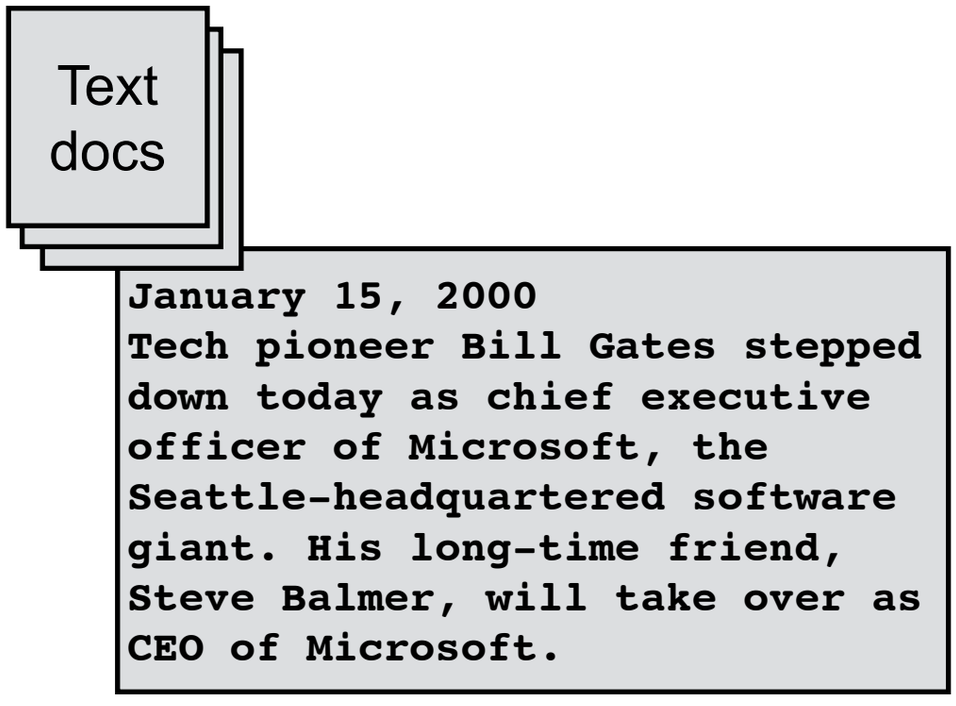
Chains of Reasoning over Entities, Relations, and Text using Recurrent Neural Networks

Rajarshi Das, Arvind Neelakantan, David Belanger, Andrew McCallum




UMassAmherst

Relation Extraction



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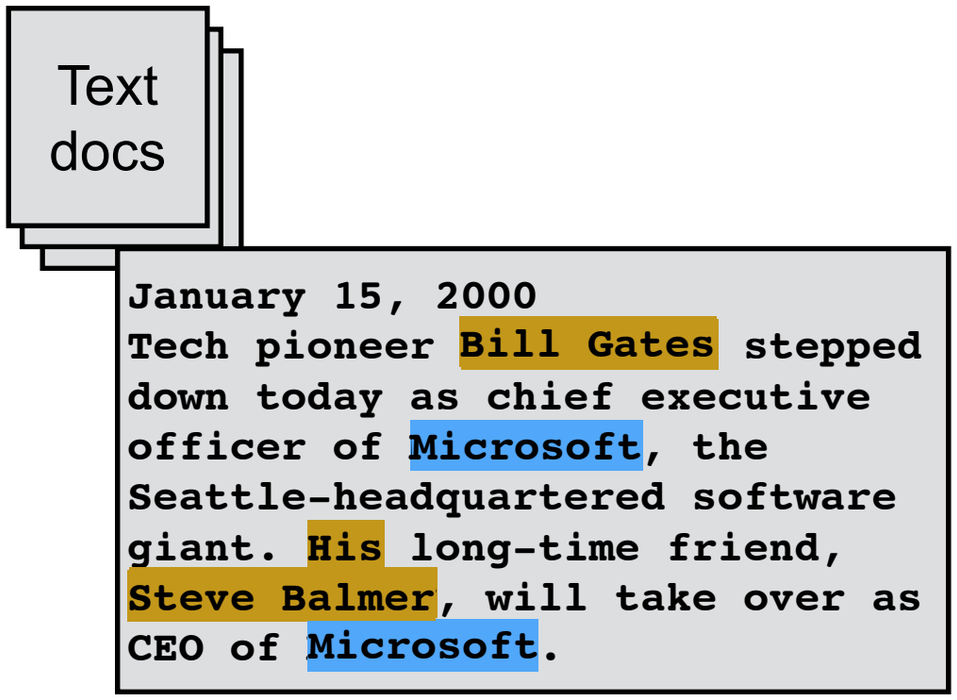

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Steve Balmer	Microsoft
Bill Gates	Steve Balmer

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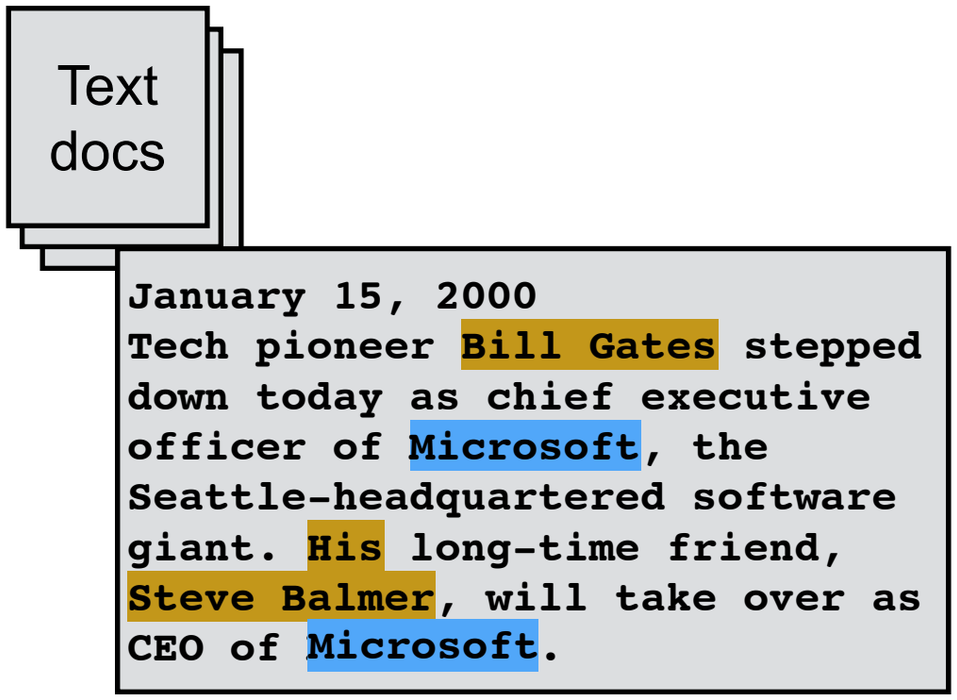

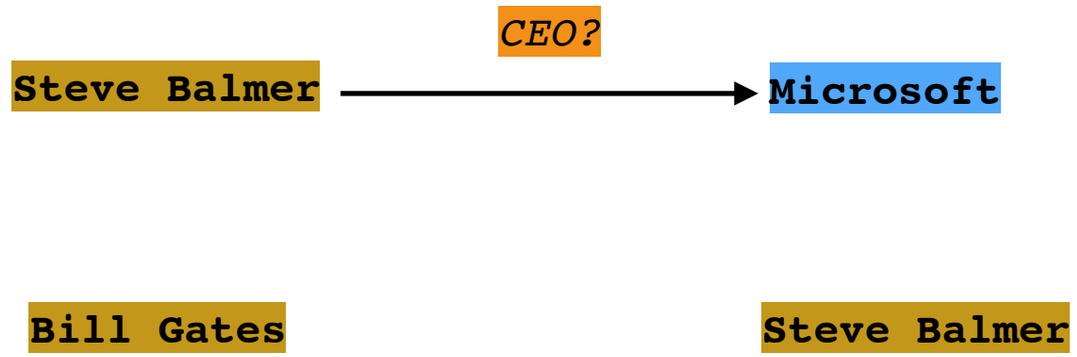

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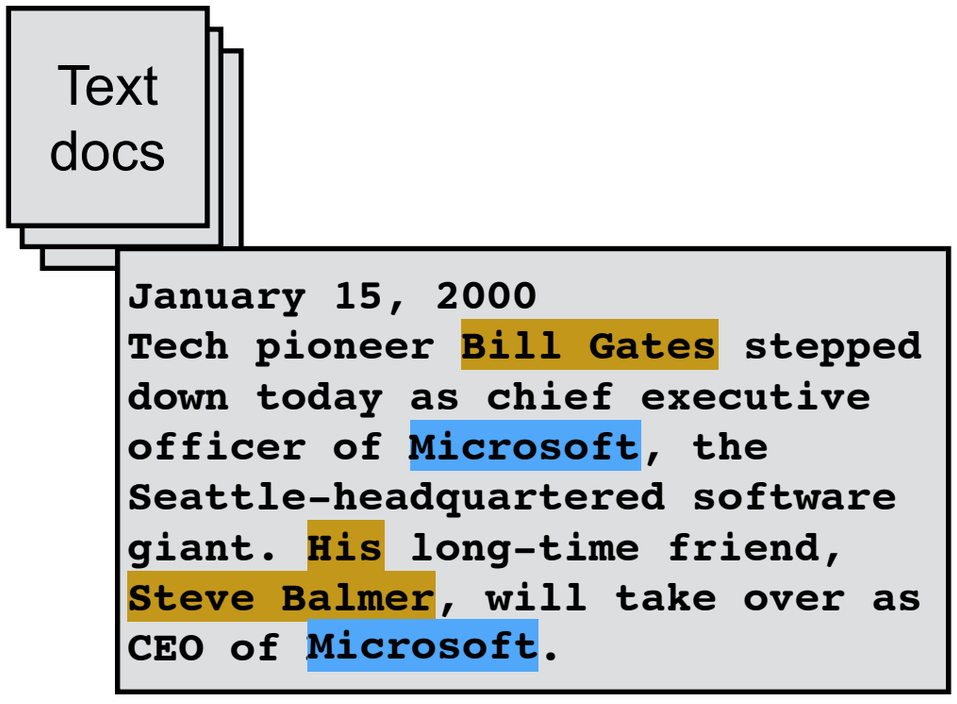

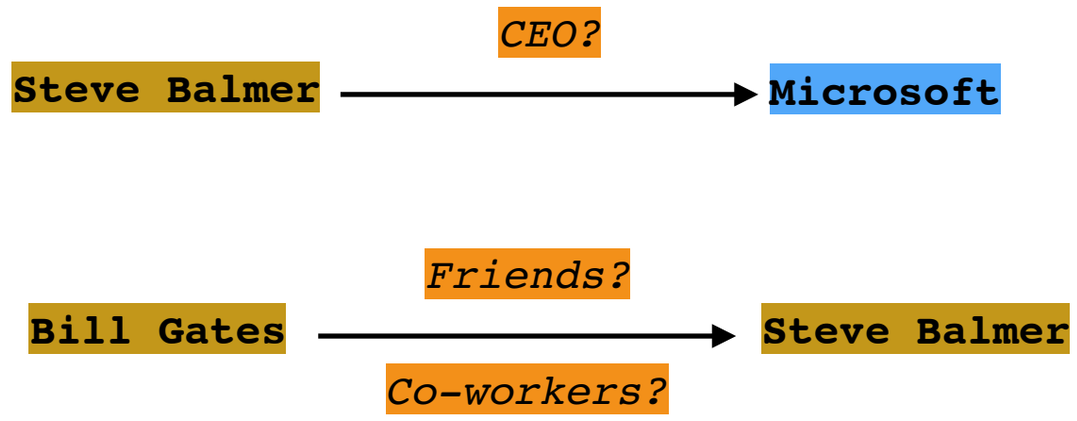

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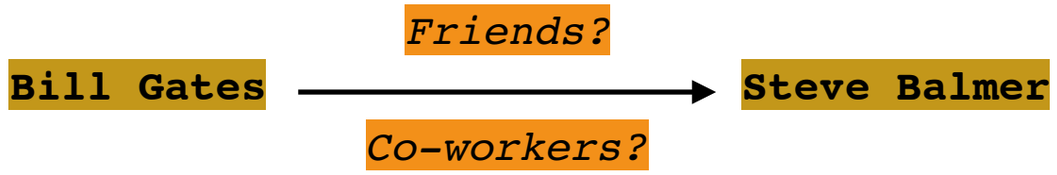

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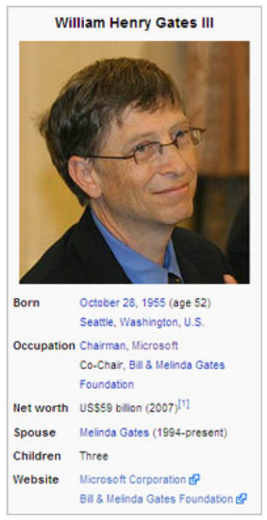

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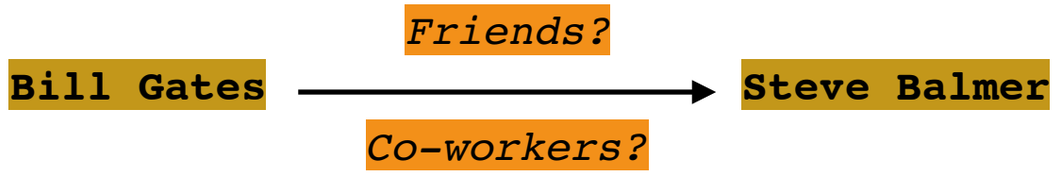

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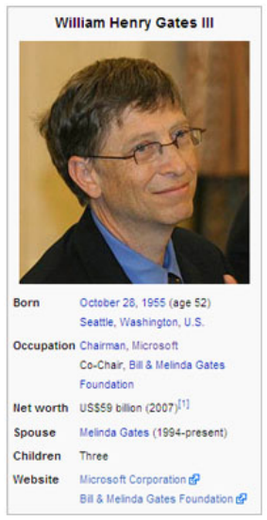

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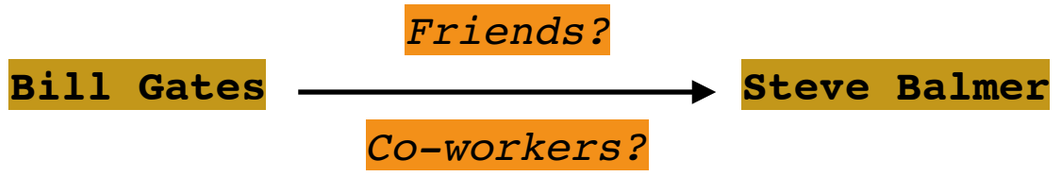

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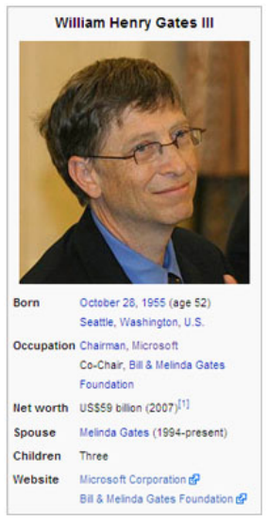

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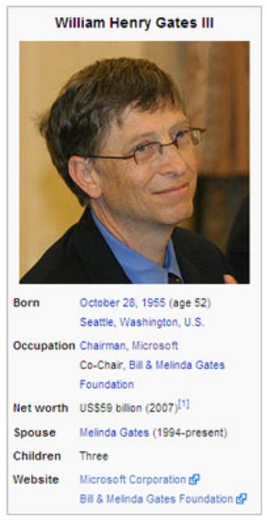

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Riedel, Yao, McCallum, Marlin, 2013

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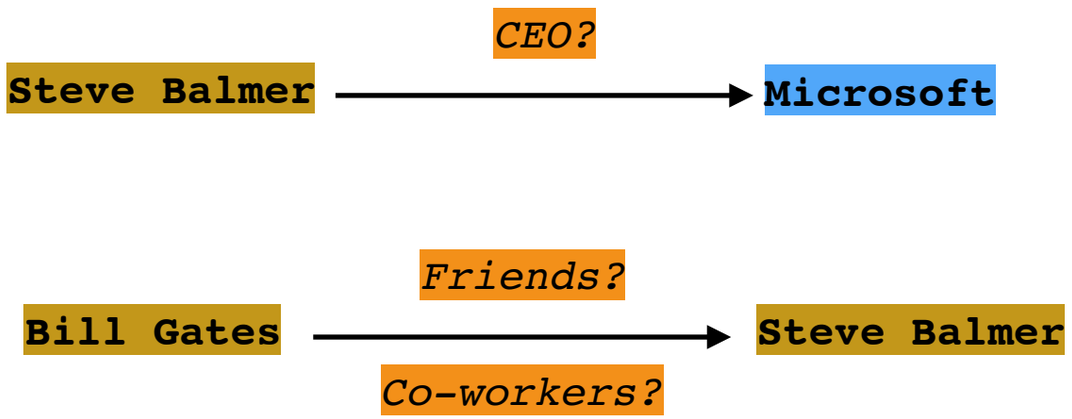

Union of all relation types from all structured sources and text

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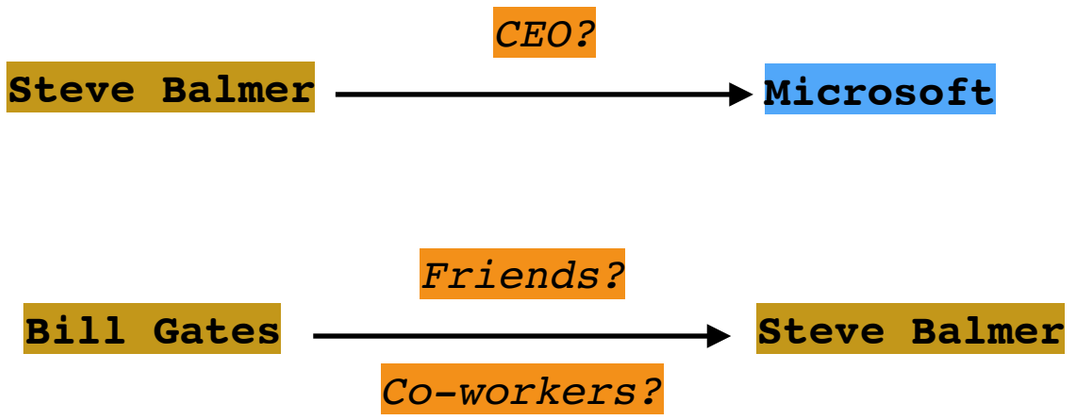

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Predict **relation** between **entities** based on **mentions** in **text**

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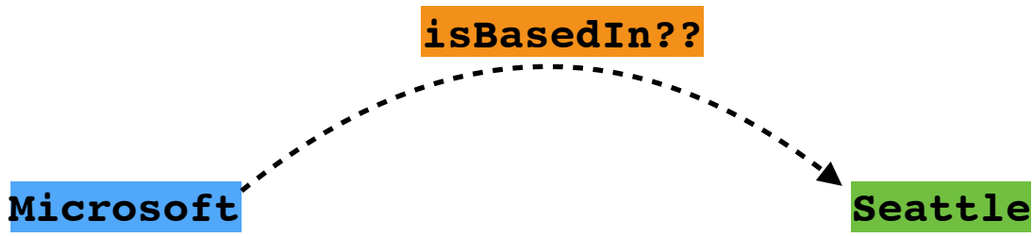

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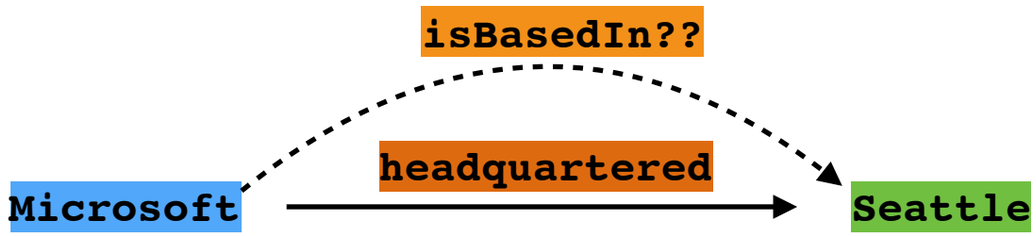

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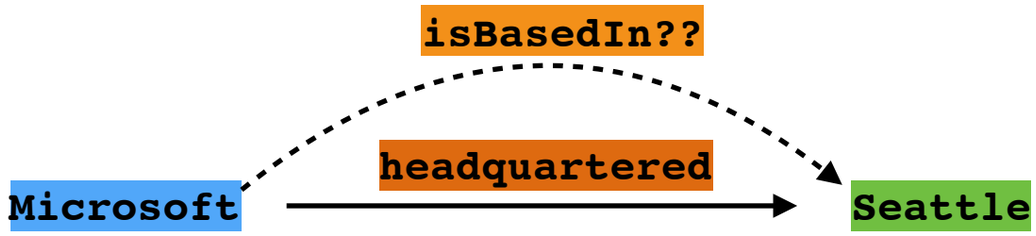

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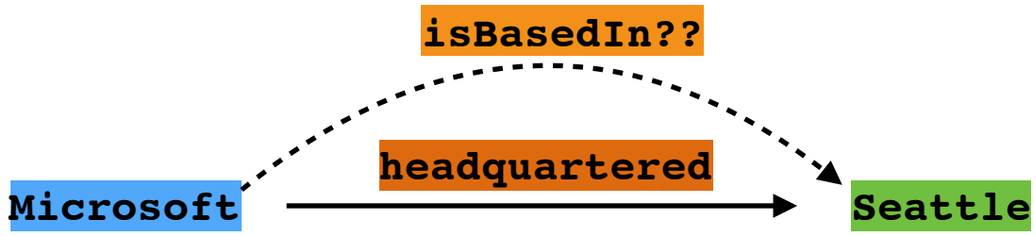

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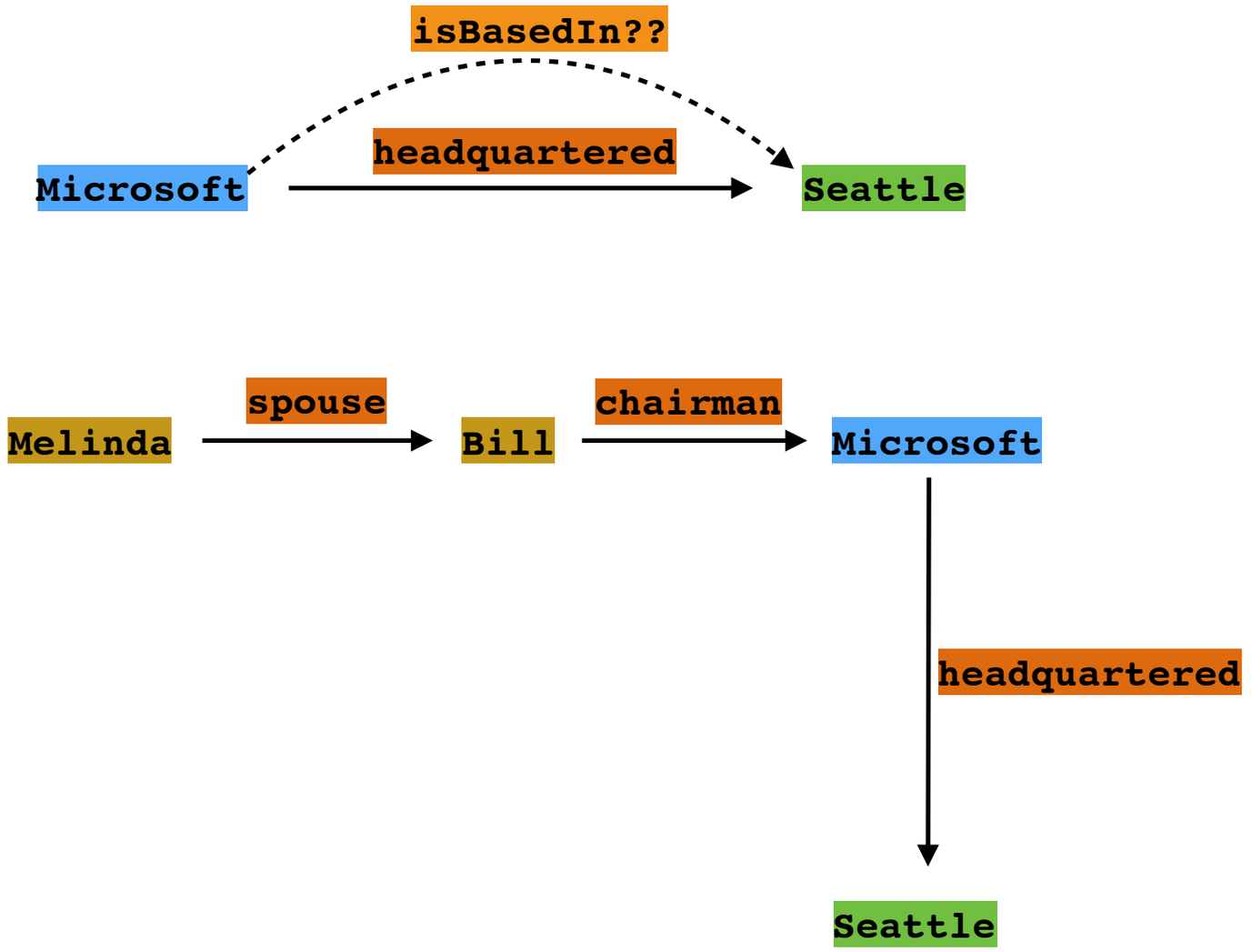

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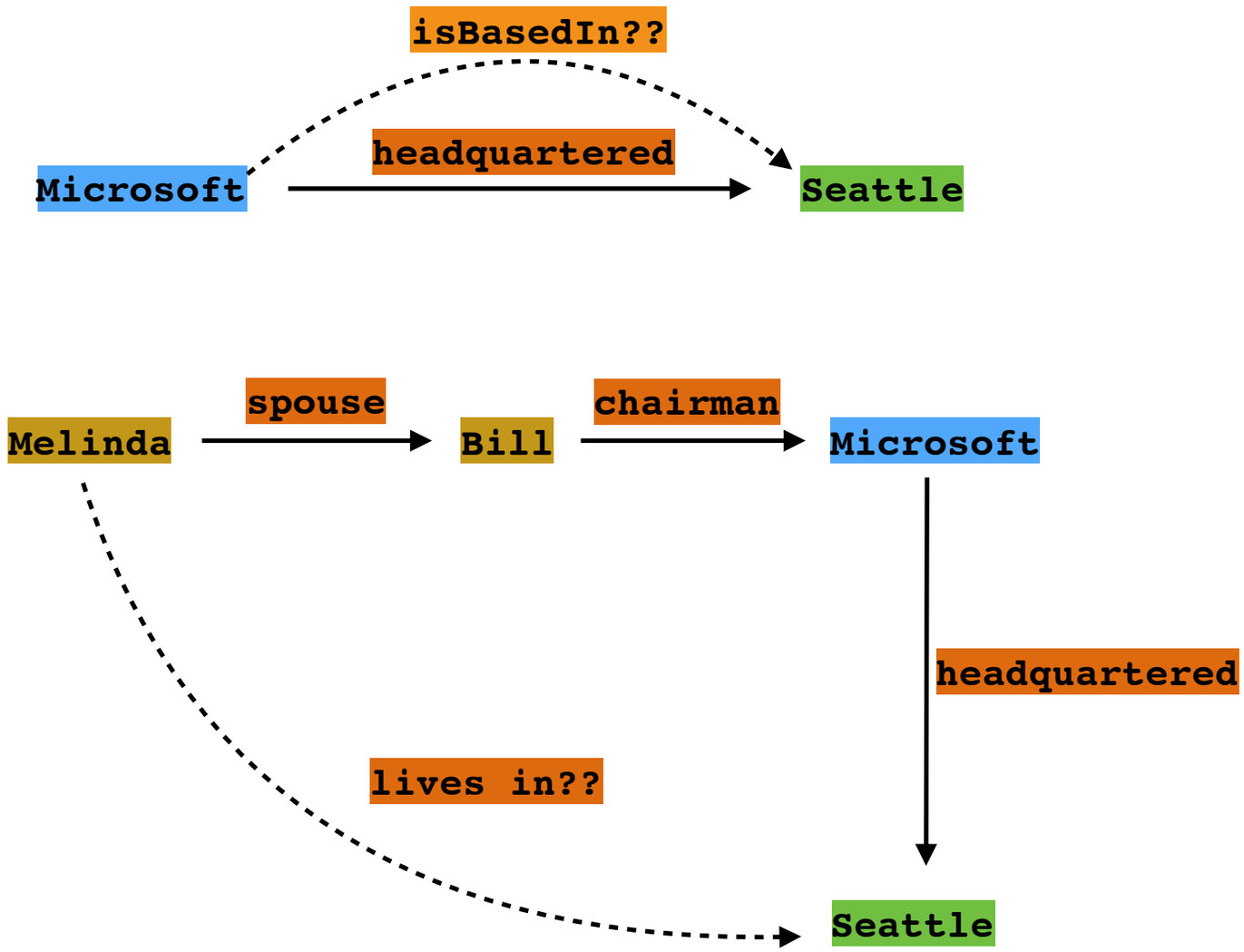

