naïve: O(n3); Tarjan: O(n2)
  - Applicable to non-projective graphs



Step 1 & 2

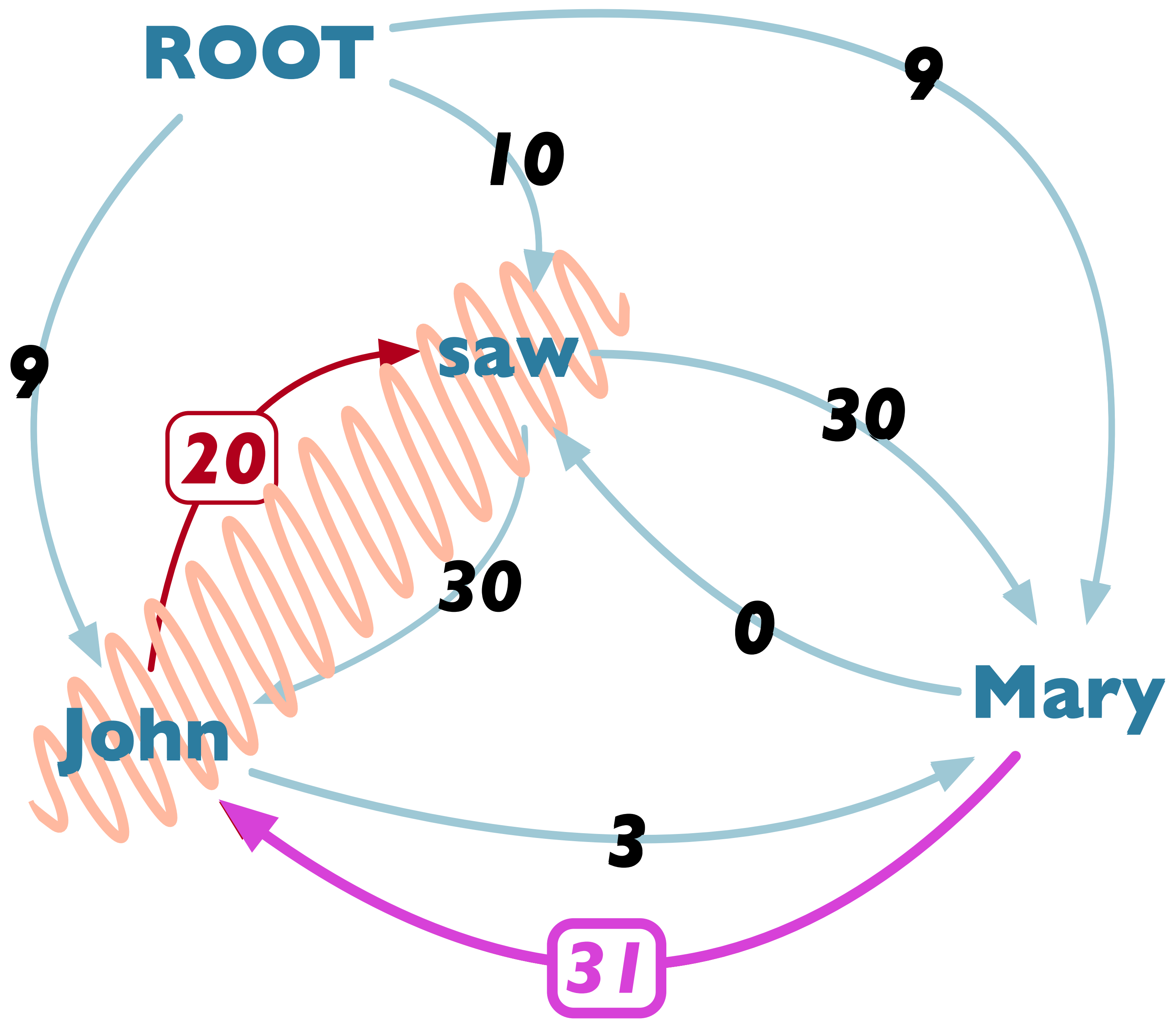
- Find, for each word, the highest scoring incoming edge.
- Is it a tree?
  - No, there's a cycle.
- Collapse the cycle
- And re-examine the edges again



Calculating Weights for Collapsed Vertex

- Since there's a cycle:
  - Contract cycle & reweight
  - John+saw as single vertex
  - Calculate weights in & out as:
- Recurse

