Improving the Robustness of QA Models to Challenge Sets with Variational Question-Answer Pair Generation

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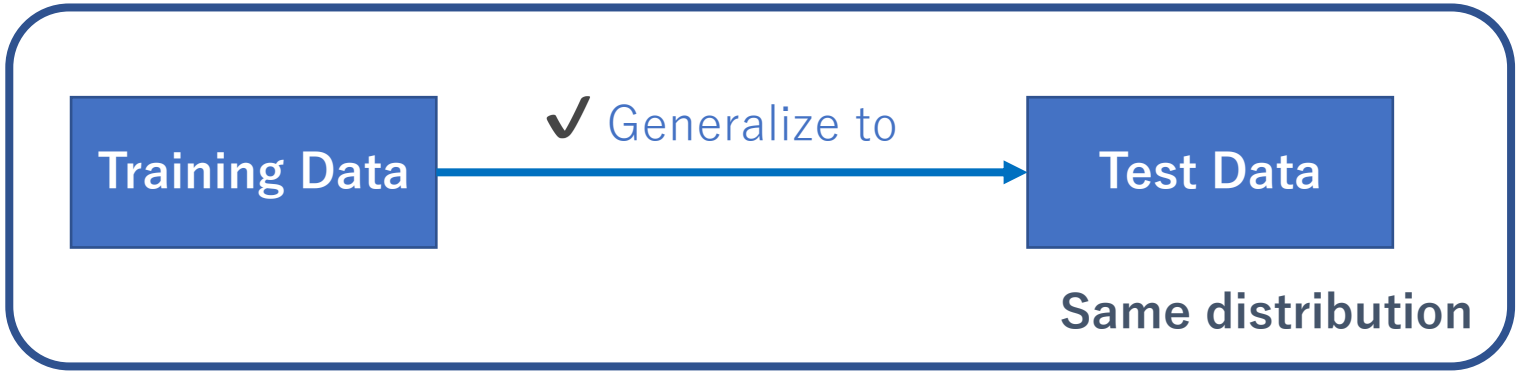
Question Answering (QA)

Context:
Beyoncé Giselle Knowles-Carter (born September 4, 1981) is an American singer, songwriter, record producer and actress. Born and raised in Houston, Texas, she performed in various singing and dancing competitions as a child, and rose to fame in the late 1990s as lead singer of R&B girl-group Destiny's Child. Managed by her father, Mathew Knowles, the group became one of the world's best-selling girl groups of all time. Their hiatus saw the release of Beyoncć's debut album, Dangerously in Love (2003), which established her as a solo artist worldwide, earned five Grammy Awards and featured the Billboard Hot 100 number-one singles "Crazy in Love" and "Baby Boy".
Question-answer pair:
What album made her a worldwide known artist? — Dangerously in Love What was the name of Beyoncé's first solo album? — Dangerously in Love

SQuAD dataset (Rajpurkar et al., 2016)

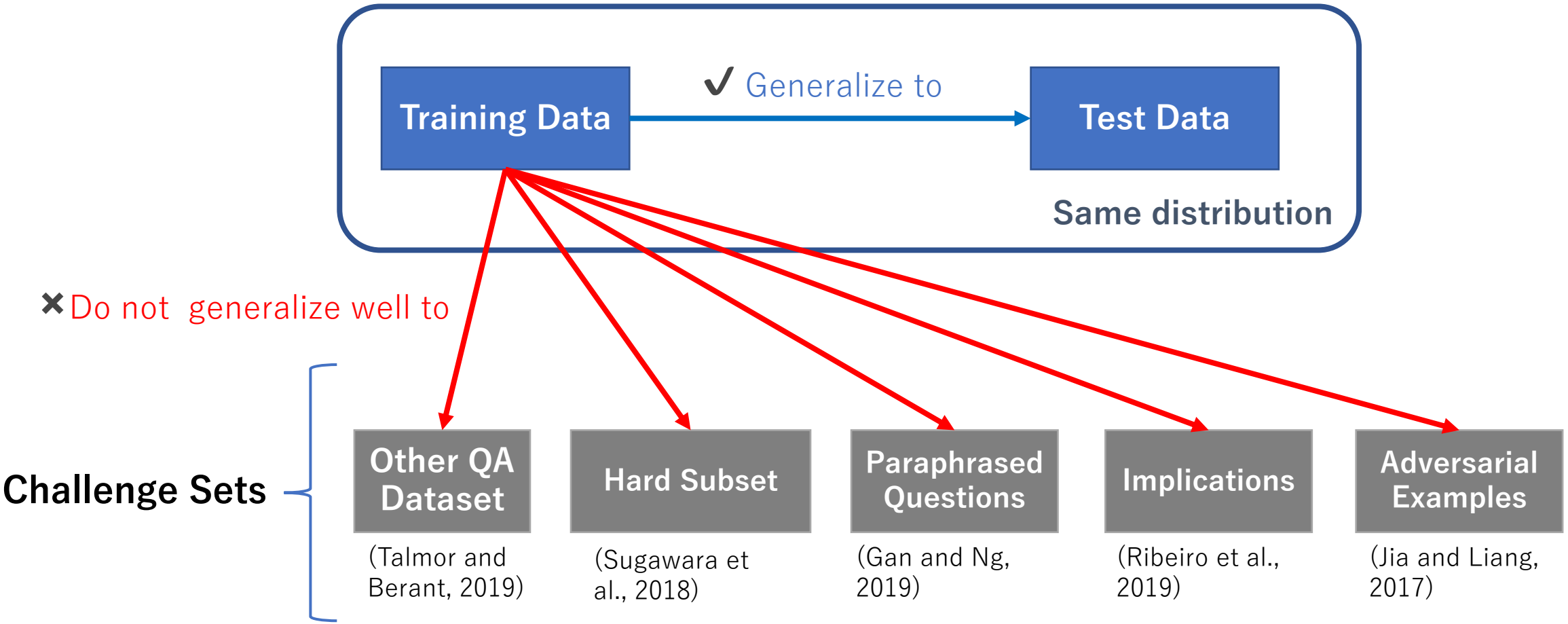
✔A central NLU task requiring broad NLP techniques

