Background 00 00	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary

A Generative Model for Parsing Natural Language to Meaning Representations

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March 9, 2015

Background 00 00	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary

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Outline

Background Key Concepts Purpose and Structure Generative Model Process Tree probability

Parameters

Decoding

Discriminative reranking

Averaged Perceptron

Evaluation

Methodology Results

Background ●0 ○○	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary

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Key Concepts

Outline Background Key Concepts Purpose and Structure

Background ○● ○○	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary
Key Concepts				

 Meaning Representation (MR): Formal representation of meaning. Written using a meaning representation language (MRL).

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Background ○● ○○	Generative Model 00 0000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary
Key Concepts				

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- Semantic Category
- Function Symbol
- Arguments

Background ○● ○○	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary
Key Concepts				

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NUM : count(STATE)

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Background ○● ○○	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary
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 Semantic Parsing: Mapping of natural language (NL) sentences to meaning representations.

Background ○○ ●○	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation 00 000	Summary
Purpose and Structure				

A ∃ ► ∃ = 1 ≤ 1000

Outline Background **Key Concepts** Purpose and Structure

Background ○○ ○●	Generative Model 00 000000 000000	Discriminative reranking 0000	Evaluation 00 000	Summary	
Purpose and Structure					

Purpose

Learn a generative model to map NL sentences to MR trees.

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Learn an implicit grammar.

Background ○○ ○●	Generative Model 00 0000000 000000	Discriminative reranking 0000	Evaluation 00 000	Summary
Purpose and Structure				

Purpose

- Learn a generative model to map NL sentences to MR trees.
- Learn an implicit grammar.

System Structure



Background 00 00	Generative Model ●O ○○ ○○ ○○ ○○	Discriminative reranking 0000	Evaluation 00 000	Summary

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Process

Outline

Key Concepts Generative Model Process

Results

Background 00 00	Generative Model ○● ○○○○○○○ ○○	Discriminative reranking	Evaluation 00 000	Summary
Process				

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Goal

Simultaneous generation of NL sentence and MR structure.

Background 00 00	Generative Model ⊙ ○ ○ ○ ○ ○ ○	Discriminative reranking 0000	Evaluation 00 000	Summary
Process				

Goal

Simultaneous generation of NL sentence and MR structure.



Background 00 00	Generative Model ○○ ●○ ○○○○○○ ○○	Discriminative reranking	Evaluation 00 000	Summary

▲ Ξ ► Ξ Ξ = √Q0

Tree probability

Outline

Background Key Concepts Purpose and Structure

Generative Model

Process

Tree probability

Parameters

Decoding

Discriminative reranking

Averaged Perceptron

Evaluation

Methodology

Results

Background 00 00	Generative Model ○○ ○○ ○○○○○○ ○○	Discriminative reranking 0000	Evaluation 00 000	Summary

Tree probability





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Background 00 00	Generative Model ○○ ○○ ○○○○○○ ○○	Discriminative reranking 0000	Evaluation 00 000	Summary

Tree probability



$$P(\widehat{\mathbf{w}}, \widehat{\mathbf{m}}, \mathcal{T}) = P(\mathcal{M}_a) \times P(m_a | \mathcal{M}_a) \times P(\overline{w_1 \mathcal{M}_b w_2 \mathcal{M}_c} | m_a) \\ \times P(m_b | m_a, \arg = 1) \times P(\dots | m_b) \\ \times P(m_c | m_a, \arg = 2) \times P(\dots | m_c)$$

 $\widehat{\boldsymbol{w}}: \text{ words } \quad \widehat{\boldsymbol{m}}: \text{ MR structures } \quad \mathcal{T}: \text{ hybrid tree}$

$$P(\overline{w_1 \mathcal{M}_b w_2 \mathcal{M}_c} | m_a) = P(m \to w \mathcal{Y} w \mathcal{Z} | m_a) \times P(w_1 | m_a)$$
$$\times P(\mathcal{M}_b | m_a, w_1) \times P(w_2 | m_a, w_1, \mathcal{M}_b)$$
$$\times P(\mathcal{M}_c | m_a, w_1, \mathcal{M}_b, w_2)$$
$$\times P(\text{END} | m_a, w_1, \mathcal{M}_b, w_2, \mathcal{M}_c)$$

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Background	Generative Model	Discriminative reranking	Evaluation	Summary
00 00	00 00 000000 00	0000	00 000	

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Parameters

Outline

Background Key Concepts Purpose and Structure

Generative Model

Process Tree probability

Parameters

Decoding

Discriminative reranking

Averaged Perceptron

Evaluation

Methodology

Results

Background 00 00	Generative Model ○○ ○●○○○○ ○○	Discriminative reranking	Evaluation 00 000	Summary
Demonstration				
Parameters				

► MR model parameters: ∑_{m'} ρ(m'|m_j, arg = k) = 1 for all j and k = 1,2

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- Pattern parameters: ∑_r φ(r|m_j) = 1 for all j r: hybrid pattern, e.g. w𝔅w𝔅
- Emission parameters: ∑_t θ(t|m_j, Λ) = 1 for all j t: any node in T Λ: preceding context

Background 00 00	Generative Model ○○ ○○●○○○ ○○	Discriminative reranking	Evaluation 00 000	Summary
Parameters				

Different contexts (Λ) result in different models.

