BridgeTower: Building Bridges Between Encoders in Vision-Language Representation Learning

Xiao Xu[1,2], Chenfei Wu[2], Shachar Rosenman[3], Vasudev Lal[3], Wanxiang Che[1], Nan Duan[2]

[1]Harbin Institute of Technology, [2]Microsoft Research Asia, [3]Intel Labs

Presenter: Xiao Xu

Work done during the internship of Microsoft Research Asia.

Vision-Language Pre-training Background

ViLBERT
Aug, 2019

VisualBERT
Aug, 2019

B2T2
Aug, 2019

Unicoder-VL
Aug, 2019

LXMERT
Aug, 2019

VL-BERT
Aug, 2019

Unified VLP
Sep, 2019

UNITER
Sep, 2019

12-in-1
Dec, 2019

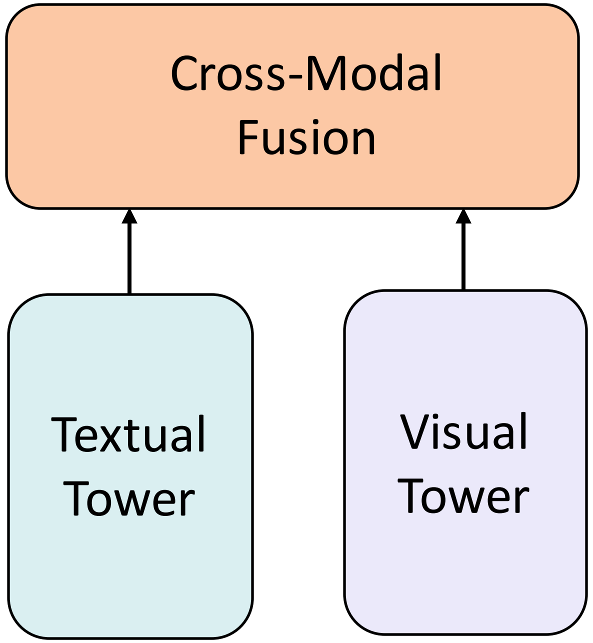
ImageBERT
Jan, 2020

PixelBERT
Apr, 2020

Oscar
Apr, 2020

VILLA
June, 20

Traditional Two-Tower Architecture



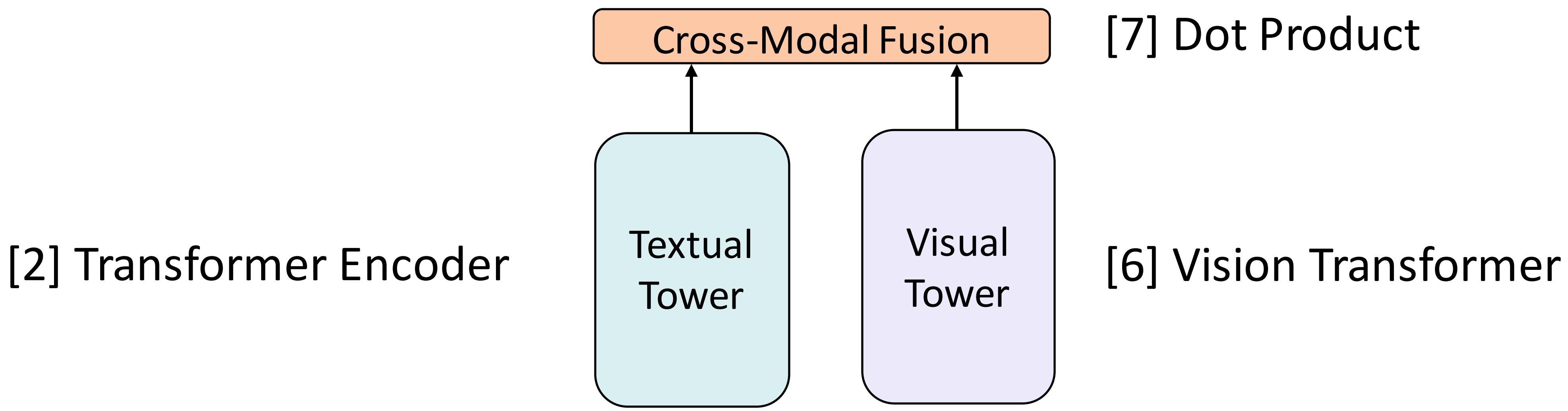
[7] Dot Product
[8] Transformer Encoder
[9] Transformer Decoder
[10] Transformer Encoder (MoE)

[1] Word Embedding
[2] Transformer Encoder

[3] Linear Projection
[4] CNN
[5] Object Detector
[6] Vision Transformer

	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
Textual-Tower	[2]	[1]	[1]	[1]	[1]	[2]	[2]	[1]	[1]	[2]
Visual-Tower	[6]	[4]	[5]	[3]	[5]	[6]	[6]	[4]	[3]	[6]
Cross-Fusion	[7]	[8]	[8]	[8]	[8] + [9]	[8]	[9]	[8] + [9]	[10]	[8] + [9]

Traditional Two-Tower Architecture



	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
Textual-Tower	[2]	[1]	[1]	[1]	[1]	[2]	[2]	[1]	[1]	[2]
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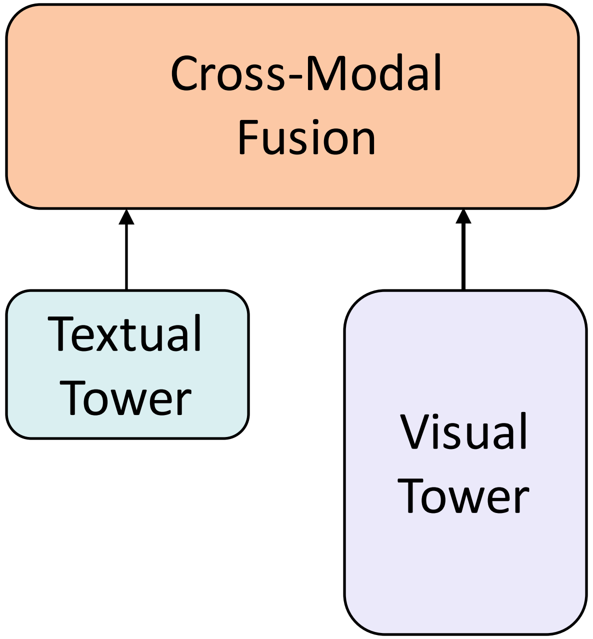
Traditional Two-Tower Architecture