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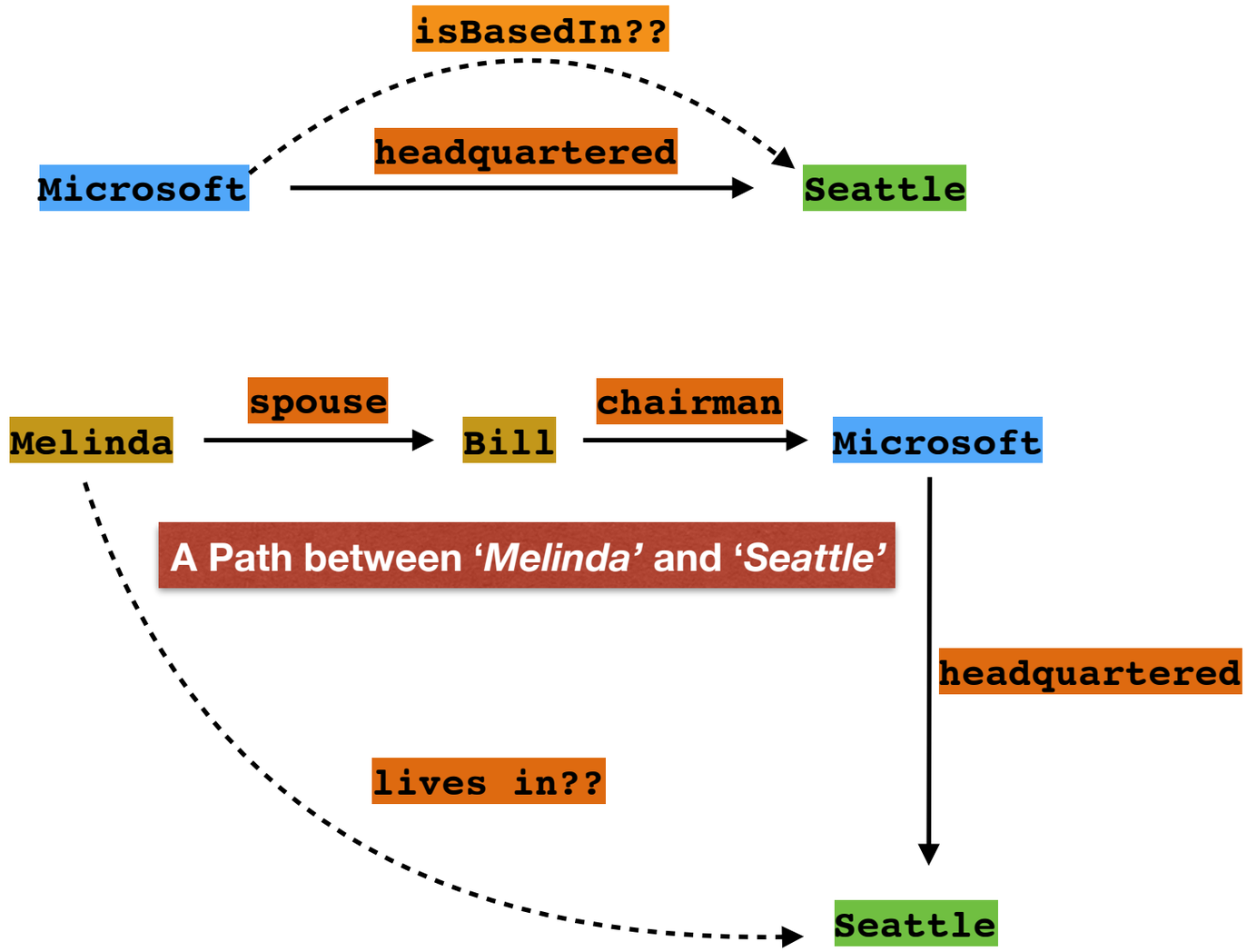

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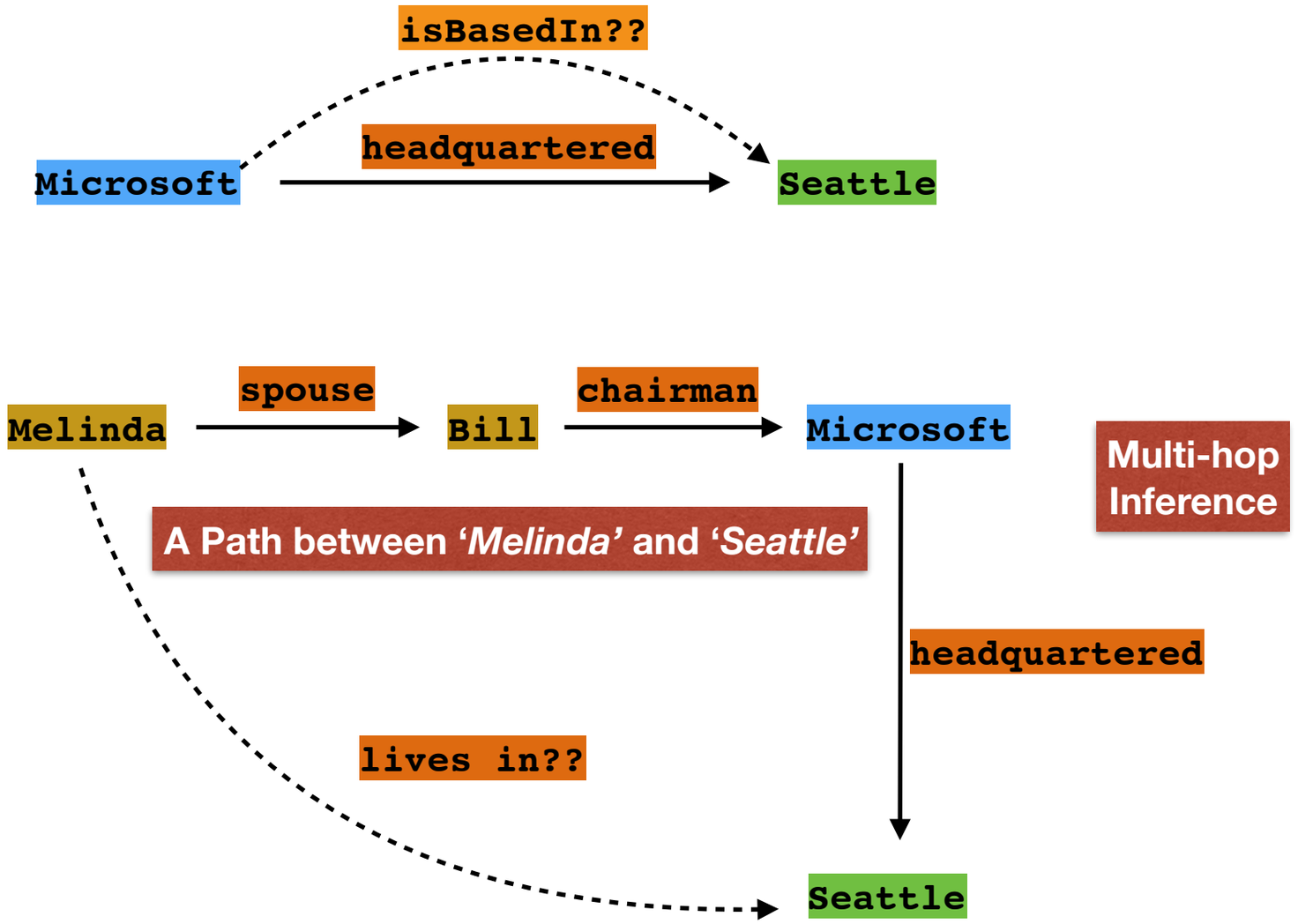

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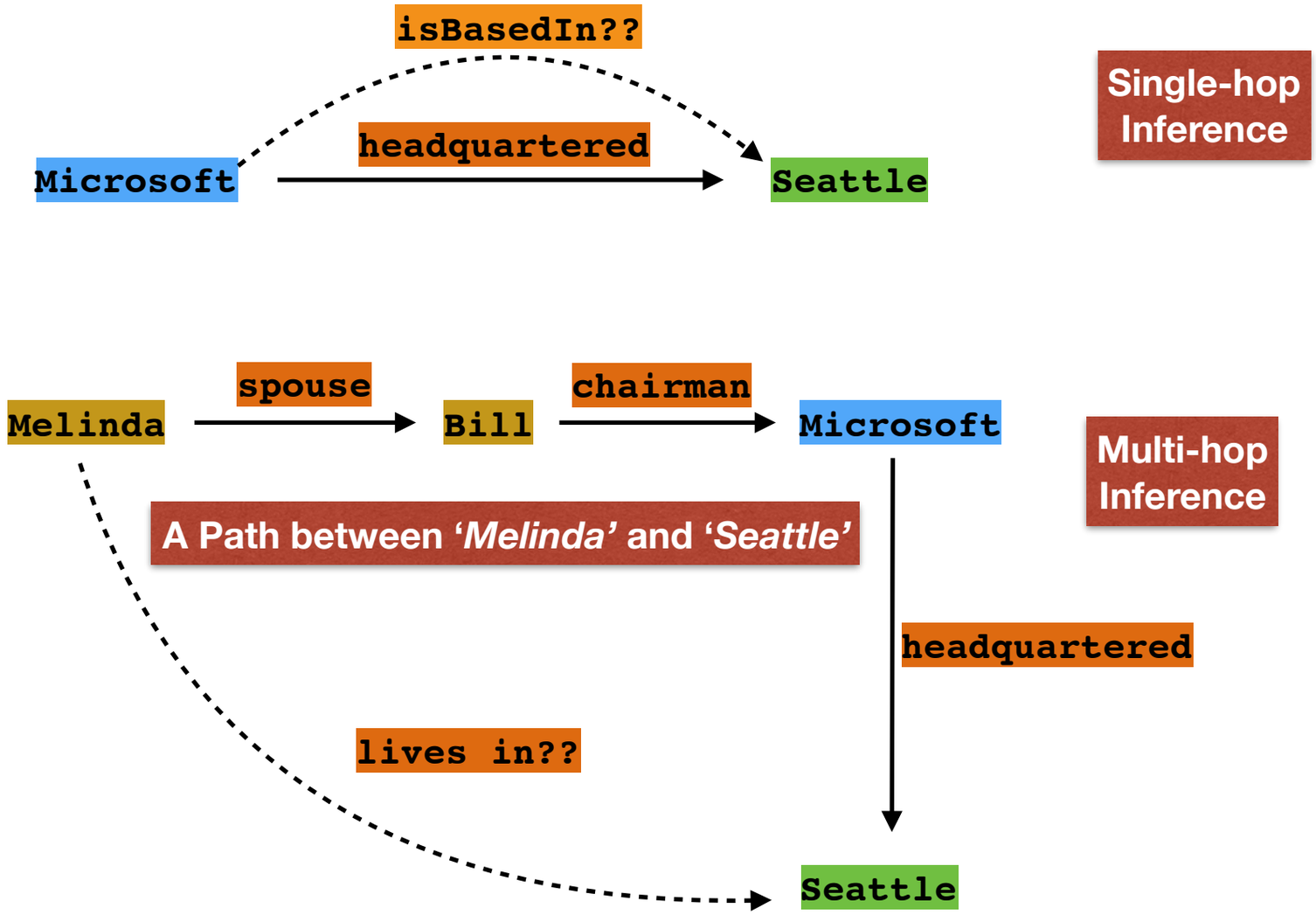

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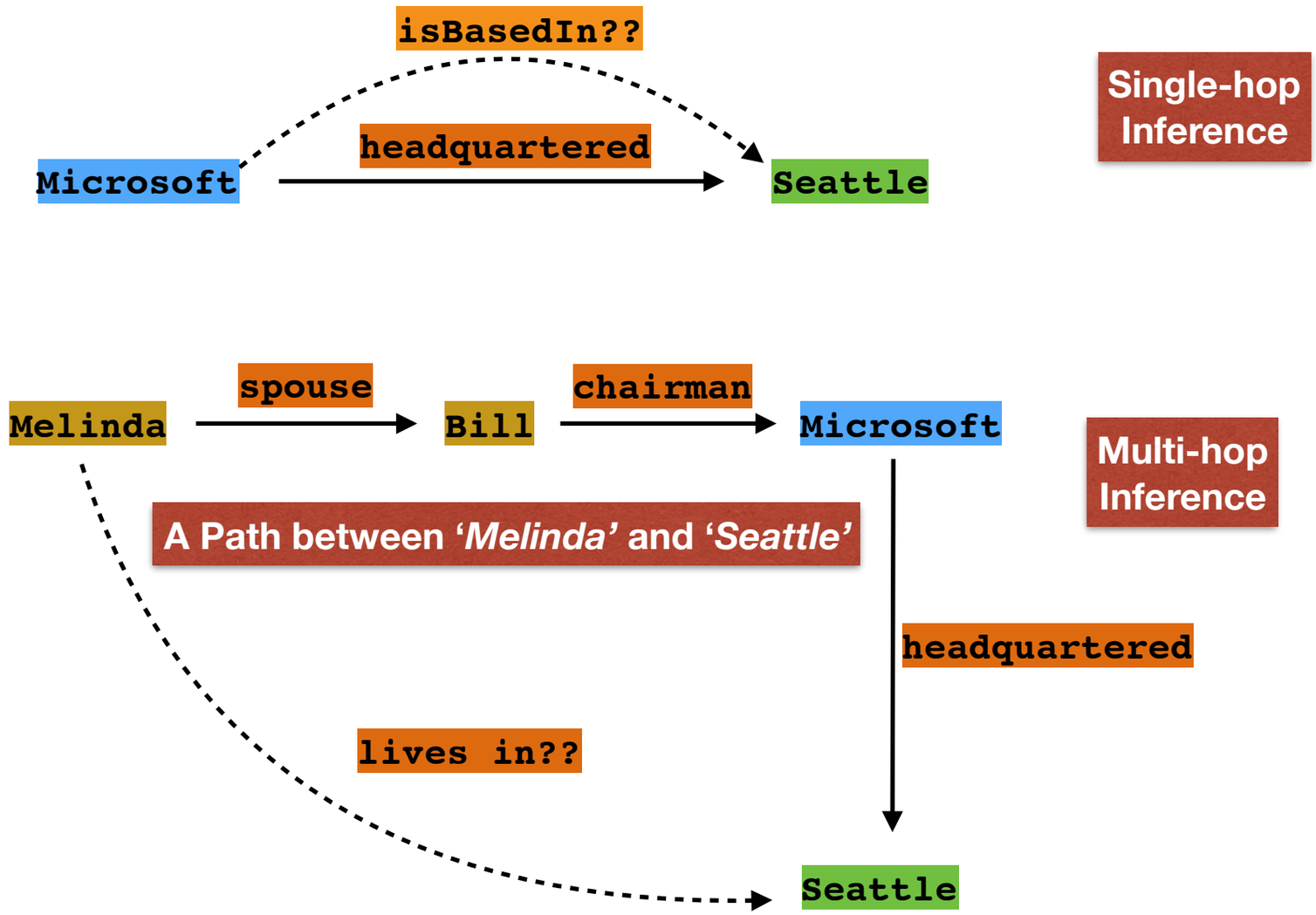

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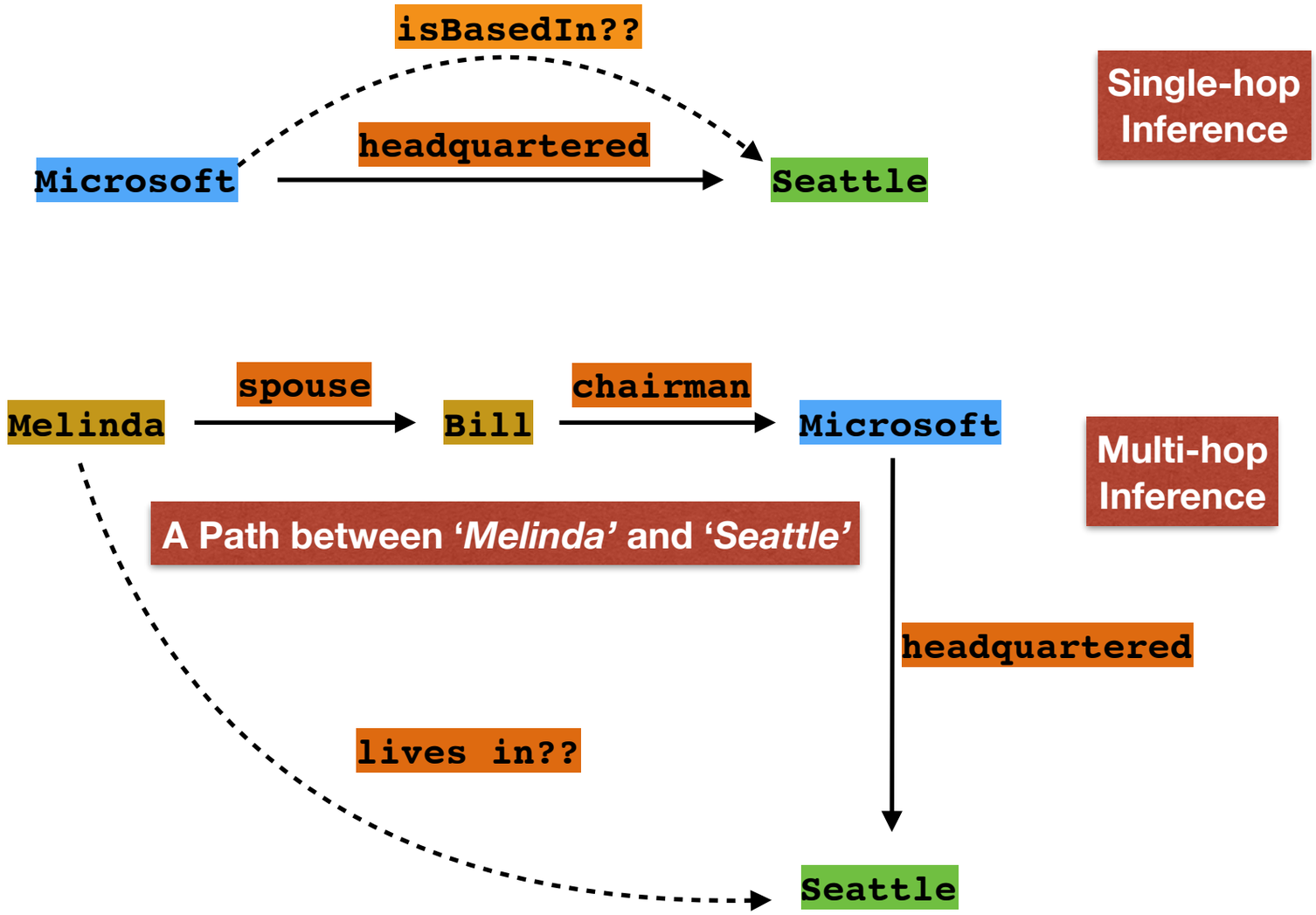

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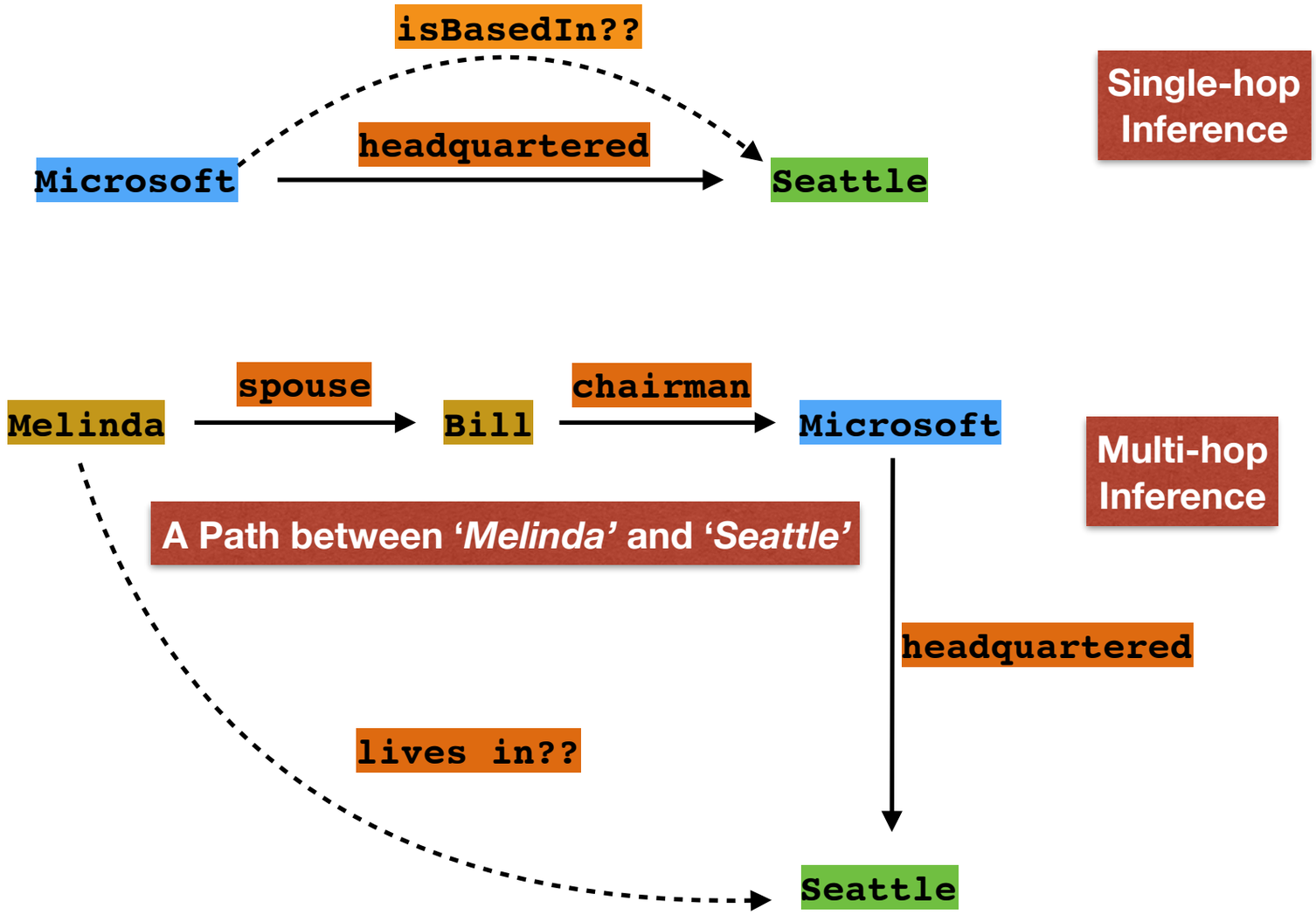

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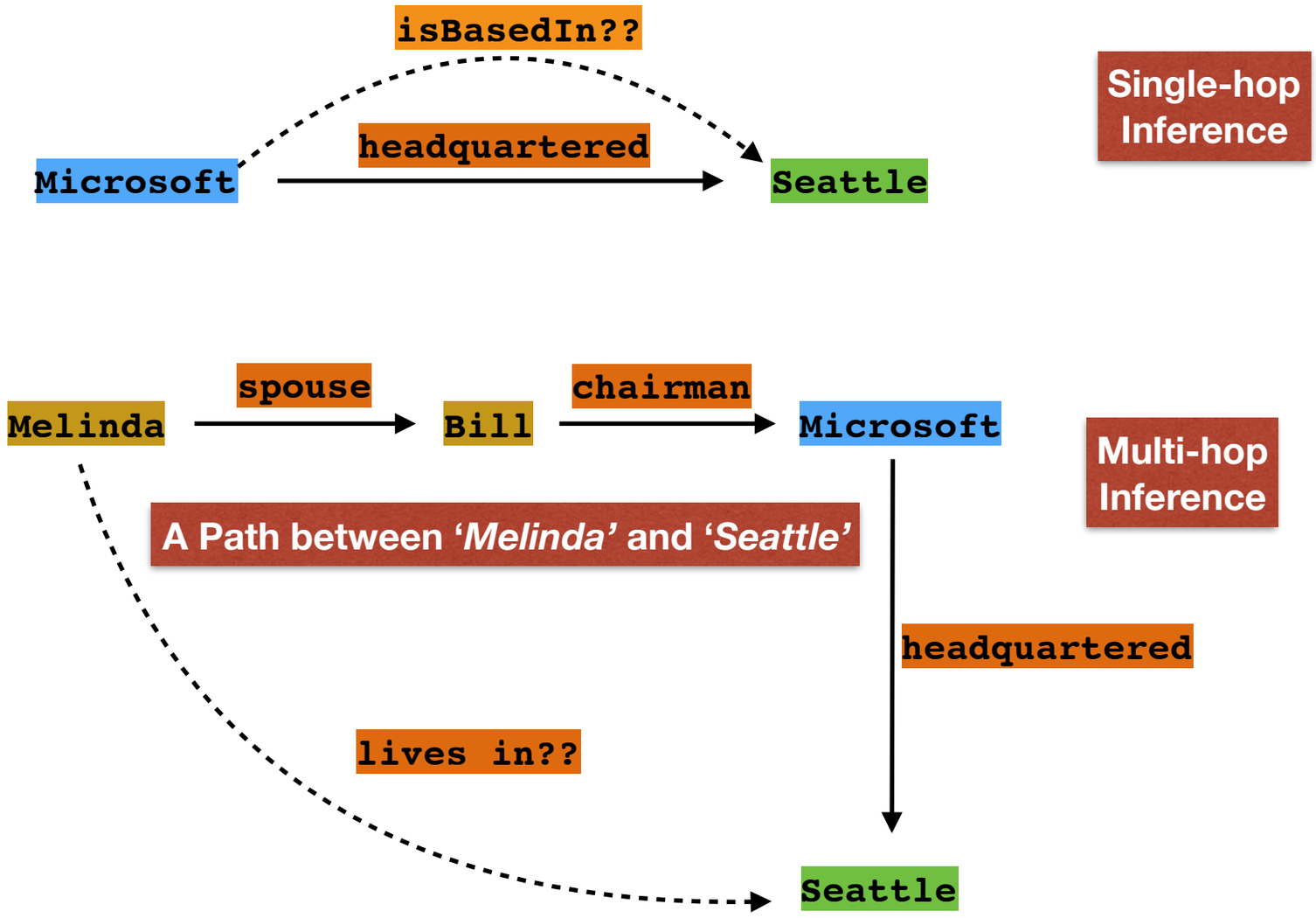

