Multi-Passage Machine Reading Comprehension with Cross-Passage Answer Verification

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Outline

- Background / Motivation
 - Machine Reading Comprehension (MRC)
 - Why Multi-Passage MRC is Challenging?
- **☐** Model Architecture
 - Answer Boundary Prediction
 - Answer Content Modeling
 - Cross-Passage Answer Verification
 - Joint Training and Prediction
- Experiments
 - Results on MS-MARCO and DuReader
 - Ablation Study
 - Quantitative Analysis
- Conclusion



Passage: ... Tesla later approached Morgan to ask for more funds to build a more powerful transmitter. When asked where all the money had gone, Tesla responded by saying that he was affected by the Panic of 1901, which he (Morgan) had caused Morgan was shocked by the reminder of his part in the stock market ...

Question: On what did Tesla blame for the loss of the initial money?

[from SQuAD v1.1^[1]]

Passage: ... Tesla later approached Morgan to ask for more funds to build a more powerful transmitter. When asked where all the money had gone, Tesla responded by saying that he was affected by the Panic of 1901, which he (Morgan) had caused Morgan was shocked by the reminder of his part in the stock market ...

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Single-passage MRC

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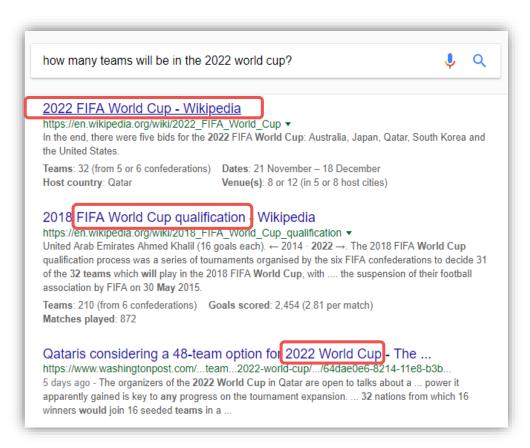
Single-passage MRC

- **Different types:** cloze test, entity extraction, span extraction, multiple-choice ...
- Various models: Match-LSTM^[2], BiDAF^[3], R-Net^[4], QANet^[5] ...
- Very impressive performance

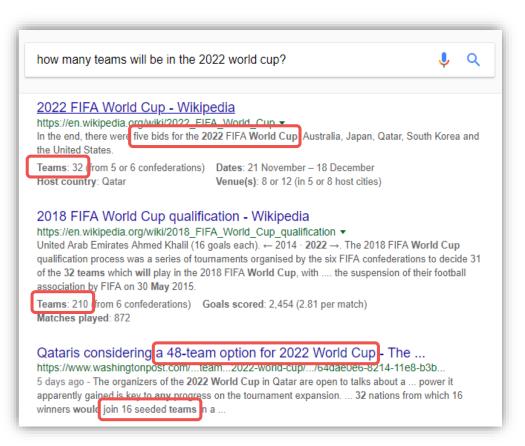
Reading the Web to Answer Questions?

how many teams will be in the 2022 world cup? 2022 FIFA World Cup - Wikipedia https://en.wikipedia.org/wiki/2022 FIFA World Cup ▼ In the end, there were five bids for the 2022 FIFA World Cup: Australia, Japan, Qatar, South Korea and the United States. Teams: 32 (from 5 or 6 confederations) Dates: 21 November – 18 December Host country: Qatar Venue(s): 8 or 12 (in 5 or 8 host cities) 2018 FIFA World Cup qualification - Wikipedia https://en.wikipedia.org/wiki/2018 FIFA World Cup qualification ▼ United Arab Emirates Ahmed Khalil (16 goals each). ← 2014 · 2022 →. The 2018 FIFA World Cup qualification process was a series of tournaments organised by the six FIFA confederations to decide 31 of the 32 teams which will play in the 2018 FIFA World Cup, with the suspension of their football association by FIFA on 30 May 2015. Teams: 210 (from 6 confederations) Goals scored: 2,454 (2.81 per match) Matches played: 872 Qataris considering a 48-team option for 2022 World Cup - The ... https://www.washingtonpost.com/...team...2022-world-cup/.../64dae0e6-8214-11e8-b3b... 5 days ago - The organizers of the 2022 World Cup in Qatar are open to talks about a ... power it apparently gained is key to any progress on the tournament expansion. ... 32 nations from which 16 winners would join 16 seeded teams in a ...