Lack of QA model robustness



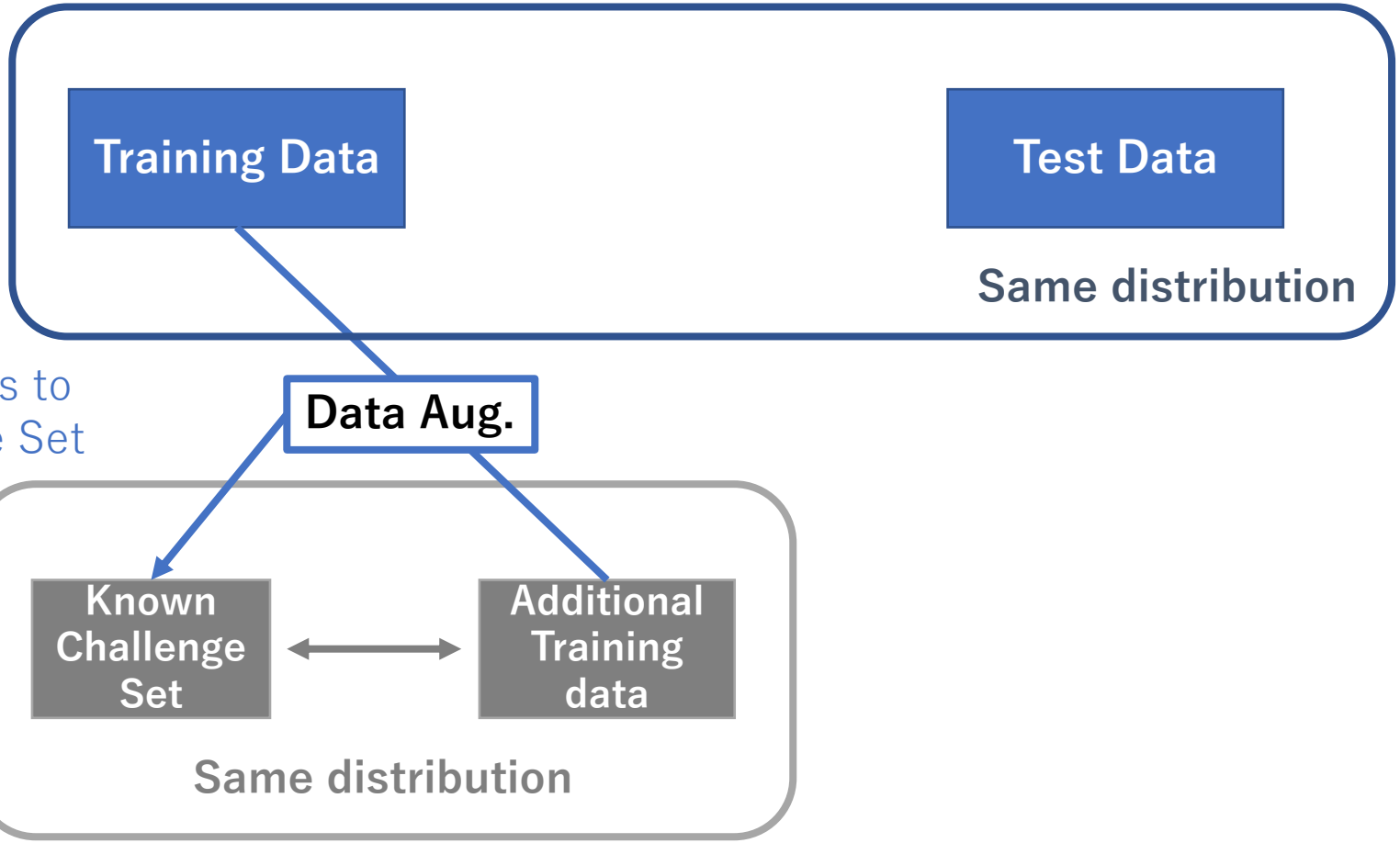
Introduction

Lack of QA model robustness



Adding Examples Similar to a Challenge Set