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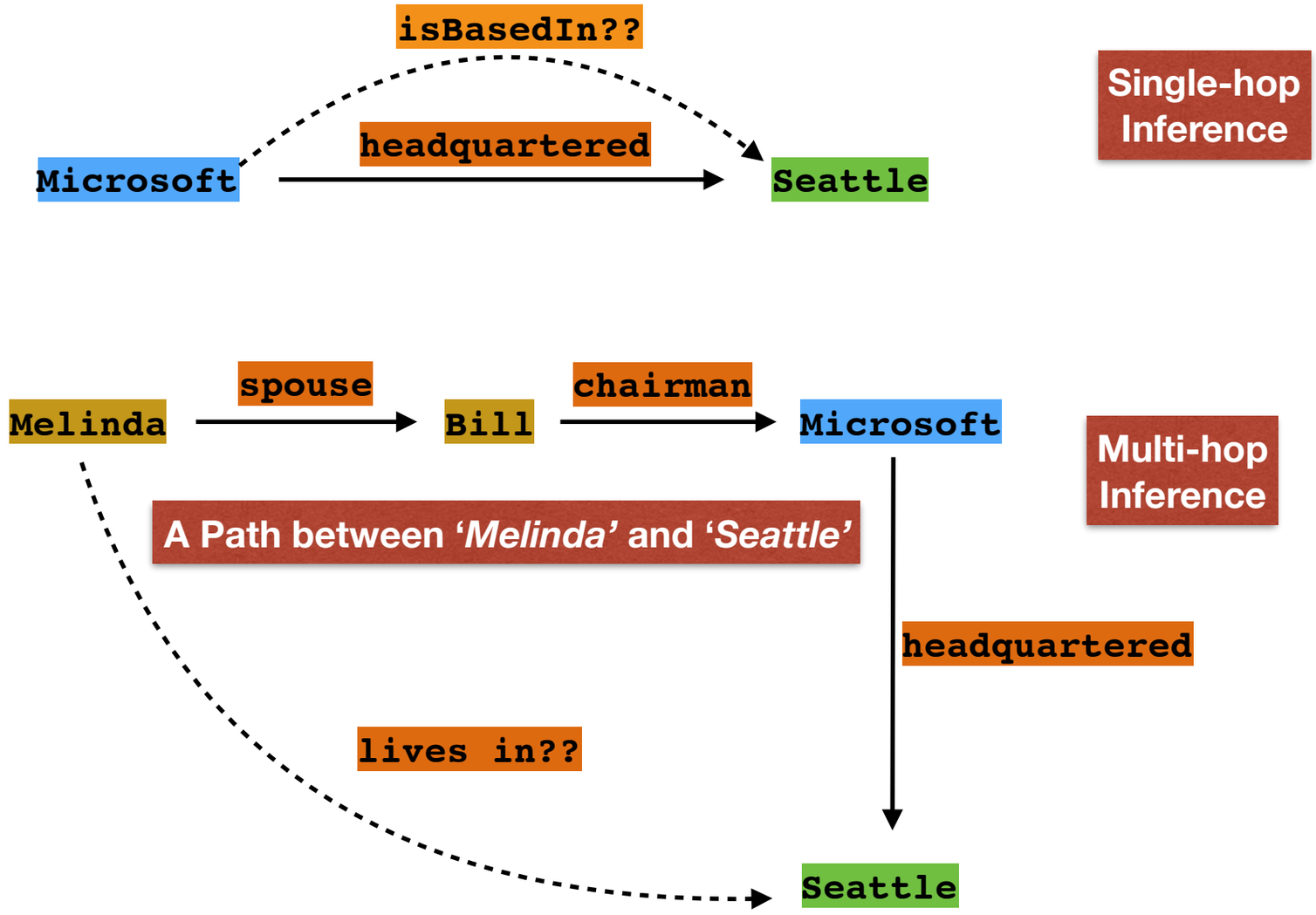

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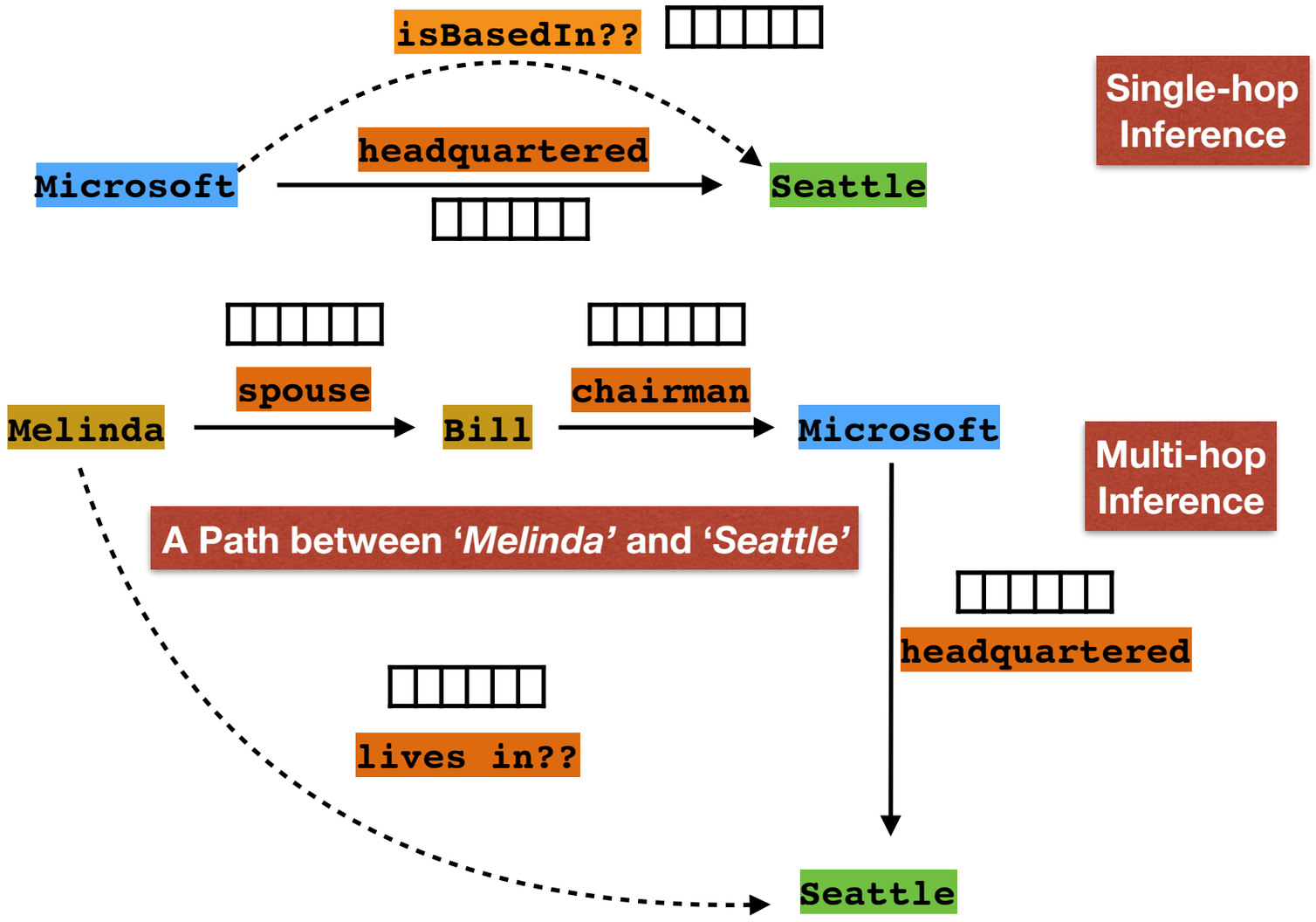

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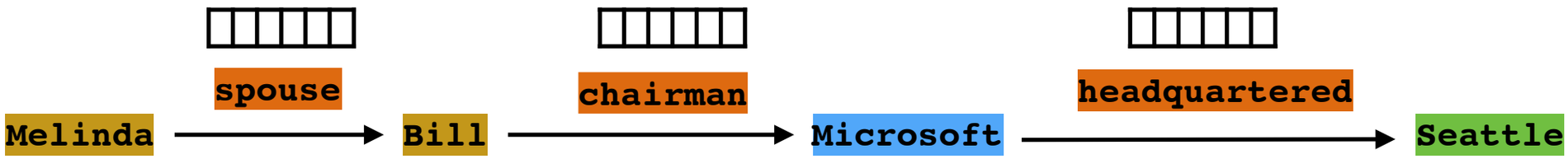
RNNs for Chains of Reasoning



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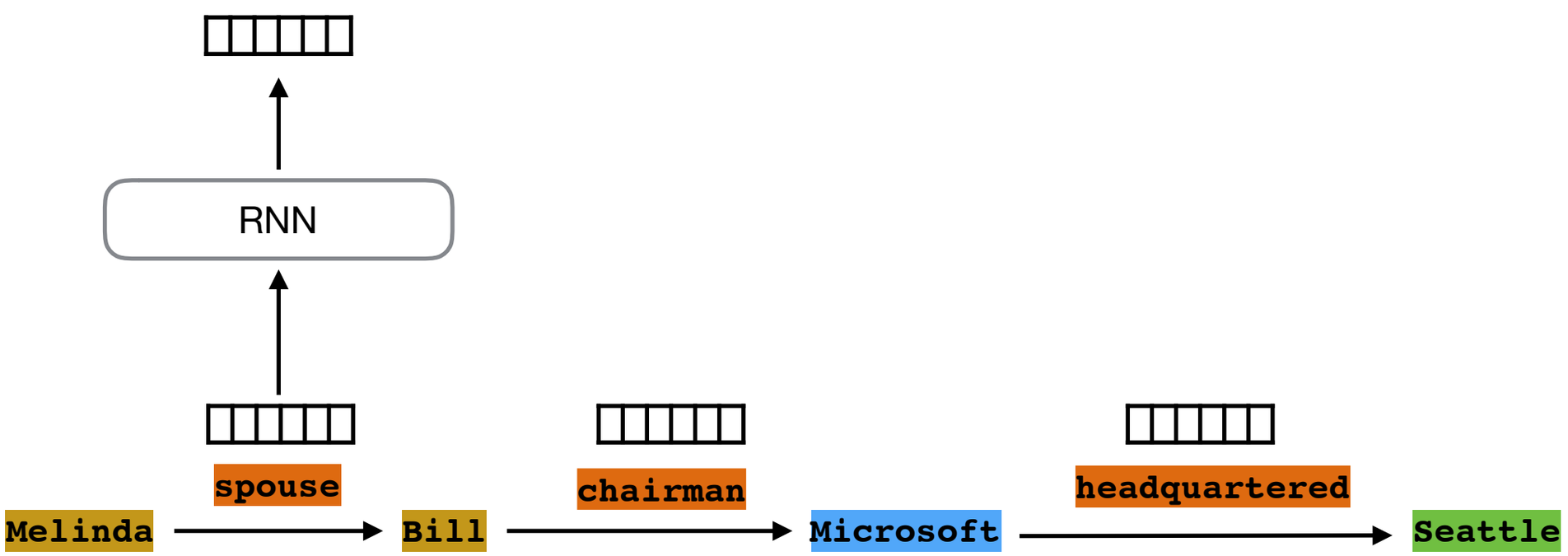

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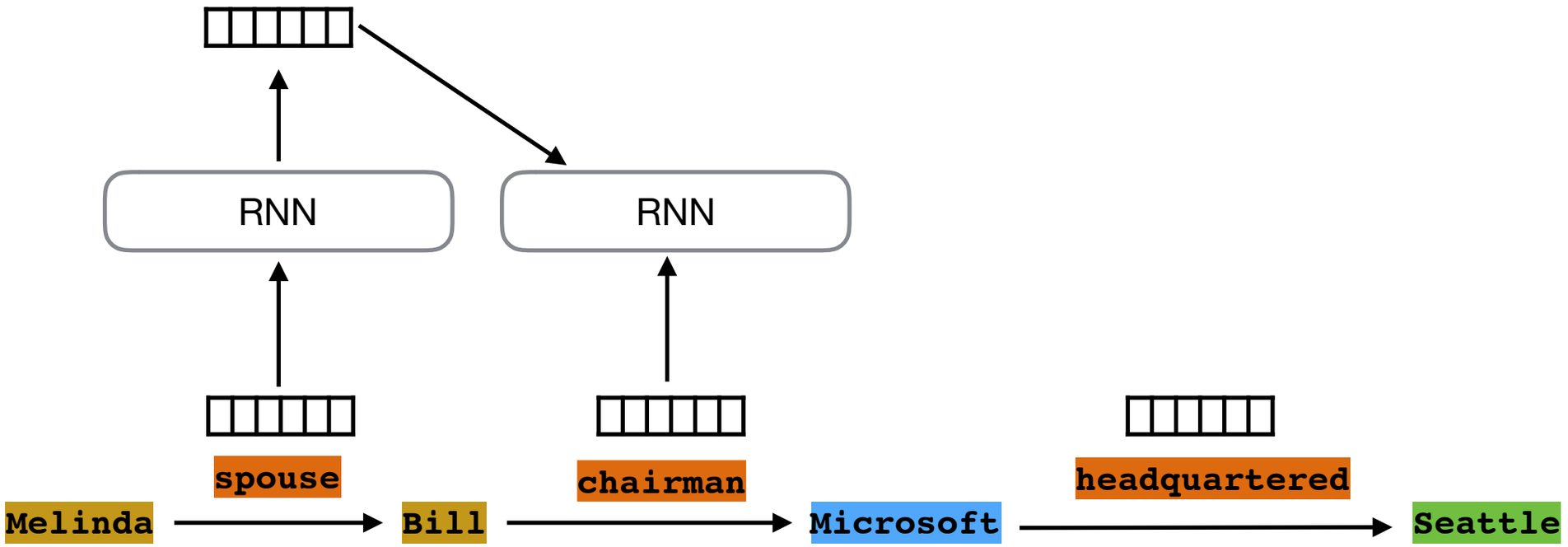

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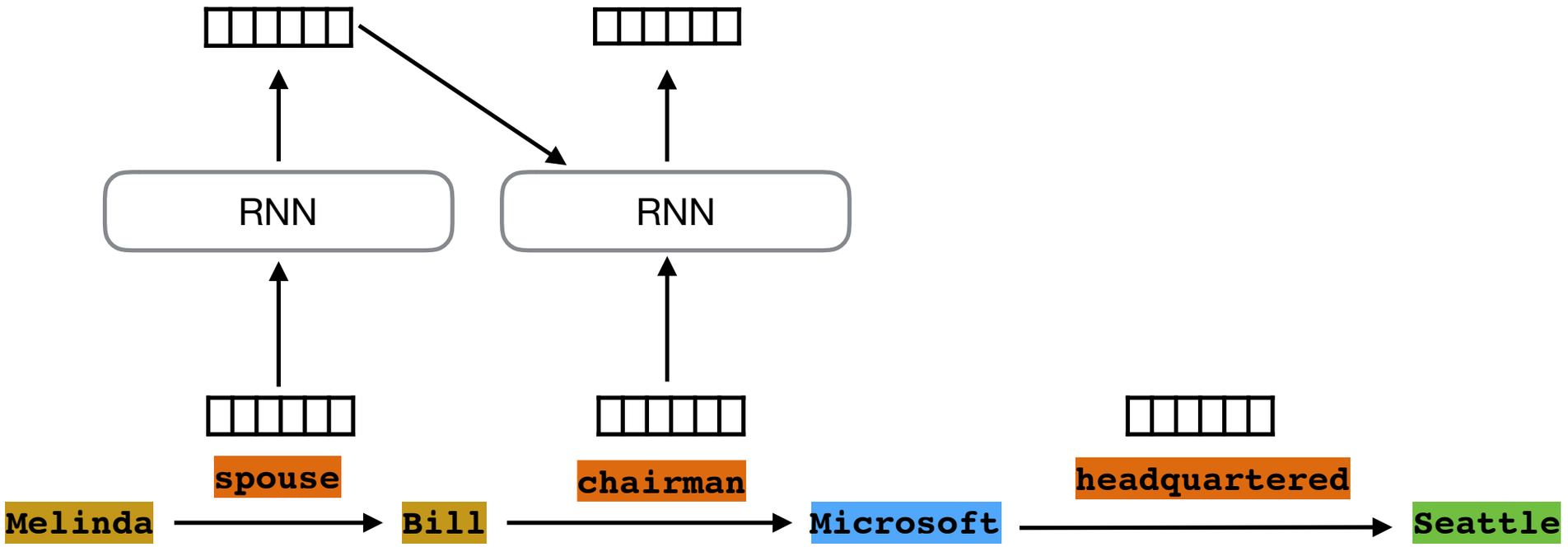

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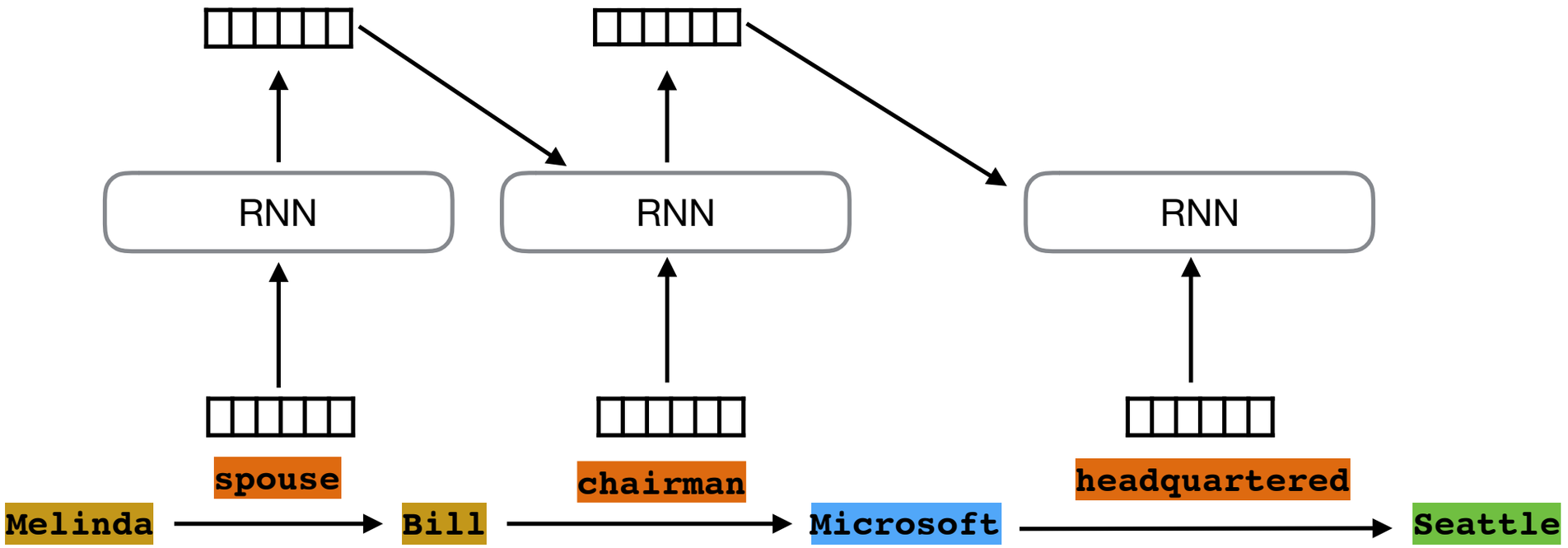

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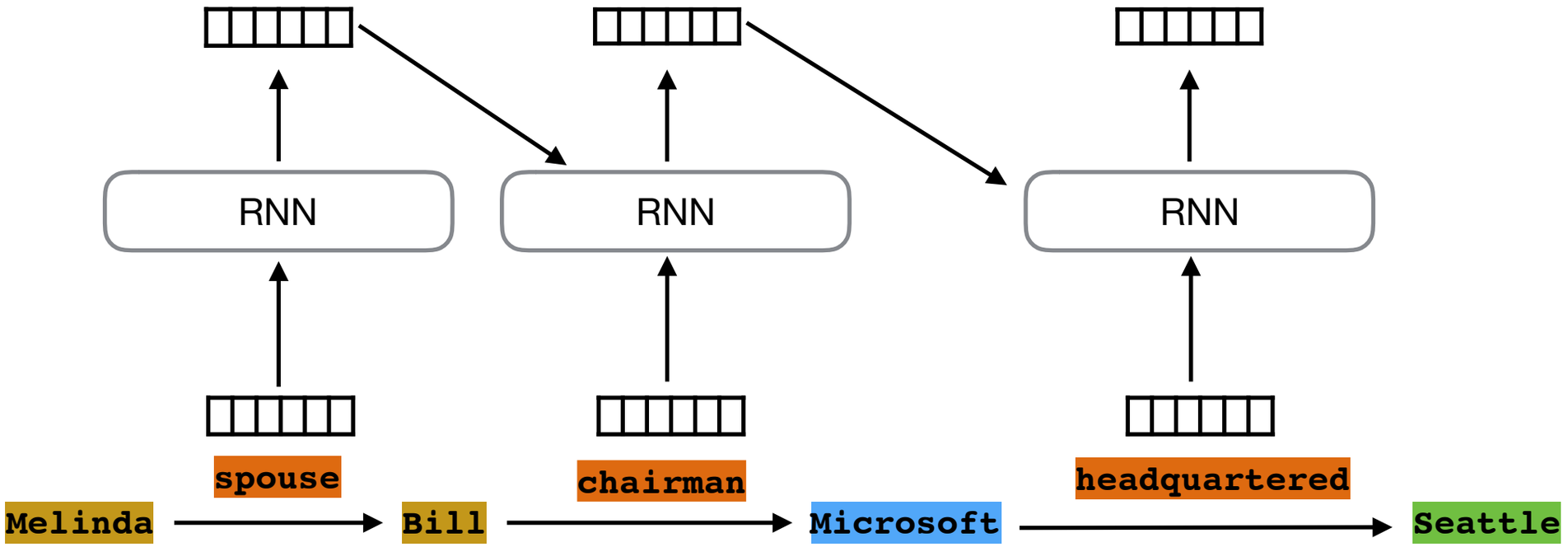

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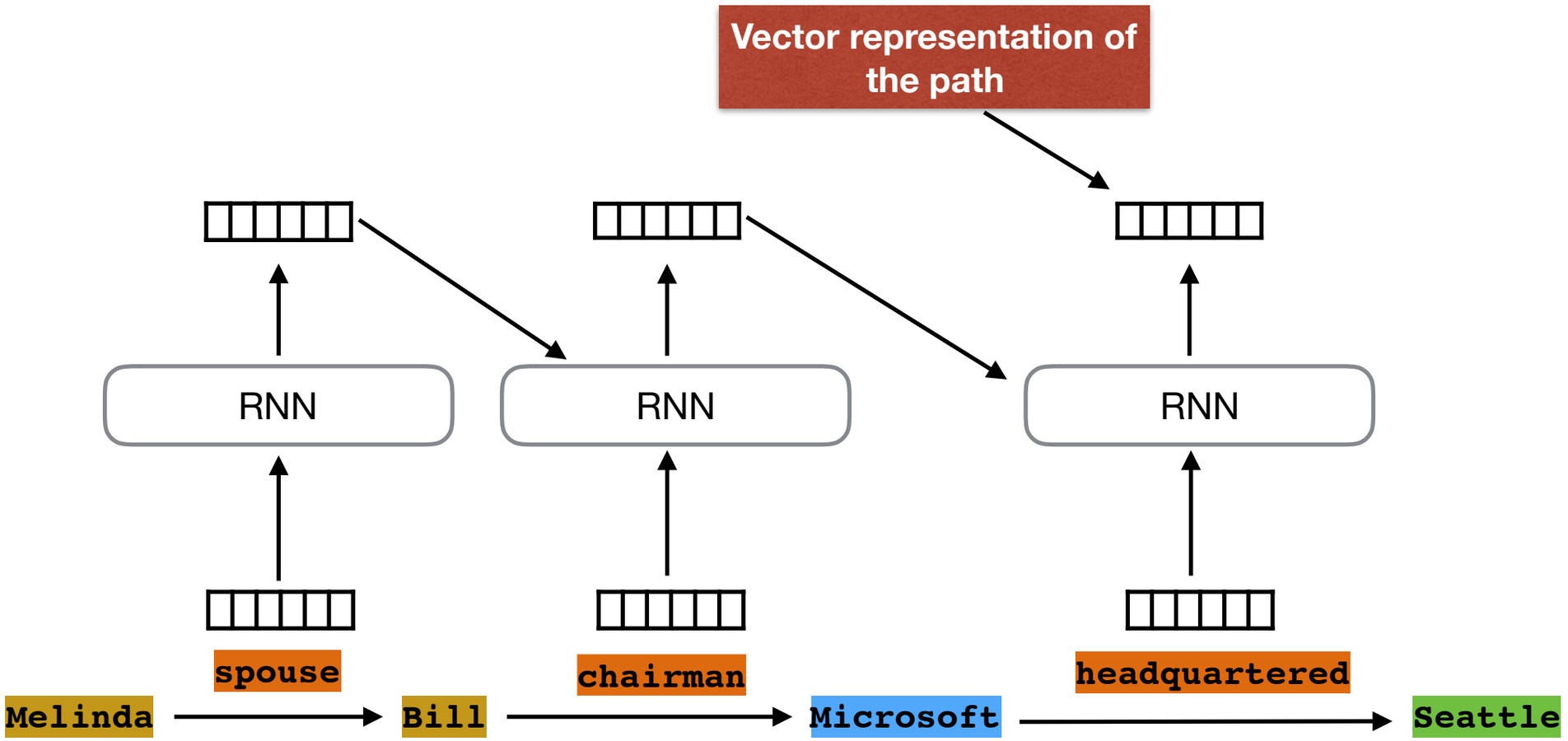

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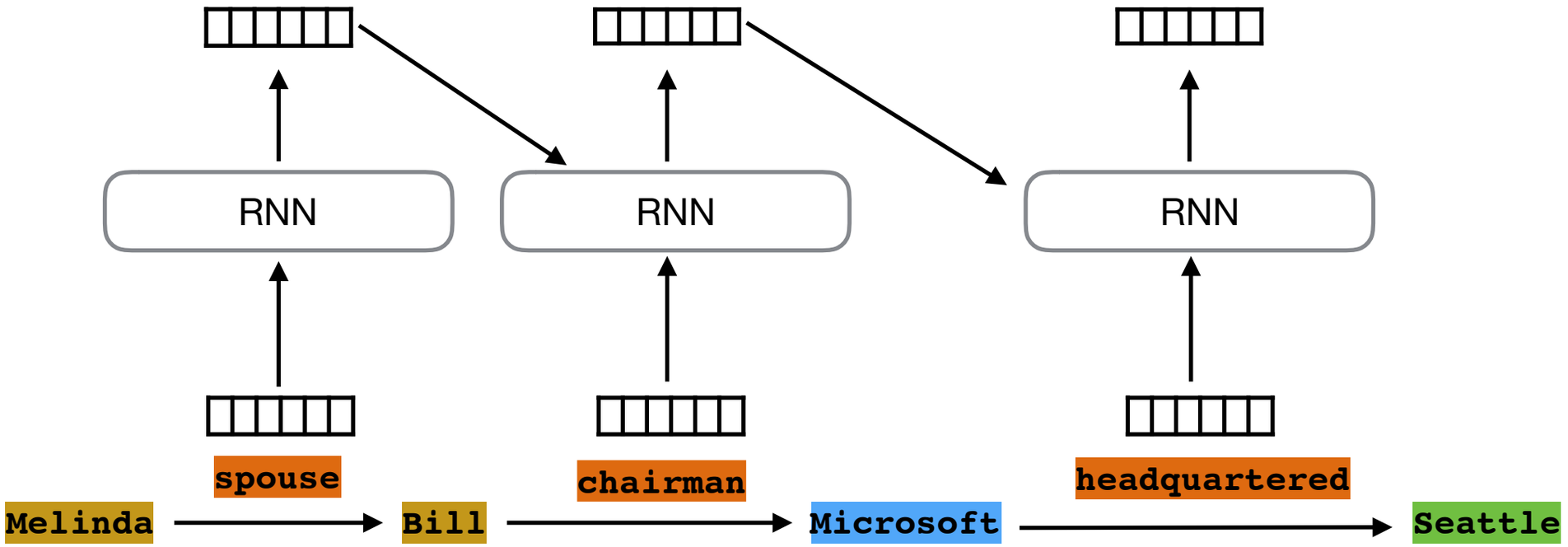