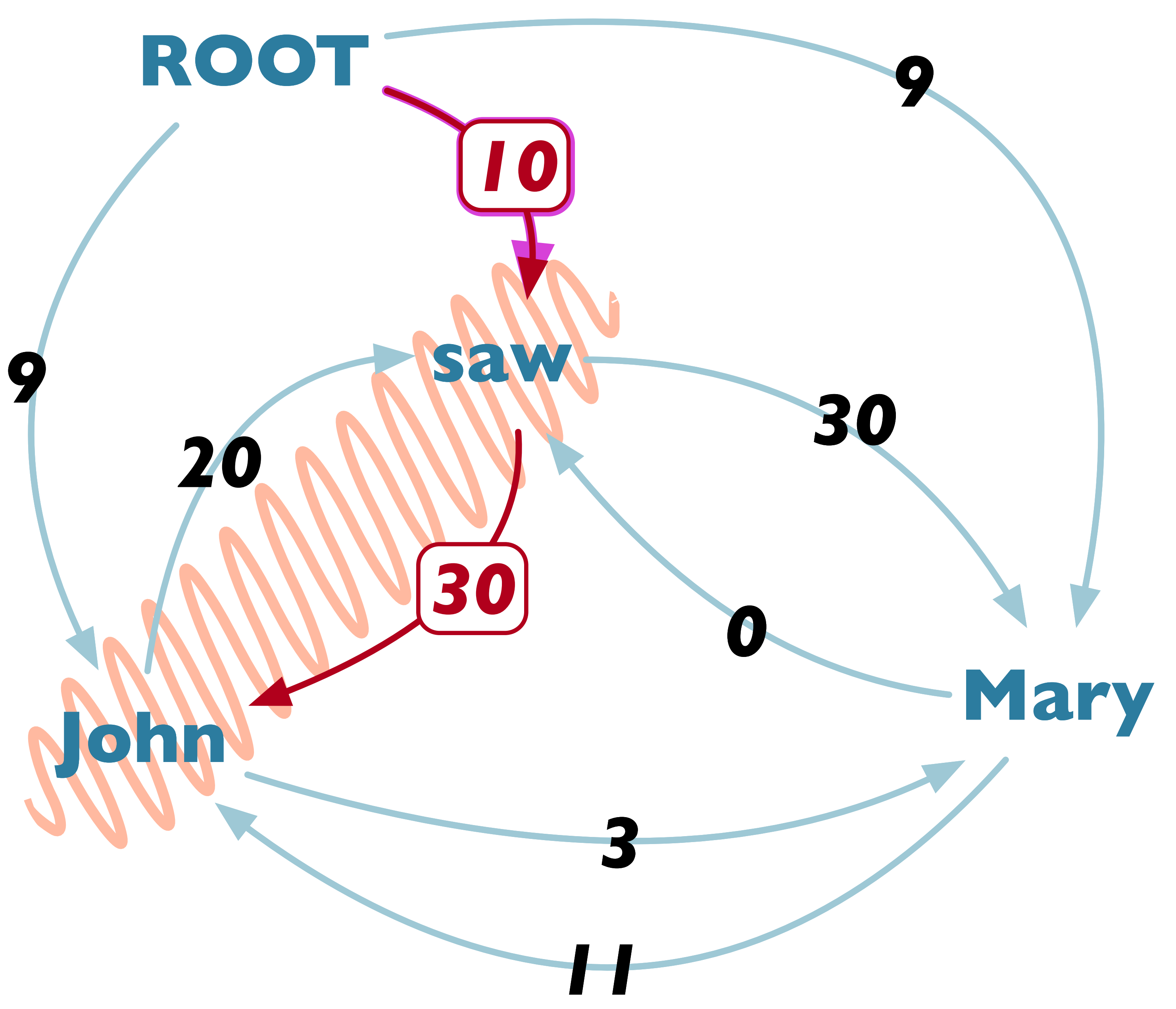
s(Mary, C) 11 + 20 = 31



Calculating Weights for Collapsed Vertex

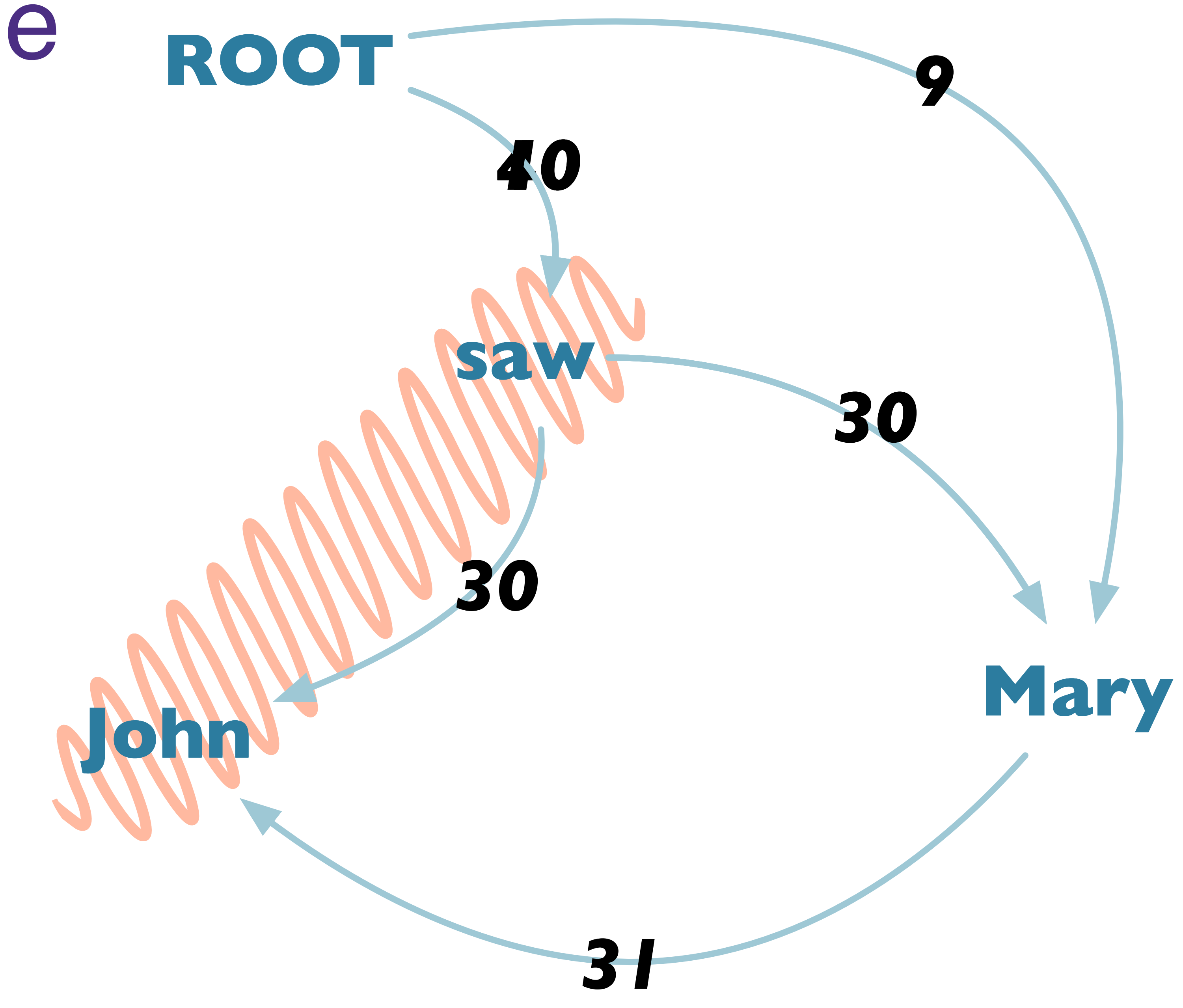
- Since there's a cycle:
  - Contract cycle & reweight
  - John+saw as single vertex
  - Calculate weights in & out as:
- Recurse