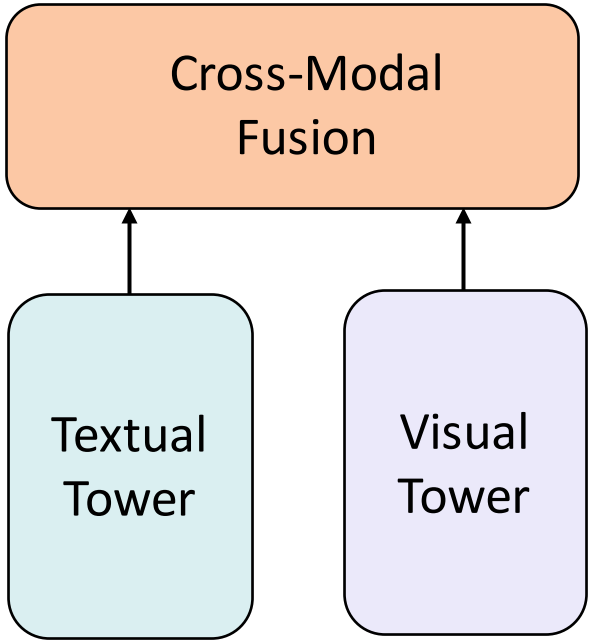
[8] Transformer Encoder

[1] Word Embedding

[5] Faster R-CNN

	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
Textual-Tower	[2]	[1]	[1]	[1]	[1]	[2]	[2]	[1]	[1]	[2]
Visual-Tower	[6]	[4]	[5]	[3]	[5]	[6]	[6]	[4]	[3]	[6]
Cross-Fusion	[7]	[8]	[8]	[8]	[8] + [9]	[8]	[9]	[8] + [9]	[10]	[8] + [9]

Traditional Two-Tower Architecture



[8] Transformer Encoder

[2] RoBERTa

[6] CLIP-ViT / Swin Transformer

	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
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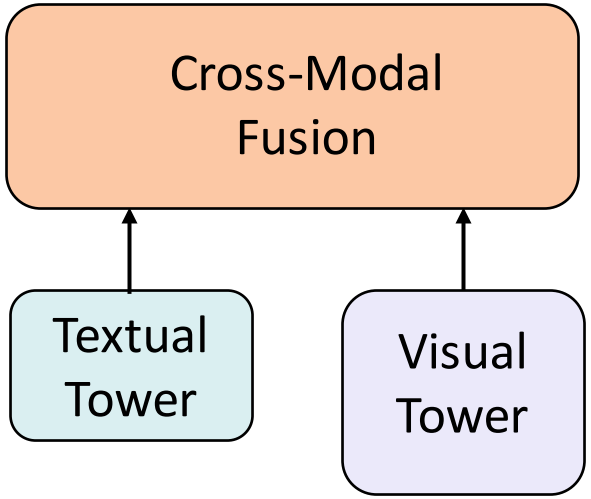
Visual-Tower	[6]	[4]	[5]	[3]	[5]	[6]	[6]	[4]	[3]	[6]
Cross-Fusion	[7]	[8]	[8]	[8]	[8] + [9]	[8]	[9]	[8] + [9]	[10]	[8] + [9]

Traditional Two-Tower Architecture

[8] Transformer Encoder
[9] Transformer Decoder



[1] Word Embedding

[4] ResNet (the first three blocks)

	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
Textual-Tower	[2]	[1]	[1]	[1]	[1]	[2]	[2]	[1]	[1]	[2]
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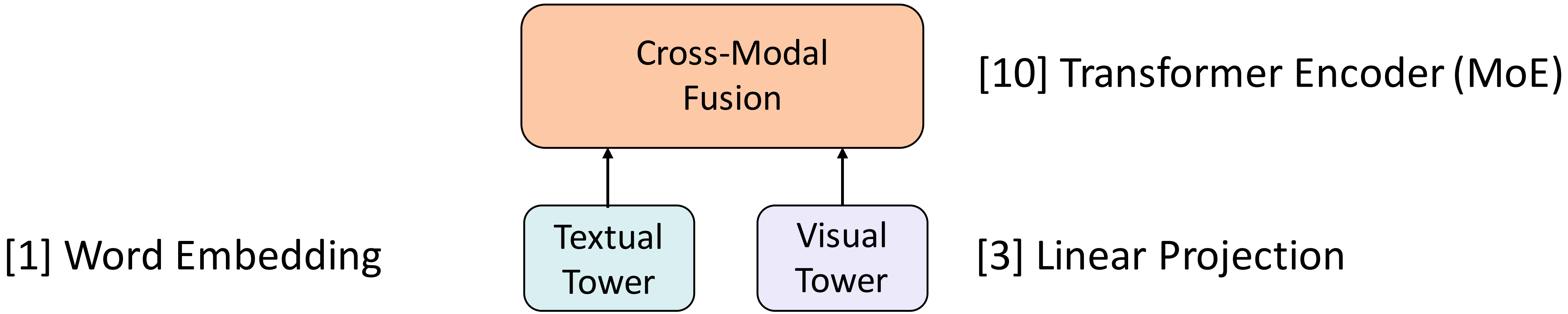
Cross-Fusion	[7]	[8]	[8]	[8]	[8] + [9]	[8]	[9]	[8] + [9]	[10]	[8] + [9]