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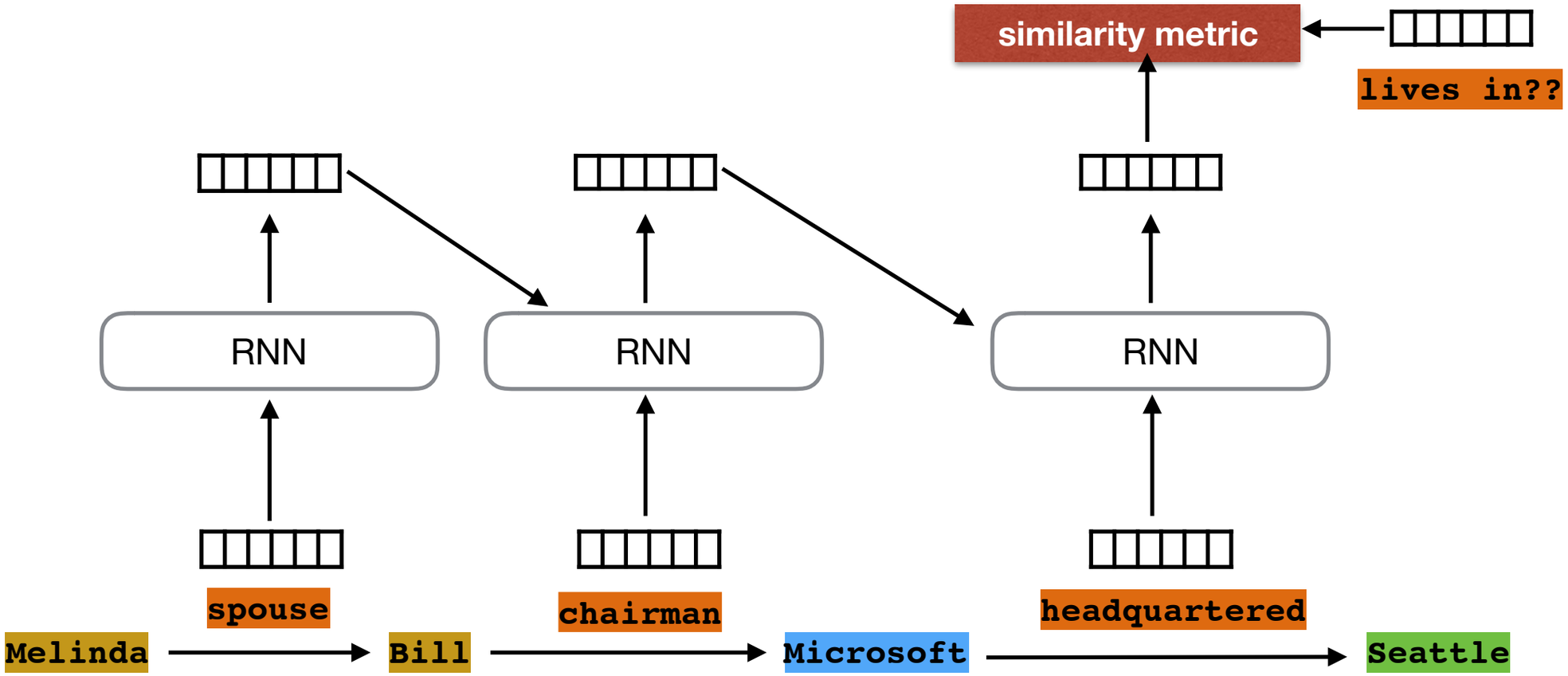

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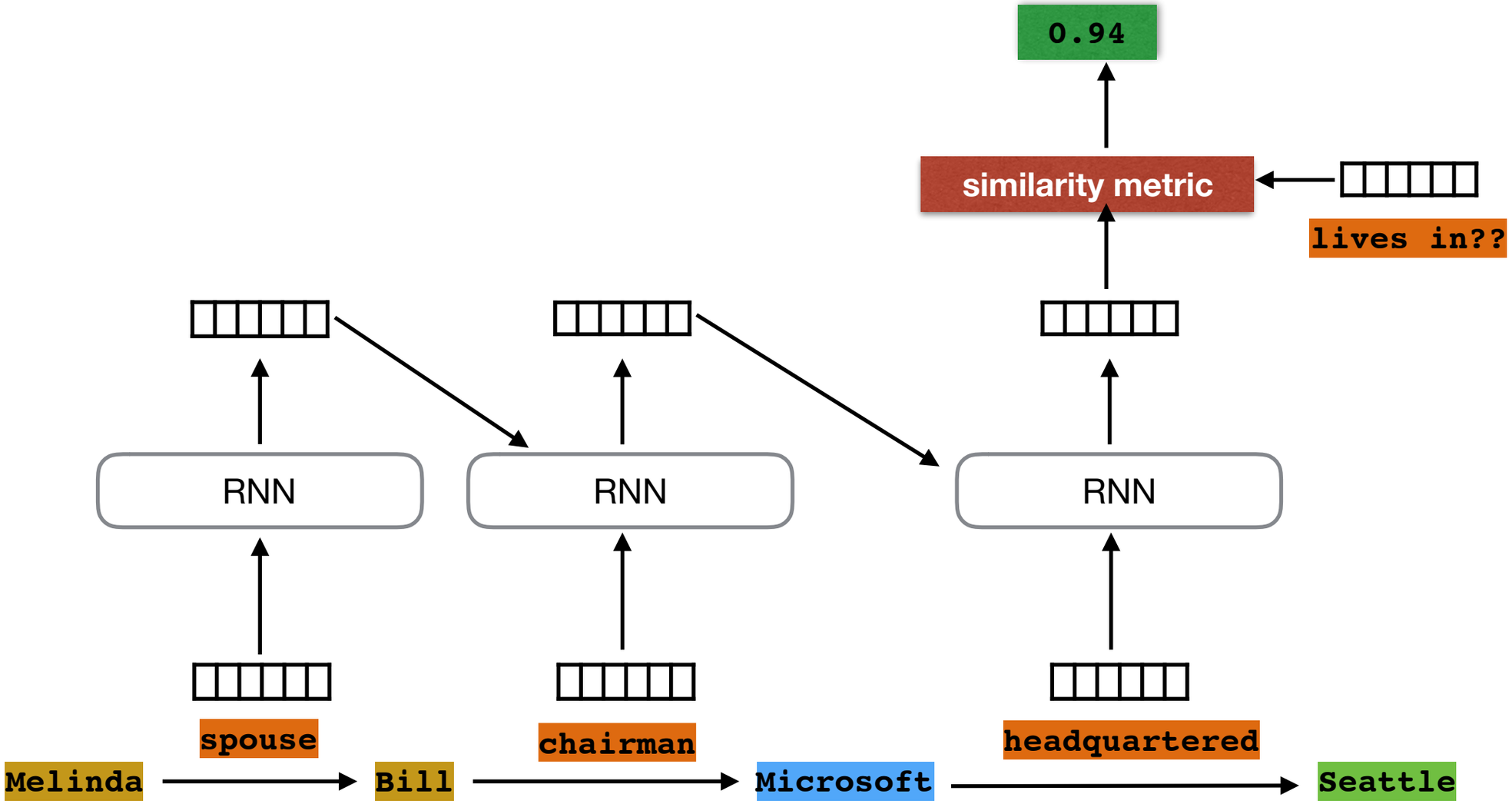
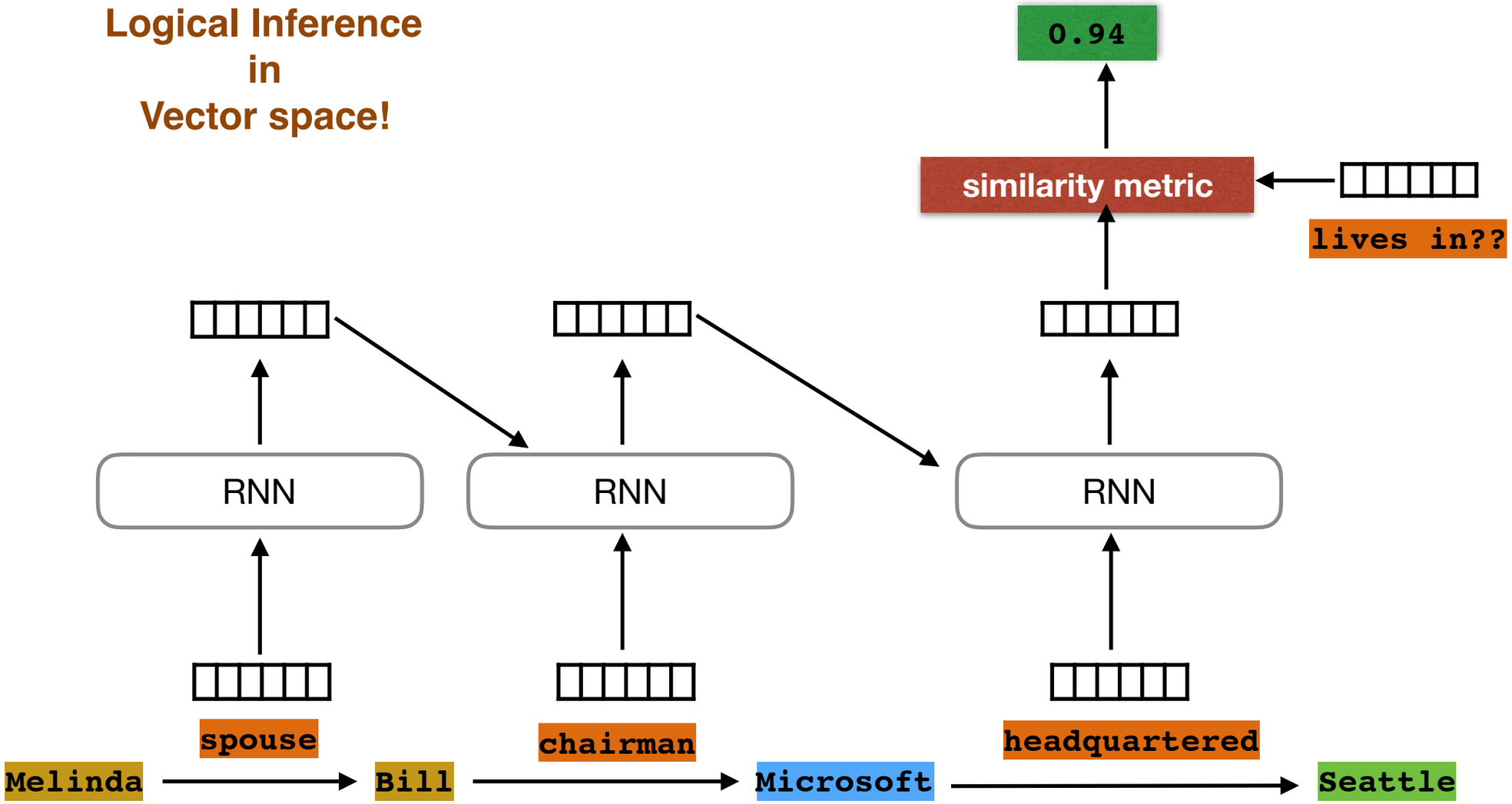


RNNs for Chains of Reasoning

Logical Inference in Vector space!



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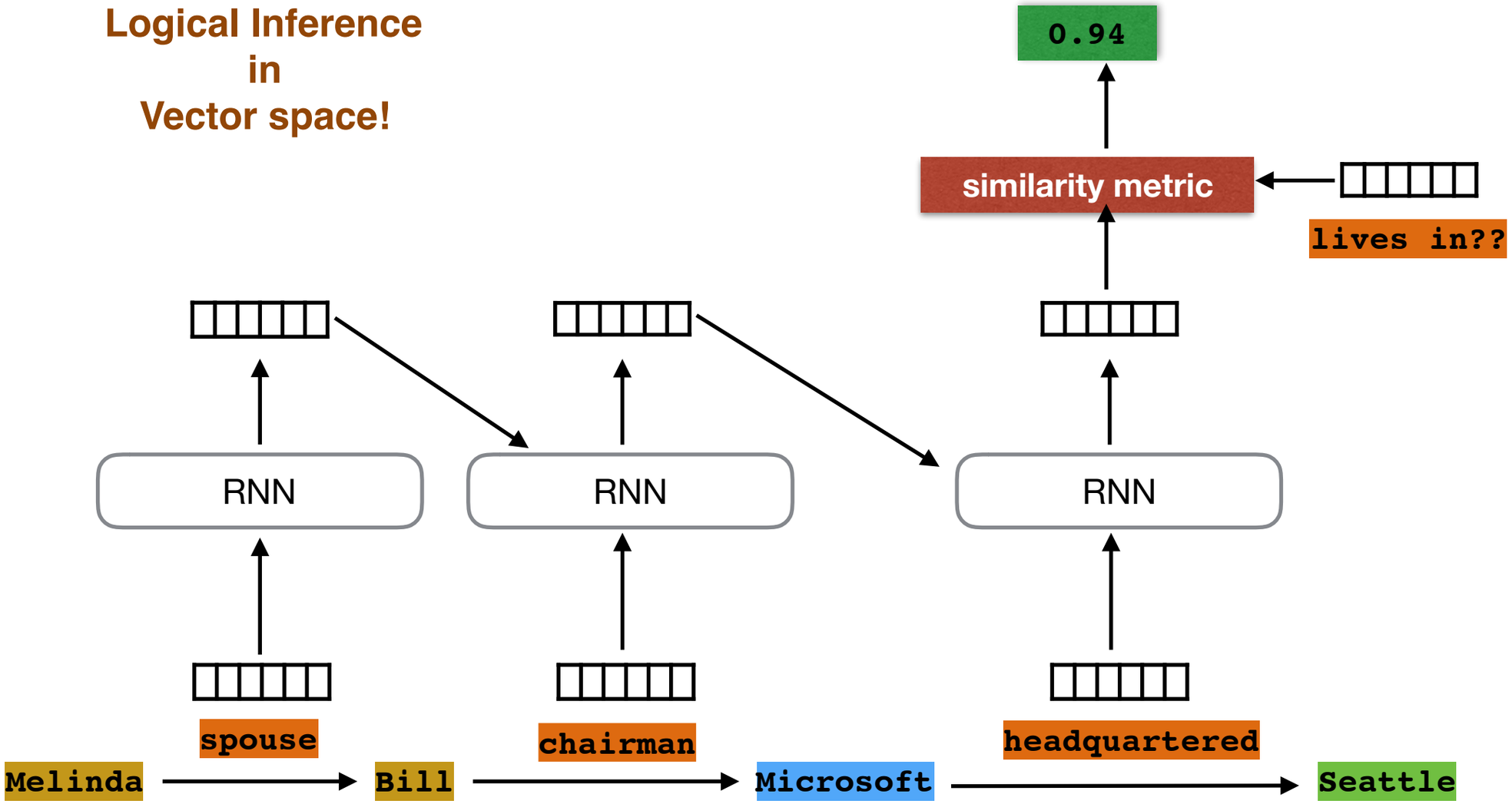
Logical Inference in Vector space!



Neelakantan et al' 15

Contributions

Contributions

1. Single RNN for chains of reasoning.

Contributions

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2. Combine evidence from multiple paths between entity pairs.

Contributions

1. Single RNN for chains of reasoning.

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%MAP 64.43% ——————————— **73.26%**

Contributions

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%MAP 64.43% —— 13.7% —— **73.26%**

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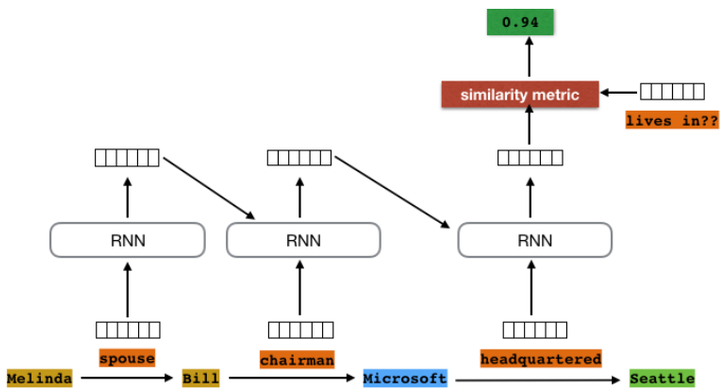

lives in??

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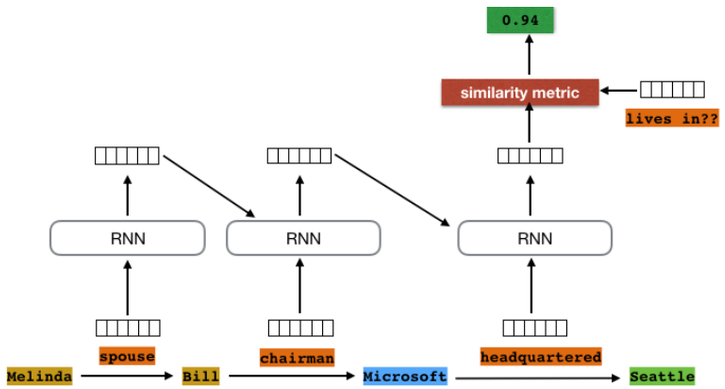
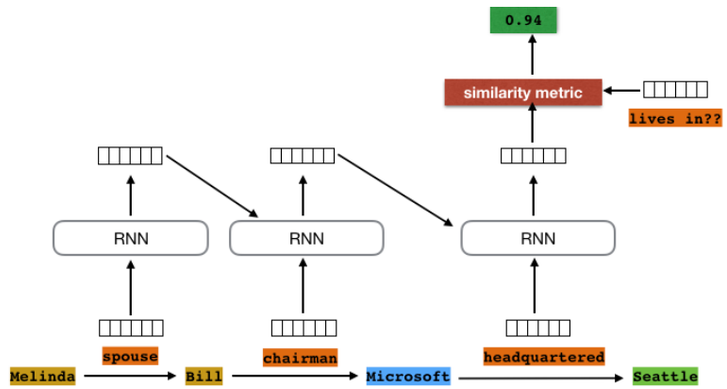


lives in??



works in??

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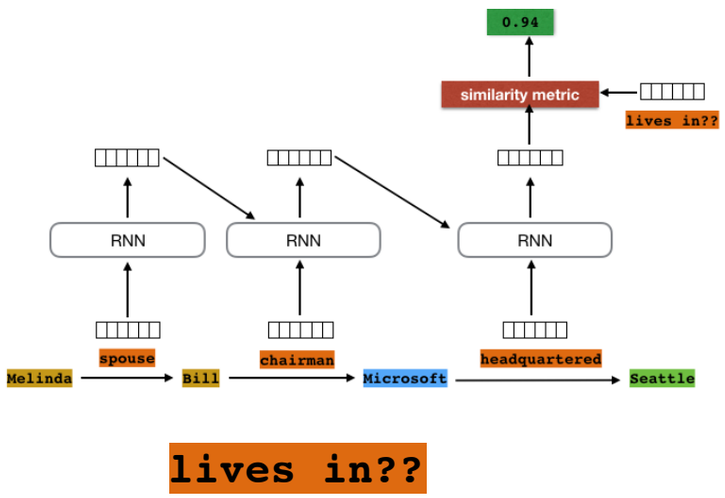
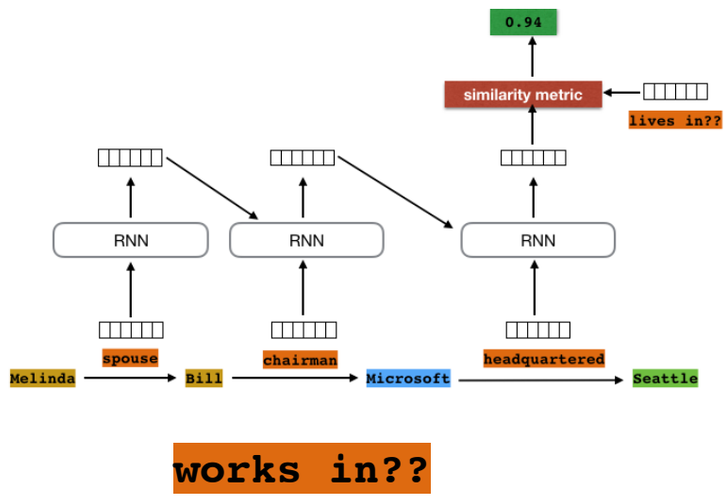
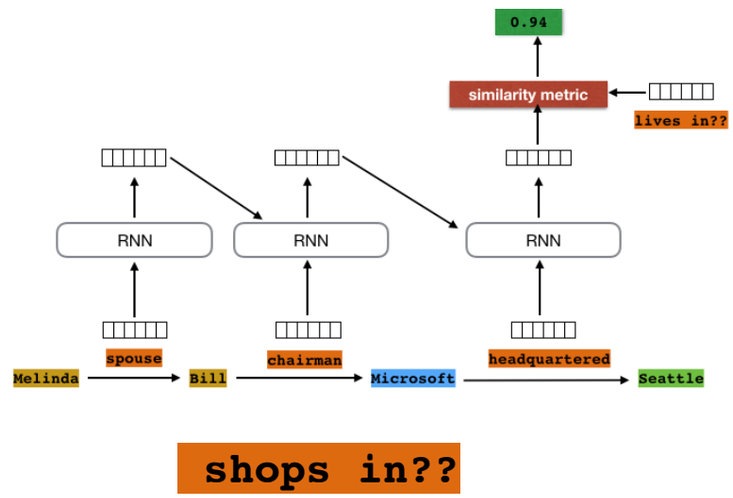


lives in??

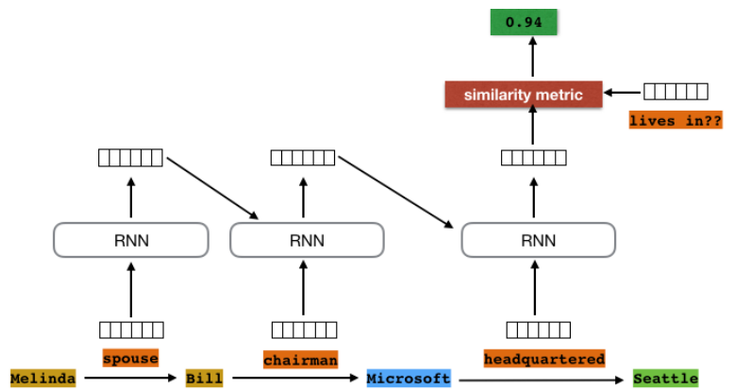


works in??



shops in??

1. Single RNN for chains of reasoning.



lives in?? / **works in??** / **shops in??** /....

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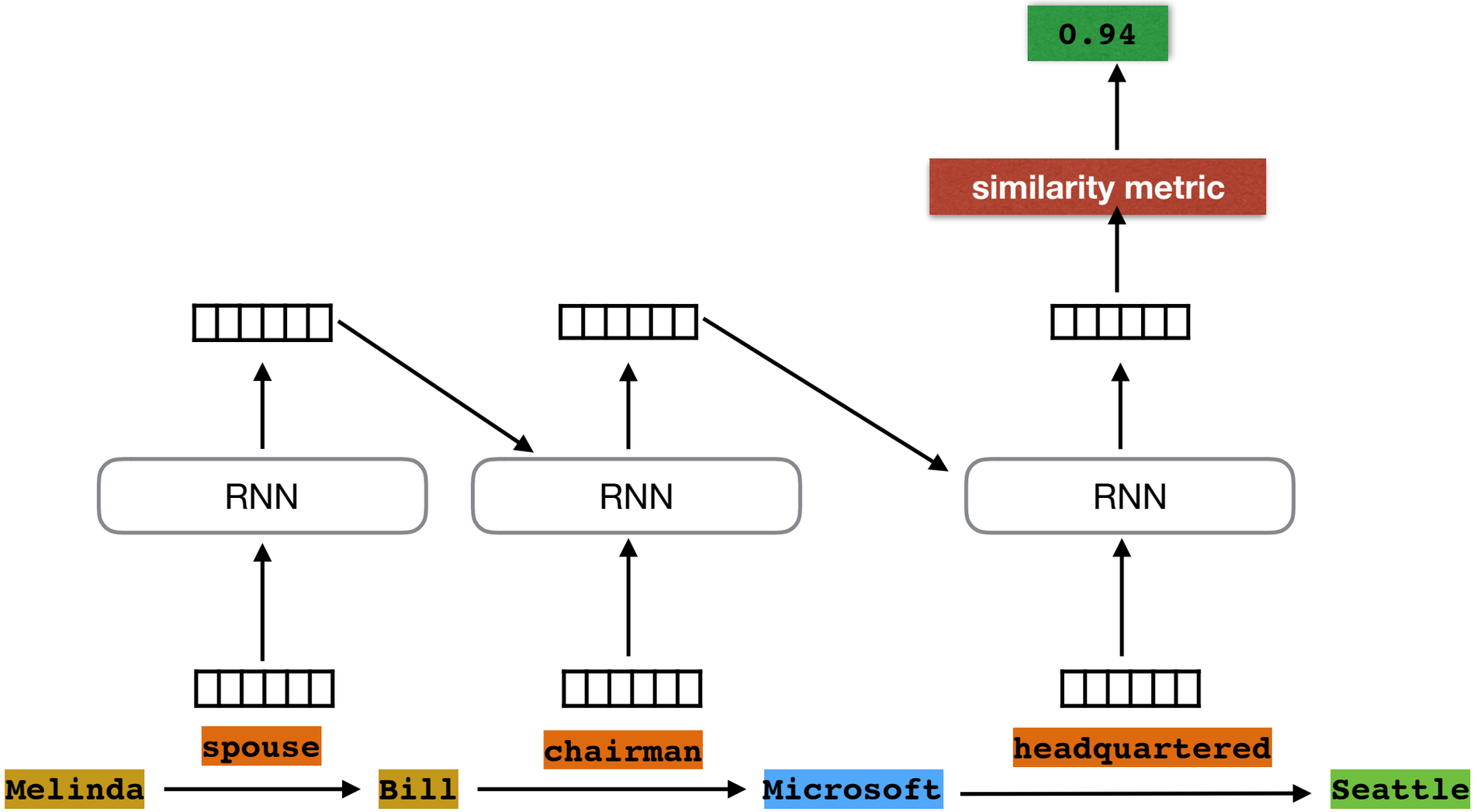

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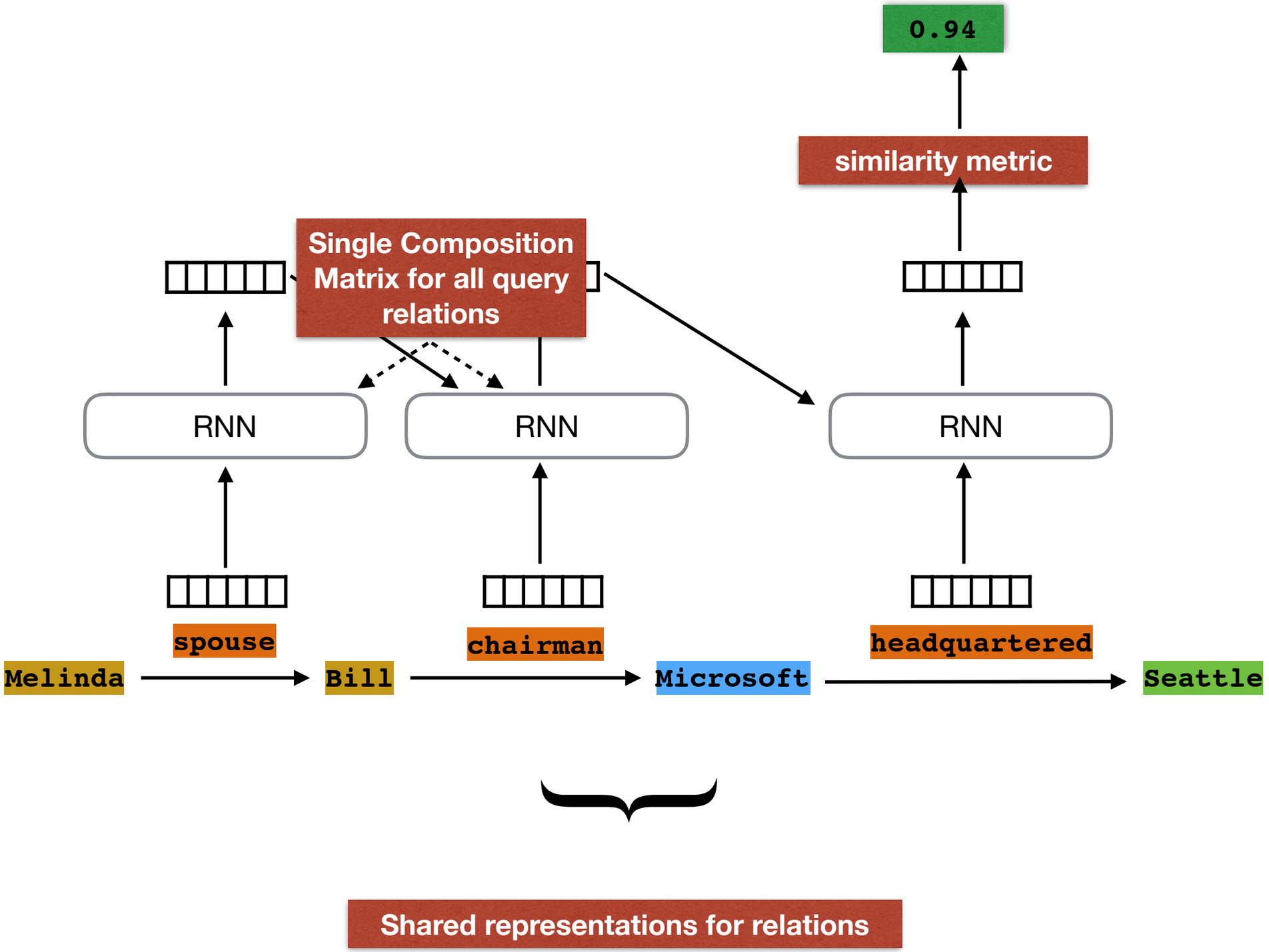

