Which Shortcut Solution Do Question Answering Models Prefer to Learn?

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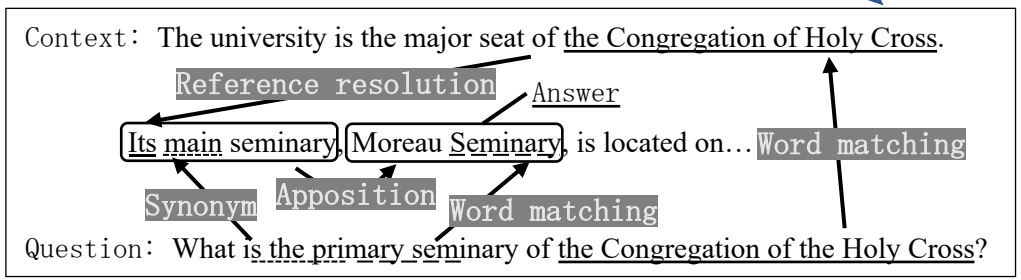
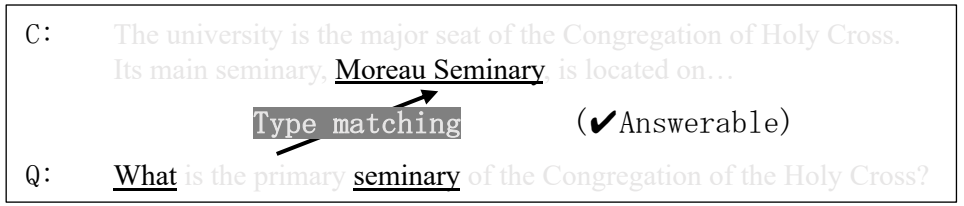
Background: Shortcut Learning of QA Models



Human-like intended solution

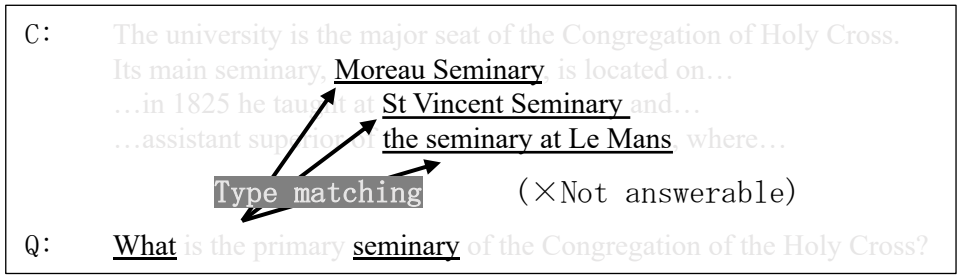
QA Model

Prefer to learn



Shortcut solution (Type matching)

✔Generalize



✖Do not generalize

An out-of-distribution example where a shortcut shortcut is not valid

Background: Shortcut Learning of QA Models

- In extractive and multiple-choice QA, existing studies found several types of shortcut solutions, which causes the lack of out-of-distribution generalization.

- Various methods (data augmentation, loss function, etc.) have been proposed to mitigate shortcut learning of QA models for each shortcut independently.

- **However, these mitigation methods have not fully taken the characteristics of shortcuts into account**.

Research Goal

- Our hypothesis:
  - studying **the learnability of shortcut solutions** (i.e., how easy it is to learn a shortcut) in QA datasets is **useful** to construct new training sets or to design data augmentation methods **to avoid learning shortcuts**.

- To verify our hypothesis,
  - we first compare the learnabilities of the shortcuts with behavioral (**RQ1**), qualitative (**RQ2**), and quantitative (**RQ3**) analyses.
  - Then, we study the requirements of data balancing to avoid learning shortcuts (**RQ4**) and discuss the connection between learnability and data balancing.