- Model I: $\theta(t_k|m_j, \Lambda) = P(t_k|m_j)$ (Unigram)
- Model II: $\theta(t_k|m_j, \Lambda) = P(t_k|m_j, t_{k-1})$ (Bigram)
- ► Model III: $\theta(t_k | m_j, \Lambda) = \frac{1}{2} \times (\text{Model I} + \text{Model II})$ (Interpolation)

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Background 00 00	Generative Model ○○ ○○○ ○○○●○○ ○○	Discriminative reranking	Evaluation 00 000	Summary
Parameters				

Estimation

- MR model parameters: count and normalize.
- Pattern and Emission parameters: EM algorithm Unknown alignment between NL words and MR structures in training data.

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Background 00 00	Generative Model ○○ ○○○○●○ ○○	Discriminative reranking 0000	Evaluation 00 000	Summary
Parameters				

EM: inside and outside probabilities



- Inside and outside probabilities used to calculate estimated counts.
- O(n⁶m) time for 1 EM iteration, where n is length of NL sentence and m the size of the MR structure.
- Modification implemented to bring complexity down to O(n³m).

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Background 00 00	Generative Model ○○ ○○○ ○○○○○● ○○	Discriminative reranking 0000	Evaluation 00 000	Summary
Parameters				

Modification

- Idea: aggregate probabilities of NL-MR subsequences to use in subsequent computations.
- Aggregate probabilities for a given NL-MR subsequence $\langle m_v, w_v \rangle$ and a given pattern *r*, e.g. $w \mathcal{Y} w \mathcal{Z}$.
- ► This aggregate probability can be used to calculate the partial inside or outside probability for a given (m_v, w_v).

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By summing over all r, we get the total inside or outside probability.

Background 00 00	Generative Model ○○ ○○○○○○○ ●○	Discriminative reranking 0000	Evaluation 00 000	Summary

A ∃ ► ∃ = 1 ≤ 1000

Decoding

Outline

Background Key Concepts Purpose and Structur

Generative Model

Process Tree probability Parameters

Decoding

Discriminative reranking

Averaged Perceptron

Evaluation

Methodology

Results

Background 00 00	Generative Model ○○ ○○○○○○○ ○●	Discriminative reranking 0000	Evaluation 00 000	Summary
Decoding				

Goal: Most probable MR structure $\widehat{\mathbf{m}}^*$ given NL sentence $\widehat{\mathbf{w}}$.

$$\widehat{\mathbf{m}}^* = \operatorname*{argmax}_{\widehat{\mathbf{m}}} \sum_{\mathcal{T}} P(\widehat{\mathbf{m}}, \mathcal{T} | \widehat{\mathbf{w}})$$

But summing over all possible trees \mathcal{T} is expensive. Approximate with the most likely tree (Viterbi approximation).

$$\widehat{\mathbf{m}}^* = \underset{\widehat{\mathbf{m}}}{\operatorname{argmax}} \max_{\mathcal{T}} P(\widehat{\mathbf{m}}, \mathcal{T} | \widehat{\mathbf{w}}) = \underset{\widehat{\mathbf{m}}}{\operatorname{argmax}} \max_{\mathcal{T}} P(\widehat{\mathbf{w}}, \widehat{\mathbf{m}}, \mathcal{T})$$

In practice, ranked list of k best trees is output.

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Background 00 00	Generative Model 00 000000 000000	Discriminative reranking ●000	Evaluation 00 000	Summary
Averaged Perceptron				

▲ Ξ ► Ξ Ξ = √Q0

Outline

Key Concepts Discriminative reranking Averaged Perceptron



Averaged Perceptron



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Averaged Perceptron



- Generative model cannot model long range dependencies within trees.
- Use discriminative classifier to rerank the list of k best trees generated by the generative model (k = 50).

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Averaged perceptron with separating plane.

Background 00 00	Generative Model 00 0000000 00	Discriminative reranking 00€0	Evaluation 00 000	Summary
Averaged Perceptron				

- Feature function maps a given tree *T* to a feature vector Φ(*T*).
- Weight vector **w** associated with $\Phi(\mathcal{T})$.
- ► *T* with highest score based on weights is picked as output.