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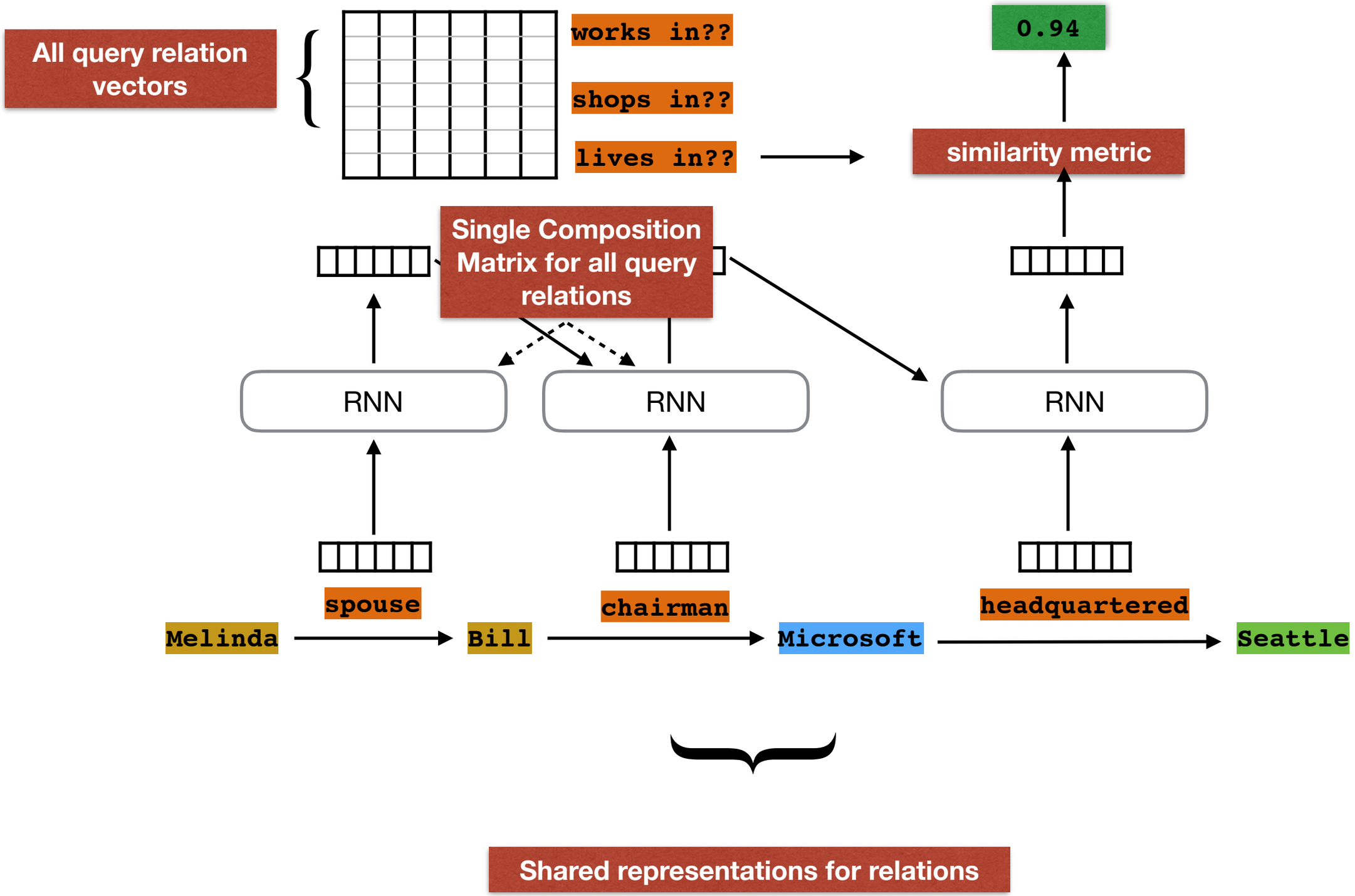

Results

Results

Model	%MAP
PRA	64.43
PRA + Bigram	64.93

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RNN-Path (Neelakantan' 15)	65.23

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5%

$p < 5e\text{-}6$

Contributions

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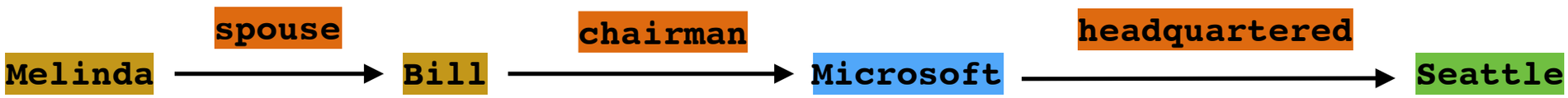
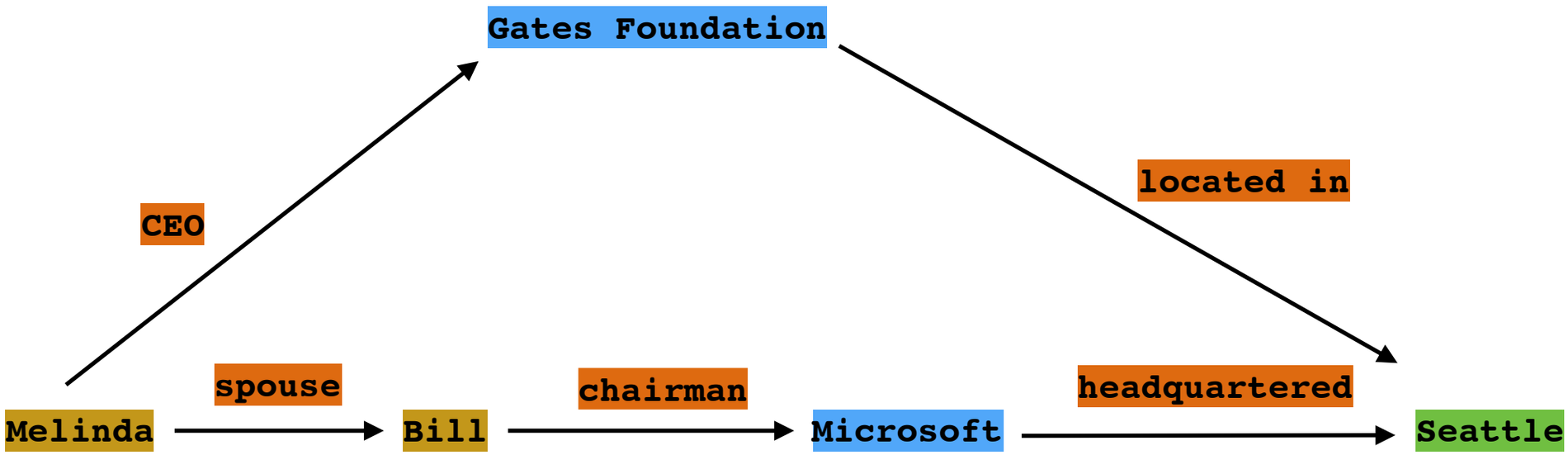
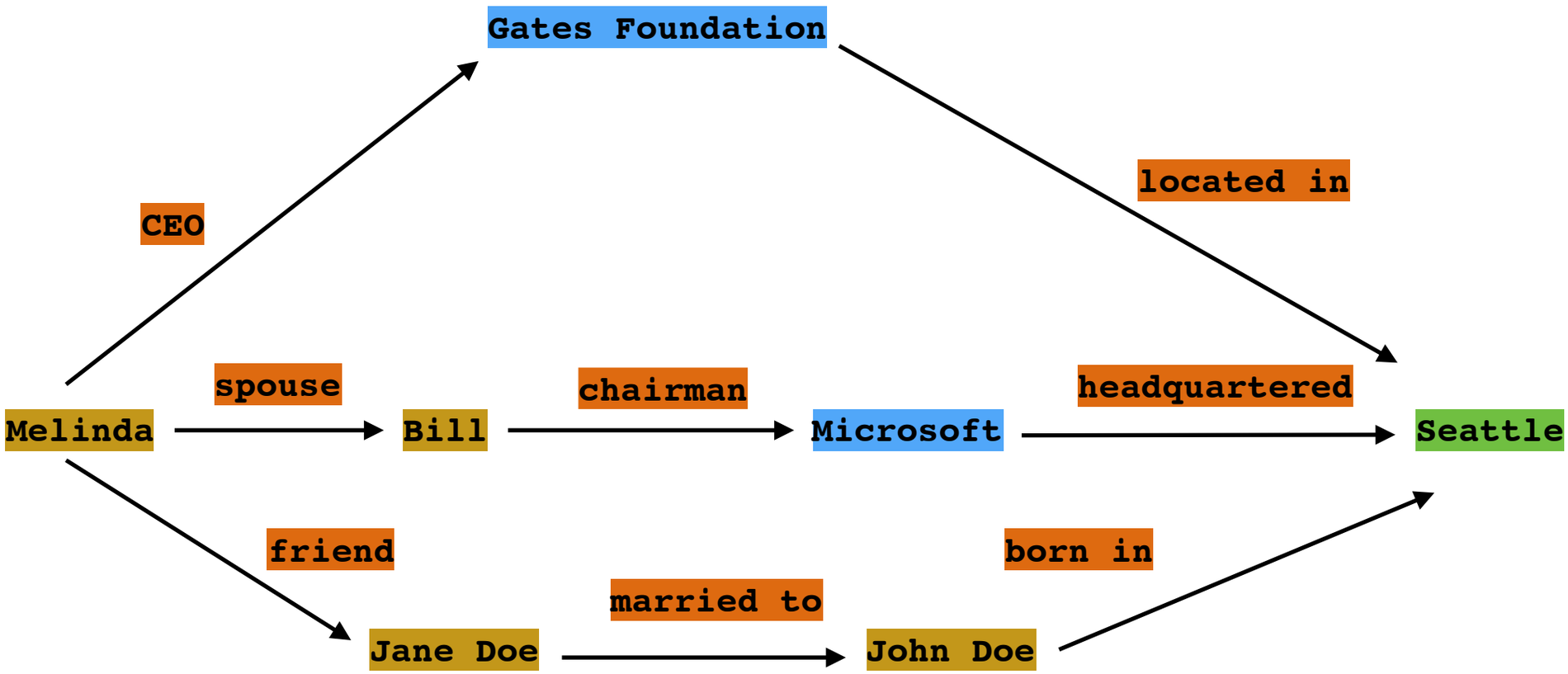
Multiple Paths



Multiple Paths



Multiple Paths



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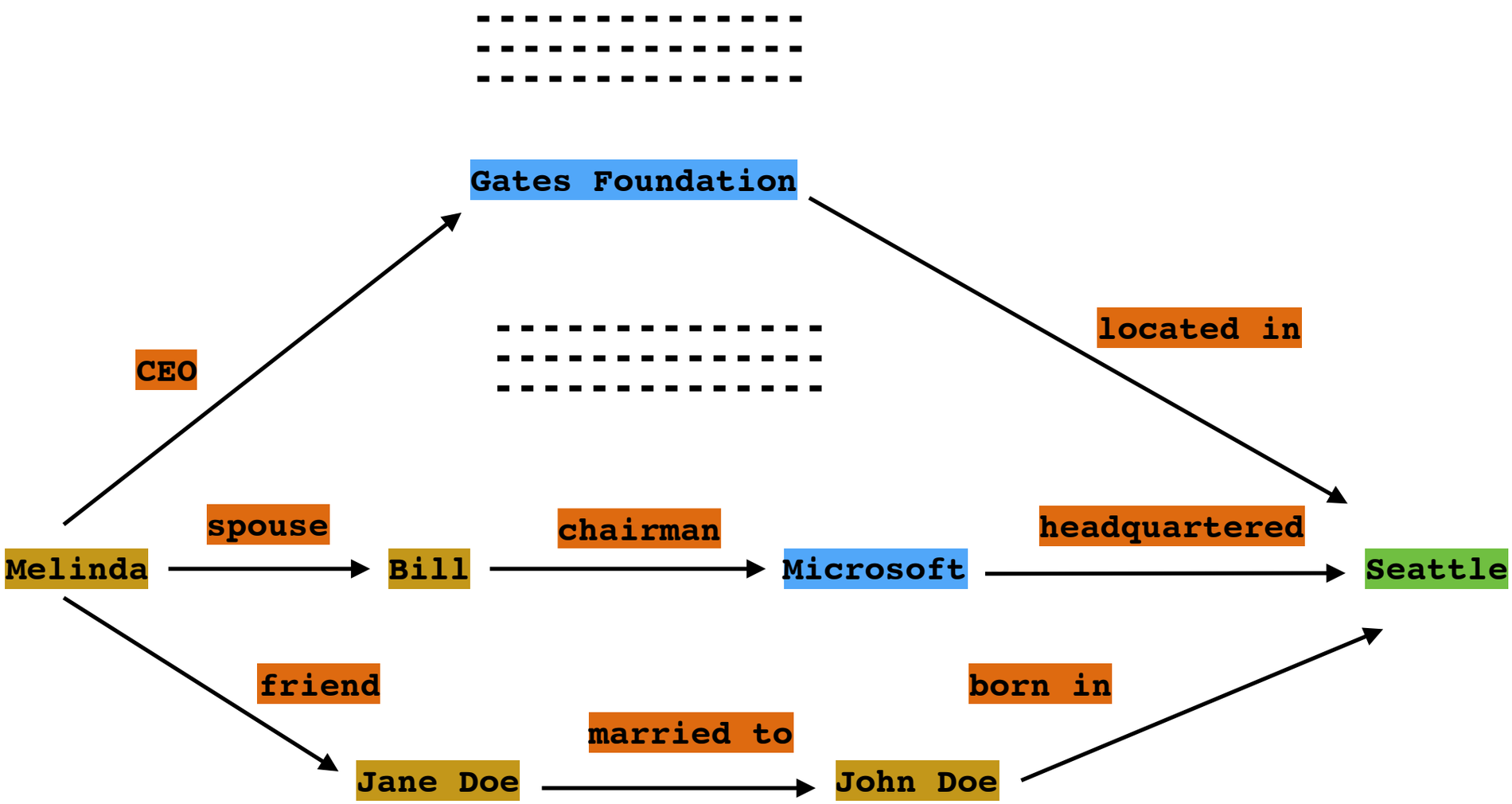

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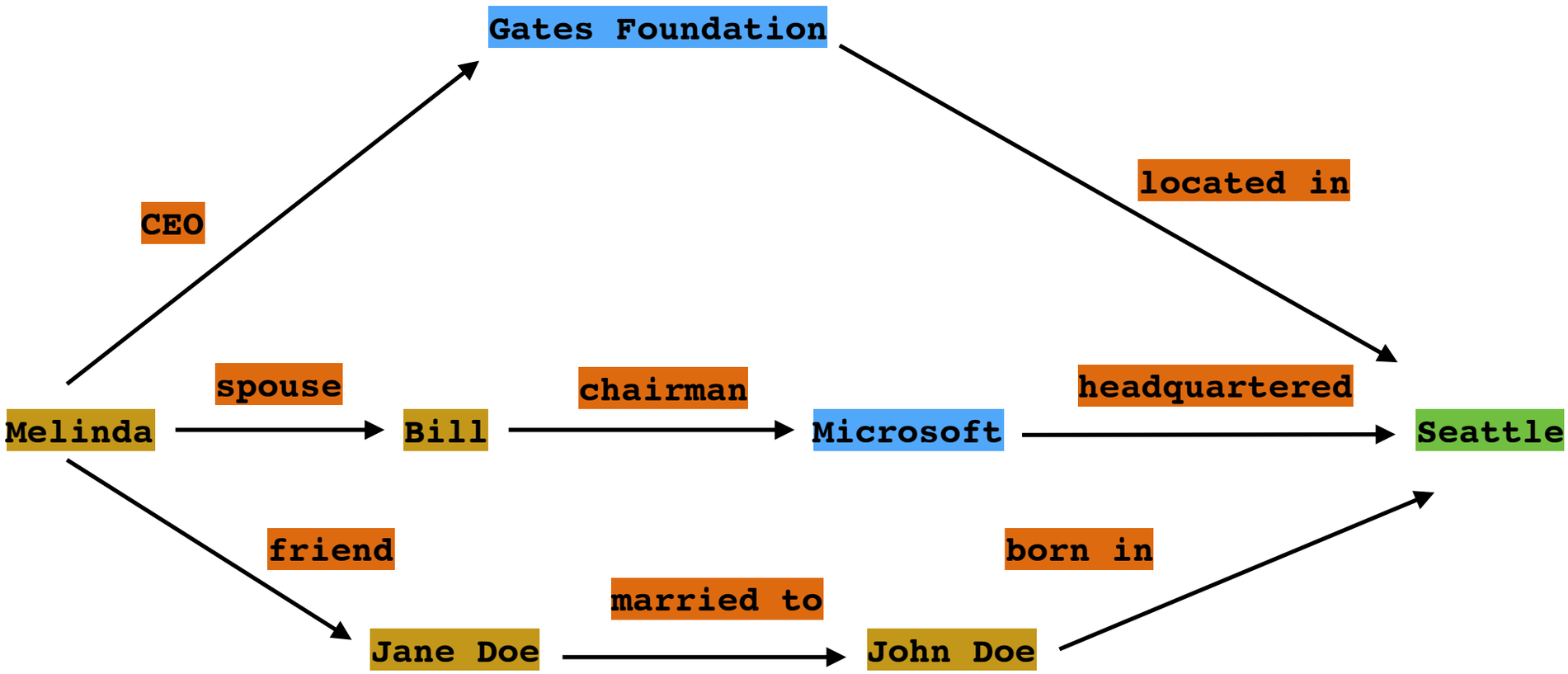

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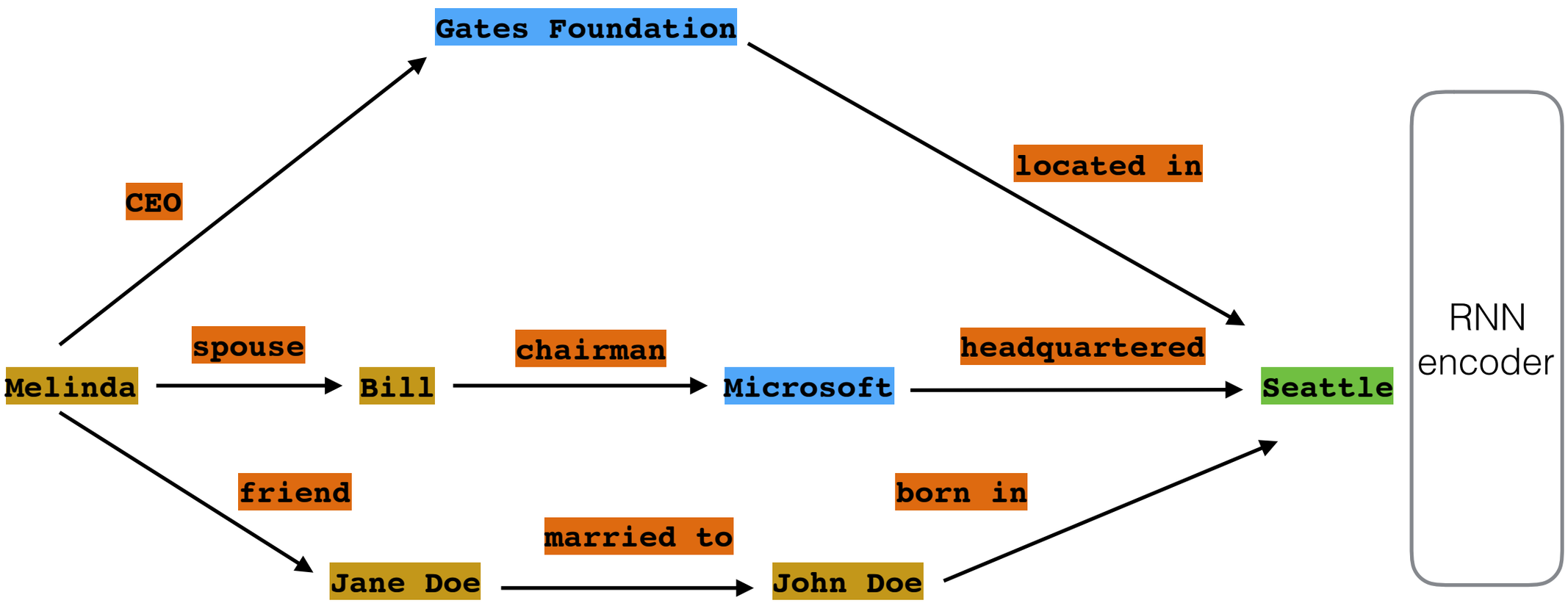

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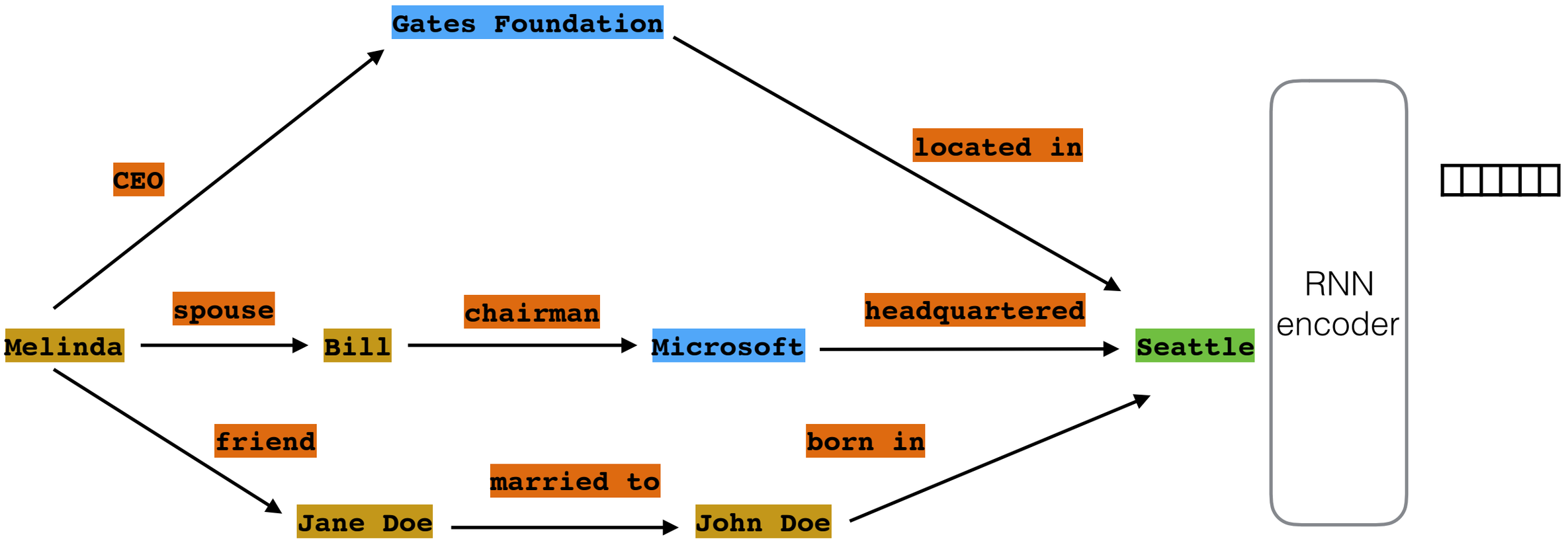

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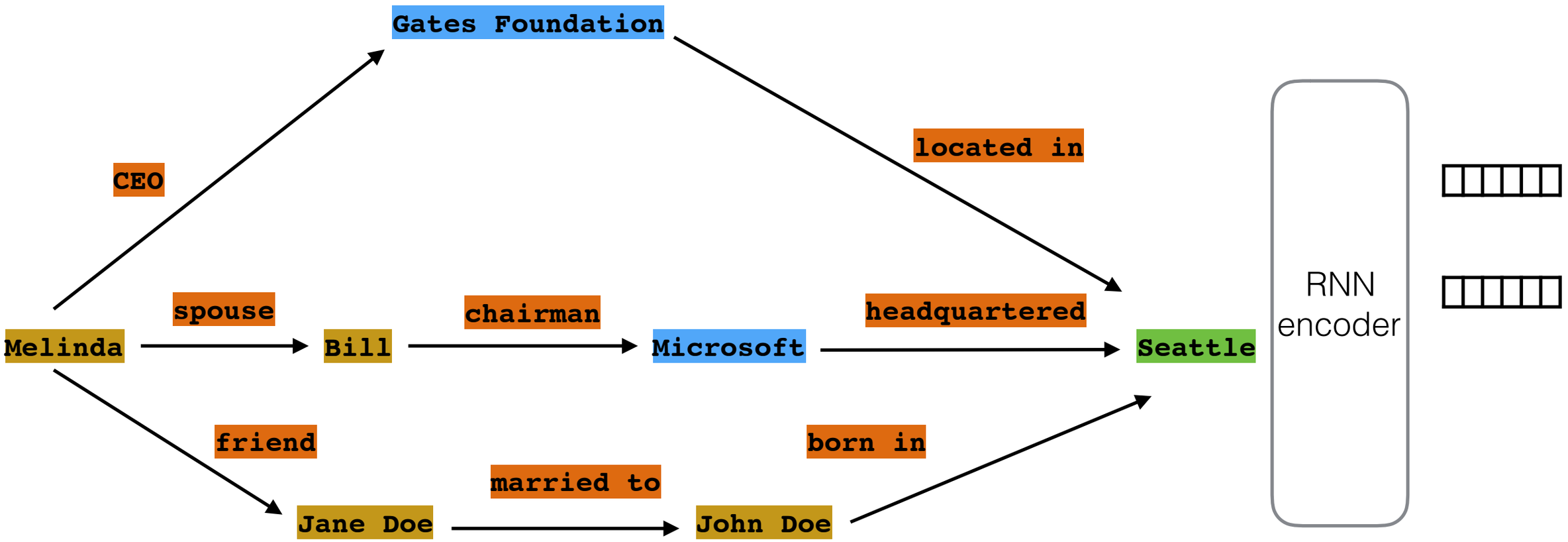

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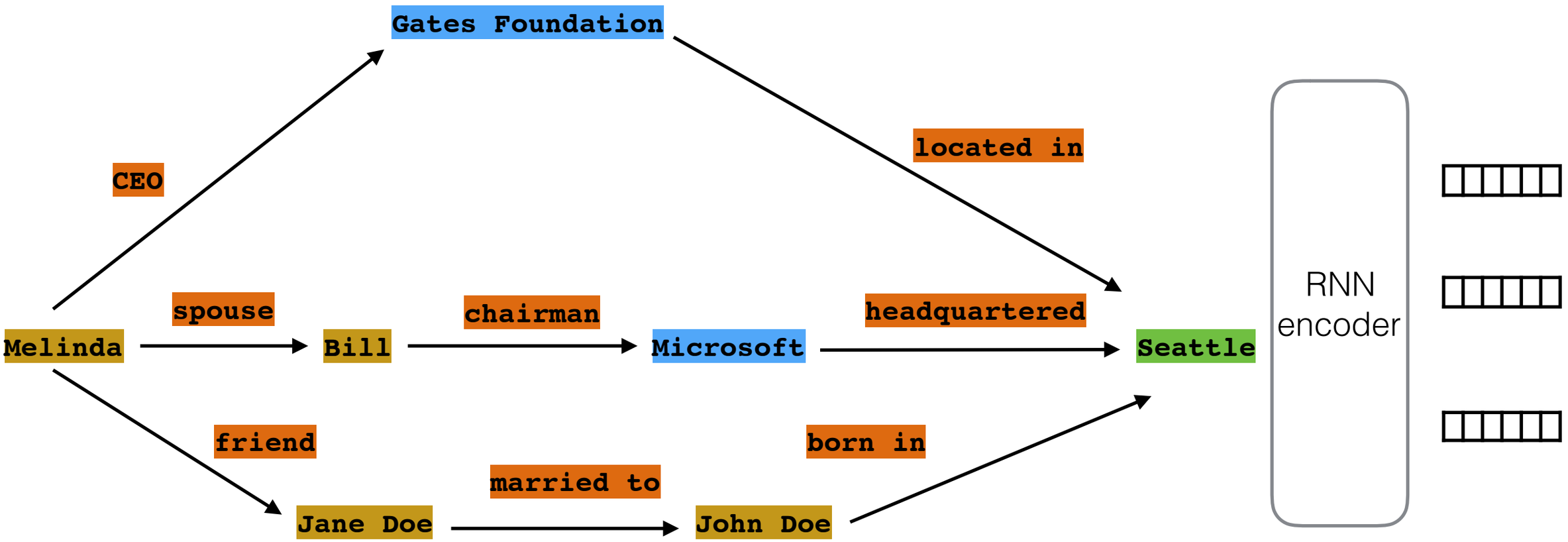