s(ROOT, C) 10 + 30 = 40



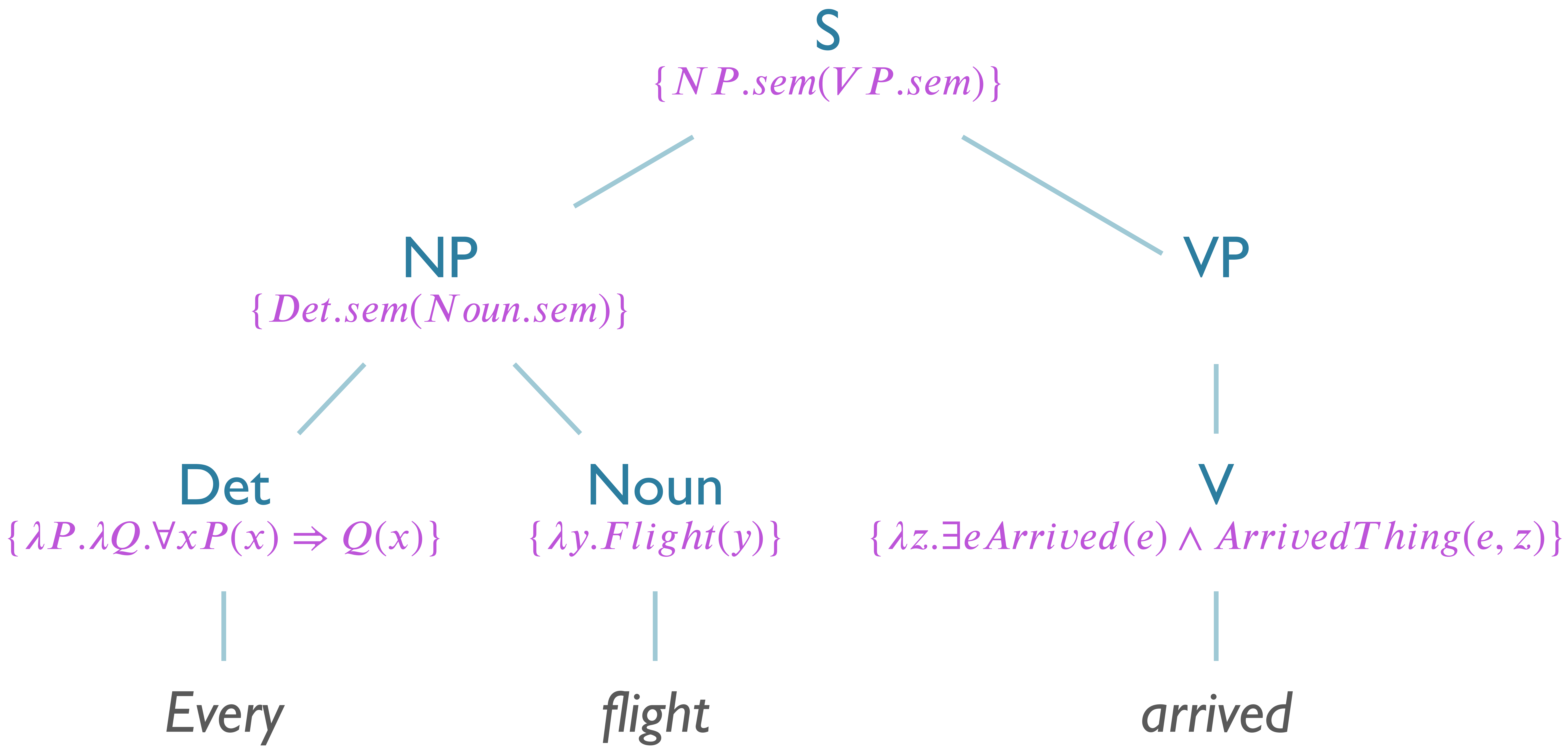
Step 3

- With cycle collapsed, recurse on step 1:
- Keep highest weighted incoming edge for each edge
- Is it a tree?
  - Yes!
  - …but must recover collapsed portions.



Semantics

- First order logic + lambda calculus
- Neo-Davidsonian event semantics
- Parsing via features
- Distributional Semantics + word embeddings
- Word Sense Disambiguation
- Semantic Role Labeling