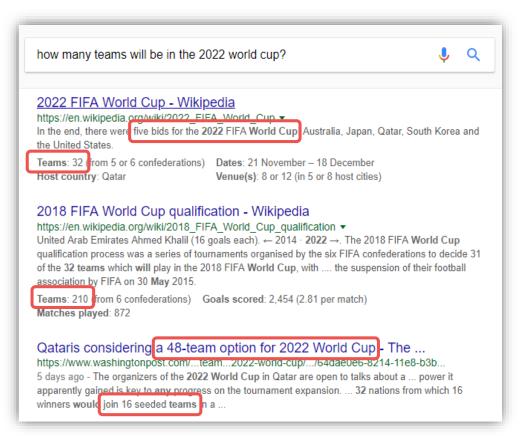
- Search engine is employed.
- Multiple passages are retrieved.



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- All of them seem relevant.



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Key challenge:

Much more misleading candidates

An Example from MS-MARCO^[6] Dataset

Question: What is the difference between a mixed and pure culture?

Passages:

- 1) A culture is a society's total way of living and a society is a group that live in a defined territory and participate in common culture. While the answer given is . . .
- 2) ... The mixed economy is a balance between socialism and capitalism. As a result, some institutions are owned and maintained by . . .
- 3) A pure culture is one in which only one kind of microbial species is found whereas in mixed culture two or more microbial species formed colonies. Culture on the . . .
- 4) ... A pure culture comprises a single species or strains. A mixed culture is taken from a source and may contain multiple strains or species. A contaminated . . .
- 5) ... It will be at that time when we can truly obtain a pure culture. A pure culture is a culture consisting of only one strain. You can obtain a pure culture by picking . . .
- 6) A pure culture is one in which only one kind of microbial species is found whereas in mixed culture two or more microbial species formed colonies. A pure culture . . .

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Passages:

■ Correct

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Passages:

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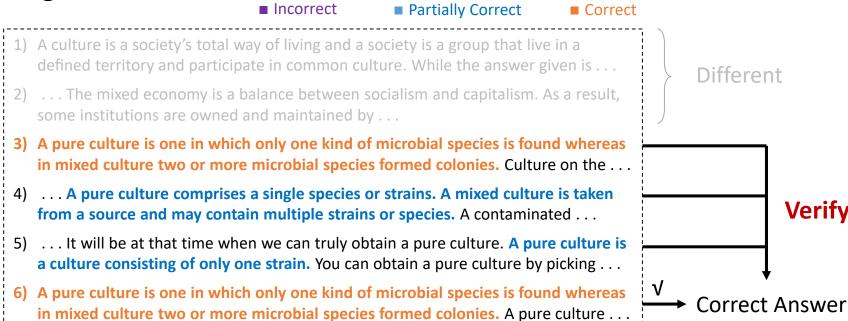
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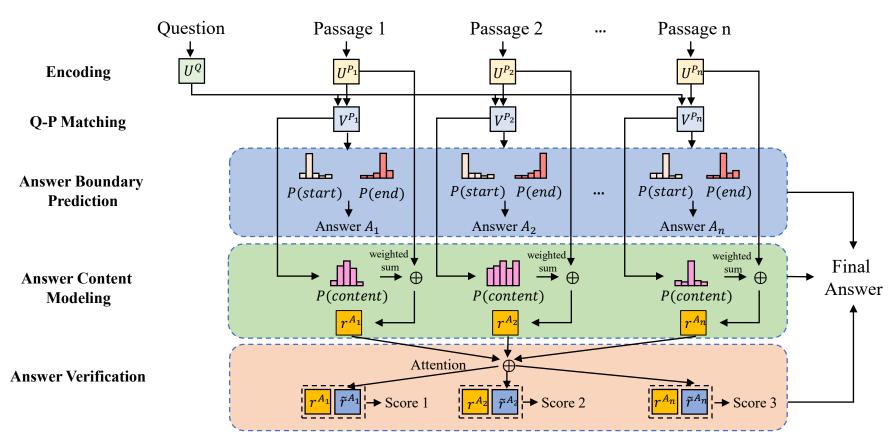
Different