Existing Approach



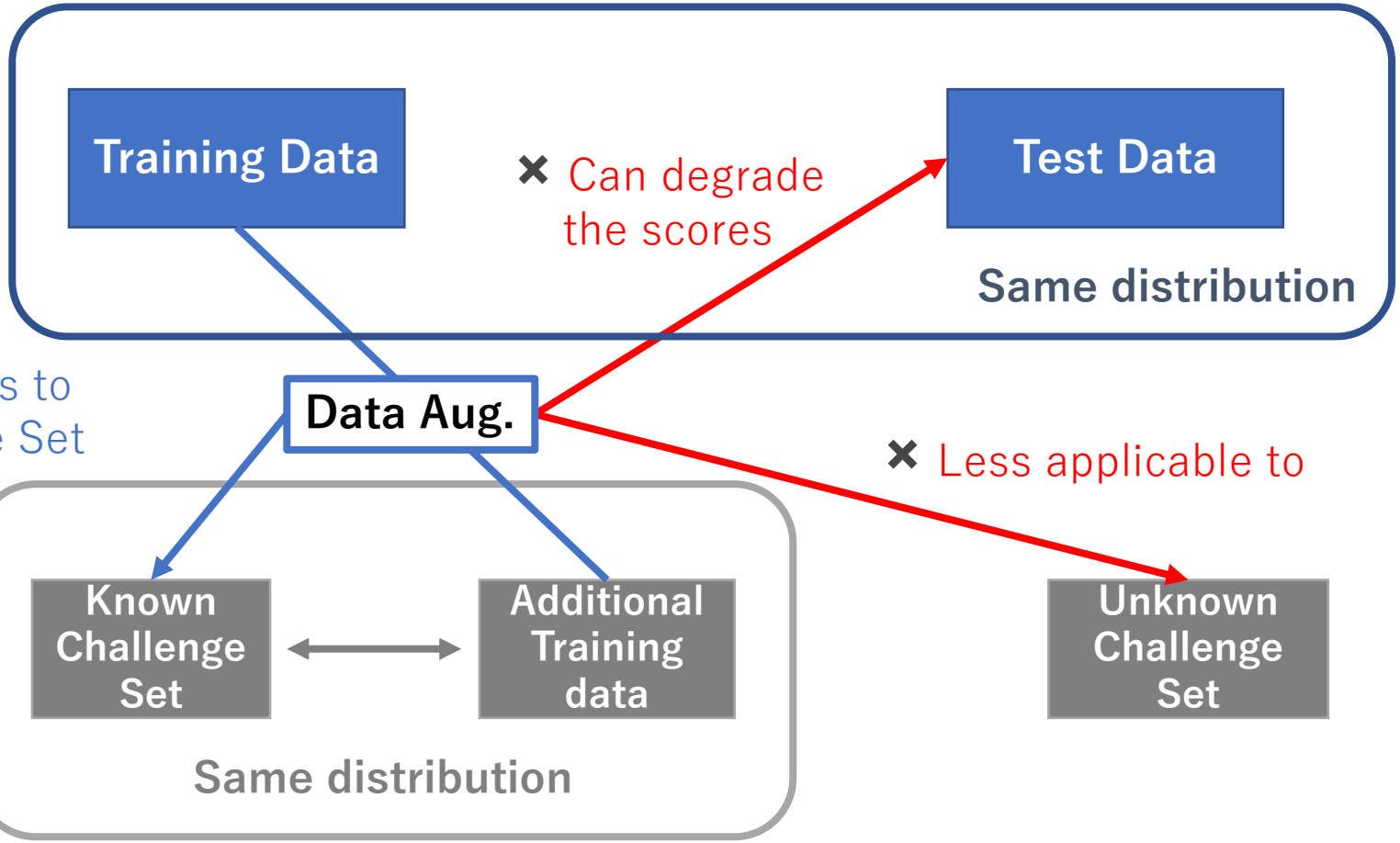
✓Improve Robustness to a Known Challenge Set

(Gan and Ng, 2019)
(Ribeiro et al., 2019)
(Ravichander et al., 2021)