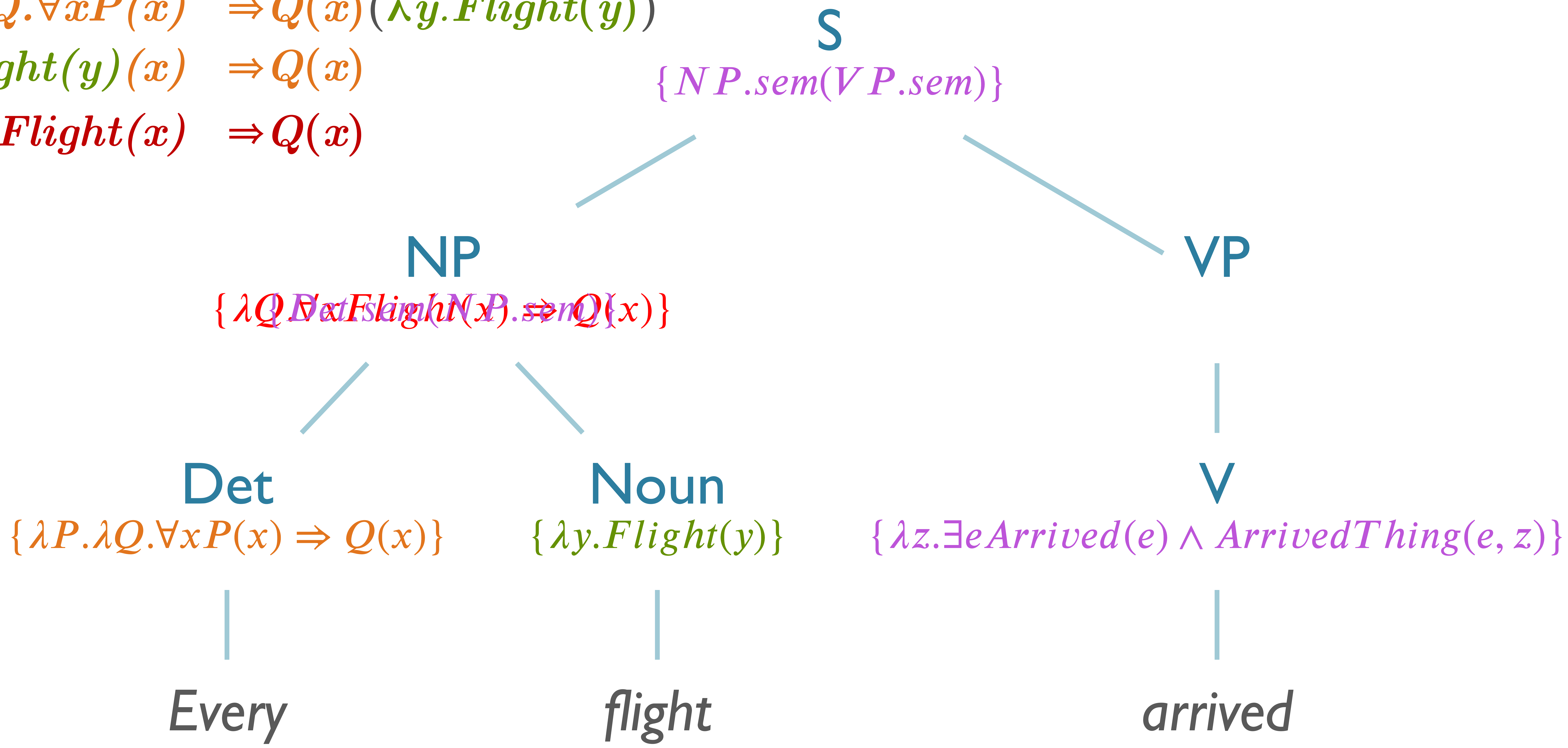

S
$\{NP.sem(VP.sem)\}$
NP
$\{Det.sem(Noun.sem)\}$
VP
Det
$\{\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)\}$
Noun
$\{\lambda y.Flight(y)\}$
V
$\{\lambda z.\exists e Arrived(e) \wedge ArrivedThing(e, z)\}$
Every
flight
arrived