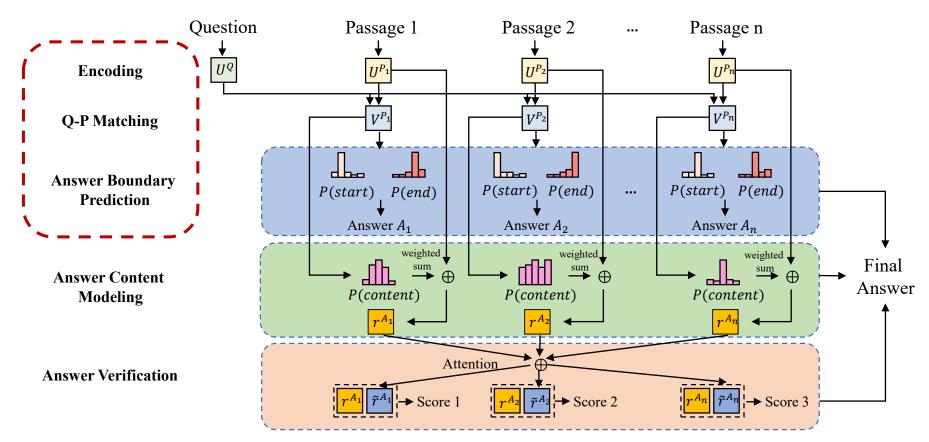
Similar or same

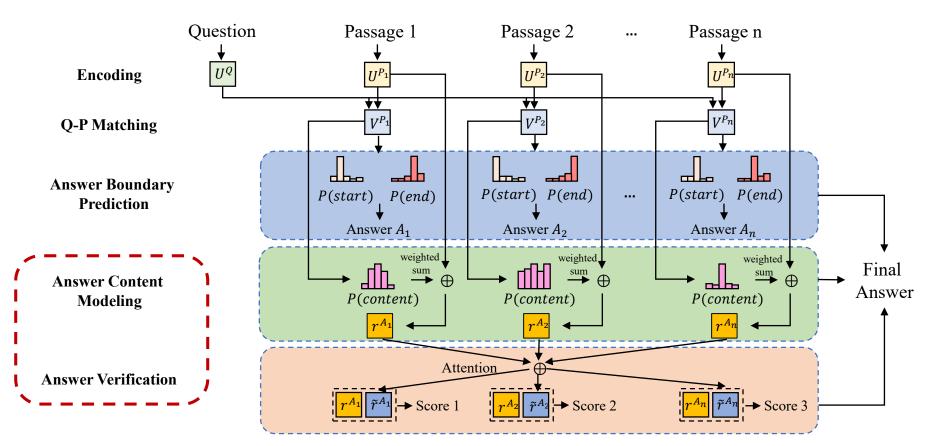
Question: What is the difference between a mixed and pure culture?

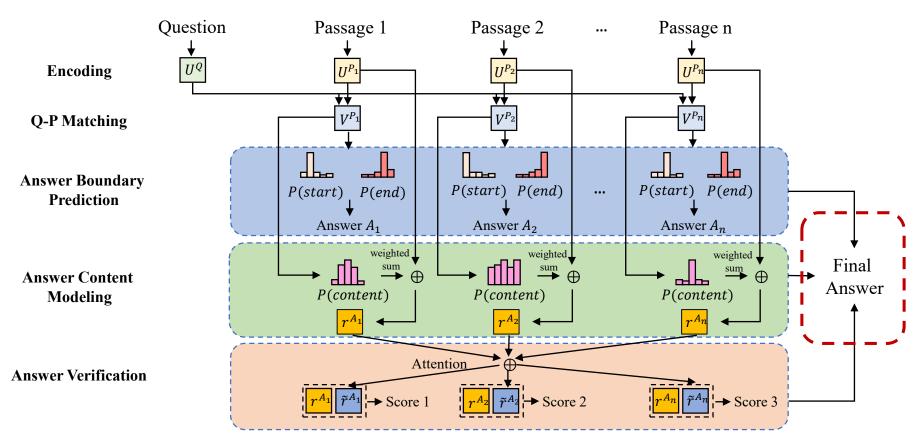
Passages:











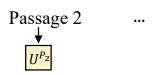
Input

Question Passage 1 Passage 2 ... Passage n

Question and Passage Encoding





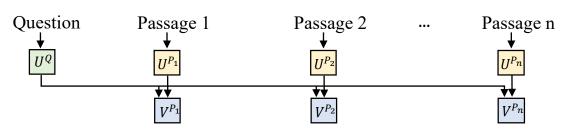




• Encoding with Bi-LSTM:

$$\begin{aligned} \mathbf{u}_t^Q &= \text{BiLSTM}_Q(\mathbf{u}_{t-1}^Q, [\mathbf{e}_t^Q, \mathbf{c}_t^Q]) \\ \mathbf{u}_t^{P_i} &= \text{BiLSTM}_P(\mathbf{u}_{t-1}^{P_i}, [\mathbf{e}_t^{P_i}, \mathbf{c}_t^{P_i}]) \end{aligned}$$

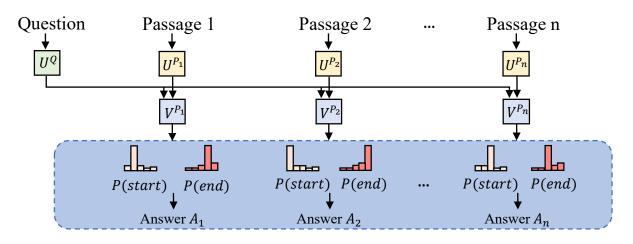
Question-Passage Matching



- Bi-directional Attention Flow (Seo et al., 2016)
- Dot attention matrix:

$$\mathbf{S}_{t,k} = \mathbf{u}_t^{Q\intercal} \cdot \mathbf{u}_k^{P_i}$$

Answer Boundary Prediction



• Start and end pointer:

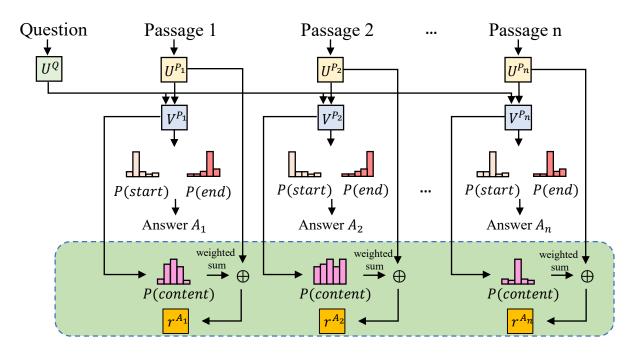
$$g_k^t = \mathbf{w}_1^{a\intercal} \tanh(\mathbf{W}_2^a[\mathbf{v}_k^P, \mathbf{h}_{t-1}^a])$$

$$\alpha_k^t = \exp(g_k^t) / \sum_{j=1}^{|\mathbf{P}|} \exp(g_j^t)$$

$$\mathbf{c}_t = \sum_{k=1}^{|\mathbf{P}|} \alpha_k^t \mathbf{v}_k^P$$

$$\mathbf{h}_t^a = \text{LSTM}(\mathbf{h}_{t-1}^a, \mathbf{c}_t)$$

Answer Content Modeling



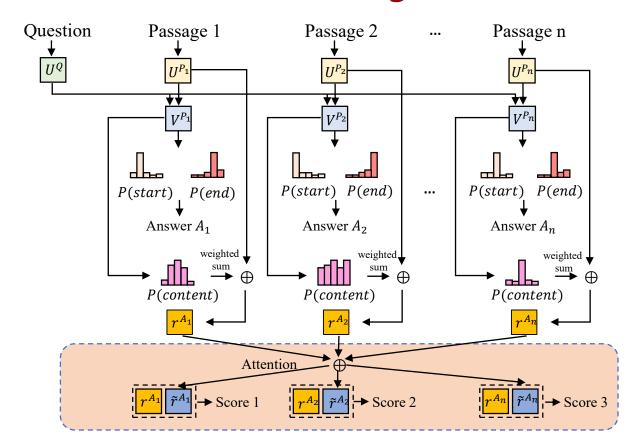
Content score for each

$$p_k^c = \operatorname{sigmoid}(\mathbf{w}_1^{c\intercal} \operatorname{ReLU}(\mathbf{W}_2^c \mathbf{v}_k^{P_i}))$$

• Representation for A^i :

$$\mathbf{r}^{A_i} = rac{1}{|\mathbf{P}_i|} \sum
olimits_{k=1}^{|\mathbf{P}_i|} p_k^c[\mathbf{e}_k^{P_i}, \mathbf{c}_k^{P_i}]$$

