

# **Non-sentential Question Resolution using Sequence to Sequence Learning**

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COLING 2016

Citation count: 1

# Motivation

- Incomplete questions do not make sense to conversation system

(a)

|           |                                       |
|-----------|---------------------------------------|
| <b>Q1</b> | how old was john rolfe when he died ? |
| <b>A1</b> | 37                                    |
| <b>Q2</b> | and how did he die ?                  |
| <b>R1</b> | how did john rolfe die ?              |

(c)

|           |                                     |
|-----------|-------------------------------------|
| <b>Q1</b> | what is greece 's national sport ?  |
| <b>A1</b> | football                            |
| <b>Q2</b> | flower ?                            |
| <b>R1</b> | what is greece 's national flower ? |

(b)

|           |                                     |
|-----------|-------------------------------------|
| <b>Q1</b> | what animal has a 7 lettered name ? |
| <b>A1</b> | cheetah                             |
| <b>Q2</b> | and how fast can it run ?           |
| <b>R1</b> | how fast can a cheetah run ?        |

(d)

|           |  |
|-----------|--|
| <b>Q1</b> | what do road runners eat ?                     |
| <b>A1</b> | small reptiles                                 |
| <b>Q2</b> | how often ?                                    |
| <b>R1</b> | how often do road runners eat small reptiles ? |

# Methodology

|        |  |
|--------|--|
| Source | what is greece 's national sport ? END football END flower ? |
| Target | what is greece 's national flower ?                          |

Table 3: Parallel corpus formulation of Table 1(c)

# Challenge

- How to handle OOV in small dataset (7k)

|        |  |
|--------|--|
| Source | what is greece 's national sport ? END football END flower ? |
| Target | what is greece 's national flower ?                          |

Q1 : what is UNK 's national UNK ?

A1 : UNK

Q2 : UNK ?

R1 : what is UNK 's national UNK ?

# Syntactic Sequence Model

|           |                                 |
|-----------|---------------------------------|
| <b>Q1</b> | what is UNK1 's national UNK2 ? |
| <b>A1</b> | UNK3                            |
| <b>Q2</b> | UNK4 ?                          |
| <b>R1</b> | what is UNK1 's national UNK4 ? |

|          |      |
|----------|------|
| greece   | UNK1 |
| sport    | UNK2 |
| football | UNK3 |
| flower   | UNK4 |

|           |                                  |
|-----------|----------------------------------|
| <b>Q1</b> | what UNK1 has a UNK2 UNK3 name ? |
| <b>A1</b> | UNK4                             |
| <b>Q2</b> | and how fast can it run ?        |
| <b>R1</b> | how fast can a UNK4 run ?        |

|          |      |
|----------|------|
| animal   | UNK1 |
| 7        | UNK2 |
| lettered | UNK3 |
| cheetah  | UNK4 |

# Problem

- Fails to utilize the meaning of each word, only the syntactic information

(a)

|           |                                     |
|-----------|-------------------------------------|
| <b>Q1</b> | What is Greece 's national sport ?  |
| <b>A1</b> | football                            |
| <b>Q2</b> | flower ?                            |
| <b>R1</b> | What is Greece 's national flower ? |

(b)

|           |                                    |
|-----------|------------------------------------|
| <b>Q1</b> | What is Greece 's national sport ? |
| <b>A1</b> | football                           |
| <b>Q2</b> | India ?                            |
| <b>R1</b> | What is India 's national sport ?  |

|           |                                 |
|-----------|---------------------------------|
| <b>Q1</b> | What is UNK1 's national UNK2 ? |
| <b>A1</b> | UNK3                            |
| <b>Q2</b> | UNK4 ?                          |
| <b>R1</b> | What is UNK1 's national UNK4 ? |

|          |      |
|----------|------|
| Greece   | UNK1 |
| sport    | UNK2 |
| football | UNK3 |
| flower   | UNK4 |

|           |                                 |
|-----------|---------------------------------|
| <b>Q1</b> | What is UNK1 's national UNK2 ? |
| <b>A1</b> | UNK3                            |
| <b>Q2</b> | UNK4 ?                          |
| <b>R1</b> | What is UNK4 's national UNK2 ? |

|          |      |
|----------|------|
| Greece   | UNK1 |
| sport    | UNK2 |
| football | UNK3 |
| India    | UNK4 |

# Semantic Sequence Model

- Assign each OOV a category number by k-means algorithm
- Use word embedding as clustering features

(a)

|           |                               |
|-----------|-------------------------------|
| <b>Q1</b> | What is CL1 's national CL3 ? |
| <b>A1</b> | CL3                           |
| <b>Q2</b> | CL3 ?                         |
| <b>R1</b> | What is CL1 's national CL3 ? |

|                         |     |
|-------------------------|-----|
| Greece                  | CL1 |
| sport, football, flower | CL3 |