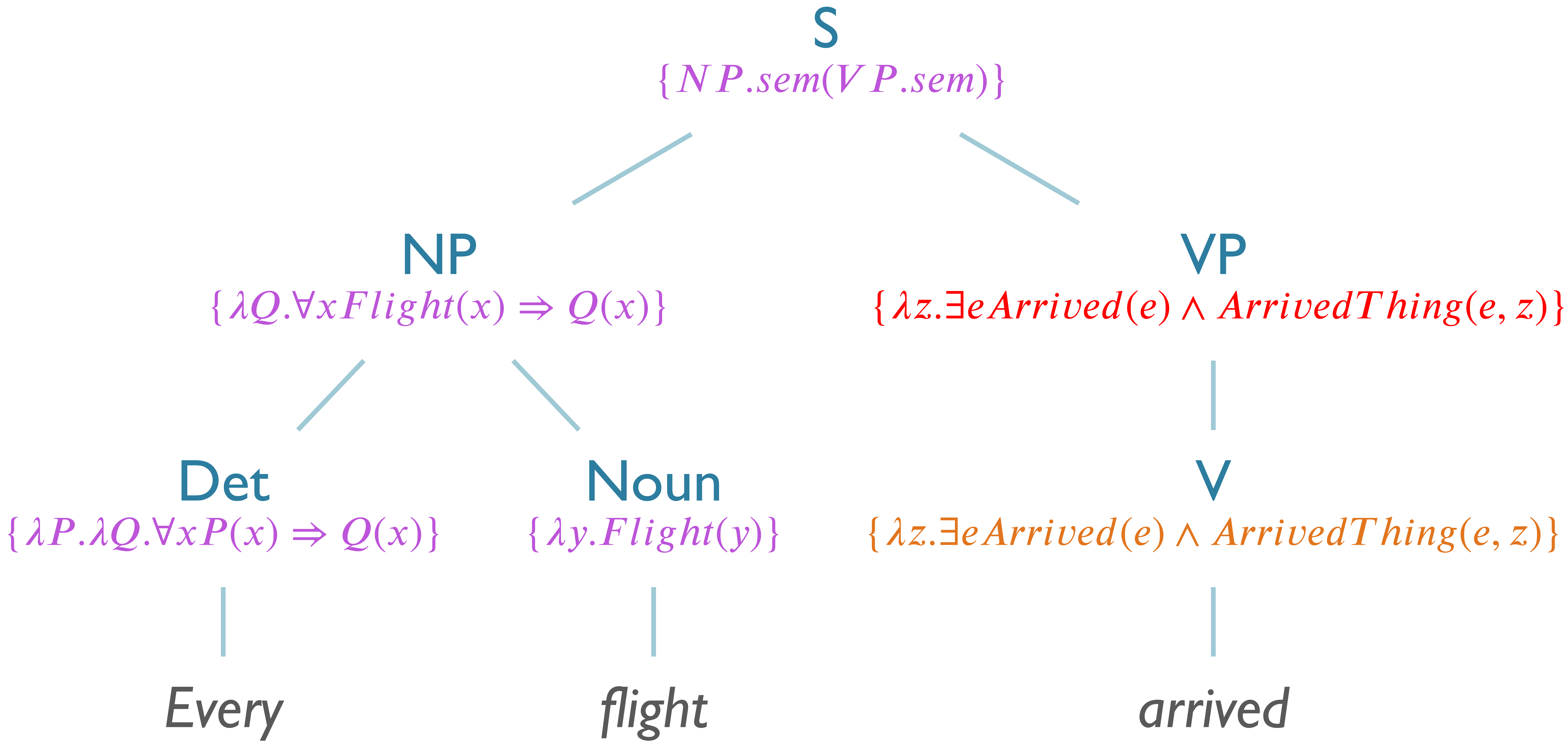
$$NP \rightarrow Det.sem(NP.sem)$$

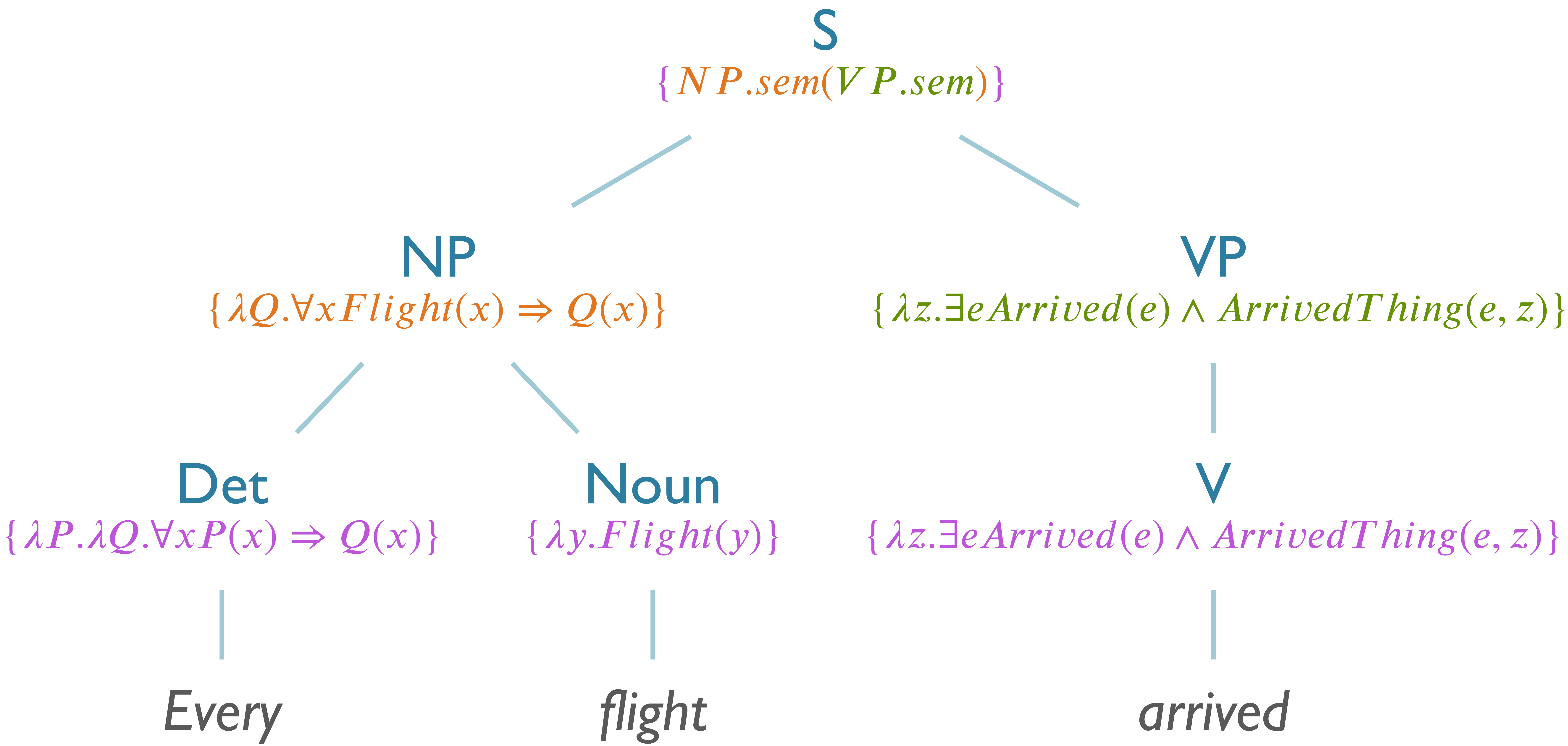
$$\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)(\lambda y.Flight(y))$$

$$\lambda Q.\forall x \lambda y.Flight(y)(x) \Rightarrow Q(x)$$

$$\lambda Q.\forall x Flight(x) \Rightarrow Q(x)$$




S
$\{NP.sem(VP.sem)\}$
NP
$\{\lambda Q.\forall x Flight(x) \Rightarrow Q(x)\}$
VP
$\{\lambda z.\exists e Arrived(e) \land ArrivedThing(e, z)\}$
Det
$\{\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)\}$
Noun
$\{\lambda y.Flight(y)\}$
V
$\{\lambda z.\exists e Arrived(e) \land ArrivedThing(e, z)\}$
Every
flight
arrived


S
{NP.sem(VP.sem)}
NP
{λQ.∀x Flight(x) ⇒ Q(x)}
VP
{λz.∃e Arrived(e) ∧ ArrivedThing(e, z)}
Det
{λP.λQ.∀x P(x) ⇒ Q(x)}
Noun
{λy.Flight(y)}
V
{λz.∃e Arrived(e) ∧ ArrivedThing(e, z)}
Every
flight
arrived