Examined Shortcut Solutions

- Extractive QA:
  - Answer-**Position** (Ko et al. 2020)
    - Finding answers from the first sentences
  - **Word** Matching (Sugawara et al. 2018)
    - Finding answers from the most similar sentences in contexts
  - **Type** Matching (Weissenborn et al. 2017)
    - Matching types of questions and answers

Examined Shortcut Solutions

- Multiple-choice QA:
  - Word-label Correlation (Top-1):
    - We identify the Top-1 word, which is the most highly correlated with the labels in terms of z-statistics (Gardner et al. 2021).

RACE		ReClor	
w	z^*	w	z^*
and	23.6	a	6.7
above	20.7	result	5.3
may	20.7	an	5.1

For the RACE dataset,

Top-1 shortcut = predicting that an option is correct if it contains “and”.

Examined Shortcut Solutions

- Multiple-choice QA:
  - Word-label Correlation (Top-1):
    - We identify the Top-1 word, which is the most highly correlated with the labels in terms of z-statistics (Gardner et al. 2021).
  - Lexical **Overlap**:
    - Choosing options that has the maximum lexical overlap with context+question.

For each shortcut solution k, we define a rule-based function to divide a dataset $\mathcal{D}$ into **shortcut examples** $\mathcal{D}_k$, where the shortcut is available, and **anti-shortcut examples** $\overline{\mathcal{D}_k}$, where it is not.

Research Questions

- RQ1: *When every shortcut is valid for answering every question in biased training sets, which shortcut do QA models prefer to learn?*
- RQ2: *Why are certain shortcuts learned in preference to other shortcuts from the biased training sets?*
- RQ3: *How quantitatively different is the learnability for each shortcut?*
- RQ4: *What proportion of anti-shortcut examples in a training set is required to avoid learning a shortcut? Is it related to the learnability of shortcuts?*

Research Questions

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RQ1: *When every shortcut is valid for answering every question in biased training sets, which shortcut do QA models prefer to learn?*