(b)

|           |                               |
|-----------|-------------------------------|
| <b>Q1</b> | What is CL1 's national CL3 ? |
| <b>A1</b> | CL3                           |
| <b>Q2</b> | CL1 ?                         |
| <b>R1</b> | What is CL1 's national CL3 ? |

|                 |     |
|-----------------|-----|
| Greece, India   | CL1 |
| sport, football | CL3 |

# Dataset

- Collected from Amazon Mechanical Turk
- 7220 conversations (Q1 A1 Q2 R1)
- 134K/65K words for input/output sequence text



# Experiment

| <b>Experiment</b> | $V$    | <b>BLEU4</b> |
|-------------------|--------|--------------|
| All-Vocab         | 12,603 | 8.24         |
| Freq-10           | 1519   | 17.76        |
| <b>Freq-20</b>    | 808    | <b>18.54</b> |
| semantic-seq-20   | 818    | 21.20        |
| syntactic-seq-20  | 823    | 29.11        |
| ensemble-20       | 823    | <b>30.15</b> |

Table 7: BLEU score on a held out set of 400.  $V$  refers to vocabulary size

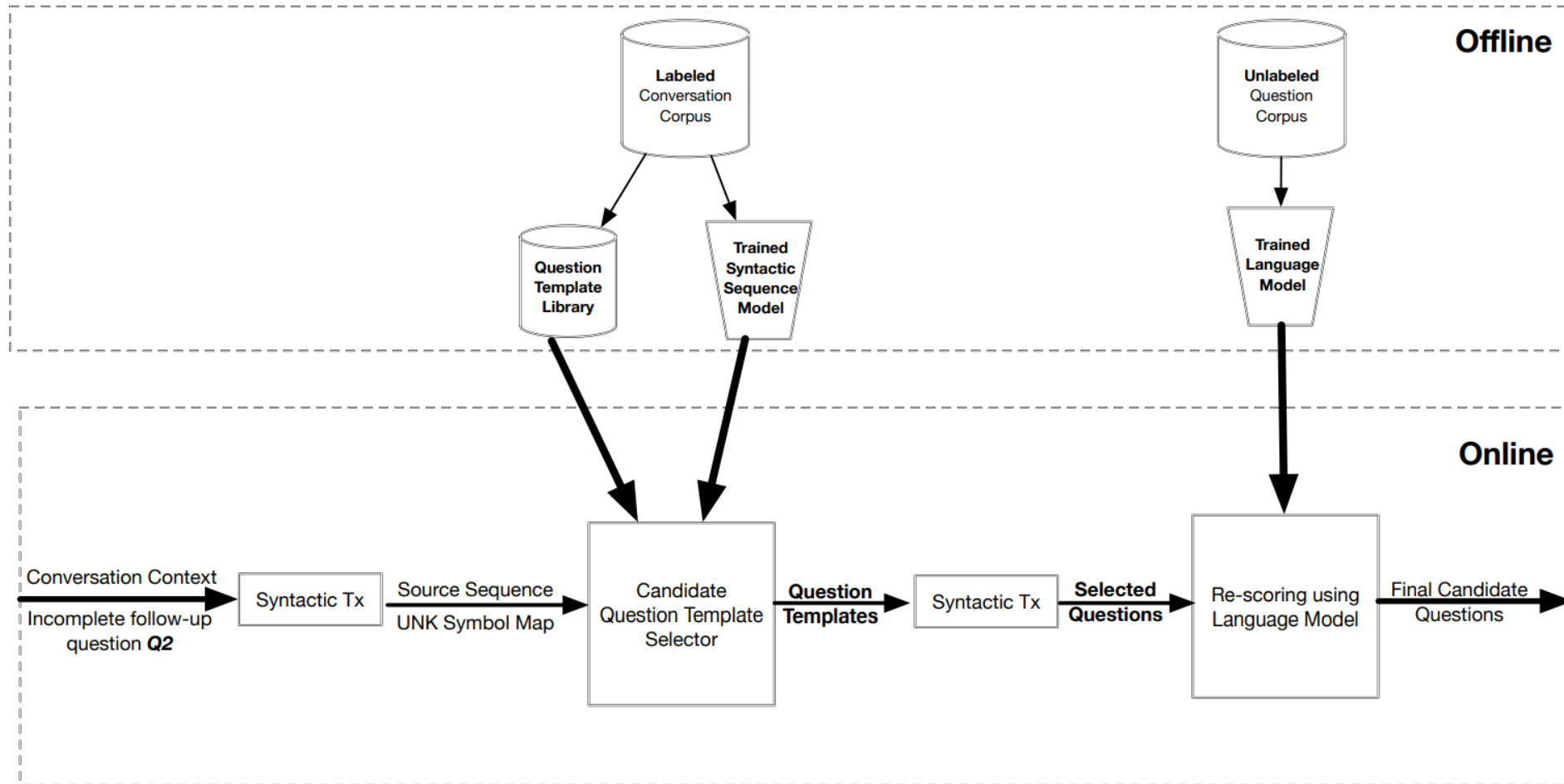
# **Incomplete Follow-up Question Resolution using Retrieval based Sequence to Sequence Learning**