Introduction

Adding Examples Similar to a Challenge Set

Existing Approach



✓Improve Robustness to a Known Challenge Set

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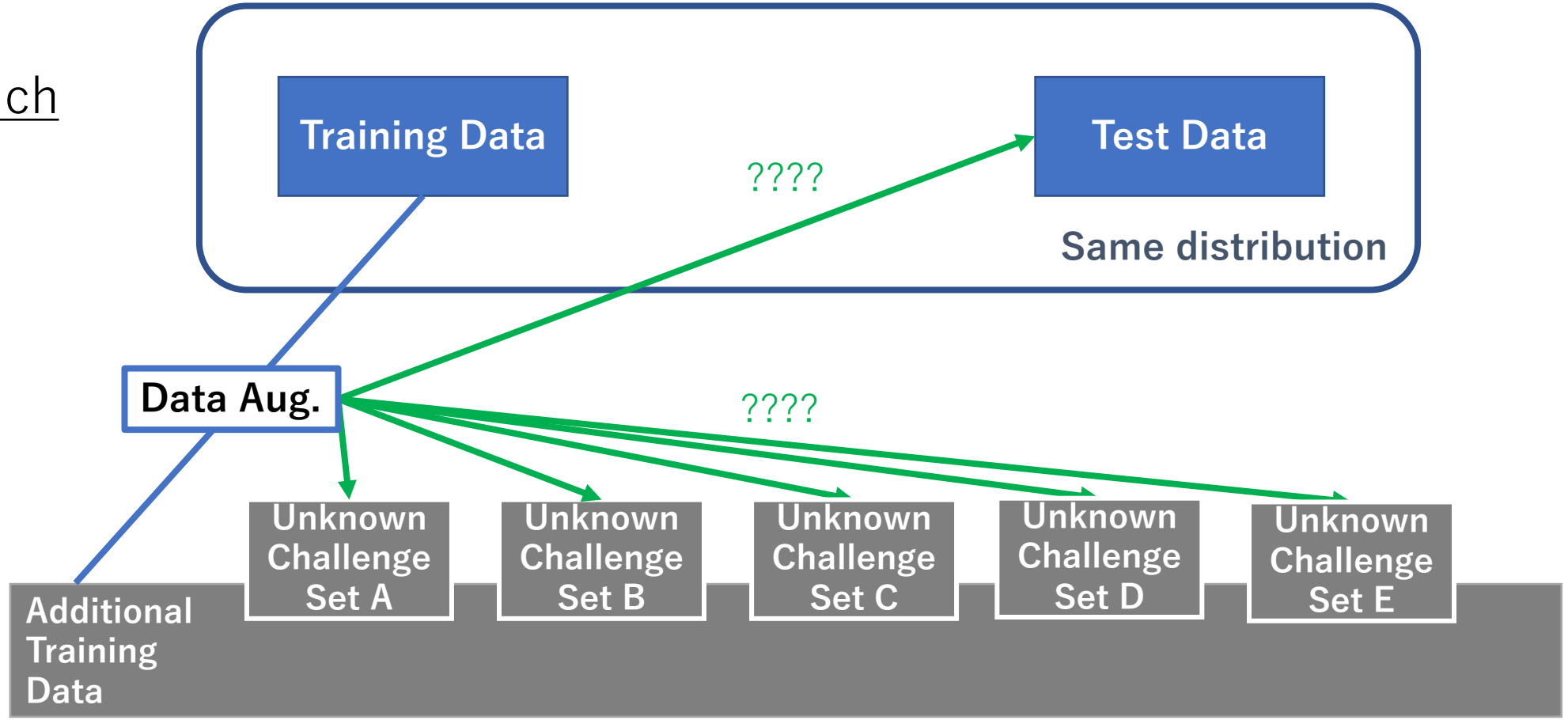
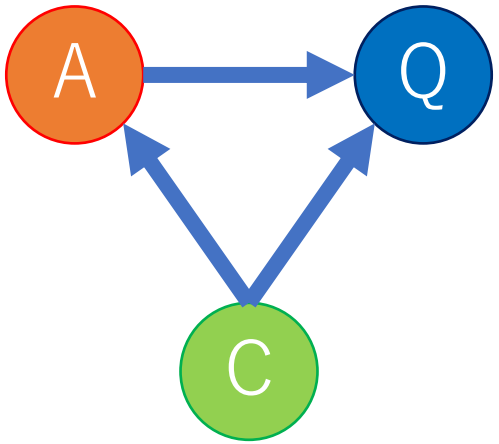
Improving the diversity of training data

Our Approach



QA Pair Generation for Question Answering

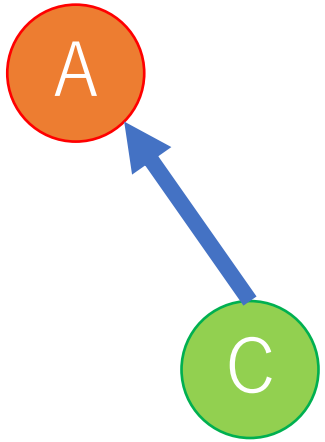
QA Pair Generation



(Du and Cardie, 2018)
(Lee et al., 2020)

=

Answer Extraction



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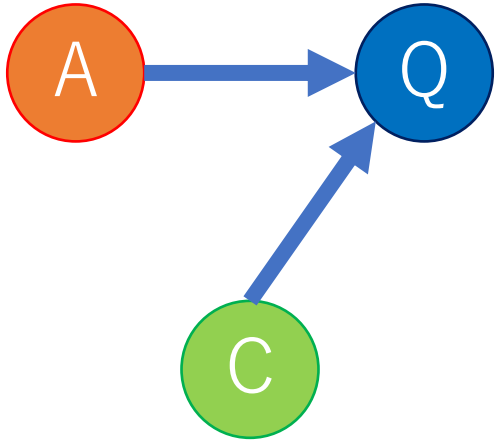
Question Generation



(Zhang and Bansal, 2019)