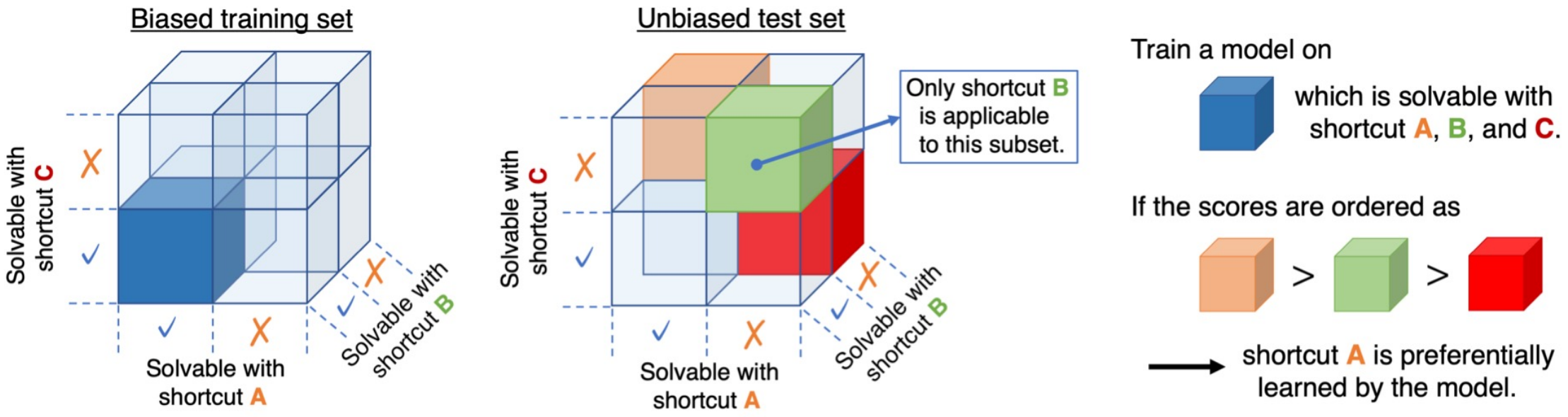
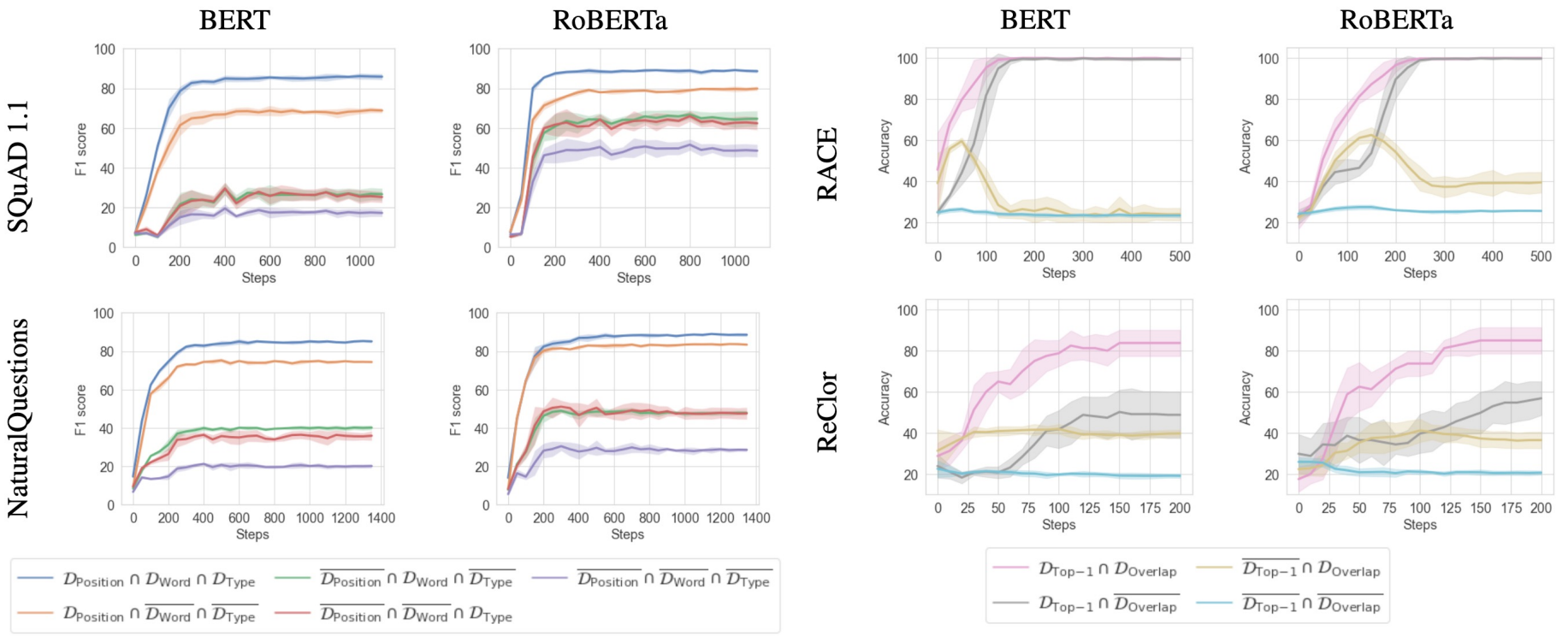


Illustration of the behavioral analysis to answer RQ1.

Results:

Extractive QA

Multiple-choice QA



- At the end of the training,
  - Extractive QA: **Position** > **Word** ≒ **Type**
  - Multiple-choice QA: **Top-1** > **Overlap**
- In the early stage of the training in multiple-choice QA, **Overlap** > **Top-1**, which may be due to the inductive bias of self attentions in transformers.