Traditional Two-Tower Architecture



	CLIP	SOHO	Unicoder-VL	ViLT	VL-T5	METER	UniT	OFA	VLMo	BLIP
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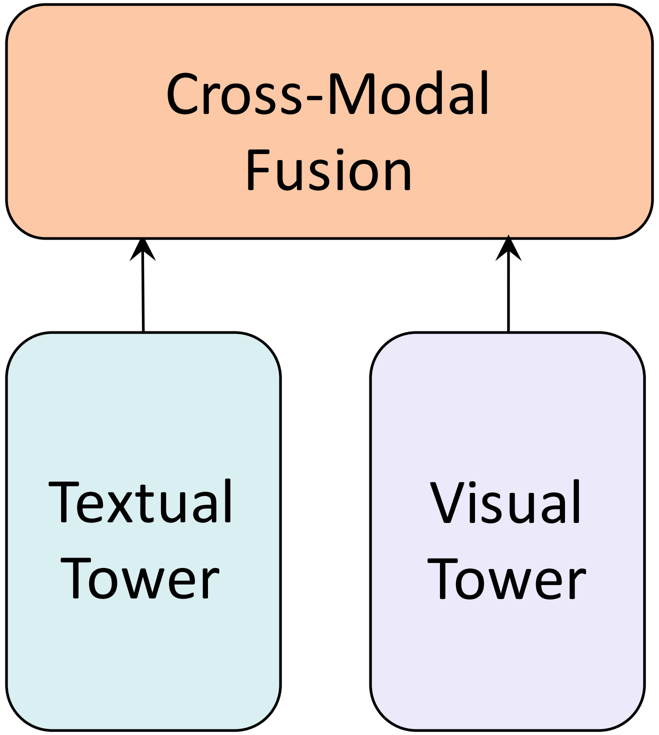
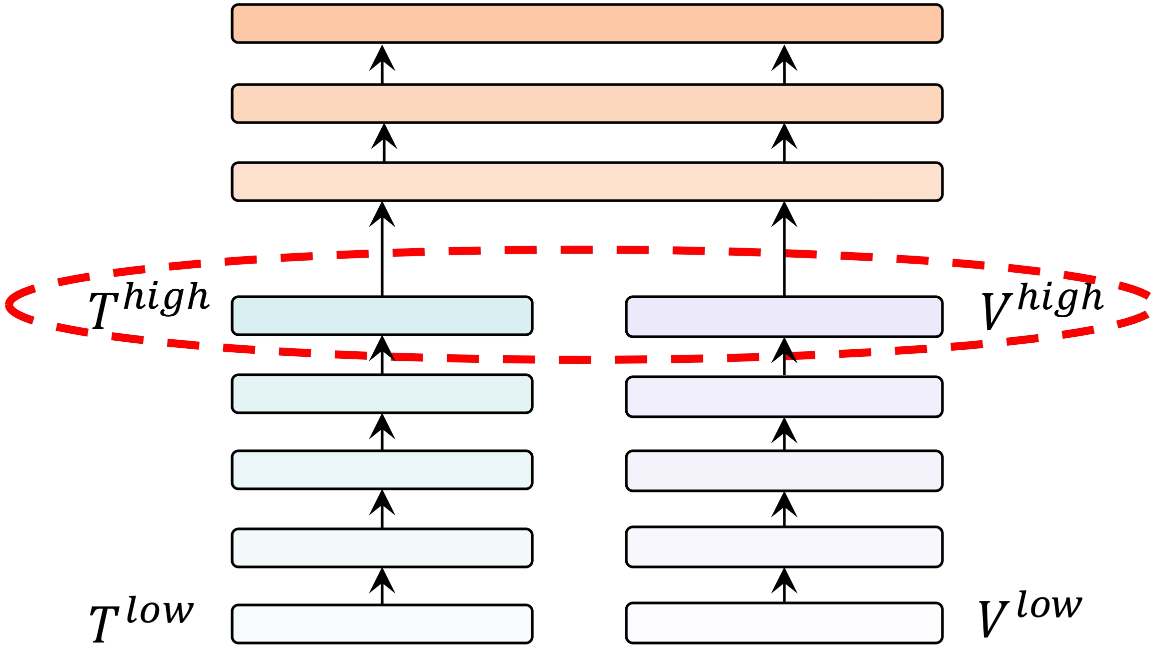
Motivation

Two-Tower architecture
only use the last-layer uni-modal features.

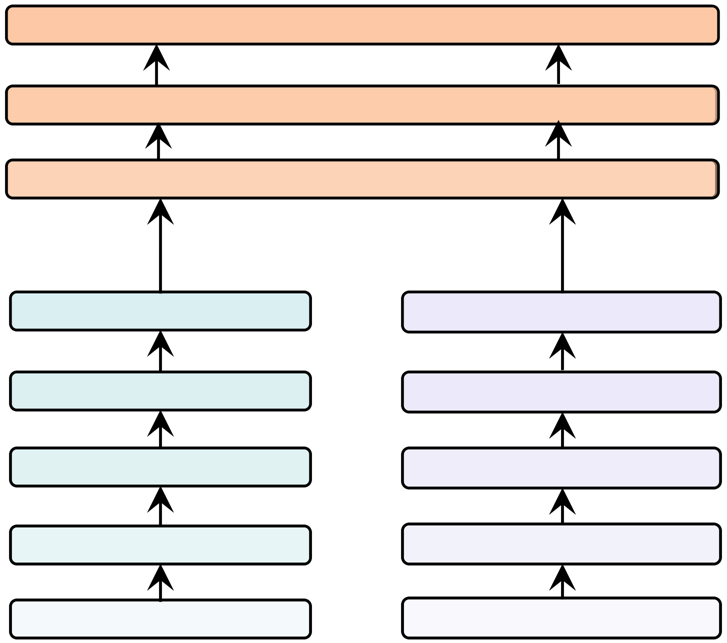




Numerous works proved: different layers encode different types of semantic information.