Cross-Passage Answer Verification



Ans-to-ans Attention:

$$s_{i,j} = \begin{cases} 0, & \text{if } i = j, \\ \mathbf{r}^{A_i \mathsf{T}} \cdot \mathbf{r}^{A_j}, & \text{otherwise} \end{cases}$$

$$\alpha_{i,j} = \exp(s_{i,j}) / \sum_{k=1}^{n} \exp(s_{i,k})$$

$$\tilde{\mathbf{r}}^{A_i} = \sum_{j=1}^{n} \alpha_{i,j} \mathbf{r}^{A_j}$$

Verification score:

$$egin{aligned} g_i^v &= \mathbf{w}^{v\intercal}[\mathbf{r}^{A_i}, \mathbf{ ilde{r}}^{A_i}, \mathbf{r}^{A_i} \odot \mathbf{ ilde{r}}^{A_i}] \ p_i^v &= \exp(g_i^v) / \sum
olimits_{j=1}^n \exp(g_j^v) \end{aligned}$$

Joint Training and Prediction

Three objectives:

- Finding the boundary of the answer
- Predicting whether each word should be included in the answer
- Selecting the best answer from all the candidates

Training Loss:

$$\mathcal{L}_{joint} = \mathcal{L}_{boundary} + \beta_1 \mathcal{L}_{content} + \beta_2 \mathcal{L}_{verify}$$

Prediction:

$$Score = S_{boundary} \times S_{content} \times S_{verify}$$

Experiments Setup

Datasets: MS-MARCO^[6] and DuReader^[7]:

	Language	Search Engine	Size	Questions with Multi Annotated Answers	Questions with Multi Answer Spans
MS-MARCO	English	Bing	100K+	9.93%	40.00%
DuReader	Chinese	Baidu	200K+	67.28%	56.38%

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• Hyper-parameters (tuned on the dev set):

Word Embedding	Character Embedding	Hidden Size	L2	Optimizer	Learning Rate	Batch Size	eta_1	eta_2
300-D Glove	30-D Random	150	3e-4	Adam	4e-4	32	0.5	0.5

Main Results

Model	ROUGE-L	BLEU-1
FastQA_Ext	33.67	33.93
Match-LSTM	37.33	40.72
ReasoNet	38.81	39.86
R-Net	42.89	42.22
S-Net	45.23	43.78
Our Model	46.15	44.47
S-Net (Ensemble)	46.65	44.78
Our Model (Ensemble)	46.66	45.41
Human	47	46

Tab 1. Performance on MS-MARCO test set

Model	ROUGE-L	BLEU-4	
Match-LSTM	39.0	31.8	
BiDAF	39.2	31.9	
PR+BiDAF	41.8	37.6	
Our Model	44.2	41.0	
Human	57.4	56.1	

Tab 2. Performance on DuReader test set

Ablation Study on MS-MARCO Dev Set

Model	ROUGE-L	Δ
Complete Model	45.65	-
- Answer Verification	44.38	-1.27
- Content Modeling	44.27	-1.38
- Joint Training	44.12	-1.53
-Yes/No Classification	41.87	-3.78
Boundary Baseline	38.95	-6.70

Question: What is the difference between a mixed and pure culture		Scores	
Answer Candidates:	Boundary	Content	Verification
[1] A culture is a society's total way of living and a society is a group	1.0×10^{-2}	$\boldsymbol{1.0\times10^{-1}}$	1.1×10^{-1}
[2] The mixed economy is a balance between socialism and capitalism.	1.0×10^{-4}	4.0×10^{-2}	3.2×10^{-2}
[3] A pure culture is one in which only one kind of microbial species is	5.5×10^{-3}	7.7×10^{-2}	1.2×10^{-1}
[4] A pure culture comprises a single species or strains. A mixed	2.7×10^{-3}	8.1×10^{-2}	1.3×10^{-1}
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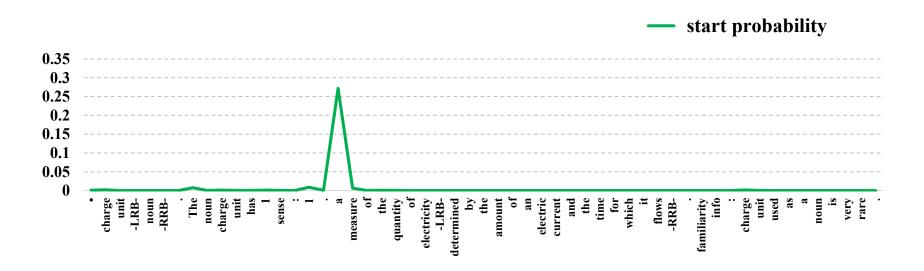
Boundary / content / verification scores are usually positively relevant

