Multi-dimensional feature merger for Question Answering

Apoorv Agarwal
Columbia University
Dec 13th 2012

Joint work with: William Murdock, Jennifer Chu-carroll, Adam Lally, Aditya Kalyanpur (IBM Research)
Question Answering
(Question) This large land animal also has large ears.
Question Answering

(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant
(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant

(Supporting passages)
(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant

(Supporting passages)
1) African Elephant is a large land animal
**Question Answering**

(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant

(Supporting passages)
1) African Elephant is a large land animal
2) African Elephants have large ears
(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant

(Supporting passages)
1) African Elephant is a large land animal
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-- Watson tries to find the best passage that supports the answer
(Question) This large land animal also has large ears.

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(Supporting passages)
1) African Elephant is a large land animal
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-- Watson tries to find the best passage that supports the answer

-- But all the information may not be present in one passage
(Question) This large land animal also has large ears.

(Candidate Answer) African Elephant

(Supporting passages)
1) African Elephant is a large land animal
2) African Elephants have large ears

-- Watson tries to find the best passage that supports the answer
-- But all the information may not be present in one passage
-- In this work we present a framework to overcome this limitation
Question Answering Set-up

```
Q
 /   \
|    / \\
CA_1|  ...  | CA_n
  /     \
|   /   \\
| p_1 | ... | p_m_1
  \\
  \\
  \\
  \\
p_1 p_2 ... p_m_1

  /   \
|    / \\
| p_1 | ... | p_m_n
  /     \\
```

Question Answering Set-up

\[
\begin{align*}
&Q \\
&\quad \text{CA}_1 \\
&\quad \quad p_1 \quad p_2 \quad \ldots \quad p_{m_1} \\
&\quad \quad \ldots \\
&\quad \text{CA}_n \\
&\quad \quad p_1 \quad p_2 \quad \ldots \quad p_{m_n}
\end{align*}
\]

\[
< Q_1, \text{CA}_1, -1 >, < Q_1, \text{CA}_2, -1 >, \ldots, < Q_1, \text{CA}_i, 1 >, \ldots, < Q_1, \text{CA}_{n_1}, -1 > \\
< Q_2, \text{CA}_1, -1 >, < Q_2, \text{CA}_2, -1 >, \ldots, < Q_2, \text{CA}_j, 1 >, \ldots, < Q_2, \text{CA}_{n_2}, -1 > \\
\ldots \\
< Q_m, \text{CA}_1, -1 >, < Q_m, \text{CA}_2, -1 >, \ldots, < Q_m, \text{CA}_k, 1 >, \ldots, < Q_m, \text{CA}_{n_m}, -1 >
\]
Outline

1. Brief overview of passage scorers in the system
Outline

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2. How features produced by passage scorers per passage are combined to get one feature for a candidate -- feature merger
Outline

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2. How features produced by passage scorers per passage are combined to get one feature for a candidate -- feature merger

3. A new feature merger framework
Outline

1. Brief overview of passage scorers in the system

2. How features produced by passage scorers per passage are combined to get one feature for a candidate -- feature merger

3. A new feature merger framework

4. Experiments and results
Passage Scoring Features
Passage Scoring Features

1. Capture how well Question matches supporting passages
Passage Scoring Features

1. Capture how well Question matches supporting passages

2. Four types:
Passage Scoring Features

1. Capture how well Question matches supporting passages

2. Four types:
   a. **Passage Term Match**: Assigns a score based on which question terms are included in the passage, regardless of word order or grammatical relationship.
Passage Scoring Features

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   a. Passage Term Match: Assigns a score based on which question terms are included in the passage, regardless of word order or grammatical relationship.
   
   b. Skip Bigram: pairs of terms that are connected or nearly connected in the syntactic-semantic structure
Passage Scoring Features

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   c. **Textual Alignment**: how well the word order of the passage aligns with that of the question
Passage Scoring Features

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   a. **Passage Term Match**: Assigns a score based on which question terms are included in the passage, regardless of word order or grammatical relationship.

   b. **Skip Bigram**: pairs of terms that are connected or nearly connected in the syntactic-semantic structure

   c. **Textual Alignment**: how well the word order of the passage aligns with that of the question

   d. **Logical Form Answer Candidate Scorer (LFACS)**: Targets high-precision matching between the syntactic structures of passages and questions.
Passage Scoring Feature

[Question]
This large land animal also has large ears

[Candidate Answer 1]
African Elephant

[P1.1]
The African elephant is a very large land animal
[P1.2] African Elephants have large ears

[Candidate Answer 2]
Hippo

[P2.1] A hippo is a large land animal
[P2.2] Hippos have relatively small ears
Passage Scoring Feature