Research Questions

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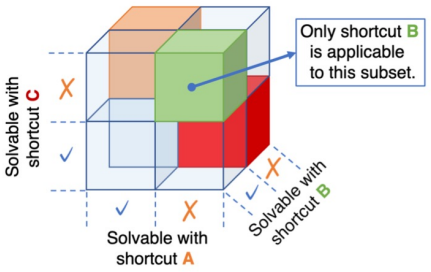
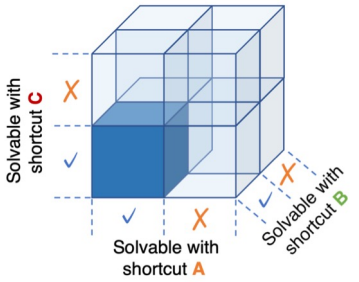
RQ2: *Why are certain shortcuts learned in preference to other shortcuts from the biased training sets?*

- (1) We train a model on a subset where only one shortcut is available and the others are not. We assume that the model learns the available shortcut, which is verified experimentally.
- (2) Then, we visualize the loss surface on the biased training set, which was used as the training set in RQ1. We repeat the same procedure for each shortcut.

(1) Train a model on one of the subsets:



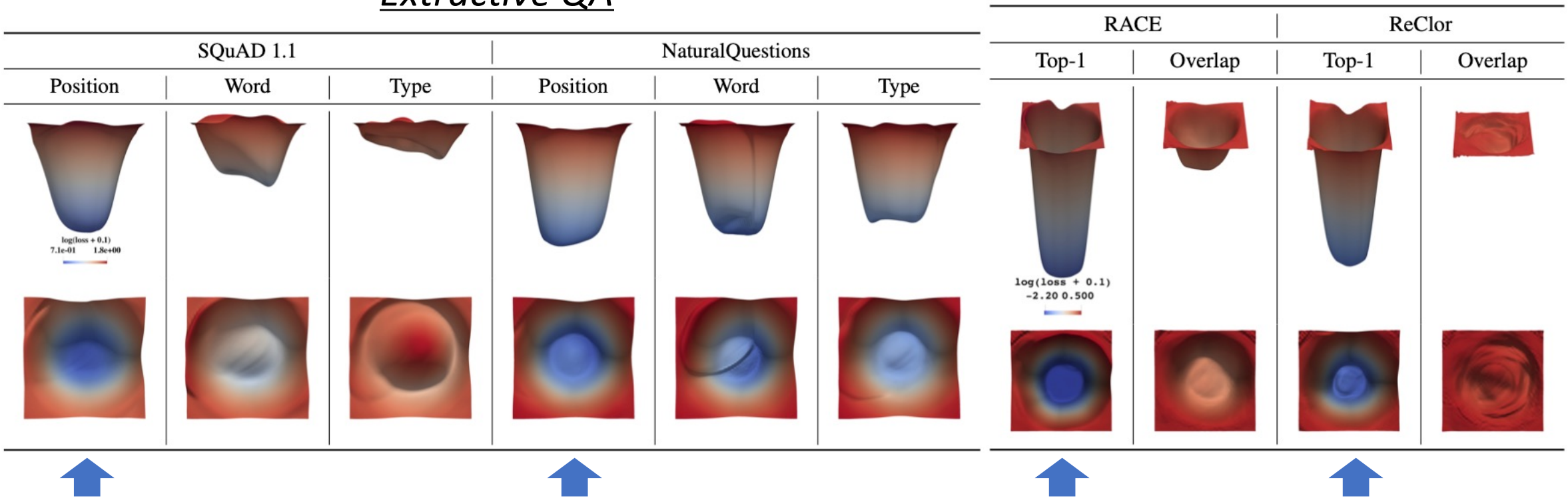
(2) Visualize the loss surface on the subset:



Results:

Extractive QA

Multiple-choice QA



- The preferred shortcuts (**Position** and **Top-1**) tend to lie in flatter and deeper loss surfaces in the parameter space.
- The orders of the flatness and depth of the loss surfaces are roughly correlated with the preferential order of learning shortcuts in RQ1.