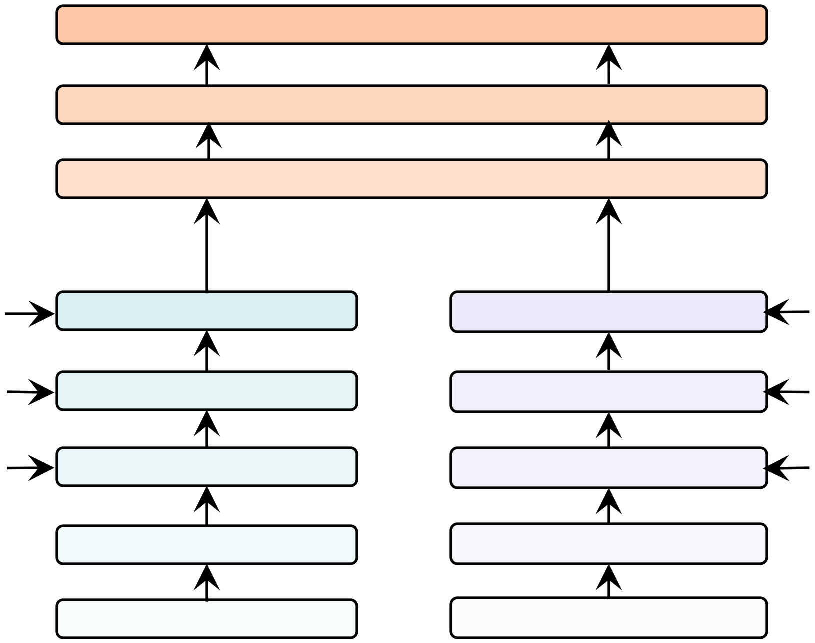
Question: can we build a bridge between different layers of uni-modal towers and the cross-modal fusion module?