[Question]
This large land animal also has large ears

[Candidate Answer 1]
African Elephant

[P1.1]
The African elephant is a very large land animal

[P1.2]
African Elephants have large ears

[Candidate Answer 2]
Hippo

[P2.1]
A hippo is a large land animal

[P2.2]
Hippos have relatively small ears

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<tbody>
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**Passage Scoring Feature**

**[Question]**
This large land animal also has large ears

**[Candidate Answer 1]**
African Elephant

**[Candidate Answer 2]**
Hippo

- **[P1.1]** The African elephant is a very large land animal
- **[P1.2]** African Elephants have large ears
- **[P2.1]** A hippo is a large land animal
- **[P2.2]** Hippos have relatively small ears

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\[ f = \max_i (\sum_{j=1}^{N} a_{i,j}) \]
Other Merger Strategies

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1. MAX

\[ \max_i \left( \sum_{j=1}^{N} a_{i,j} \right) \]
Other Merger Strategies

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1. **MAX** \[ \max_i \left( \sum_{j}^{N} a_{i,j} \right) \]  

Pl.1, score = 3
Other Merger Strategies

1. MAX
\[
\max_i \left( \sum_{j=1}^{N} a_{i,j} \right)
\]

2. SUM
\[
\sum_i \sum_j a_{i,j}
\]

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P1.1, score = 3

Thursday, December 13, 12
### Other Merger Strategies

**Elephant**

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1. **MAX**

\[
\text{max}_i \left( \sum_{j}^{N} a_{i,j} \right) \quad \text{Pl.1, score = 3}
\]

2. **SUM**

\[
\sum_i \sum_j a_{i,j} \quad \text{score = 5}
\]
Other Merger Strategies

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1. **MAX**
   \[ \max_i \left( \sum_j^N a_{i,j} \right) \]
   Pl.1, score = 3

2. **SUM**
   \[ \sum_i \sum_j a_{i,j} \]
   score = 5

3. Decaying Sum
   \[ \sum_i \alpha^i \sum_j a_{i,j} \quad 0 < \alpha < 1 \]
Other Merger Strategies

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1. **MAX**

\[ \max_i \left( \sum_{j}^{N} a_{i,j} \right) \quad \text{Pl.1, score = 3} \]

2. **SUM**

\[ \sum_i \sum_j a_{i,j} \quad \text{score = 5} \]

3. Decaying Sum

\[ \sum_i \alpha^i \sum_j a_{i,j} \quad 0 < \alpha < 1 \]

Our contribution: Introduce a framework to capture the distribution of this matrix.
More Formally...

\[ \text{Q} \]

\[ CA_1 \quad CA_2 \quad \ldots \quad CA_n \]
More Formally...

Q

CA_1

p_1 p_2 \ldots p_{m_1}

\ldots

CA_n

p_1 p_2 \ldots p_{m_n}
More Formally...

Question terms

Supporting passages
More Formally...

Question terms

Supporting passages
More Formally...

Question terms

Supporting passages

Question 1

Question 2
More Formally...

Question terms

Supporting passages

Cannot simply linearize this matrix

Question 1

Question 2
Multi-dimensional Feature Merger (MDM Features)

\[
M = \begin{pmatrix}
\text{pl} & q1 & q2 & q3 & q4 & q5 \\
\text{p2} \\
\text{p3} \\
\text{p4}
\end{pmatrix}
\]
Multi-dimensional Feature Merger (MDM Features)

Introduce features that capture the distribution of this matrix

\[
M = \begin{array}{cccccc}
 & q1 & q2 & q3 & q4 & q5 \\
 p1 &   &   &   &   &   \\
p2 &   &   &   &   &   \\
p3 &   &   &   &   &   \\
p4 &   &   &   &   &   \\
\end{array}
\]
Multi-dimensional Feature Merger (MDM Features)

Introduce features that capture the distribution of this matrix

\[
M = \begin{array}{ccccc}
q1 & q2 & q3 & q4 & q5 \\
p1 &    &    &    &    \\
p2 &    &    &    &    \\
p3 &    &    &    &    \\
p4 &    &    &    &    \\
\end{array}
\]

Some terminology:
Multi-dimensional Feature Merger (MDM Features)

Introduce features that capture the distribution of this matrix

\[ \begin{array}{ccccc}
 & q1 & q2 & q3 & q4 & q5 \\
p1 &     &     &     &     &     \\
p2 &     &     &     &     &     \\
p3 &     &     &     &     &     \\
p4 &     &     &     &     &     \\
\end{array} \]

M =

Some terminology:

1. \( S = \text{sum}(M) \) = vector of column sums
Multi-dimensional Feature Merger (MDM Features)

Introduce features that capture the distribution of this matrix

\[
M = \begin{array}{ccccc}
q1 & q2 & q3 & q4 & q5 \\
p1 \\
p2 \\
p3 \\
p4 \\
\end{array}
\]

Some terminology:

1. \( S = \text{sum}(M) = \text{vector of column sums} \)