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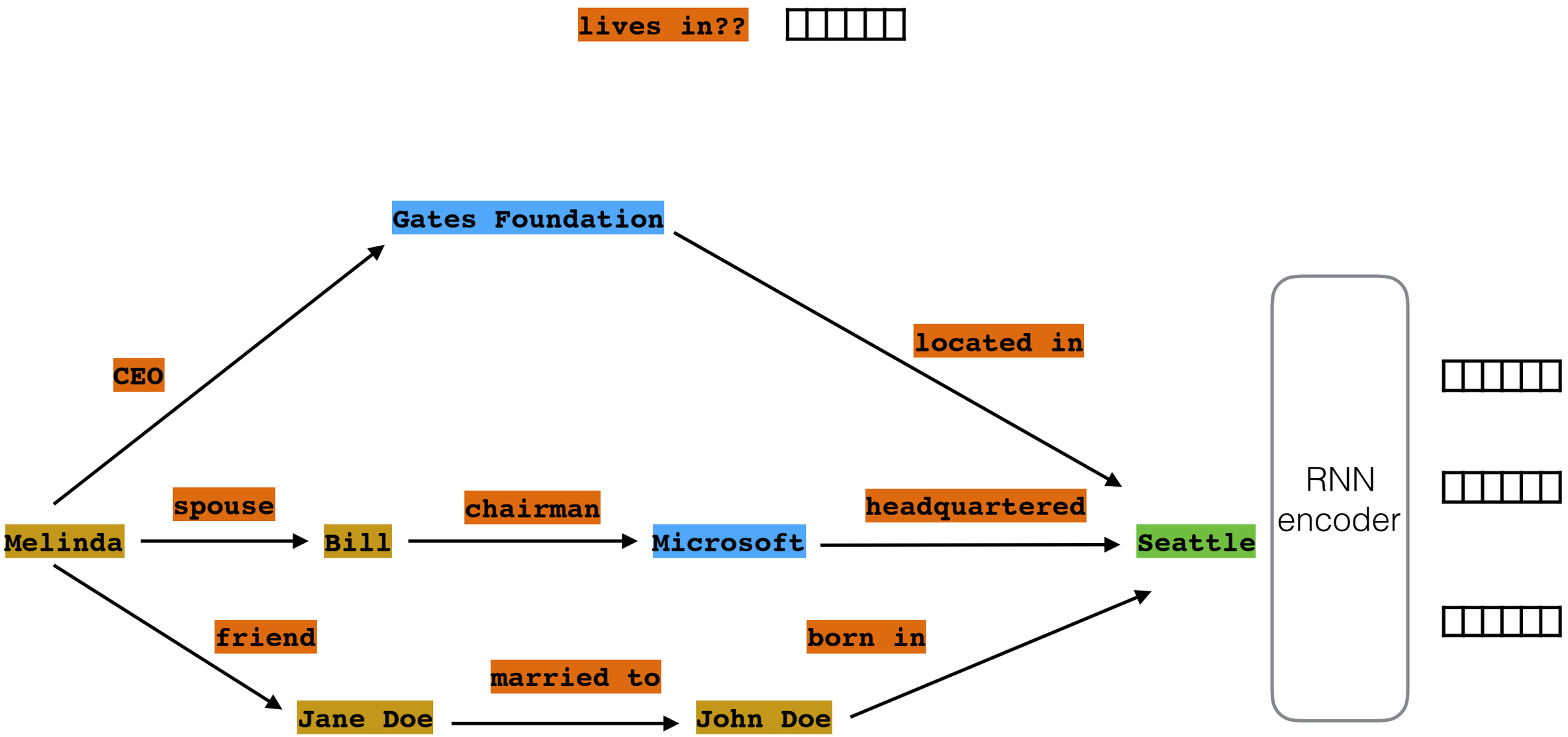

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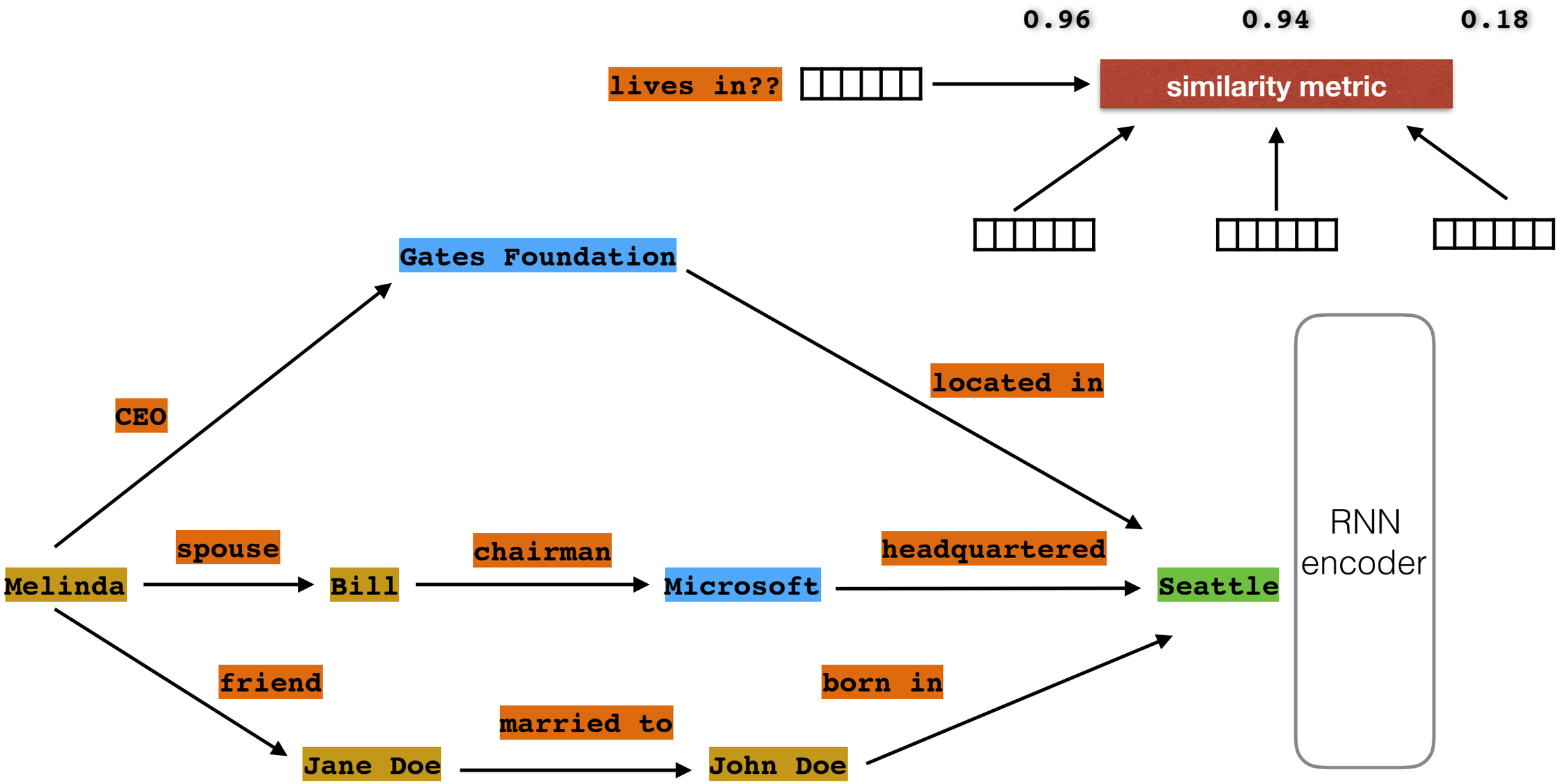
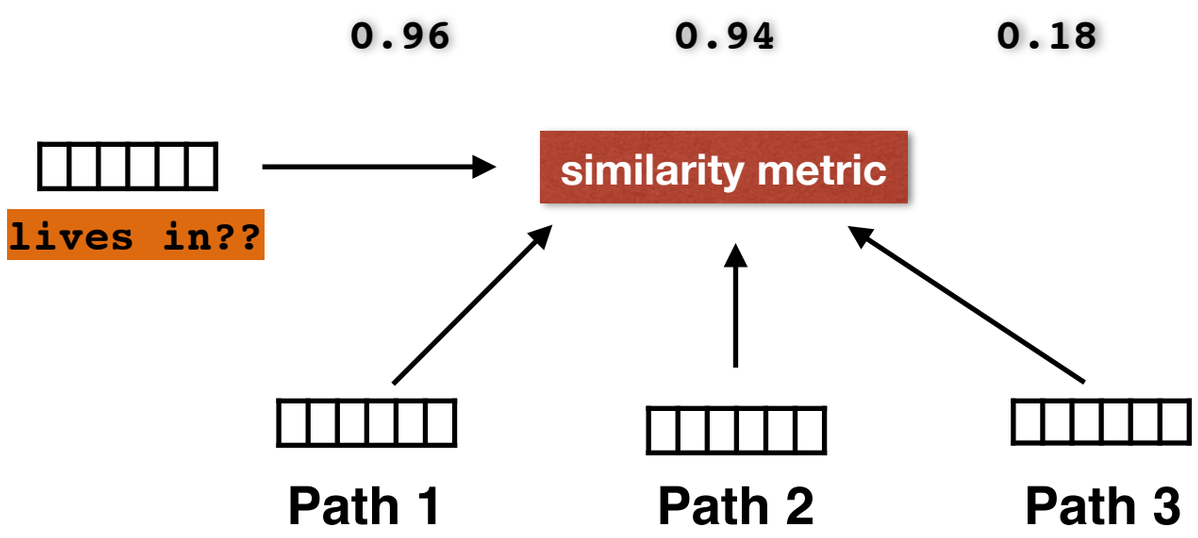


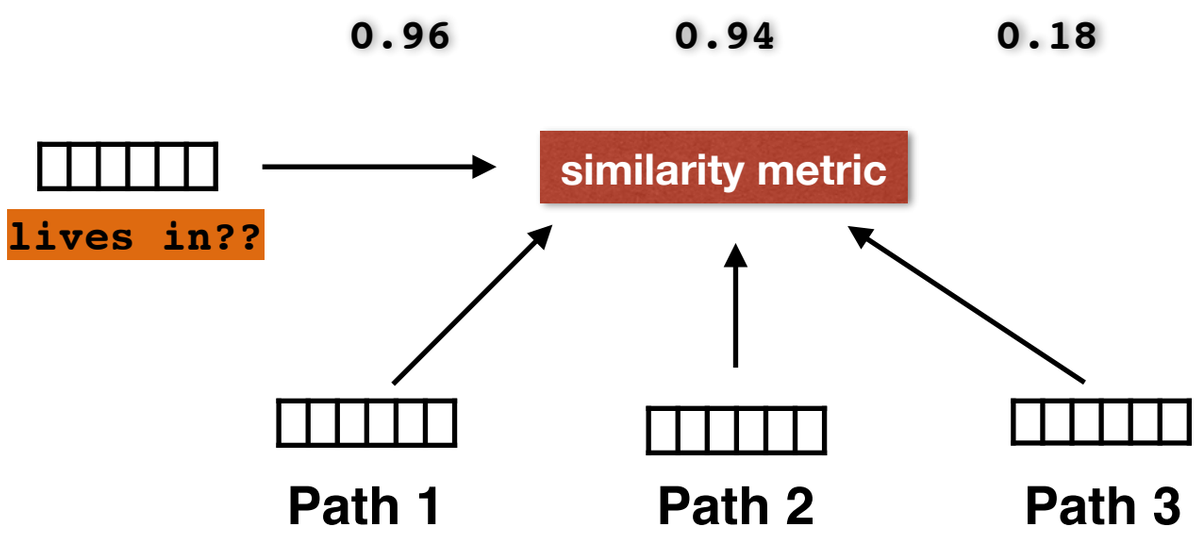
Score Pooling



Score Pooling

1. Max pool: $\max(\alpha_1, \alpha_2, \ldots, \alpha_N)$

Neelakantan et al' 15



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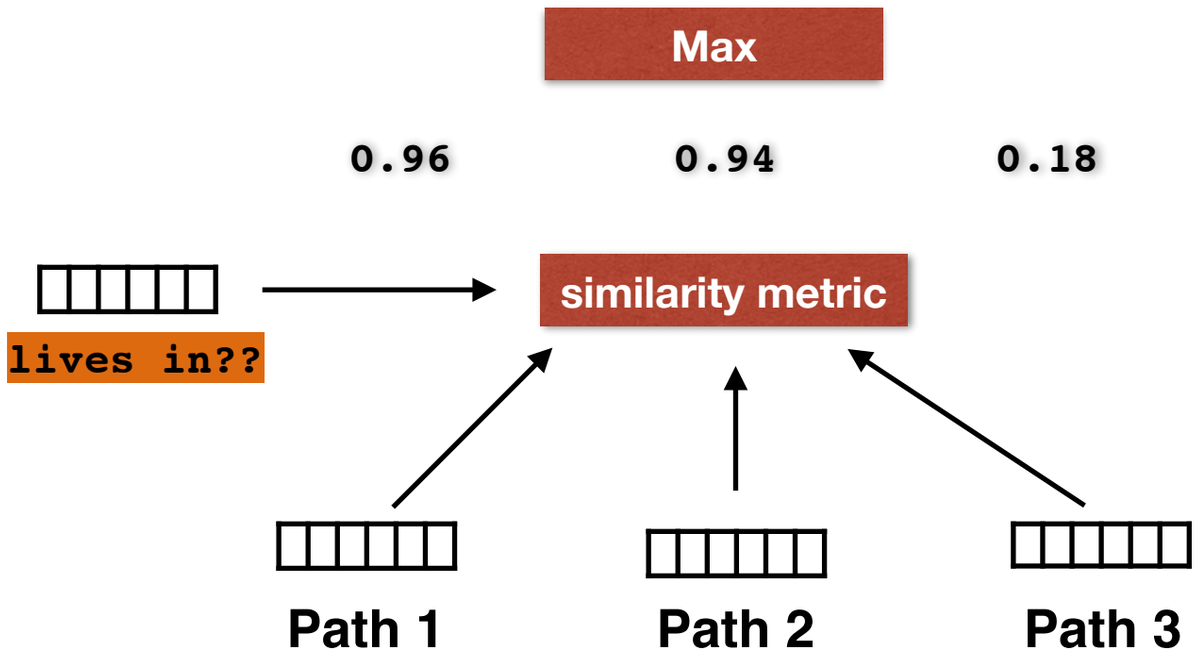

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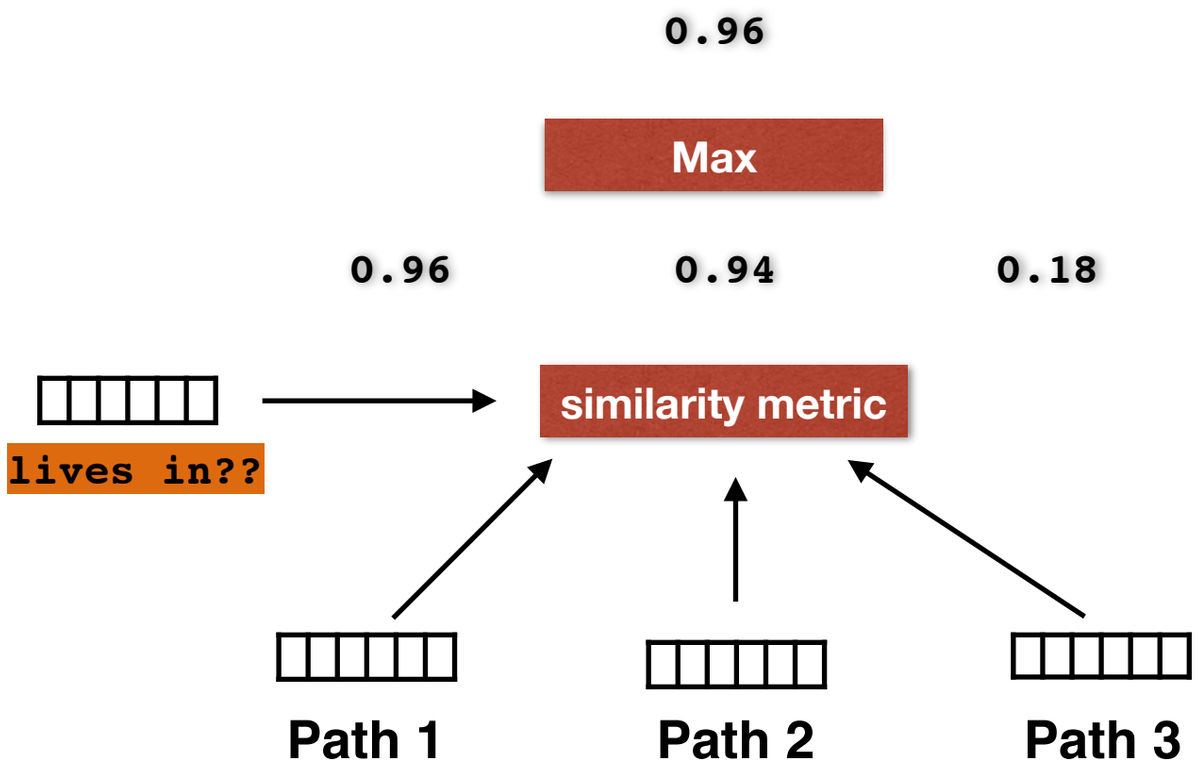

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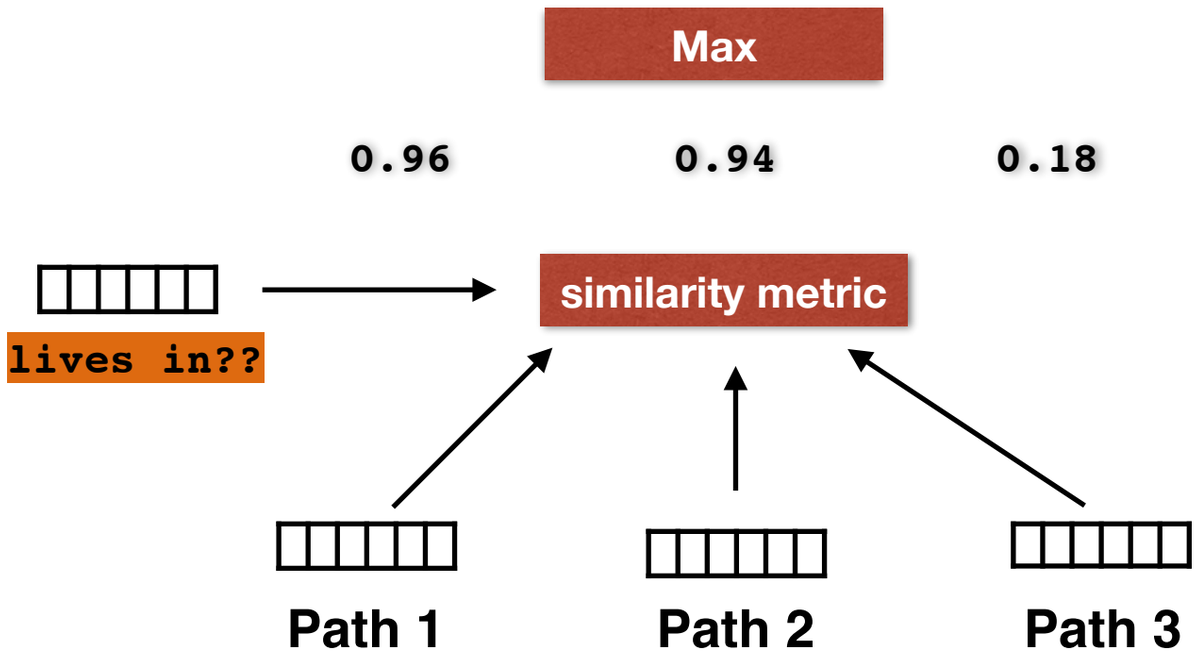

Score Pooling

Neelakantan et al' 15

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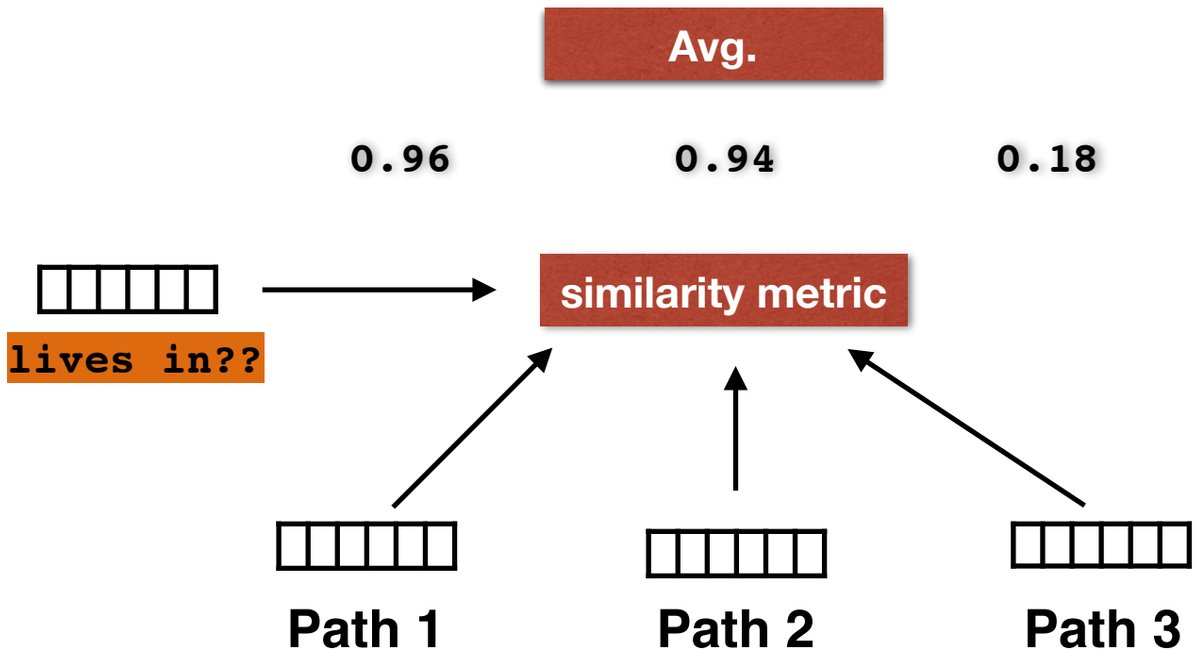

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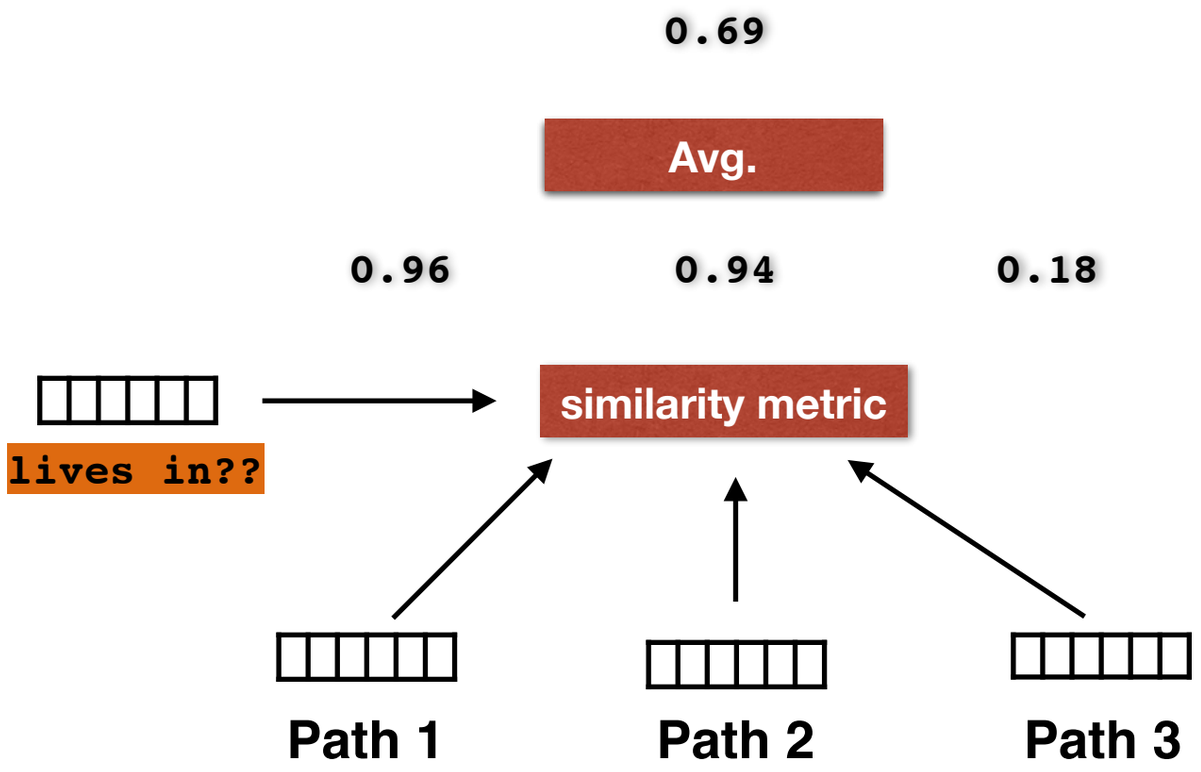

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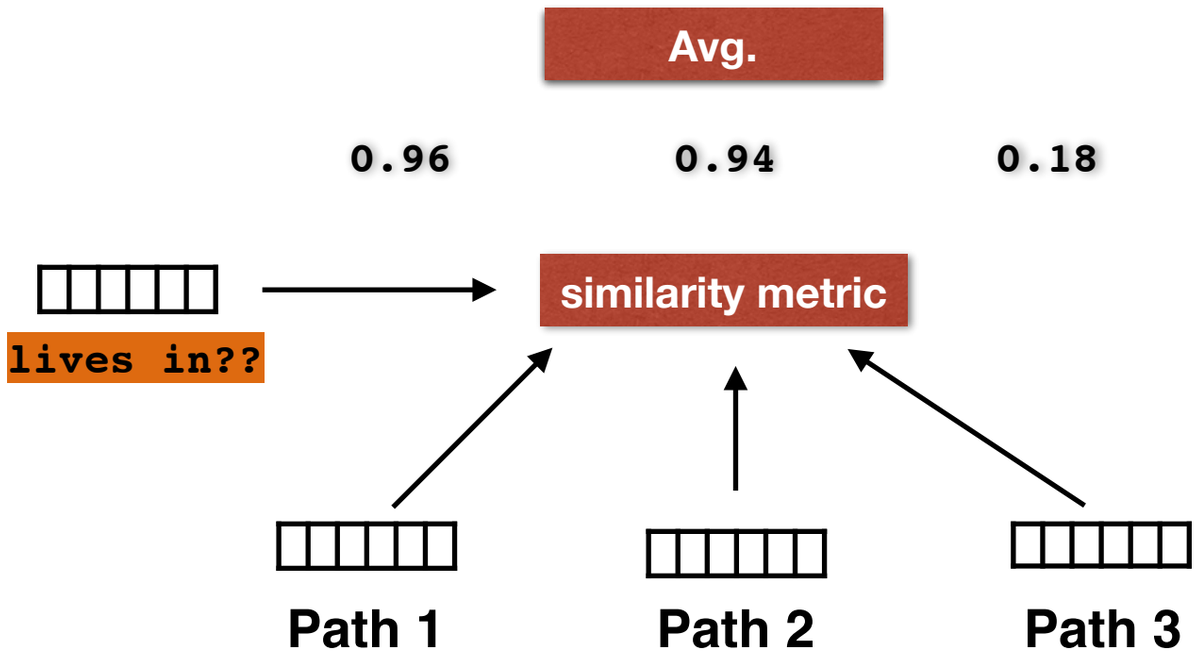