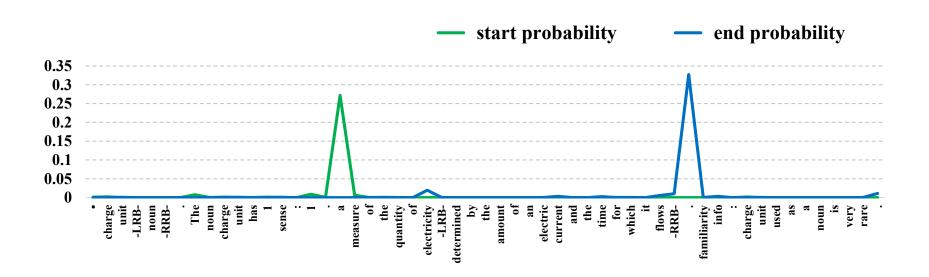
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		///	

More commonality --> larger verification score

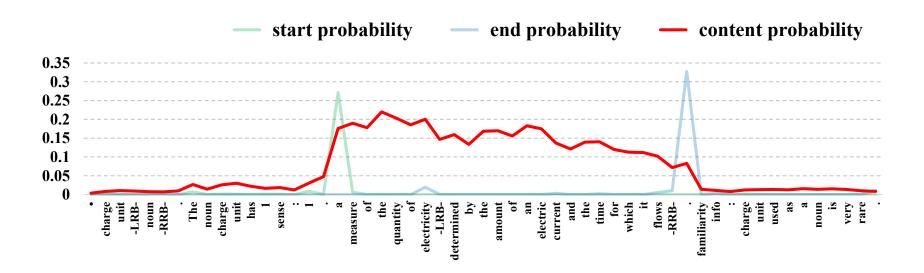
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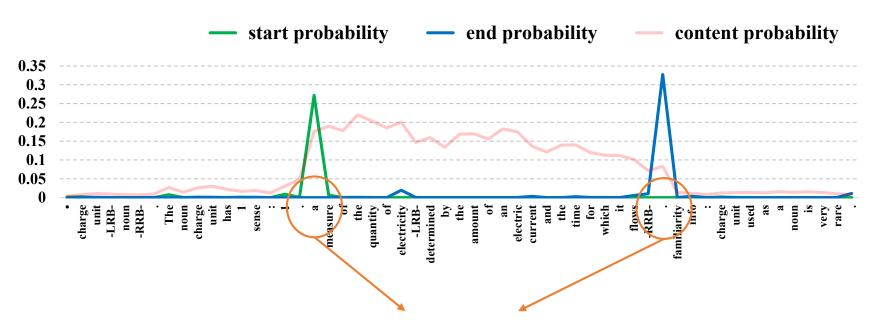
Correct answer is selected by considering verification!



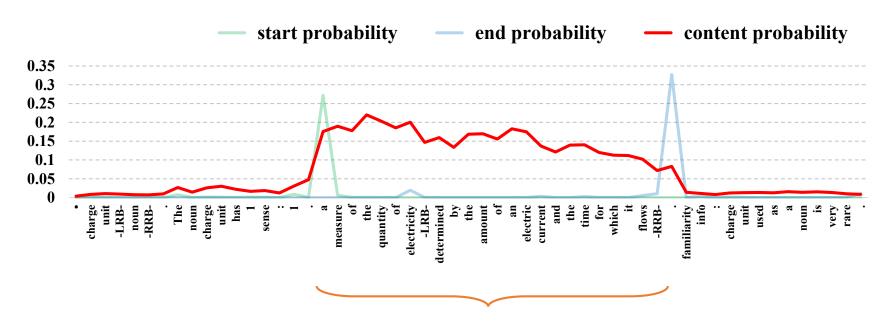


Visualization of the Probability Distribution





When the answer is long, boundary words carry little information.



Content words reflect the real semantics of this answer.

Conclusion

- Multi-passage MRC: much more misleading answers
- End-to-end model for multi-passage MRC:
 - Find the answer boundary
 - Model the answer content
 - Cross-passage answer verification
 - Joint training and prediction
- SOTA performance on two datasets created from real-world web data:
 - MS-MARCO (English)
 - DuReader (Chinese)

References

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Thank you!

Q & A

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