2. \( M' = \text{transpose of matrix } M \)
Multi-dimensional Feature Merger (MDM Features)

Some terminology:

1. $S = \text{sum}(M) = \text{vector of column sums}$

2. $M' = \text{transpose of matrix } M$

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<tr>
<th></th>
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Multi-dimensional Feature Merger (MDM Features)

Some terminology:

1. $S = \text{sum}(M) =$ vector of column sums

2. $M' =$ transpose of matrix $M$

$$f : M \rightarrow \mathbb{R}^N$$
Multi-dimensional Feature Merger (MDM Features)

Some terminology:

1. \( S = \text{sum}(M) = \text{vector of column sums} \)

2. \( M' = \text{transpose of matrix } M \)

\[
f : M \rightarrow \mathbb{R}^N
\]

\[
f(M) = \langle g(M), g(M') \rangle
\]
Multi-dimensional Feature Merger (MDM Features)

Some terminology:

1. $S = \text{sum}(M) = \text{vector of column sums}$

2. $M' = \text{transpose of matrix } M$

$$f : M \rightarrow \mathbb{R}^N$$

$$f(M) = \langle g(M), g(M') \rangle$$

$$g : M \rightarrow \mathbb{R}^{N/2}$$
Multi-dimensional Feature Merger (MDM Features)

Some terminology:

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2. \( M' = \) transpose of matrix \( M \)

\[
f : M \rightarrow \mathbb{R}^N
\]

\[
f(M) = < g(M), g(M') >
\]

\[
g : M \rightarrow \mathbb{R}^{\frac{N}{2}}
\]

\[
g(M) = < \text{sum}(S), \text{avg}(S), \text{std}(S), \text{max}(S), \text{min}(S), \text{dim}(S), \text{non-zero}(S) >
\]
Performance of new features
Performance of new features

Metrics:
Performance of new features

**Metrics:**

1. Correlation with the gold class in the training data
Performance of new features

**Metrics:**

1. Correlation with the gold class in the training data

2. Component level analysis
Performance of new features

**Metrics:**

1. Correlation with the gold class in the training data

2. Component level analysis
   -- Baseline = some basic features + passage scoring feature
Performance of new features

**Metrics:**

1. Correlation with the gold class in the training data

2. Component level analysis
   - Baseline = some basic features + passage scoring feature
   - New performance = some basic features + passage scoring feature + MDM features for that passage scoring feature
Performance of new features

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3. End-to-end analysis
Performance of new features

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**Data:**
Performance of new features

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**Data:**

1. Jeopardy!
Performance of new features

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3. End-to-end analysis

**Data:**

1. Jeopardy!

2. Doctor’s Dilemma (Medical domain)
Performance of new features

**Metrics:**

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2. Component level analysis
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3. End-to-end analysis

**Data:**

1. Jeopardy!

2. Doctor’s Dilemma (Medical domain)

Eg: CARDIOLOGY: Murmur associated with this condition is harsh, systolic, diamond-shaped, and increases in intensity with Valsalva
Performance of new features

**Metrics:**

1. Correlation with the gold class in the training data

2. Component level analysis
   -- Baseline = some basic features + passage scoring feature
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3. End-to-end analysis

**Data:**

1. Jeopardy!

2. Doctor’s Dilemma (Medical domain)

Eg: CARDIOLOGY: Murmur associated with this condition is harsh, systolic, diamond-shaped, and increases in intensity with Valsalva

(A: Hypertrophic cardiomyopathy)
**Distribution of data-sets**

<table>
<thead>
<tr>
<th>Training</th>
<th>#Q</th>
<th>#Pos</th>
<th>#Neg</th>
<th>#Avg cand per Q</th>
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<tbody>
<tr>
<td>Jeopardy!</td>
<td>11,520</td>
<td>12,173</td>
<td>2,555,396</td>
<td>222.87</td>
</tr>
<tr>
<td>DD</td>
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Test Data:

1. Jeopardy! 3,505
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### Test Data:

1. Jeopardy! 3,505
2. DD 905
Correlation with the gold class (Jeopardy!)
Correlation with the gold class (DD)
Component Level Analysis (DD)
## Component Level Analysis (DD)

<table>
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<tr>
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<th>Prec@70%</th>
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Baseline

Prec@70%

37.2
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Why the heck is it called Multi-dimensional?

Passage scorer 1
Why the heck is it called Multi-dimensional?

Passage scorer 1

Passage scorer 2
Why the heck is it called Multi-dimensional?

Q

CA_1 ... CA_n

p_1 p_2 ... p_{m_1} p_1 p_2 ... p_{m_n}

Passage scorer 1

Passage scorer 2

Passage scorer 3
Why the heck is it called Multi-dimensional?

Future Work!
Conclusion

1. Introduced new features for QA (not specific to Watson)
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Thanks and Questions?