Research Questions

- RQ1: *When every shortcut is valid for answering every question in biased training sets, which shortcut do QA models prefer to learn?*
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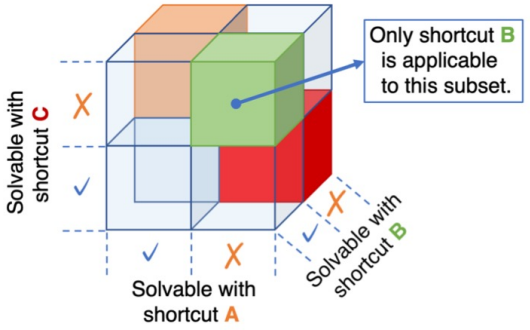
RQ3: *How quantitatively different is the learnability for each shortcut?*

- We propose **Rissanen Shortcut Analysis (RSA)** to quantitatively compare the learnabilities of shortcuts. RSA approximates the minimum description length (MDL) on a biased dataset where only one of the shortcuts is available. MDLs are approximated with the online code algorithm following Perez et al. (2021).
- RSA can measure how easy it is to learn the task when one shortcut is available and the others are not.

RSA approximates the MDL of one of the subsets:



Results:

- The availability of the preferred shortcuts (**Position** and **Top-1**) tends to make the task easier to learn.
- The orders of MDLs are roughly aligned with the previous experiments.

	Shortcut	BERT	RoBERTa
Extractive QA	*SQuAD 1.1*		
	Position	4.65 ± 0.12	4.22 ± 0.23
	Word	4.94 ± 0.24	3.73 ± 0.17
	Type	5.75 ± 0.30	4.52 ± 0.06
	NaturalQuestions		
	Position	6.28 ± 0.15	5.37 ± 0.24
	Word	12.24 ± 0.14	9.08 ± 0.20
	Type	11.76 ± 0.55	8.83 ± 0.38
Multiple-choice QA	*RACE*		
	Top-1	0.52 ± 0.34	0.41 ± 0.29
	Overlap	4.16 ± 0.55	3.55 ± 0.10
	ReClor		
	Top-1	0.33 ± 0.07	0.28 ± 0.03
	Overlap	0.55 ± 0.03	0.52 ± 0.02

Minimum description lengths (kbits) on biased datasets where only one shortcut is available.