Notation

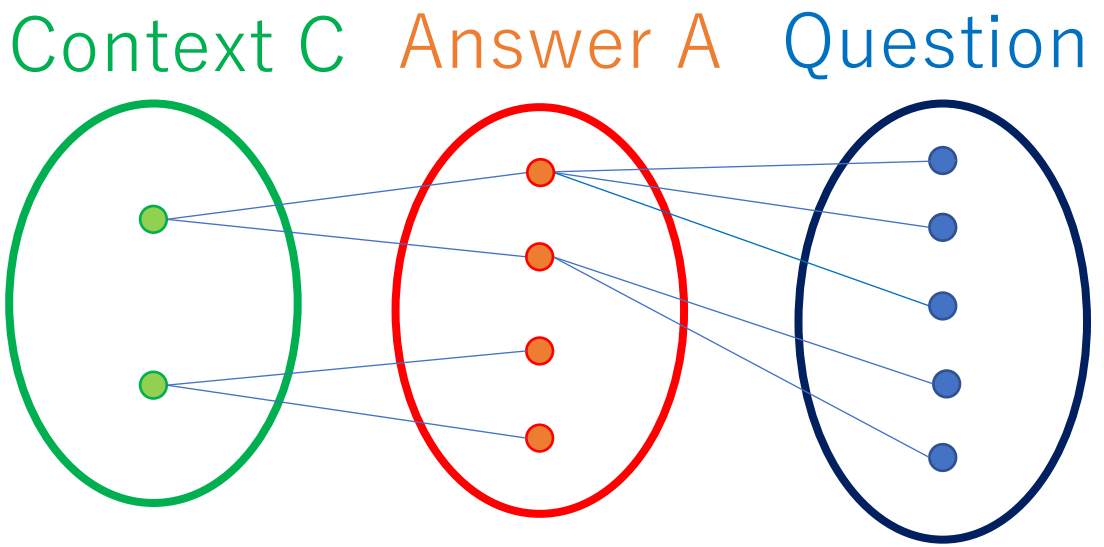
- Context: C
- Question: Q
- Answer: A

Two Levels of Diversity in QA Pairs

Context:
Beyoncé Giselle Knowles-Carter (born September 4, 1981) is an American singer, songwriter, record producer and actress. Born and raised in Houston, Texas, she performed in various singing and dancing competitions as a child, and rose to fame in the late 1990s as lead singer of R&B girl-group Destiny's Child. Managed by her father, Mathew Knowles, the group became one of the world's best-selling girl groups of all time. Their hiatus saw the release of Beyoncć's debut album, Dangerously in Love (2003), which established her as a solo artist worldwide, earned five Grammy Awards and featured the Billboard Hot 100 number-one singles "Crazy in Love" and "Baby Boy".
Question-answer pair:
What album made her a worldwide known artist? — Dangerously in Love
What was the name of Beyoncé's first solo album? — Dangerously in Love

SQuAD dataset (Rajpurkar et al., 2016)

Underlined phrases are used as answers in SQuAD

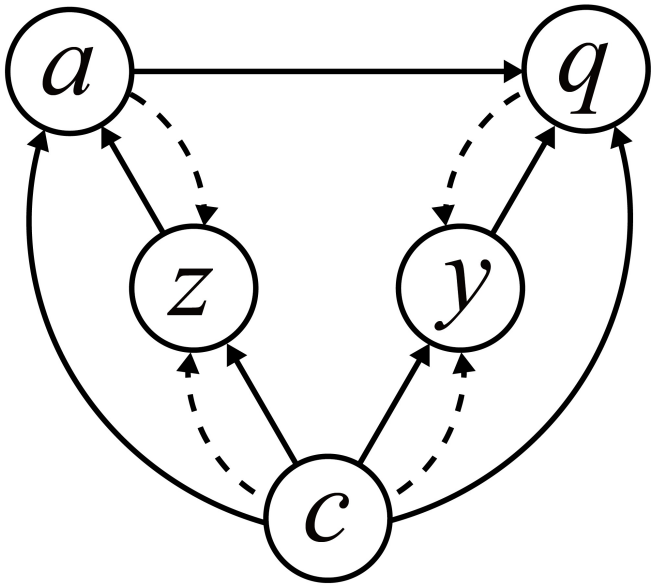


✓Multiple answer candidates can be extracted from a context

✓Multiple questions can be created from a context-answer pair

Approach

Variational Question-Answer Pari Generation



$$\log p_\theta(q, a|c) \geq \mathbb{E}_{q_\phi(z,y|q,a,c)}[\log p_\theta(q|y, a, c) + \log p_\theta(a|z, c)] - D_{\mathrm{KL}}(q_\phi(z|a, c)||p_\theta(z|c)) - D_{\mathrm{KL}}(q_\phi(y|q, c)||p_\theta(y|c)),$$

Generative model θ

Inference model ϕ

Mitigating the Posterior Collapse Issue

Posterior collapse:

a model generates almost the same output
from different latent variables (Bowman et al., 2016)

The modified objective function:

$$\begin{aligned}\mathcal{L} = \mathbb{E}_{q_\phi(z,y|q,a,c)}[&\log p_\theta(q|y,a,c) \\ &+ \log p_\theta(a|z,c)] \\ &- |D_{\mathrm{KL}}(q_\phi(z|a,c)||p_\theta(z|c)) - \mathrm{C_a}| \\ &- |D_{\mathrm{KL}}(q_\phi(y|q,c)||p_\theta(y|c)) - \mathrm{C_q}|, \quad (1)\end{aligned}$$

(Burgess et al., 2018)

Main Difference

- HarQG (Du and Cardie, 2018)
  - Supervised learning
- SemQG (Zhang and Bansal, 2019)
  - Using reinforcement learning to improve the quality of questions
- InfoHCVAE (Lee et al., 2020)
  - CVAE + Maximizing I(Q; A) to improve the consistency of QA pairs
- VQAG (ours)
  - CVAE + Explicitly controlling I(Q; Y|C) and I(A; Z|C) to further enhance the diversity

Result

Answer Extraction & Question Generation

	Relevance				Diversity
	Precision		Recall		Dist
	Prop.	Exact	Prop.	Exact	
NER	34.44	19.61	64.60	45.39	30.0k
HarQG	45.96	33.90	41.05	28.37	-
InfoHCVAE	31.59	16.18	78.75	59.32	70.1k
VQAG					
$C_a = 0$	**58.39**	**47.15**	21.82	16.38	3.1k
$C_a = 5$	30.16	13.41	**83.13**	**60.88**	71.2k
$C_a = 20$	21.95	5.75	72.26	42.15	**103.3k**

Answer Extraction

✓Improve diversity while preserving recall-oriented scores

	Relevance				Diversity		
	B1-R	ME-R	RL-R	Token	D1	E4	SB4
SemQG	**62.32**	**36.77**	**62.87**	7.0M	15.8k	18.28	91.44
VQAG							
$C_q = 0$	35.57	18.31	33.92	7.6M	14.4k	17.33	97.61
$C_q = 5$	44.19	25.84	45.18	11.5M	19.0k	19.71	82.59
$C_q = 20$	48.19	25.29	48.26	4.9M	**22.4k**	**19.72**	**44.41**