S

$\{\forall x Flight(x) \Rightarrow \exists e Arrived(e) \wedge ArrivedThing(e, x)\}$

$\{NP.sem(VP.sem)\}$

NP

$\{\lambda Q.\forall x Flight(x) \Rightarrow Q(x)\}$

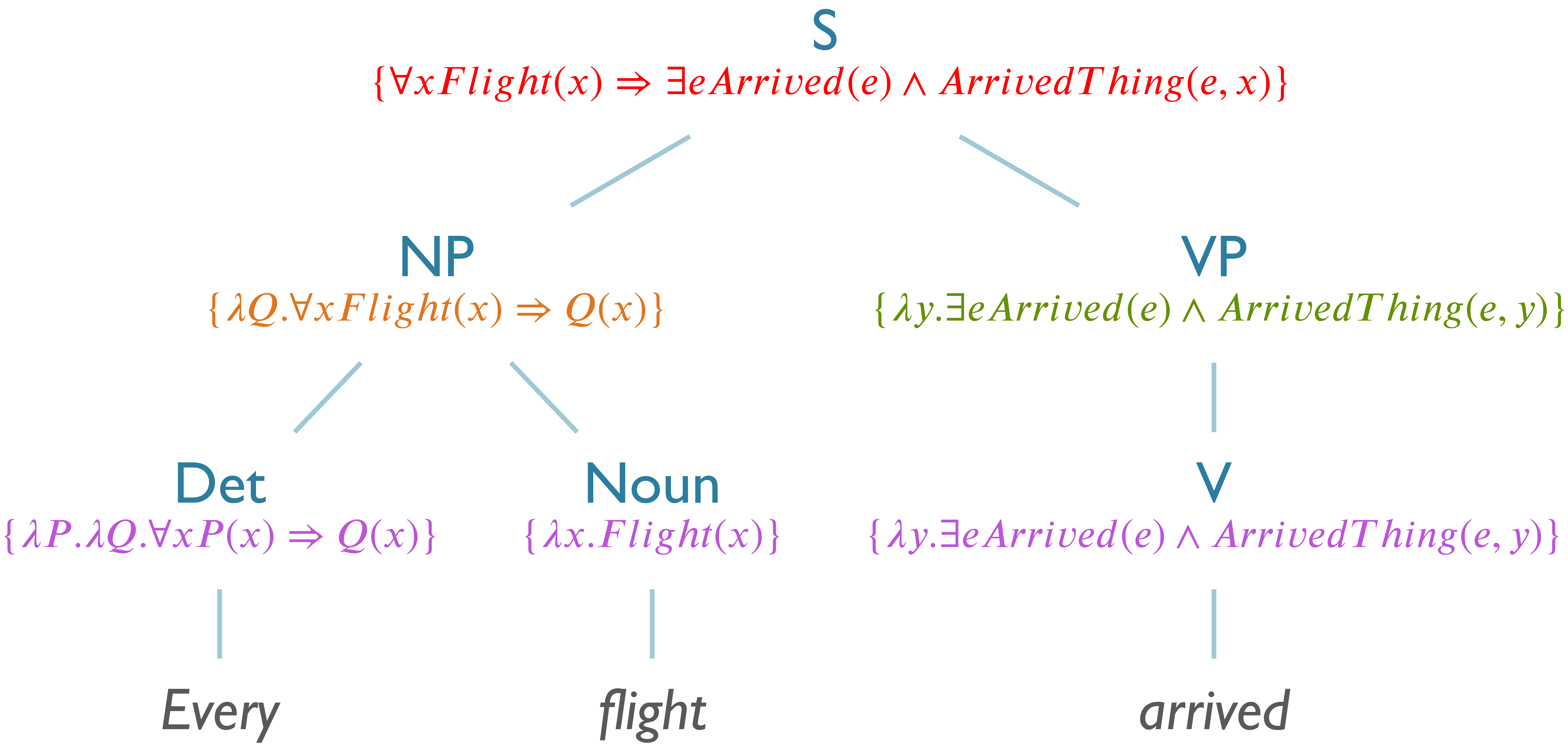
VP

$\{\lambda z.\exists e Arrived(e) \wedge ArrivedThing(e, z)\}$

$$\lambda Q.\forall x Flight(x) \Rightarrow Q(x)(\lambda z.\exists e Arrived(e) \wedge ArrivedThing(e, z))$$

$$\forall x Flight(x) \Rightarrow \lambda z.\exists e Arrived(e) \wedge ArrivedThing(e, z)(x)$$

$$\forall x Flight(x) \Rightarrow \exists e Arrived(e) \wedge ArrivedThing(e, x)$$