Two-Tower vs BridgeTower



Two-Tower

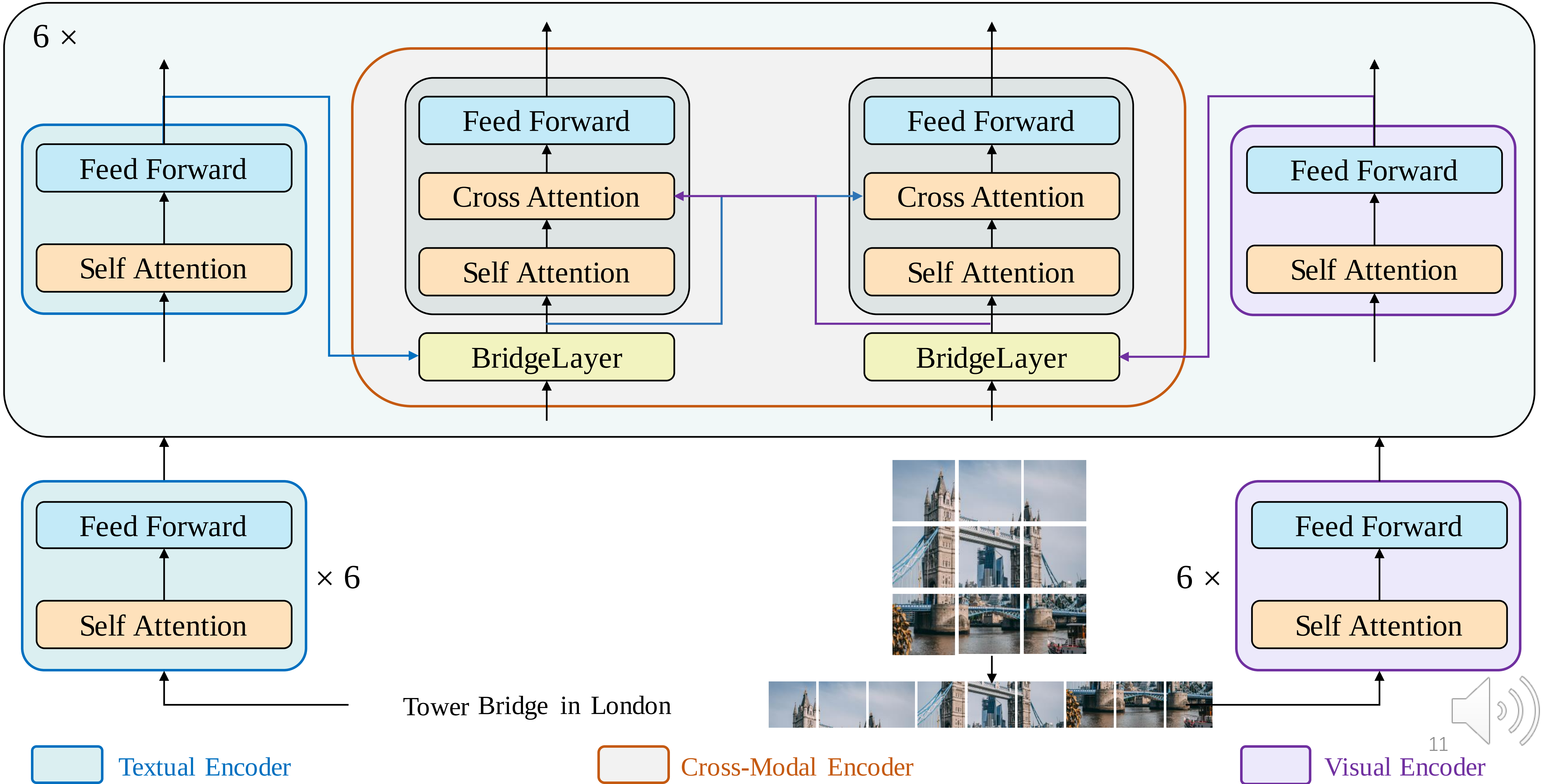
only fuse the
last layer features



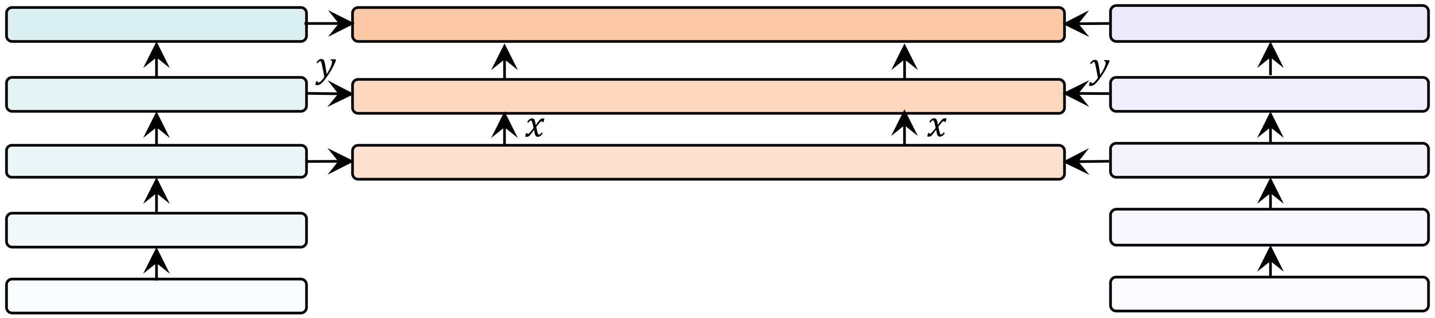
BridgeTower

gradually fuse
multiple top layer features

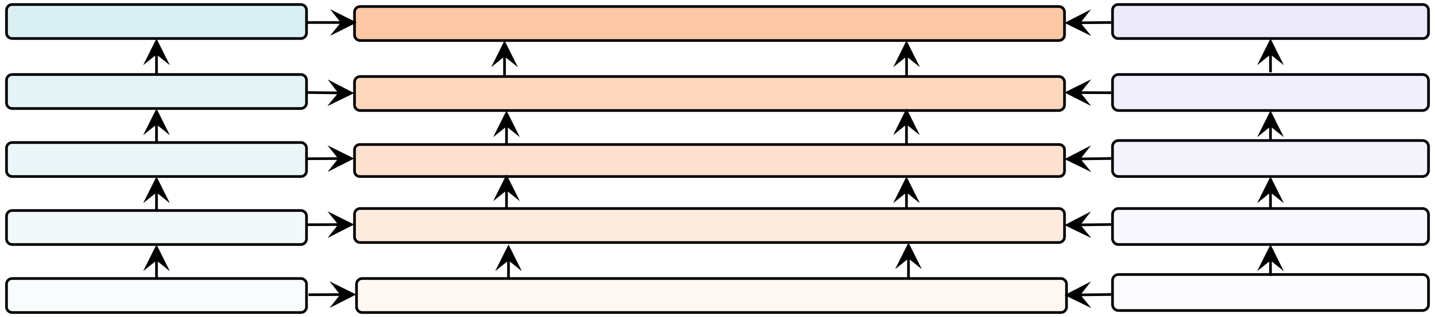
Our BridgeTower Architecture



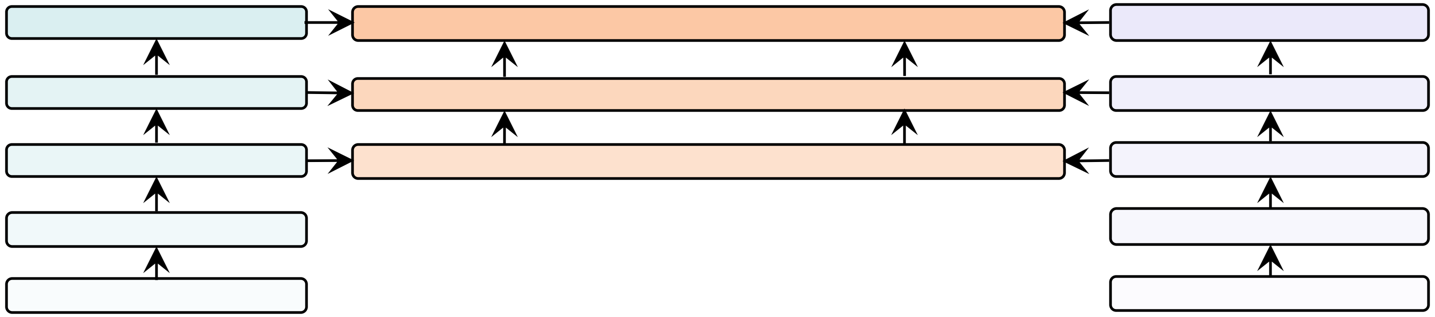
Ablation Study



Design I: Definition of Bridges

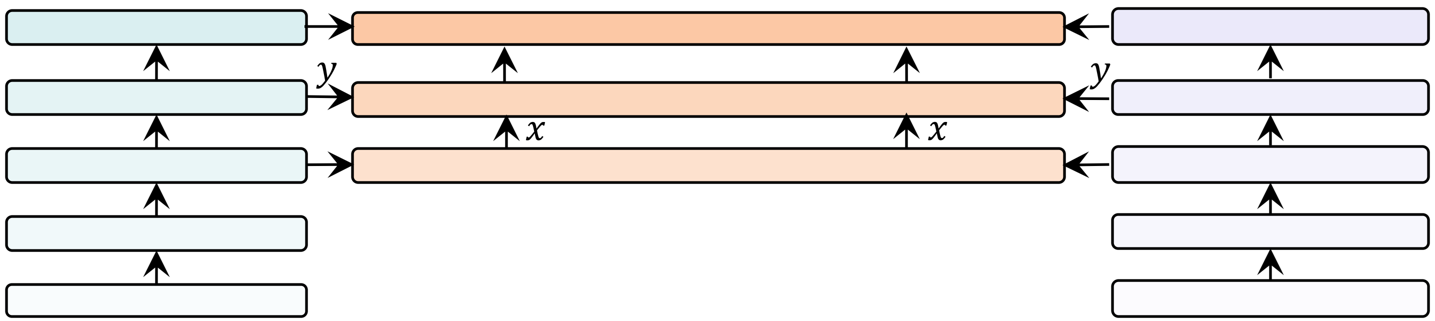


Design II: Number of Layers



Design III: Number of Bridges

Design I: Definition of Bridges



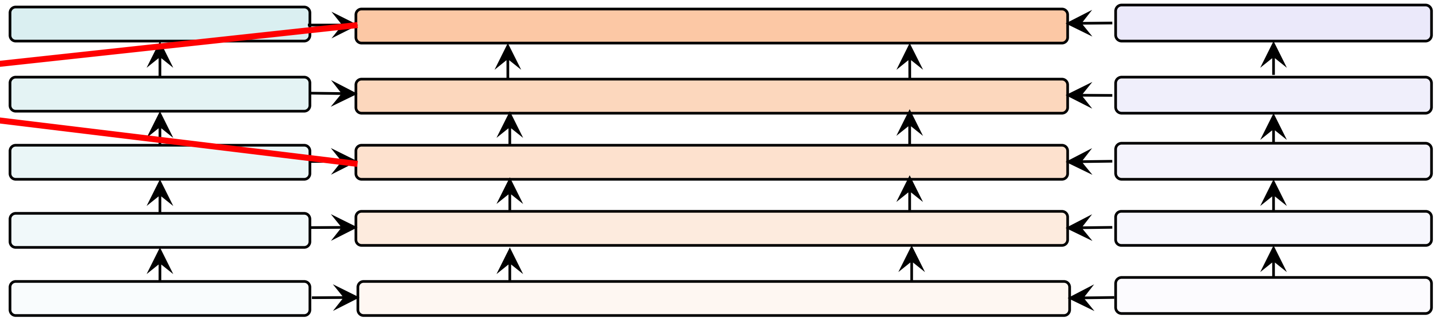
BridgeLayer(x, y)	# Params	Test-Dev	RSUM
(a) $x + y$	**18.4K**	**75.18**	**533.8**
(b) $x \odot y$	18.4K	73.41	530.4
(c) $\alpha x + (1 - \alpha) y, \alpha \in \mathbb{R}^{D_Z}$	26.0K	75.09	532.9
(d) $\alpha x + (1 - \alpha) y, \alpha = \sigma(\mathbf{W}[x; y])$	11.8M	75.13	533.1
(e) $\mathbf{W}[x; y]$	11.8M	74.55	532.2
(f) $\mathbf{W}_2(\mathrm{GeLU}(\mathbf{W}_1[x; y]))$	35.4M	74.26	530.2
(g) $\mathrm{MCA}(x, y)$	23.6M	73.67	514.3
(h) $\mathrm{FFN}(\mathrm{MCA}(x, y))$	70.8M	73.54	511.1
(i) $x + y + \mathbf{W}_*[x; y]$	11.8M	75.10	533.1