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SIGIR 2017  
Citation count: 2

# Methodology



# Offline Question Template Library

|           |                                 |          |      |
|-----------|---------------------------------|----------|------|
| <b>Q1</b> | what is UNK1 's national UNK2 ? | greece   | UNK1 |
| <b>A1</b> | UNK3                            | sport    | UNK2 |
| <b>Q2</b> | UNK4 ?                          | football | UNK3 |
| <b>R1</b> | what is UNK1 's national UNK4 ? | flower   | UNK4 |

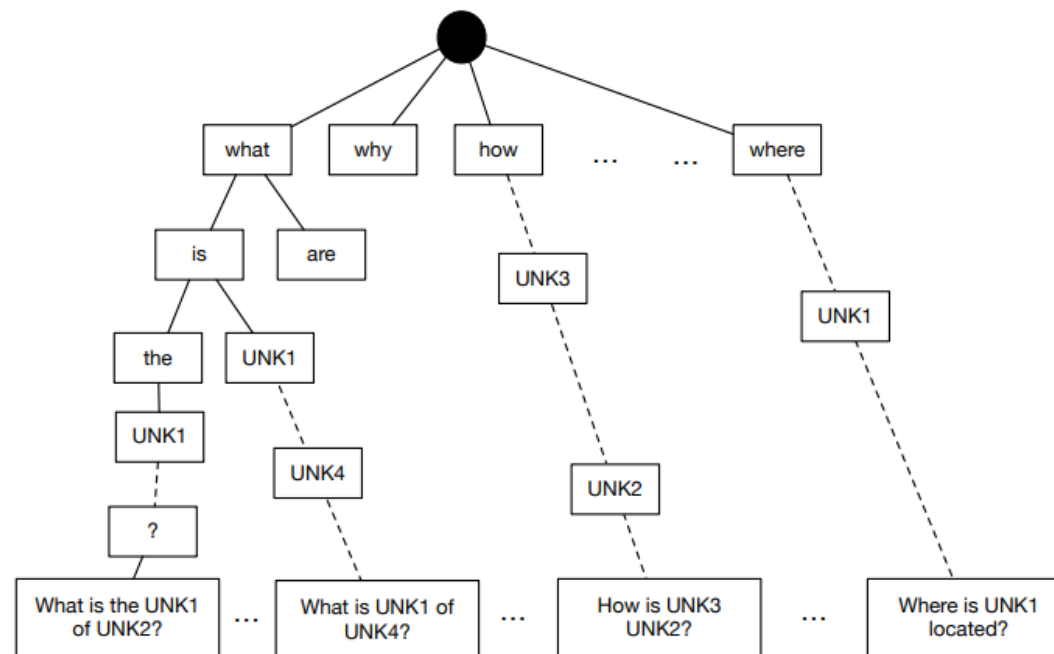
|           |                                  |          |      |
|-----------|----------------------------------|----------|------|
| <b>Q1</b> | what UNK1 has a UNK2 UNK3 name ? | animal   | UNK1 |
| <b>A1</b> | UNK4                             | 7        | UNK2 |
| <b>Q2</b> | and how fast can it run ?        | lettered | UNK3 |
| <b>R1</b> | how fast can a UNK4 run ?        | cheetah  | UNK4 |

- 6420 → 5451

# Problem

- Template library size is still too large (5k)
- Make online inference slow

# Candidate Question Template Selector



**Figure 2: Prefix tree for syntactic question templates.**  
**Nodes at the first level denote start of a question template**  
**The leaves denote all the question templates.**

# Re-ranking with Language Model

- Template selector seq2seq score:  $ss = \frac{1}{T_y} \sum_{i=1}^{T_y} Pr(y_i | x_1, x_2, \dots, x_{T_x}, y_1, \dots, y_{i-1})$

- Language model score:  $ls = \frac{1}{t} \sum_{i=1}^t Pr(x_i | x_1, x_2, \dots, x_{i-1})$

- Total score:  $score_i = \lambda * \frac{ss_i}{\max_{j=1}^k ss_j} + (1 - \lambda) * \frac{ls_i}{\max_{j=1}^k ls_j}$

# Same Dataset

- Collected from Amazon Mechanical Turk
- 7220 conversations (Q1 A1 Q2 R1)
- 134K/65K words for input/output sequence text

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*Q1* What is a native animal of Ireland?  
*A1* Hedgehog  
*Q2* What about Australia?  
*R1* What is a native animal of Australia?