S
$\{\forall x Flight(x) \Rightarrow \exists e Arrived(e) \wedge ArrivedThing(e, x)\}$
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VP
$\{\lambda y.\exists e Arrived(e) \wedge ArrivedThing(e, y)\}$
Det
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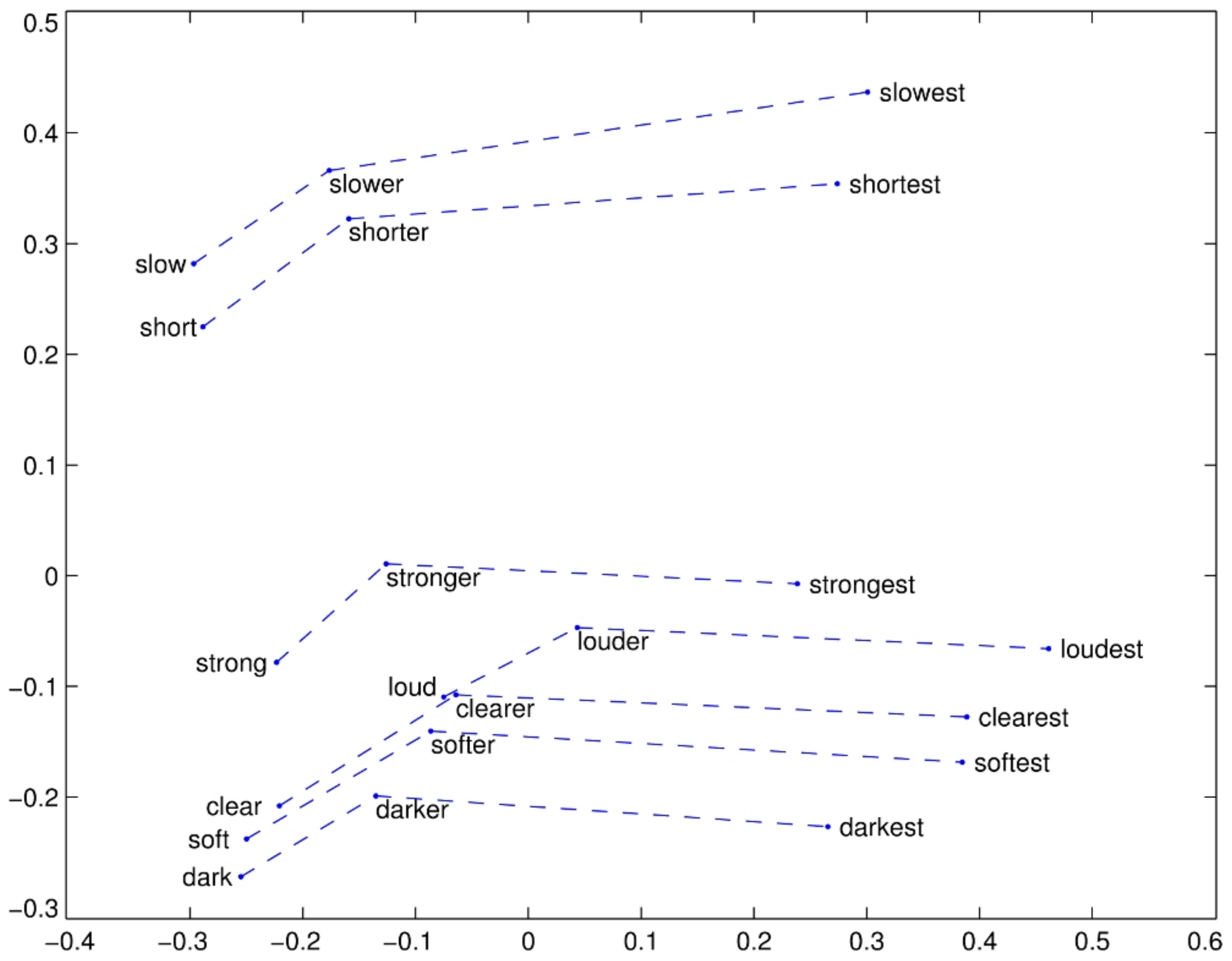
Noun
$\{\lambda x.Flight(x)\}$
V
$\{\lambda y.\exists e Arrived(e) \wedge ArrivedThing(e, y)\}$
Every
flight
arrived

Word Vectors



Pragmatics

- Discourse phenomena
- Coreference resolution [esp. pronominal]
  - Hobbs' Algorithm
- Segmentation / Cohesion
- Discourse parsing: hierarchical structure of coherence relations

Summary

- Deep Processing techniques for NLP
  - Parsing, semantic analysis, logical forms, reference, etc
  - Create richer computational models of natural language
    - Closer to language understanding
- Shallow processing techniques have dominated many areas
  - IR, QA, MT, WSD, etc
    - More computationally tractable, fewer required resources
- Deep processing techniques experience resurgence
  - Some big wins – e.g. QA
  - Improved resources: treebanks (syntactic/discourse, FrameNet, Propbank)
  - Improved learning algorithms: structured learners, neural nets
  - Increased computation: cloud resources, Grid, etc
    - Current goal: leveraging these resources to do deep processing [e.g. semi-supervised learning]

Thank you!

Course evaluations:

http://bit.ly/571-aut19-eval