x: the output cross-modal representation of the previous layer

y: the corresponding input uni-modal representation

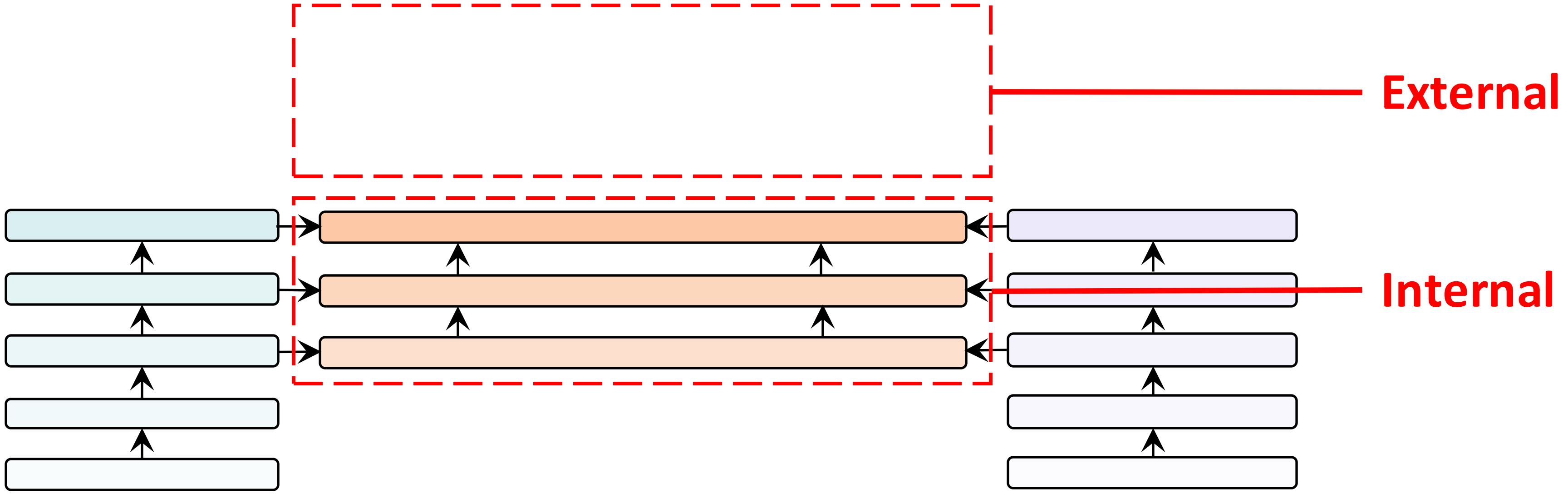
Design II: Number of Layers

L_Z
number of layers
starting from the top



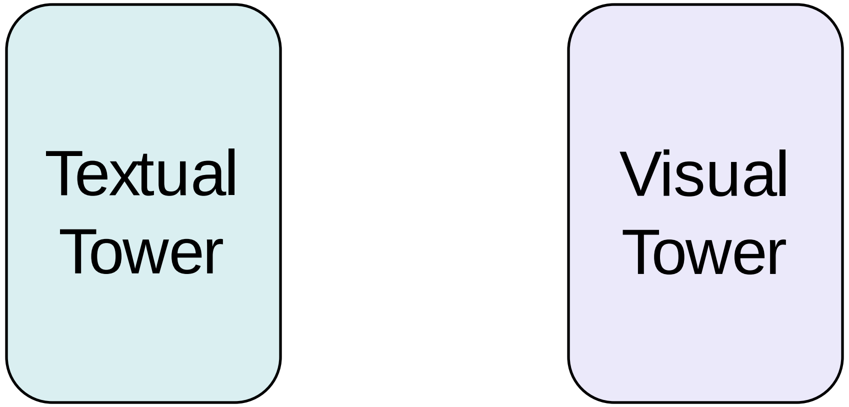
L_Z	# Params	VQAv2 Test-Dev METER	VQAv2 Test-Dev Ours	Flickr30K RSUM METER	Flickr30K RSUM Ours
2	37.8M	72.84	74.12 (↑ 1.28)	526.0	527.1 (↑ 1.1)
3	56.8M	73.47	74.36 (↑ 0.89)	526.5	528.6 (↑ 2.1)
4	75.6M	73.71	75.00 (↑ 1.29)	527.9	529.7 (↑ 1.8)
5	94.6M	73.80	74.98 (↑ 1.18)	528.8	531.8 (↑ 3.0)
6	113.4M	74.04	**75.18** (↑ 1.14)	530.7	**533.8** (↑ 3.1)
8	151.2M	73.97	75.07 (↑ 1.10)	530.0	531.6 (↑ 1.6)
10	189.0M	73.45	75.06 (↑ 1.61)	529.6	531.7 (↑ 2.1)
12	226.8M	71.88	74.94 (↑ 3.06)	528.7	531.4 (↑ 2.7)

Design III: Number of Bridges



	# Internal	# External	VQAv2 Test-Dev	Flickr30K RSUM
BridgeTower	6	0	**75.18**	**533.8**
	4	2	75.06 (↓ 0.12)	533.1 (↓ 0.7)
	3	3	74.97 (↓ 0.21)	532.8 (↓ 1.0)
	2	4	74.71 (↓ 0.47)	532.3 (↓ 1.5)
Two-Tower(METER)	0	6	74.04 (↓ 1.14)	530.7 (↓ 3.1)

Apply Different Uni-modal **Backbones**



Visual Backbone	Textual Backbone	VQAv2 Test-Dev		Flickr30K RSUM	
		METER	Ours	METER	Ours
DeiT B-224/16	RoBERTa	69.98	70.83 (↑ 0.85)	448.0	455.7 (↑ 7.7)
ViT B-224/16	RoBERTa	70.26	72.24 (↑ 1.98)	472.7	476.9 (↑ 4.2)
ViT B-384/16	RoBERTa	70.52	72.38 (↑ 1.86)	472.8	477.1 (↑ 4.3)
CLIP-VIT-B/32	RoBERTa	72.19	72.91 (↑ 0.72)	508.8	512.0 (↑ 3.2)
CLIP-VIT-B/16	BERT	74.09	74.89 (↑ 0.80)	522.1	526.5 (↑ 4.4)
CLIP-VIT-B/16	RoBERTa	74.04	**75.18** (↑ 1.14)	530.7	**533.8** (↑ 3.1)

Pre-training Settings

- **Pre-training Objectives**
  - Masked Language Modeling – MLM
  - Image-Text Matching – ITM
- **Pre-training Datasets**
  - 4M Images, ~9M Image-Text Pairs

	COCO	VG	CC	SBU
# Images	113K	108K	2.9M	860K
# Captions	567K	4.8M	2.9M	860K

Hyperparameters	$\text{BRIDGETOWER}_{\text{BASE}}$	$\text{BRIDGETOWER}_{\text{LARGE}}$
Number of Layers	6	6
Hidden size	768	1,024
FFN inner hidden size	3,072	4,096
Number of Attention heads	12	16
Dropout Ratio	0.1	0.1
Attention dropout	0.1	0.1
Total Steps	100k	100k
Batch Size	4,096	4,096
Textual Encoder	$\text{RoBERTa}_{\text{BASE}}$	$\text{RoBERTa}_{\text{LARGE}}$
Visual Encoder	CLIP-ViT-B	CLIP-ViT-L
Patch Size	16	14
Image Resolution	288	294