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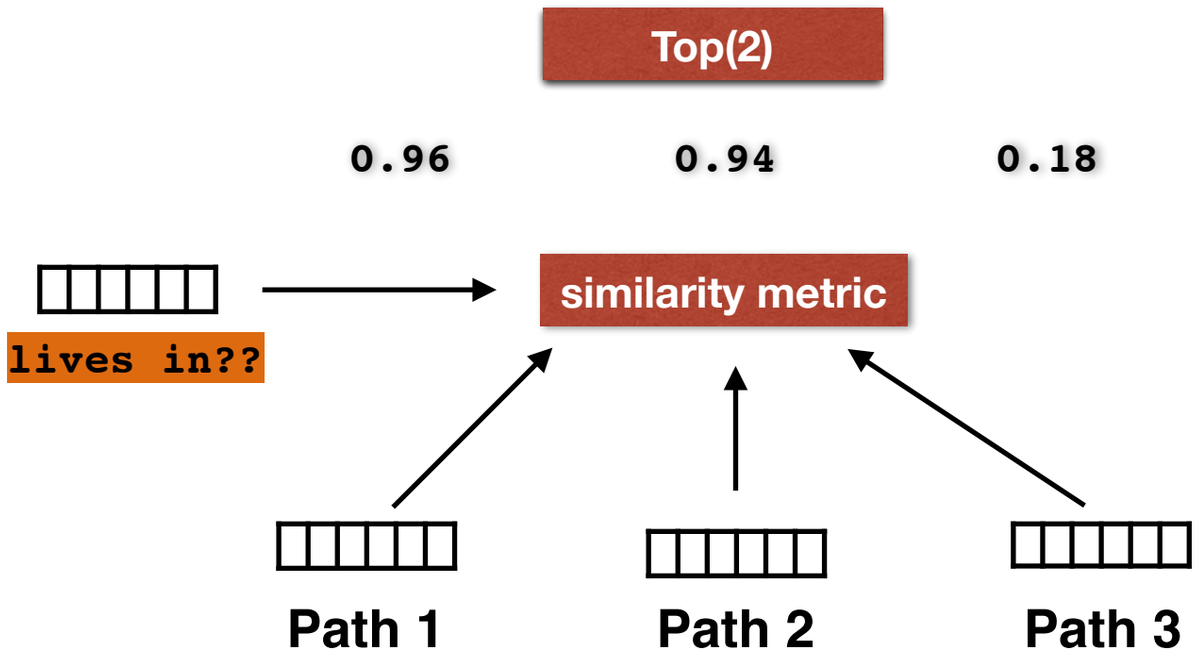

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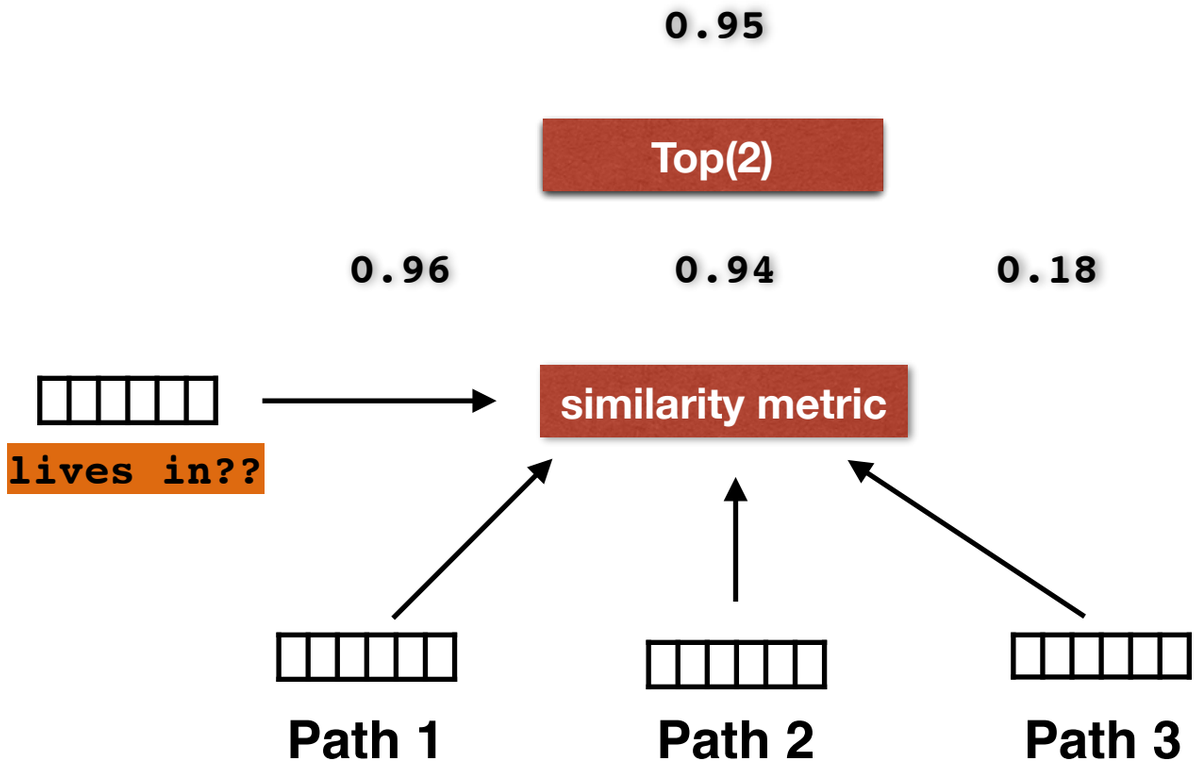
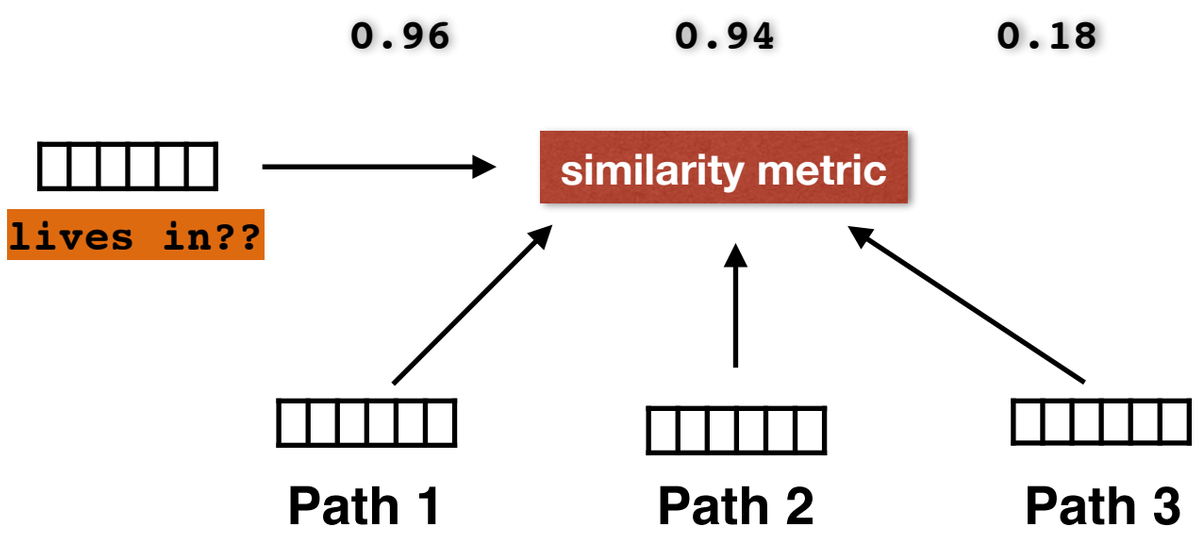


Score Pooling

4. LogSumExp: $$\log(\sum_{i=1}^{N} \exp(\alpha_i))$$



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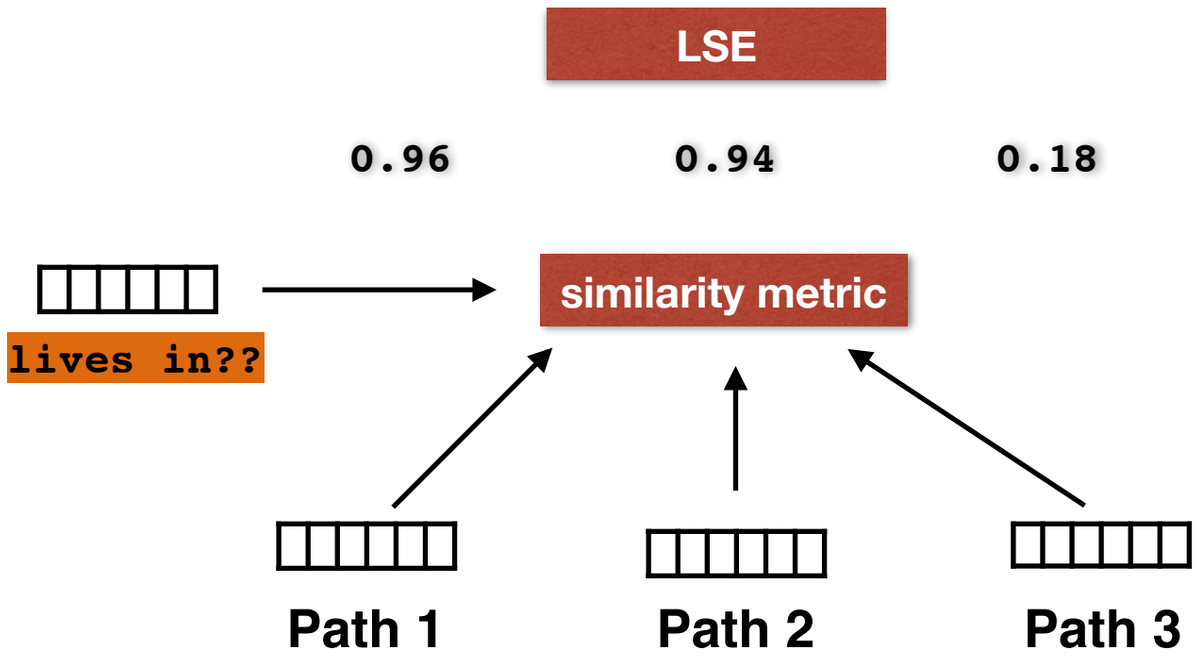

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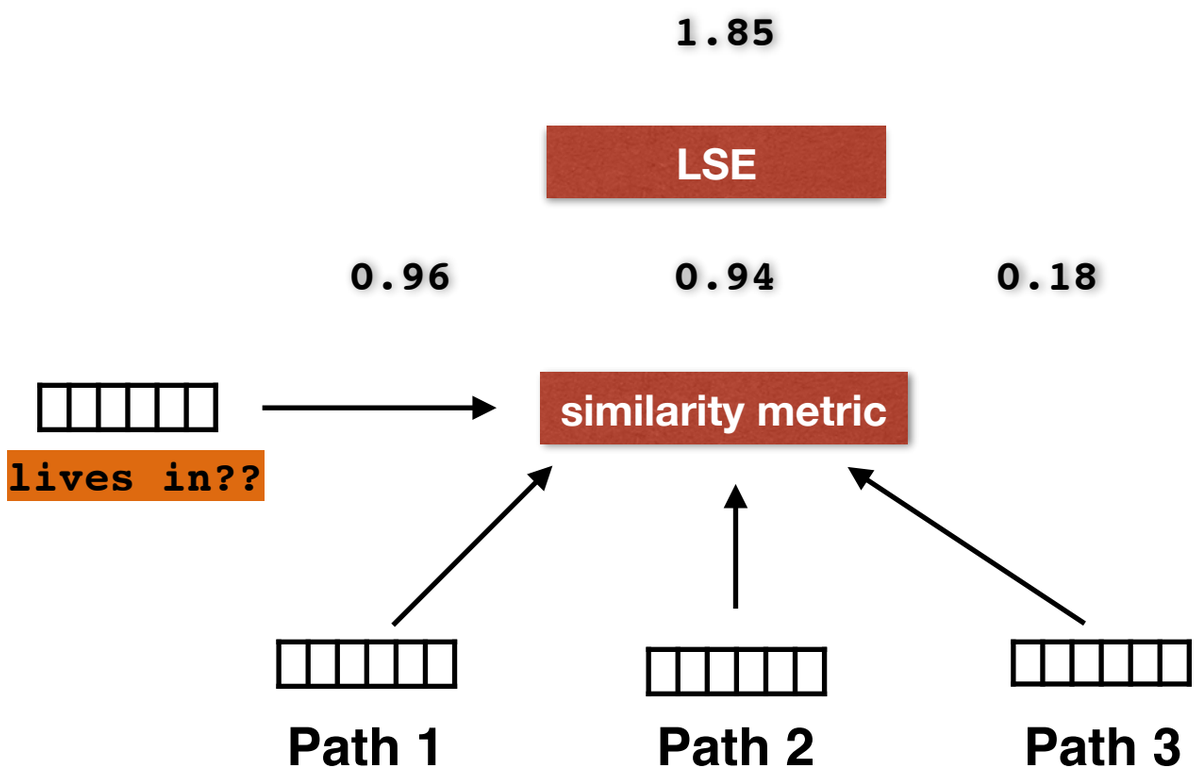

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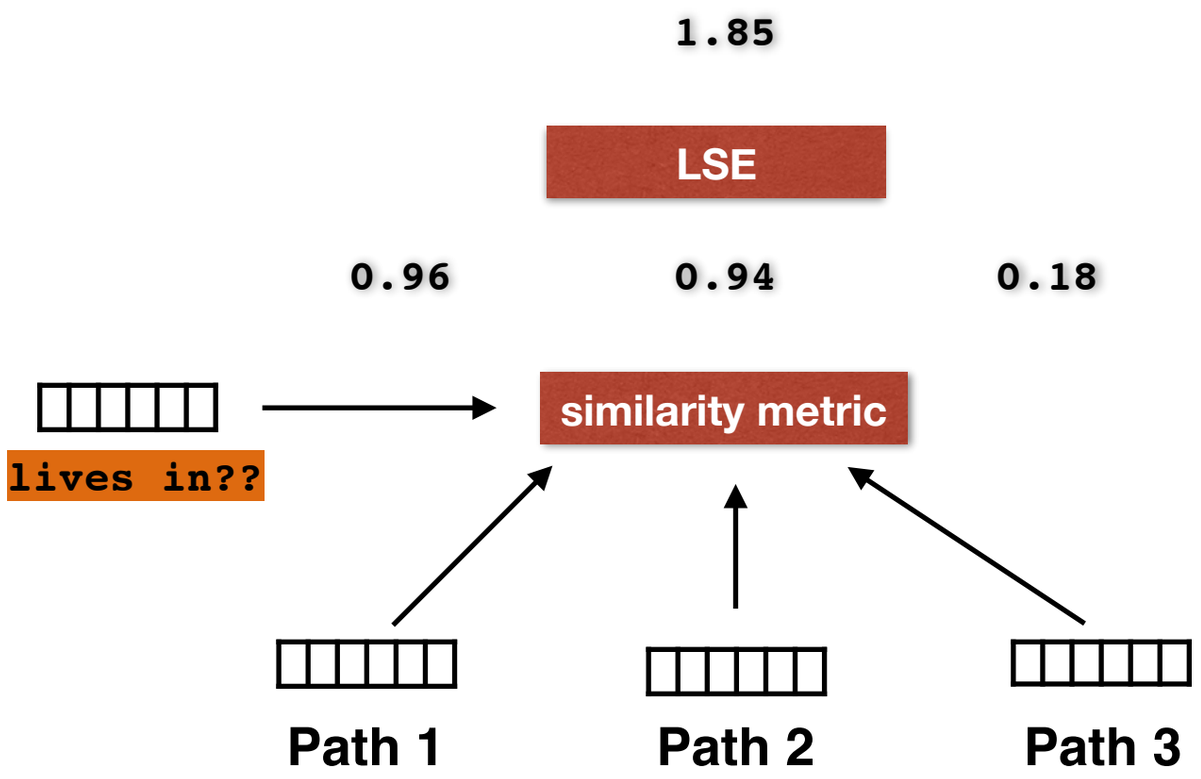

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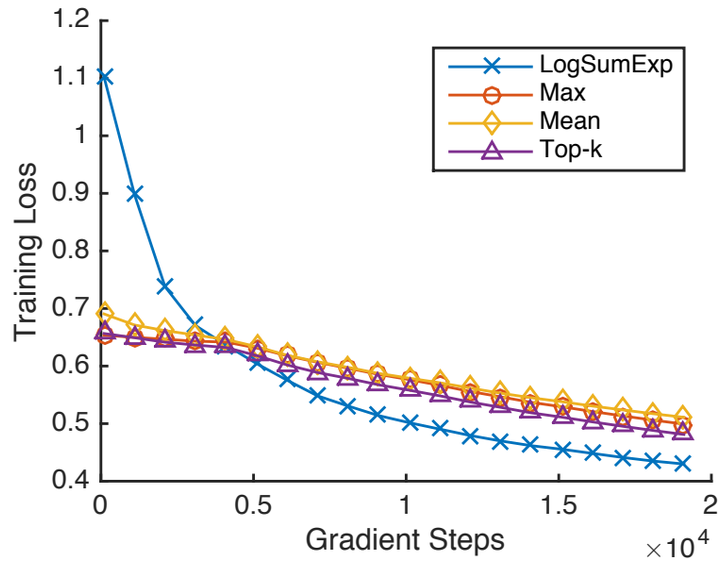
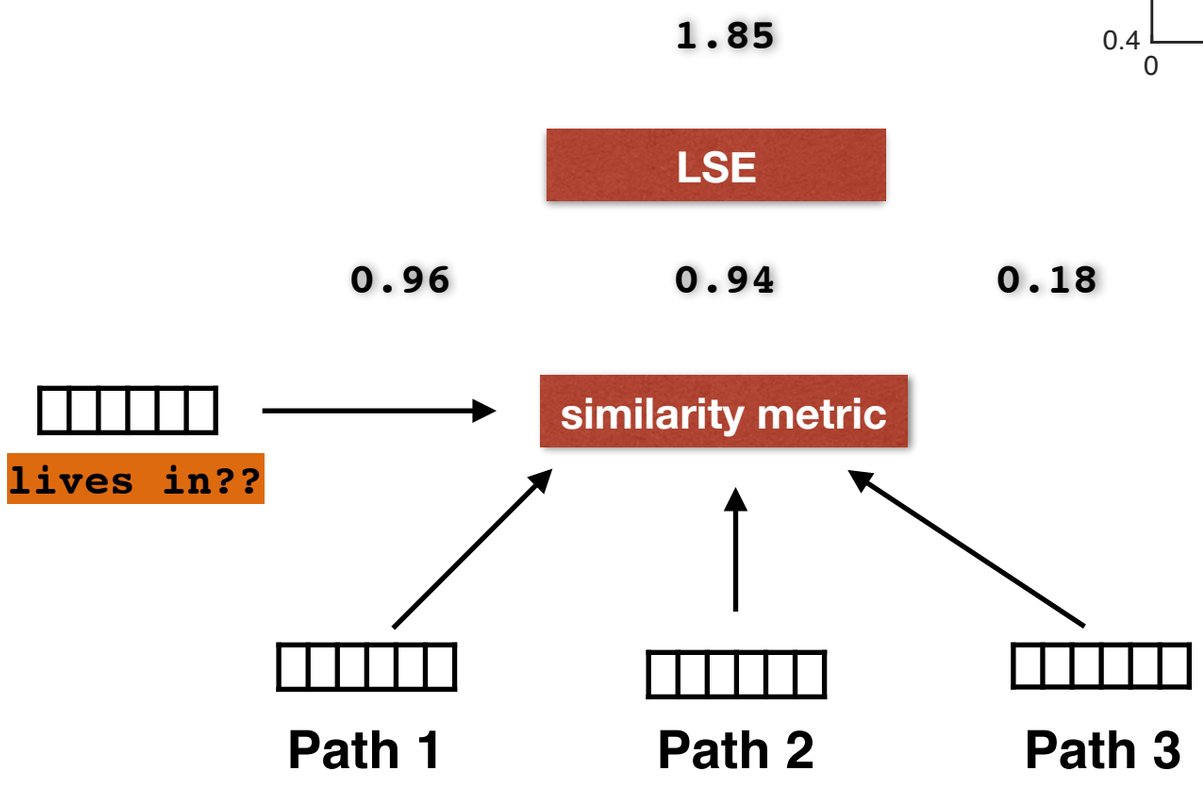
4. LogSumExp: $\log(\sum_{i=1}^{N} \exp(\alpha_i))$ $\frac{\partial LSE}{\partial \alpha_i} = \frac{\exp(\alpha_i)}{\sum_i \exp(\alpha_i)}$





Results

Results

Model	%MAP	Pooling
RNN-Path (Neelakantan ’15)	65.23	Max

Results

Model	%MAP	Pooling
RNN-Path (Neelakantan ’15)	65.23	Max
RNN-Path	**68.43**	LogSumExp

Results

Model	%MAP	Pooling
RNN-Path (Neelakantan ’15)	65.23	Max
RNN-Path	**68.43**	LogSumExp
Single Model	68.77	Max
Single Model	**55.8**	Avg.
Single Model	68.20	Top(K)

Results

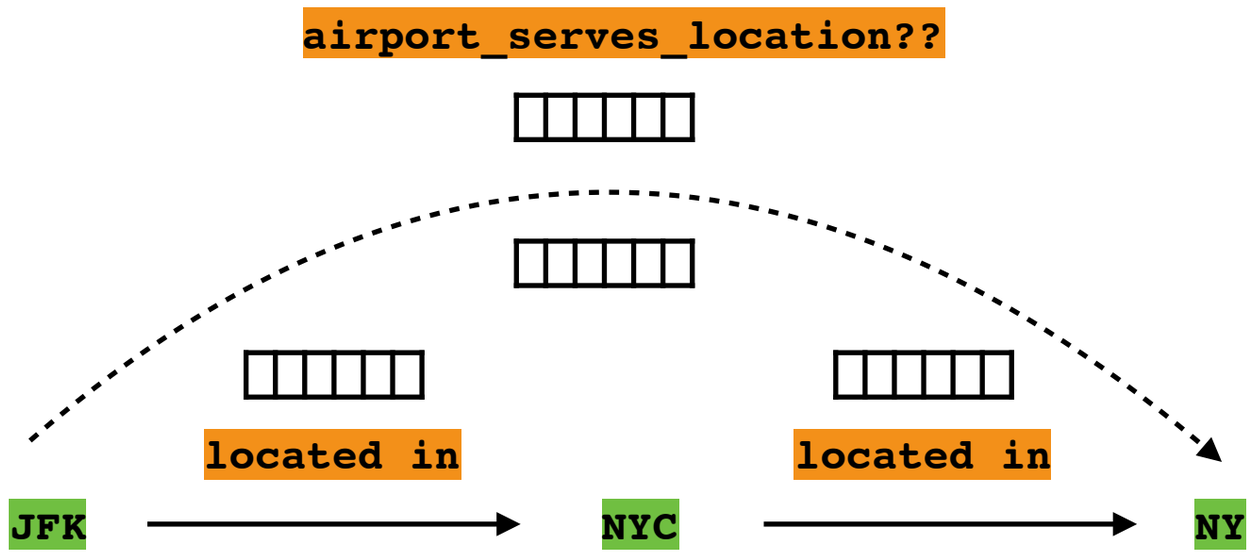
Model	%MAP	Pooling
RNN-Path (Neelakantan ’15)	65.23	Max
RNN-Path	**68.43**	LogSumExp
Single Model	68.77	Max
Single Model	**55.8**	Avg.
Single Model	68.20	Top(K)
Single Model	**70.11**	LogSumExp