Research Questions

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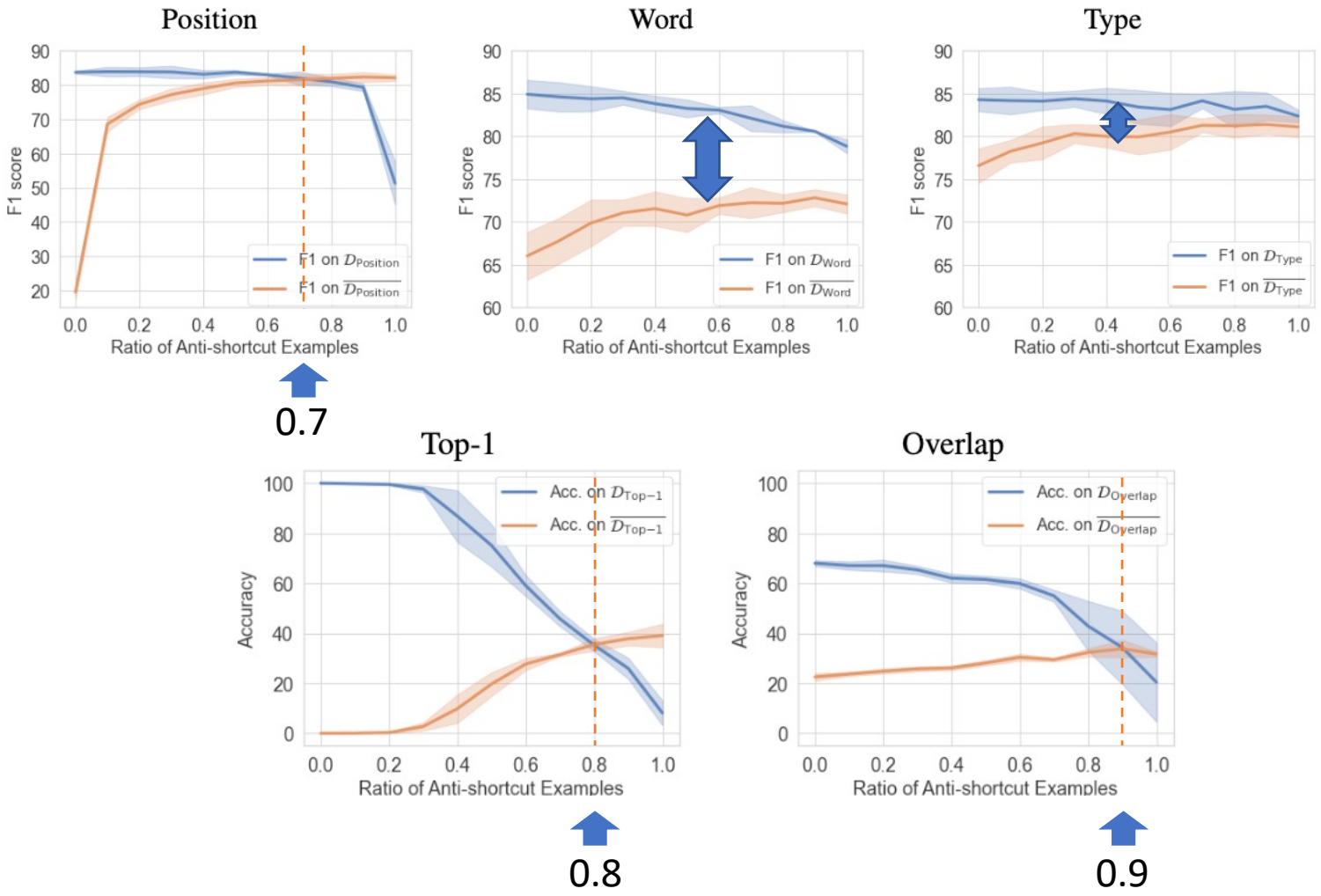
- RQ3: *How quantitatively different is the learnability for each shortcut?*
- **RQ4: *What proportion of anti-shortcut examples in a training set is required to avoid learning a shortcut? Is it related to the learnability of shortcuts?***

RQ4: *What proportion of anti-shortcut examples in a training set is required to avoid learning a shortcut? Is it related to the learnability of shortcuts?*

- We changed the proportion of anti-shortcut examples from 0 to 1 with the sizes of the training sets fixed.

- The scores on shortcut examples $\mathcal{D}_k$ and anti-shortcut examples $\overline{\mathcal{D}_k}$ are reported.

Results:



- The scores on $\mathcal{D}_k$ and $\overline{\mathcal{D}_k}$ are comparable when the proportion of anti-shortcut examples in training sets is 0.7, 0.8, and 0.9 for **Position**, **Top-1**, and **Overlap** shortcuts, resp.
- Balancing $\mathcal{D}_k$ and $\overline{\mathcal{D}_k}$ in a training set could not mitigate the accuracy gap for **Word** and **Type** shortcuts completely.
- The requirements of the proportion of anti-shortcut examples are correlated with the learnabilies of the shortcuts studied in RQ1/2/3.

Conclusion & Discussion

- We experimentally showed that the learnabilities of shortcut solutions and the requirements of data balancing are roughly correlated.
- Our study suggests that **the learnability of shortcuts can be utilized to design new approaches for mitigating shortcut learning**.
  - For example, to avoid learning less learnable shortcuts, modifying loss functions or model architectures may be needed in addition to data balancing.
  - Similarly, to avoid learning more learnable shortcuts, only data balancing may be sufficient.

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Thank you!

Codes

arXiv

If you have any questions, please contact me via

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