Question Generation

✓Improve diversity while degrading recall-oriented scores

✓Different C values correspond to different output distributions

Synthetic dataset construction

Synthetic Datasets	(C_a, C_q)
$\mathcal{D}_{5,5}$	(5, 5)
$\mathcal{D}_{5,20}$	(5, 20)
$\mathcal{D}_{20,20}$	(20, 20)

✔Different C values correspond to different output distributions
→ Combine them to further enhance the diversity of QA pairs

Result

Human Evaluation

Experiments		SemQG	$\mathcal{D}_{5,5}$	$\mathcal{D}_{20,20}$	SQuAD
Question is well-formed	No	2.9%	23.1%	27.8%	2.3%
	Understandable	34.5%	16.0%	17.0%	10.5%
	Yes	62.6%	60.9%	55.1%	87.2%
Question is relevant	No	2.5%	9.5%	11.5%	4.0%
	Yes	97.5%	90.5%	88.5%	96.0%
Answer is correct	No	2.8%	28.8%	30.5%	7.5%
	Partially	21.8%	28.1%	26.6%	11.8%
	Yes	75.4%	43.2%	42.9%	80.6%
Answer is important	No	1.5%	10.0%	5.0%	6.0%
	Yes	98.5%	90.0%	95.0%	94.0%

✖Our synthetic datasets contains many noisy examples

✓90% of our questions are relevant to the contexts
✓90% of our answers are worth being asked about

Heatmap of extracted answers & Generated QA pairs

beyoncé 's vocal range spans [four octaves]. [jody rosen] highlights her tone and timbre as particularly distinctive , describing her voice as " one of the most compelling instruments in popular music " . while another critic says she is a " vocal acrobat , being able to sing long and complex melismas and vocal runs effortlessly , and in key . [her vocal abilities] mean she is identified as the centerpiece of destiny 's child . [the daily mail] calls beyoncé 's voice " [versatile] " , capable of exploring power ballads , soul , rock belting , operatic flourishes , and [hip hop]. jon pareles of the new york times commented that her voice is " velvety yet [tart], with an insistent flutter and reserves of soul belting " .

Q: how can one find her vocal abilities in key music ?	A: she is identified as the centerpiece of destiny 's child
Q: how many octaves spans beyoncé 's vocal range ?	A: spans four
Q: how many octaves 's vocal range spans the beyoncé hop vocal range ?	A: four
Q: who commented that her voice is tart yet tart ?	A: jon pareles

: darker words are more likely to be extracted by our model

: phrases that are used as the ground-truth answers in SQuAD

✓Our model can extract diverse phrases including not only noun phrases but also clauses and adjectives, while extracting the ground-truth answers.

✓The generated questions are not very natural but relevant to the context and answers.

Main Result

QA performance on Challenge Sets

	Training Data (Size)	Challenge Sets												
		$\text{SQuAD}^{\text{Du}}_{\text{test}}$	News	NQ	Quo	Para	APara	Hard	Imp	Add	AddO	MT	ASR	KB
Single	$\text{SQuAD}^{\text{Du}}_{\text{train}}$ (76k)	83.5	49.2	67.7	30.1	85.7	50.2	75.6	64.7	62.9	71.8	79.7	67.5	80.1
	+HarQG (1,205k)	*83.3*	*48.5*	*66.2*	31.3	*85.2*	56.5	*73.0*	*63.5*	65.1	73.1	*78.6*	70.0	80.3
	+SemQG (1,204k)	84.7	50.5	69.8	***34.5***	86.2	51.8	*75.0*	65.1	***66.5***	74.3	*79.5*	71.0	80.7
	+InfoHCVAE (824k)	**84.8**	**51.3**	**71.2**	33.8	85.6	53.3	**77.7**	64.8	66.1	**74.5**	**81.3**	**71.6**	**82.8**
	+VQAG (432k)	84.5	49.2	70.1	32.0	**86.7**	**59.0**	76.1	**66.3**	64.8	73.9	79.9	70.5	81.1
Ensemble	$\{\text{SQuAD}^{\text{Du}}_{\text{train}}\}$*3	84.2	50.4	69.4	31.3	86.4	53.2	76.6	65.7	63.6	72.6	80.3	68.7	81.2
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If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

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	If challenge set is known	-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

Red : the score is degraded
Bold: the score is the best

Other QA datasets | Variants of SQuAD | Adversarial SQuAD | NoiseQA

Main Result

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If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✖Lack of the robustness of a QA model to the challenge sets

Main Result

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If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✔QA pair generation improved the in-distribution accuracy in general

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	{+InfoHCVAE}*3	85.3	52.0	**72.2**	34.0	88.0	56.9	**79.0**	65.7	**67.7**	**75.9**	81.4	73.1	**83.2**
	{+VQAG}*3	84.9	50.9	70.1	32.3	**88.1**	**58.6**	77.3	**67.5**	64.9	73.9	80.8	71.2	81.6
	{+Sem,+Info,+V}	**85.8**	**52.1**	72.0	34.2	88.0	55.1	78.8	67.0	66.3	74.7	**82.2**	**73.5**	83.0
If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✔Different QAG methods have different benefits.