Contributions

1. Single RNN for chains of reasoning. ✓

2. Combine evidence from multiple paths between entity pairs. ✓

3. Entity Aware RNN for chains of reasoning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NYC
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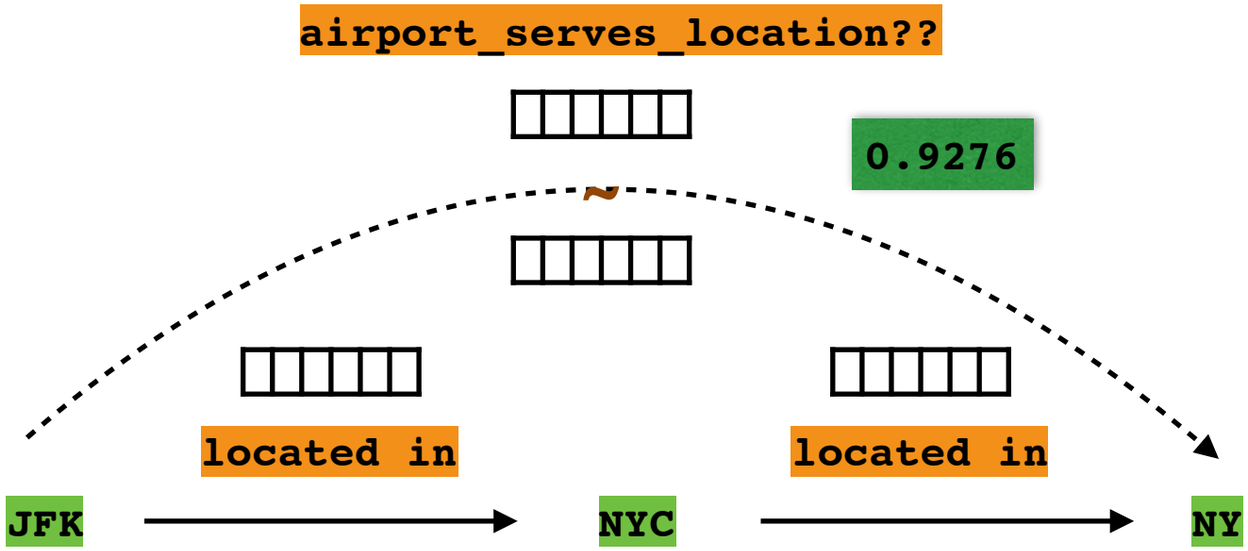
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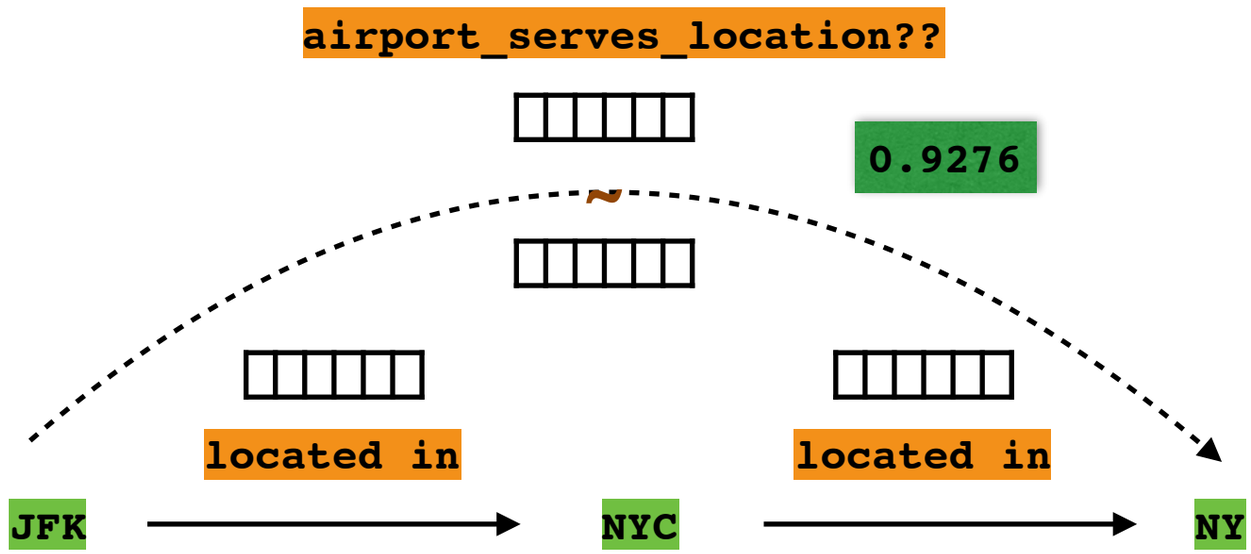
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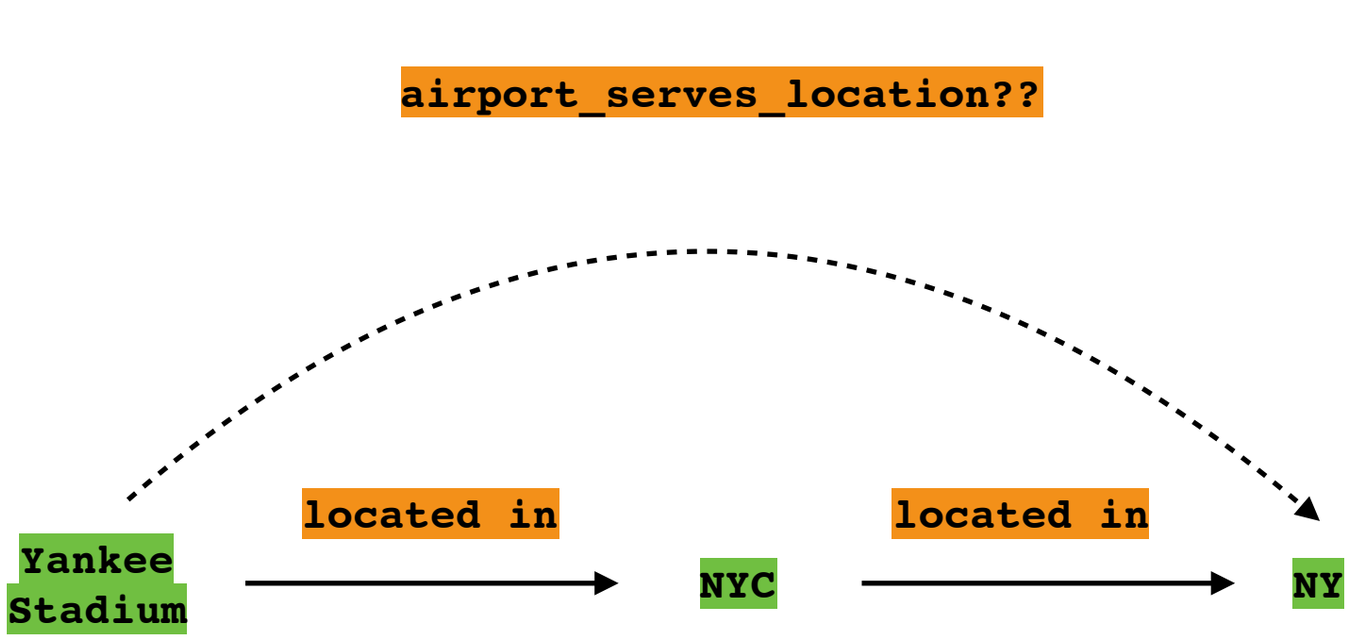
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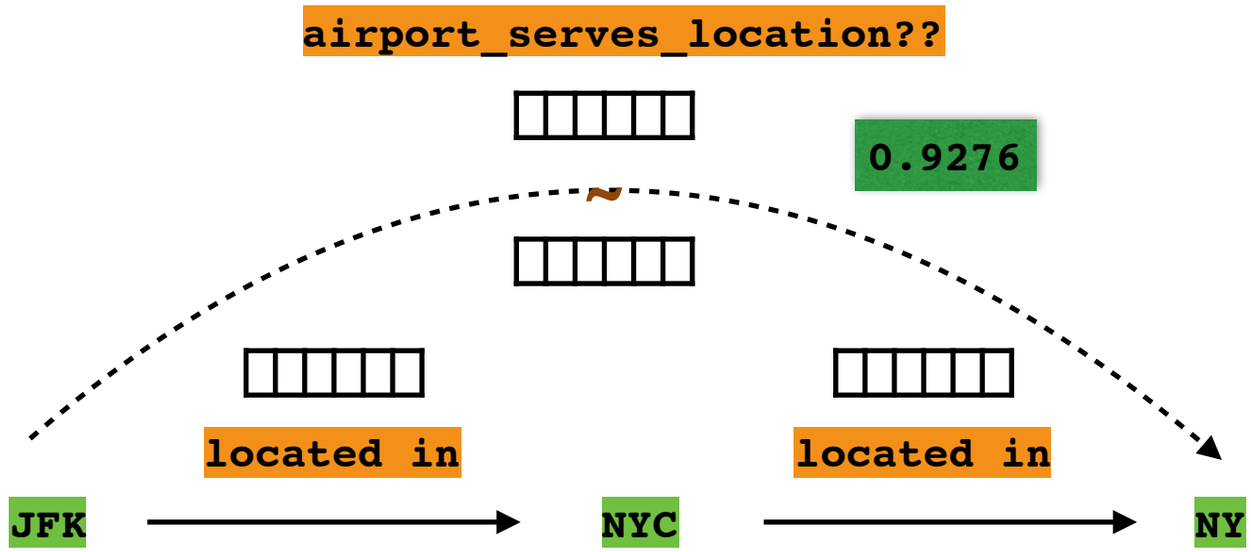
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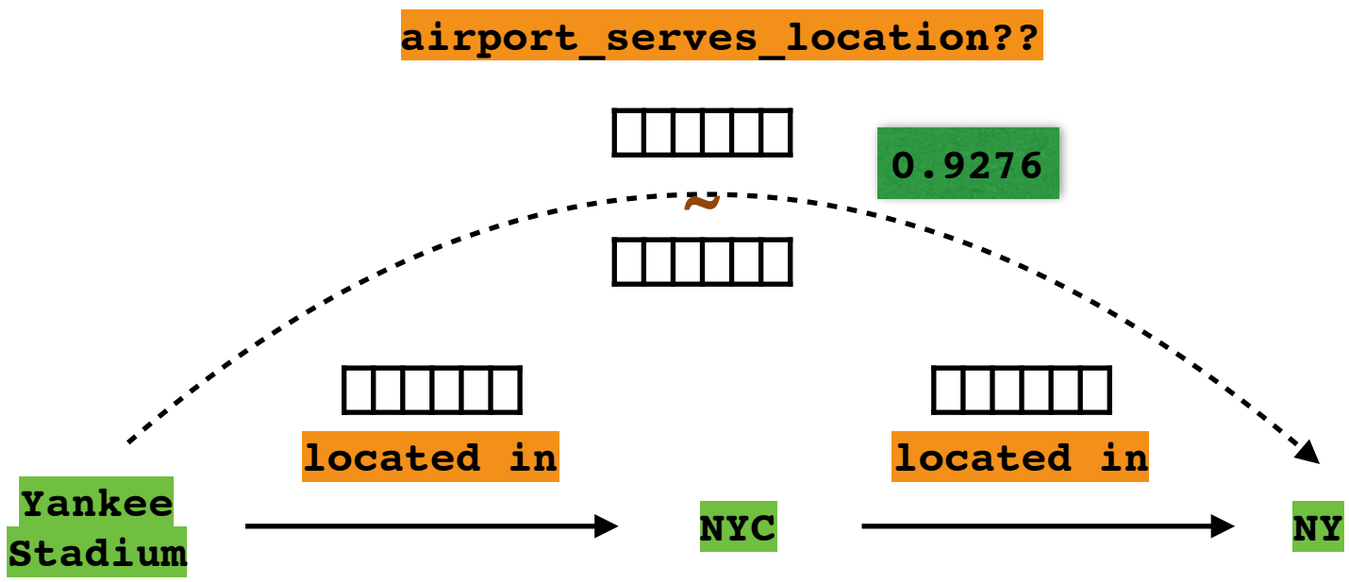
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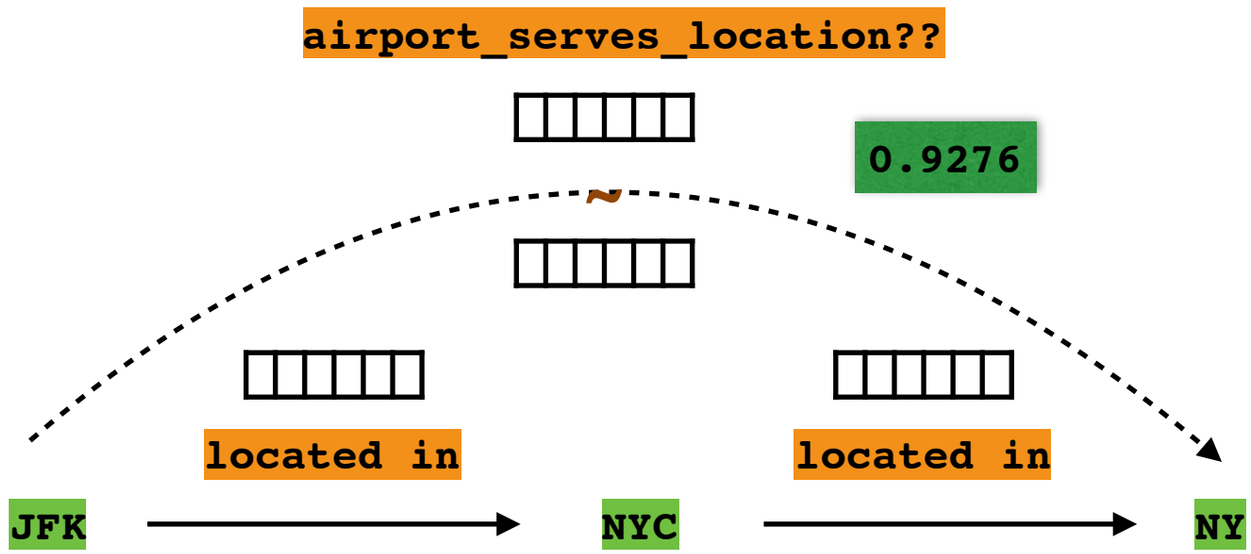
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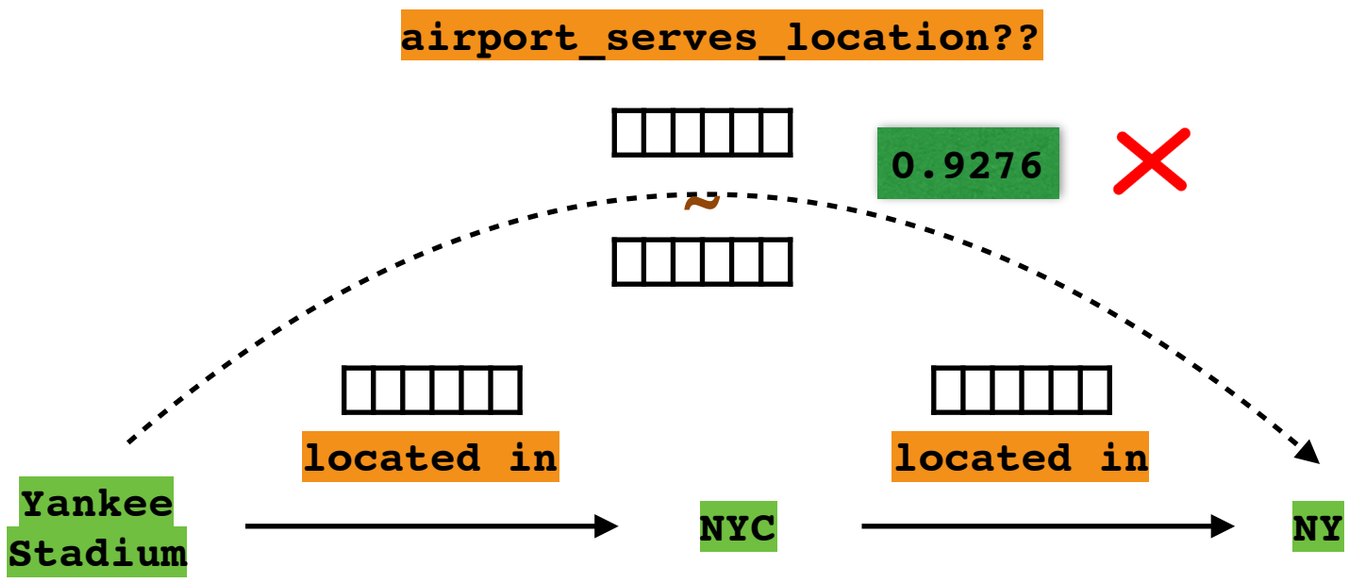
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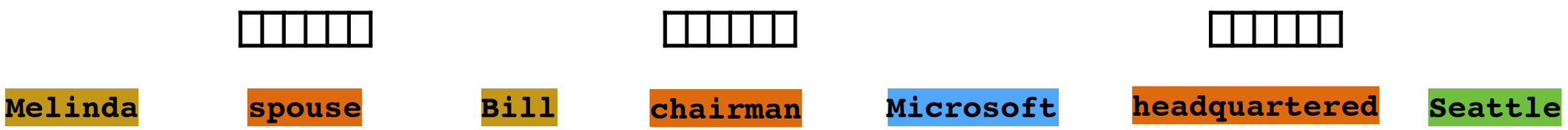
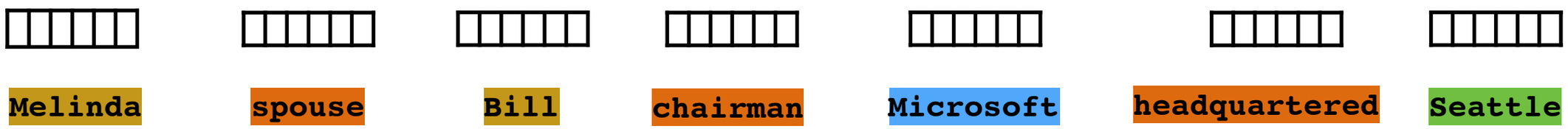
NYC
NY

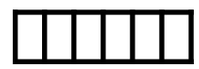
Entity Representation



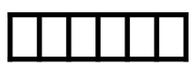
Entity Representation



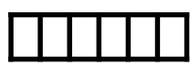
Entity Representation



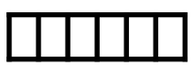
Melinda



Bill



Microsoft



Seattle

Entity Representation

1. Learn separate representation for each entity.

Entity Representation

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Entity Representation

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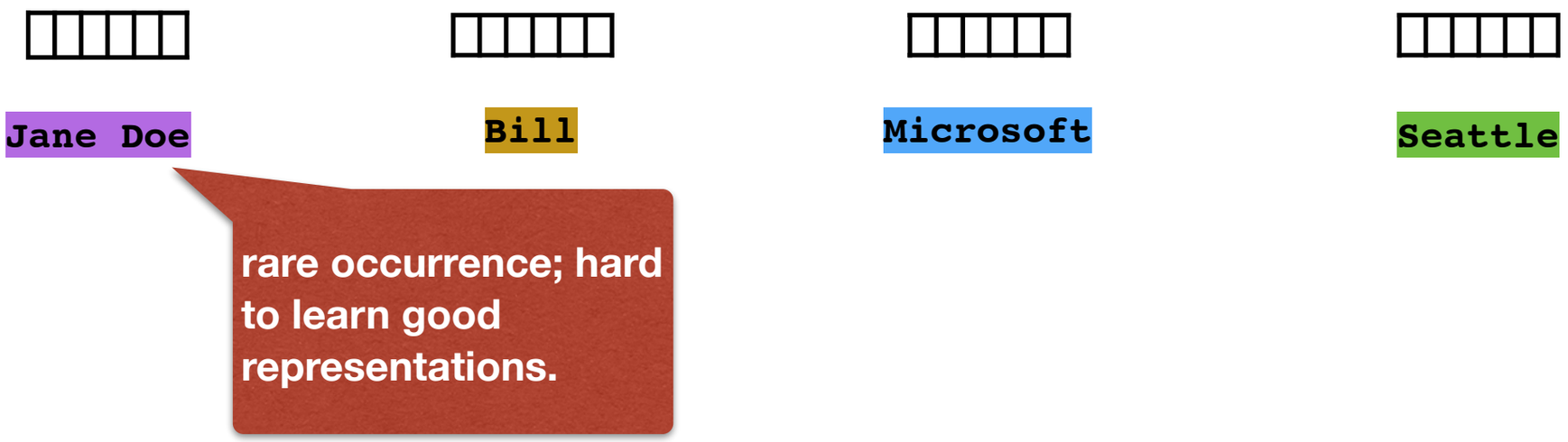
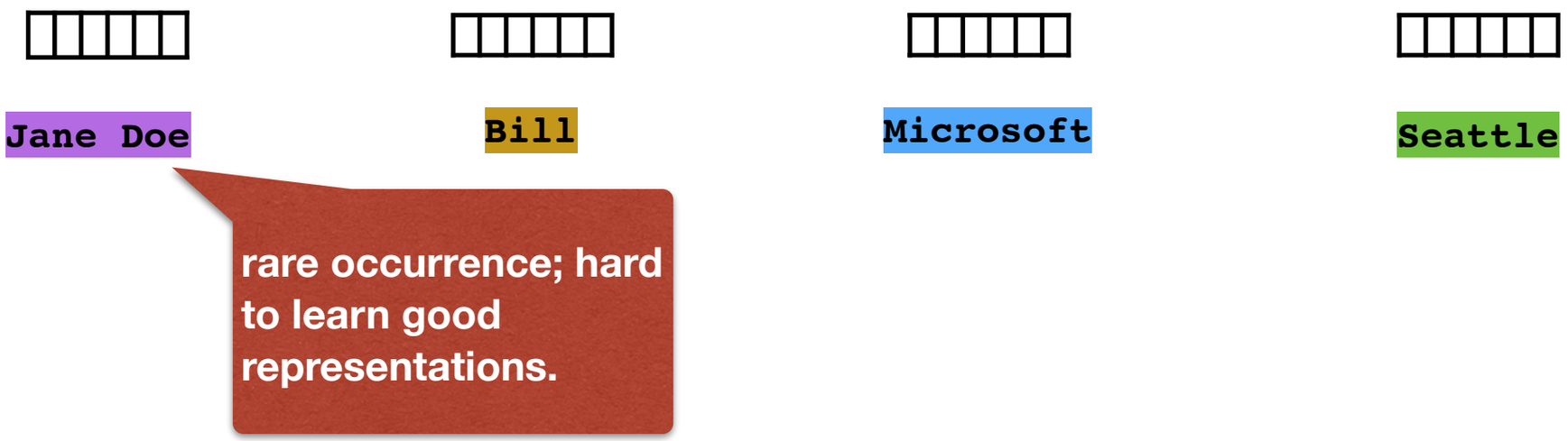


Entity Representation

1. Learn separate representation for each entity.
2. Represent entities by their annotated types



Entity Representation

1. Learn separate representation for each entity.
2. Represent entities by their annotated types

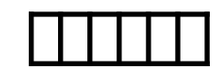
Annotated types in KB

Melinda

1. CEO
2. Philanthropist
3. Duke University alumni
4. American Citizen

Jane Doe

1. American Citizen
2. Small business owner



Jane Doe

Bill

Microsoft

Seattle

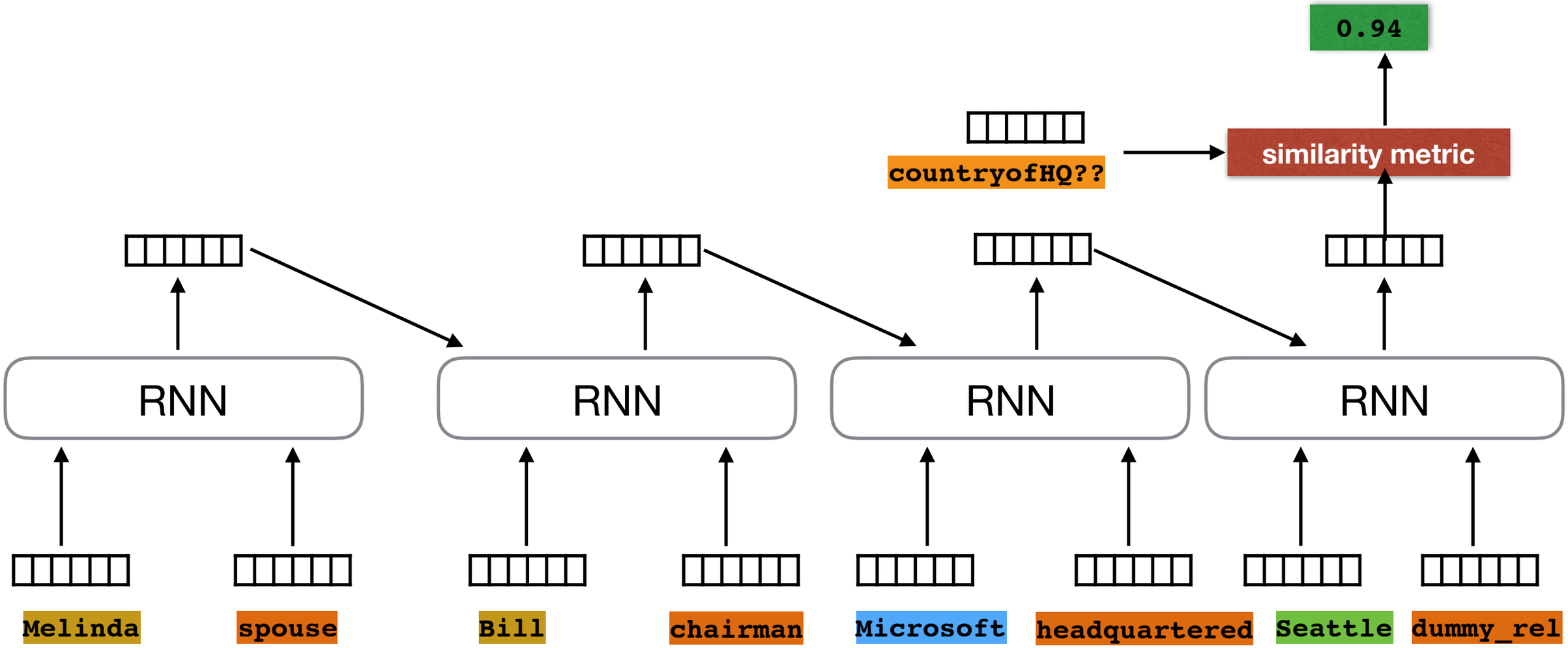
rare occurrence; hard to learn good representations.

Entity Representation

Entity Representation

Entity is represented as the sum of their annotated types

Entity Aware RNNs for Chains of Reasoning



Results

Results

Model	%MAP
Single Model	70.11

Results

Model	%MAP
Single Model	70.11
Single Model + Entity	71.74

Results

Model	%MAP
Single Model	70.11
Single Model + Entity	71.74
Single Model + Types	**73.26**

Results

Model	%MAP
Single Model	70.11
Single Model + Entity	71.74
Single Model + Types	**73.26**

4.4%

$p < 5e\text{-}6$

Results

Results

Model	%MAP	Pooling
PRA	64.43	n/a
RNN-Path (Neelkantan et al'15)	65.23	Max

Results

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PRA	64.43	n/a
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Single Model	68.77	Max

Results

Model	%MAP	Pooling
PRA	64.43	n/a
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Single Model	70.11	LogSumExp

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Model	%MAP	Pooling
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Single Model	68.77	Max
Single Model	70.11	LogSumExp
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Results

Model	%MAP	Pooling
PRA	64.43	n/a
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Single Model	68.77	Max
Single Model	70.11	LogSumExp
Single Model + Types	**73.26**	LogSumExp

13.7%

Predictive Clauses

Predictive Clauses

/people/person/place_of_birth(A,B) ⟷ 'was born in'(A,X) & 'commonly known as'(X,B)

Predictive Clauses

Freebase

/people/person/place_of_birth(A,B) ⟷ 'was born in'(A,X) & 'commonly known as'(X,B)

Predictive Clauses

Freebase

/people/person/place_of_birth(A,B) ⟷

Textual relations

’was born in’(A,X) & ‘commonly known as’(X,B)

Predictive Clauses

Universal Schema

Freebase

/people/person/place_of_birth(A,B) ⟷

Textual relations

'was born in'(A,X) & 'commonly known as'(X,B)

Predictive Clauses

Freebase

/people/person/place_of_birth(A,B) ⟷

Textual relations

’was born in’(A,X) & ‘commonly known as’(X,B)

Predictive Clauses

Freebase

Textual relations

/people/person/place_of_birth(A,B) ⟷ 'was born in'(A,X) & 'commonly known as'(X,B)

/book/written_work/original_language(A,B) ⟷ /book/written_work_author(A,X) & 'address'(X,Y)

& /people/person/nationality^{-1}(Y,Z) & people/person/languages(Z,B)

Predictive Clauses

Freebase

/people/person/place_of_birth(A,B) ⟷ Textual relations: ’was born in’(A,X) & ‘commonly known as’(X,B)

/book/written_work/original_language(A,B) ⟷ /book/written_work_author(A,X) & ‘address’(X,Y)

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Entity Aware Model

Predictive Clauses

Freebase

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Freebase

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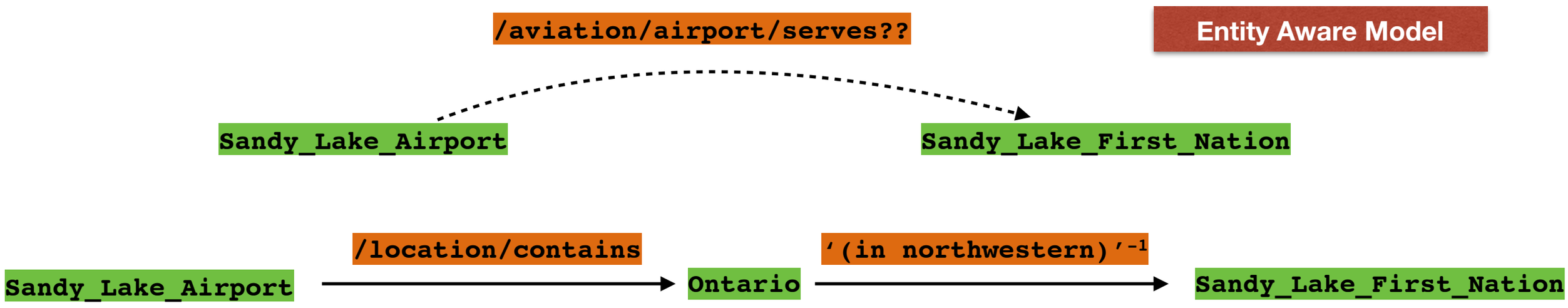

Predictive Clauses

Freebase

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/people/person/place_of_birth(A,B) ⟷ 'was born in'(A,X) & 'commonly known as'(X,B)

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Entity Aware Model

Predictive Clauses

Freebase

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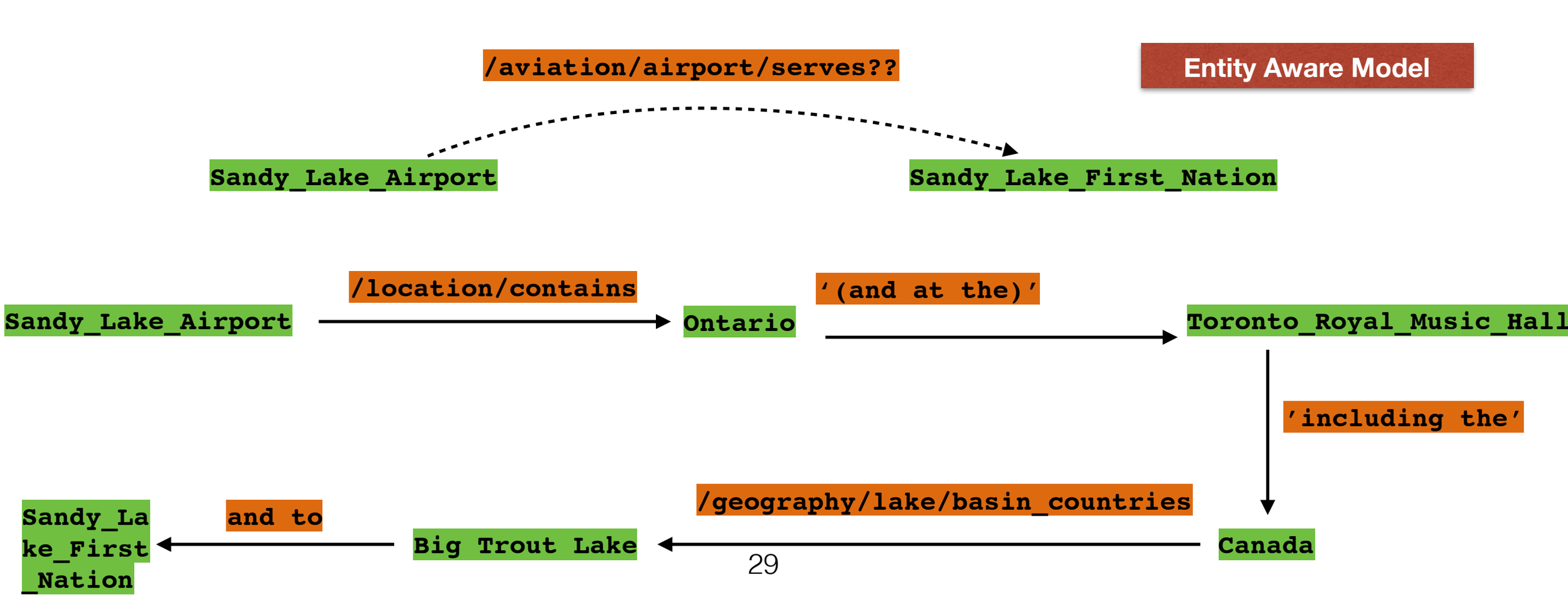

Conclusion

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- Introduced a high-capacity single RNN model for relation extraction

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- Combines evidences among multiple paths and sources of evidence

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Thanks!