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	Background 00 00	Generative Model 00 0000000 00	Discriminative reranking 00●0	Evaluation 00 000	Summary
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Separating Plane

- ► After **w** is learned, set a threshold score value *b*.
- Reject a given \mathcal{T} if it's score is less than b.
- Choose b that results in maximum F-score

Background 00 00	Generative Model 00 00 000000 00	Discriminative reranking 000●	Evaluation 00 000	Summary
Averaged Perceptron				
Features				

Feature Type	Description
1. Hybrid Rule	A MR production and its child hybrid form
2. Expanded Hybrid Rule	A MR production and its child hybrid form expanded
3. Long-range Unigram	A MR production and a NL word appearing below in tree
 Grandchild Unigram 	A MR production and its grandchild NL word
5. Two Level Unigram	A MR production, its parent production, and its child NL word
6. Model Log-Probability	Logarithm of base model's joint probability

Features 1-5 are binary $\{0,1\}$. Feature 6 is real valued.

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Background 00 00	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation ●0 ○○○	Summary
Methodology				
Outline Backgro Key	ound Concepts			
Pur	oose and Structur	e		
Generat	ive Model			
Tree	e probability			
Para	nmeters oding			
Discrim	inative reranking			
Evaluat	ion			

Methodology

Results

Background 00 00	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation ⊙● ○○○	Summary
Methodology				

Evaluated on two corpora: GEOQUERY and ROBOCUP.

- ▶ Precision, recall, and F-score reported.
- GEOQUERY: MR structure considered correct if it retrieves the same answer as the reference MR structure when used as a query to the database, regardless of differences in the string representation.
- ROBOCUP: MR structure considered correct if it has the same string representation as the reference MR structure.

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Background 00 00	Generative Model 00 000000 00	Discriminative reranking 0000	Evaluation ○○ ●○○	Summary
Results				
Outline Backgrou	nd			
Key C	oncepts			

Results

Averaged Perceptron

Evaluation

Background 00 00	Generative Model 00 000000 000000 00	Discriminative reranking 0000	Evaluation OO OOO	Summary

Results

Model	GEOQUERY (880)			ROBOCUP (300)		
Widder	Prec.	Rec.	F	Prec.	Rec.	F
I	81.3	77.1	79.1	71.1	64.0	67.4
II	89.0	76.0	82.0	82.4	57.7	67.8
III	86.2	81.8	84.0	70.4	63.3	66.7
I+R	87.5	80.5	83.8	79.1	67.0	72.6
II+R	93.2	73.6	82.3	88.4	56.0	68.6
III+R	89.3	81.5	85.2	82.5	67.7	74.4

Background	Generative Model	Discriminative reranking	Evaluation	Summary
00	00 00 000000 00	0000	00 00	

Results

Comparison to previous work

System	GEOQUERY (880)			ROBOCUP (300)		
System	Prec.	Rec.	F	Prec.	Rec.	F
SILT	89.0	54.1	67.3	83.9	50.7	63.2
WASP	87.2	74.8	80.5	88.9	61.9	73.0
KRISP	93.3	71.7	81.1	85.2	61.9	71.7
Model III+R	89.3	81.5	85.2	82.5	67.7	74.4

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Background	Generative Model	Discriminative reranking	Evaluation	Summary
00 00	00 00 000000 00	0000	00 00	

Results

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System	GEOQUERY (880)			ROBOCUP (300)		
System	Prec.	Rec.	F	Prec.	Rec.	F
SILT	89.0	54.1	67.3	83.9	50.7	63.2
WASP	87.2	74.8	80.5	88.9	61.9	73.0
KRISP	93.3	71.7	81.1	85.2	61.9	71.7
Model III+R	89.3	81.5	85.2	82.5	67.7	74.4

System	English			Spanish		
	Prec.	Rec.	F	Prec.	Rec.	F
WASP	95.42	70.00	80.76	91.99	72.40	81.03
Model III+R	91.46	72.80	81.07	95.19	79.20	86.46
System						
System		Japanese			Turkish	
System	Prec.	Japanese <i>Rec</i> .	F	Prec.	Turkish <i>Rec</i> .	F
System WASP	<i>Prec.</i> 91.98	Japanese <i>Rec.</i> 74.40	F 82.86	<i>Prec.</i> 96.96	Turkish Rec. 62.40	F 75.93

(Evaluated on a subset of GEOQUERY.)

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Background	Generative Model	Discriminative reranking	Evaluation	Summary
00 00	00 00 000000 00	0000	00 000	

Summary

- Learn a generative model which outputs a list of k best NL-MR hybrid trees from a given NL sentence.
- Rerank the k best list according to score assigned by the averaged perceptron with separating plane.

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Choose tree with highest score as output.

References

References I

W. Lu, H. T. Ng, W. S. Lee, L. S. Zettlemoyer. "A Generative Model for Parsing Natural Language to Meaning Representations". Conference on Empirical Methods on Natural Language

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