*Q1* Where does a white faced saki live?  
*A1* Suriname  
*Q2* What does it eat?  
*R1* What does a white faced saki eat?

*Q1* Where are Porsche made?  
*A1* Germany  
*Q2* and when was the first?  
*R1* When was the first Porsche produced?

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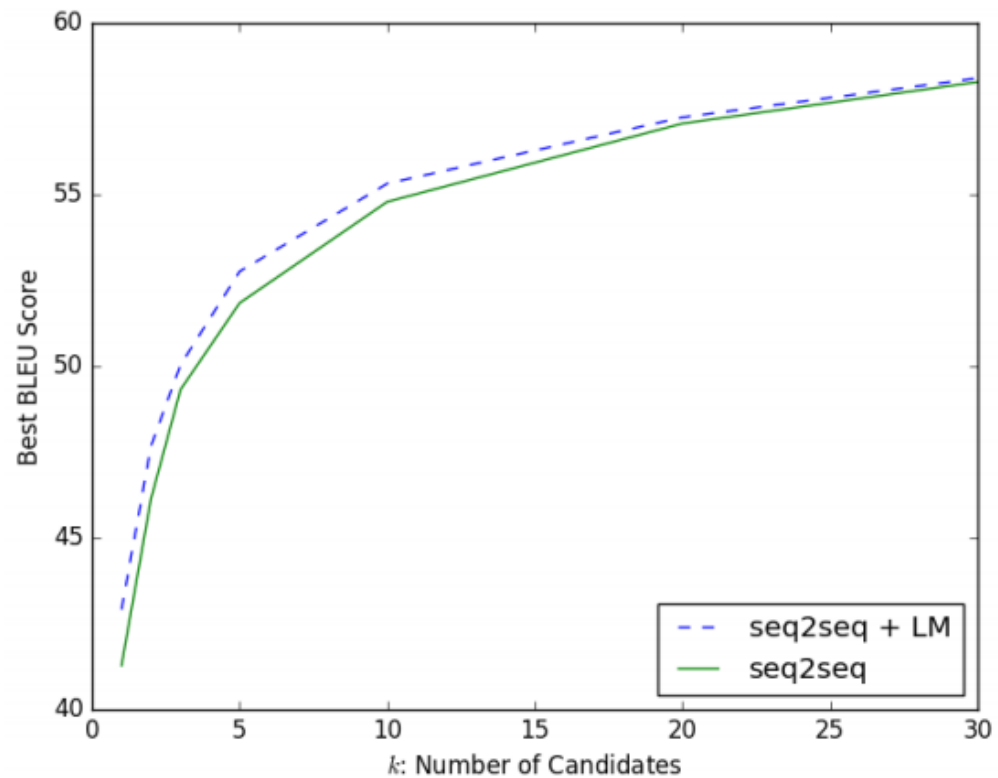


# Experiment

**Table 6: BLEU Score on Test Set**

| Model                                   | BLEU         |
|---|--------------|
| Baseline RNN (Kumar & Joshi) [25]       | 18.54        |
| Syntactic Sequence (Kumar & Joshi) [25] | 29.11        |
| Our approach: Retrieval Model           | <b>41.28</b> |
| Our approach: Retrieval Model + LM      | <b>42.91</b> |

# Window Size of Prefix Tree



**Figure 3: BLEU Scores**

# Siri Experiment (only dataset released)

| System     | Correctly Answered |
|------------|--------------------|
| Baseline   | 38/100             |
| Our System | 88/100             |

| Q1                               | Q2   | R1                                  | Siri Response | With our system |
|----------------------------------|--|-------------------------------------|---------------|-----------------|
| How many miles in 5 kilometres ? | and 15 kilometres?<br>and 15 ?                   | How many miles in 15 kilometres?    | ✓<br>X        | ✓<br>✓          |
| When did Yuan Shikai die?        | Where did he die?<br>where?                      | Where did Yuan Shikai die?          | ✓<br>X        | ✓<br>✓          |
| What is the square root of 64?   | and cube root?                                   | What is the cube root of 64?        | X             | ✓               |
| Who is the president of India?   | how about prime minister?<br>and prime minister? | Who is the prime minister of India? | ✓<br>X        | ✓<br>✓          |

# Conclusion

- Syntactic information is important
- Template method works well on the dataset
- Use language model to further enhance performance