Main Result

QA performance on Challenge Sets

	Training Data (Size)	Challenge Sets												
		$SQuAD^{Du}_{test}$	News	NQ	Quo	Para	APara	Hard	Imp	Add	AddO	MT	ASR	KB
Single	$SQuAD^{Du}_{train}$ (76k)	83.5	49.2	67.7	30.1	85.7	50.2	75.6	64.7	62.9	71.8	79.7	67.5	80.1
	+HarQG (1,205k)	*83.3*	*48.5*	*66.2*	31.3	*85.2*	56.5	*73.0*	*63.5*	65.1	73.1	*78.6*	70.0	80.3
	+SemQG (1,204k)	84.7	50.5	69.8	***34.5***	86.2	51.8	*75.0*	65.1	***66.5***	74.3	*79.5*	71.0	80.7
	+InfoHCVAE (824k)	**84.8**	**51.3**	**71.2**	33.8	85.6	53.3	**77.7**	64.8	66.1	**74.5**	**81.3**	**71.6**	**82.8**
	+VQAG (432k)	84.5	49.2	70.1	32.0	**86.7**	**59.0**	76.1	**66.3**	64.8	73.9	79.9	70.5	81.1
Ensemble	{$SQuAD^{Du}_{train}$}*3	84.2	50.4	69.4	31.3	86.4	53.2	76.6	65.7	63.6	72.6	80.3	68.7	81.2
	{+SemQG}*3	85.5	51.8	71.3	**35.1**	87.5	57.8	78.2	66.5	67.0	75.1	80.8	72.9	82.5
	{+InfoHCVAE}*3	85.3	52.0	**72.2**	34.0	88.0	56.9	**79.0**	65.7	**67.7**	**75.9**	81.4	73.1	**83.2**
	{+VQAG}*3	84.9	50.9	70.1	32.3	**88.1**	**58.6**	77.3	**67.5**	64.9	73.9	80.8	71.2	81.6
	{+Sem,+Info,+V}	**85.8**	**52.1**	72.0	34.2	88.0	55.1	78.8	67.0	66.3	74.7	**82.2**	**73.5**	83.0
If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✔Different benefits can be combined in the Ensemble setting

Main Result

QA performance on Challenge Sets

	Training Data (Size)	Challenge Sets												
		$\text{SQuAD}^{\text{Du}}_{\text{test}}$	News	NQ	Quo	Para	APara	Hard	Imp	Add	AddO	MT	ASR	KB
Single	$\text{SQuAD}^{\text{Du}}_{\text{train}}$ (76k)	83.5	49.2	67.7	30.1	85.7	50.2	75.6	64.7	62.9	71.8	79.7	67.5	80.1
	+HarQG (1,205k)	*83.3*	*48.5*	*66.2*	31.3	*85.2*	56.5	*73.0*	*63.5*	65.1	73.1	*78.6*	70.0	80.3
	+SemQG (1,204k)	84.7	50.5	69.8	***34.5***	86.2	51.8	*75.0*	65.1	***66.5***	74.3	*79.5*	71.0	80.7
	+InfoHCVAE (824k)	**84.8**	**51.3**	**71.2**	33.8	*85.6*	53.3	**77.7**	64.8	66.1	**74.5**	**81.3**	**71.6**	**82.8**
	+VQAG (432k)	84.5	49.2	70.1	32.0	**86.7**	**59.0**	76.1	**66.3**	64.8	73.9	79.9	70.5	81.1
Ensemble	$\{\text{SQuAD}^{\text{Du}}_{\text{train}}\}$*3	84.2	50.4	69.4	31.3	86.4	53.2	76.6	65.7	63.6	72.6	80.3	68.7	81.2
	{+SemQG}*3	85.5	51.8	71.3	**35.1**	87.5	57.8	78.2	66.5	67.0	75.1	80.8	72.9	82.5
	{+InfoHCVAE}*3	85.3	52.0	**72.2**	34.0	88.0	56.9	**79.0**	65.7	**67.7**	**75.9**	81.4	73.1	**83.2**
	{+VQAG}*3	84.9	50.9	70.1	32.3	**88.1**	**58.6**	77.3	**67.5**	64.9	73.9	80.8	71.2	81.6
	{+Sem,+Info,+V}	**85.8**	**52.1**	72.0	34.2	88.0	55.1	78.8	67.0	66.3	74.7	**82.2**	**73.5**	83.0
If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✔VQAG did not degrade the scores on the 12 challenge sets while improving the in-distribution accuracy

Main Result

QA performance on Challenge Sets

	Training Data (Size)	$\text{SQuAD}^{\text{Du}}_{\text{test}}$	Challenge Sets											
			News	NQ	Quo	Para	APara	Hard	Imp	Add	AddO	MT	ASR	KB
Single	$\text{SQuAD}^{\text{Du}}_{\text{train}}$ (76k)	83.5	49.2	67.7	30.1	85.7	50.2	75.6	64.7	62.9	71.8	79.7	67.5	80.1
	+HarQG (1,205k)	*83.3*	*48.5*	*66.2*	31.3	*85.2*	56.5	*73.0*	*63.5*	65.1	73.1	*78.6*	70.0	80.3
	+SemQG (1,204k)	84.7	50.5	69.8	***34.5***	86.2	51.8	*75.0*	65.1	***66.5***	74.3	*79.5*	71.0	80.7
	+InfoHCVAE (824k)	**84.8**	**51.3**	**71.2**	33.8	85.6	53.3	**77.7**	64.8	66.1	**74.5**	**81.3**	**71.6**	**82.8**
	+VQAG (432k)	84.5	49.2	70.1	32.0	**86.7**	**59.0**	76.1	**66.3**	64.8	73.9	79.9	70.5	81.1
Ensemble	$\{\text{SQuAD}^{\text{Du}}_{\text{train}}\}$*3	84.2	50.4	69.4	31.3	86.4	53.2	76.6	65.7	63.6	72.6	80.3	68.7	81.2
	{+SemQG}*3	85.5	51.8	71.3	**35.1**	87.5	57.8	78.2	66.5	67.0	75.1	80.8	72.9	82.5
	{+InfoHCVAE}*3	85.3	52.0	**72.2**	34.0	88.0	56.9	**79.0**	65.7	**67.7**	**75.9**	81.4	73.1	**83.2**
	{+VQAG}*3	84.9	50.9	70.1	32.3	**88.1**	**58.6**	77.3	**67.5**	64.9	73.9	80.8	71.2	81.6
	{+Sem,+Info,+V}	**85.8**	**52.1**	72.0	34.2	88.0	55.1	78.8	67.0	66.3	74.7	**82.2**	**73.5**	83.0
If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✔Generating too many examples may be more likely to induce the trade-off between the scores.

Main Result

QA performance on Challenge Sets

	Training Data (Size)	$\text{SQuAD}^{\text{Du}}_{\text{test}}$	Challenge Sets											
			News	NQ	Quo	Para	APara	Hard	Imp	Add	AddO	MT	ASR	KB
Single	$\text{SQuAD}^{\text{Du}}_{\text{train}}$ (76k)	83.5	49.2	67.7	30.1	85.7	50.2	75.6	64.7	62.9	71.8	79.7	67.5	80.1
	+HarQG (1,205k)	*83.3*	*48.5*	*66.2*	31.3	*85.2*	56.5	*73.0*	*63.5*	65.1	73.1	*78.6*	70.0	80.3
	+SemQG (1,204k)	84.7	50.5	69.8	***34.5***	86.2	51.8	*75.0*	65.1	***66.5***	74.3	*79.5*	71.0	80.7
	+InfoHCVAE (824k)	**84.8**	**51.3**	**71.2**	33.8	*85.6*	53.3	**77.7**	64.8	66.1	**74.5**	**81.3**	**71.6**	**82.8**
	+VQAG (432k)	84.5	49.2	70.1	32.0	**86.7**	**59.0**	76.1	**66.3**	64.8	73.9	79.9	70.5	81.1
Ensemble	$\{\text{SQuAD}^{\text{Du}}_{\text{train}}\}$*3	84.2	50.4	69.4	31.3	86.4	53.2	76.6	65.7	63.6	72.6	80.3	68.7	81.2
	{+SemQG}*3	85.5	51.8	71.3	**35.1**	87.5	57.8	78.2	66.5	67.0	75.1	80.8	72.9	82.5
	{+InfoHCVAE}*3	85.3	52.0	**72.2**	34.0	88.0	56.9	**79.0**	65.7	**67.7**	**75.9**	81.4	73.1	**83.2**
	{+VQAG}*3	84.9	50.9	70.1	32.3	**88.1**	**58.6**	77.3	**67.5**	64.9	73.9	80.8	71.2	81.6
	{+Sem,+Info,+V}	**85.8**	**52.1**	72.0	34.2	88.0	55.1	78.8	67.0	66.3	74.7	**82.2**	**73.5**	83.0
If challenge set is known		-	62.9	83.0	66.9	88.6	73.9	-	-	-	-	80.8	75.9	82.6

✖There is still a significant room for improvement in some challenge sets

Analysis

Ablation Study

Training Data (Size)	EM	F1
VQAG (432k)	81.49	88.61
$-\mathcal{D}_{5,5}$ (251k)	81.04	88.39
$-\mathcal{D}_{5,20}$ (113k)	81.00	88.48
$-\mathcal{D}_{20,20}$ (68k)	81.14	88.52

Evaluation on the SQuAD-Du dev set

✓Each synthetic dataset contributes to the QA performance

Analysis

Distributions of Question Types

Dataset	what	how	who	which	when	where	why
$\text{SQuAD}^{\text{Du}}_{\text{train}}$	58.3	10.4	10.3	6.7	6.7	4.2	1.5
$\text{SQuAD}^{\text{Du}}_{\text{test}}$	56.5	12.1	11.5	8.6	6.0	3.8	0.8
HarQG	61.3	7.8	13.8	0.7	10.1	5.8	0.5
SemQG	71.1	8.1	12.8	1.3	3.6	2.7	0.2
InfoHCVAE	77.1	6.6	5.0	1.6	5.6	3.3	0.5
VQAG							
$\mathcal{D}_{5,5}$	36.6	54.9	4.9	0.5	0.3	0.5	2.3
$\mathcal{D}_{5,20}$	9.5	35.5	3.6	49.2	1.2	0.9	0.0
$\mathcal{D}_{20,20}$	28.2	36.7	6.3	23.2	0.2	1.6	3.9
							(%)

✓Our dataset is more diverse than other datasets

✓Our method is unique in controlling the distribution using different configurations

Summary

Contributions

- We proposed the variational QA pair generation (VQAG) model with explicit KL control to generate diverse QA pairs from contexts.
- We showed that our noisy but diverse synthetic datasets are effective to improve the robustness of a QA model while improving the in-distribution score, even though the distributions of the challenge sets are not known a priori.

Future work

- We will identify the reason why noisy examples are effective to improve the QA performance.

Thank you for listening!

Our data and code are available here.

(https://github.com/KazutoshiShinoda/VQAG)