Results on VQAv2 Dataset

Model	# Pre-train Images	Visual Backbone	Test-Dev Overall	Test-Standard Yes/No	Number	Other	Overall
Base-Size Models							
ViLT$_{\text{BASE}}$ (Kim, Son, and Kim 2021)	4M	ViT-B-384/32	71.26	-	-	-	-
UNITER$_{\text{BASE}}$ (Chen et al. 2020) $*$	4M	Faster R-CNN	72.70	-	-	-	72.91
VILLA$_{\text{BASE}}$ (Gan et al. 2020) $*$	4M	Faster R-CNN	73.59	-	-	-	73.67
UNIMO$_{\text{BASE}}$ (Li et al. 2021b)	4M	Faster R-CNN	73.79	-	-	-	74.02
ALBEF$_{\text{BASE}}$ (Li et al. 2021a) $*$	4M	DeiT-B-224/16	74.54	-	-	-	74.70
ALBEF$_{\text{BASE}}$ (Li et al. 2021a) $*$	14M	DeiT-B-224/16	75.84	-	-	-	76.04
VinVL$_{\text{BASE}}$ (Zhang et al. 2021)	5.7M	ResNeXt-152	75.95	-	-	-	76.12
VLMO$_{\text{BASE}}$ (Wang et al. 2021a)	4M	BEiT-B-224/16	76.64	-	-	-	76.89
BLIP$_{\text{BASE}}$ (Li et al. 2022b) $*$	14M	DeiT-B-224/16	77.54	-	-	-	77.62
METER$_{\text{BASE}}$ (Dou et al. 2022)	4M	CLIP-ViT-B-224/16	77.68	92.49	58.07	69.20	77.64
mPLUG (Li et al. 2022a) $*$	4M	CLIP-ViT-B-224/16	77.94	-	-	-	77.96
OFA$_{\text{BASE}}$ (Wang et al. 2022b) $*\star$	54M	ResNet-101	77.98	-	-	-	78.07
SimVLM$_{\text{BASE}}$ (Wang et al. 2021c) $\star$	1.8B	ResNet-101	77.87	-	-	-	78.14
BLIP$_{\text{BASE}}$ (Li et al. 2022b) $*$	129M	DeiT-B-224/16	78.24	-	-	-	78.17
BRIDGETOWER$_{\text{BASE}}$ **(Ours)**	**4M**	CLIP-ViT-B-224/16	**78.66**	**92.92**	**60.69**	**70.51**	**78.73**
BRIDGETOWER$_{\text{BASE}}$ **(Ours)** $*$	**4M**	CLIP-ViT-B-224/16	**79.10**	**93.06**	**62.19**	**70.69**	**79.04**
Large-Size Models							
UNITER$_{\text{LARGE}}$ (Chen et al. 2020) $*$	4M	Faster R-CNN	73.82	-	-	-	74.02
VILLA$_{\text{LARGE}}$ (Gan et al. 2020) $*$	4M	Faster R-CNN	74.69	-	-	-	74.87
UNIMO$_{\text{LARGE}}$ (Li et al. 2021b)	4M	Faster R-CNN	75.06	-	-	-	75.27
VinVL$_{\text{LARGE}}$ (Zhang et al. 2021)	5.7M	ResNeXt-152	76.52	92.04	61.50	66.68	76.63
SimVLM$_{\text{LARGE}}$ (Wang et al. 2021c)	1.8B	ResNet-152	79.32	-	-	-	79.56
VLMO$_{\text{LARGE}}$ (Wang et al. 2021a)	4M	BEiT-L-224/16	79.94	-	-	-	79.98
OFA$_{\text{LARGE}}$ (Wang et al. 2022b) $*\star$	54M	ResNet-152	80.43	93.32	**67.31**	72.71	80.67
BRIDGETOWER$_{\text{LARGE}}$ **(Ours)**	**4M**	CLIP-ViT-L-224/14	**81.25**	**94.69**	64.58	**73.16**	**81.15**
BRIDGETOWER$_{\text{LARGE}}$ **(Ours)** $*$	**4M**	CLIP-ViT-L-224/14	**81.52**	**94.80**	66.01	**73.45**	**81.49**

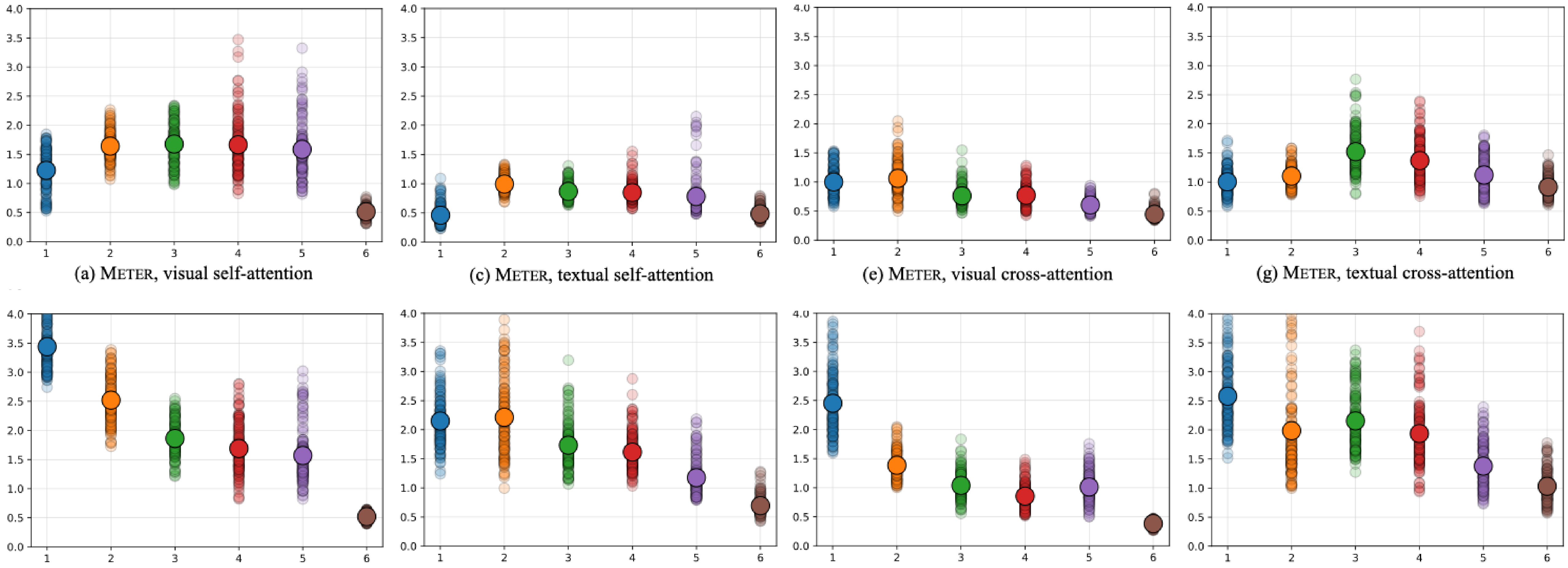
Results on VQAv2 Dataset

Model	# Pre-train Images	Visual Backbone	Test-Dev Overall	Test-Standard Yes/No	Test-Standard Number	Test-Standard Other	Test-Standard Overall
Large-Size Models							
UNITER$_{\text{LARGE}}$ (Chen et al. 2020) $*$	4M	Faster R-CNN	73.82	-	-	-	74.02
VILLA$_{\text{LARGE}}$ (Gan et al. 2020) $*$	4M	Faster R-CNN	74.69	-	-	-	74.87
UNIMO$_{\text{LARGE}}$ (Li et al. 2021b)	4M	Faster R-CNN	75.06	-	-	-	75.27
VinVL$_{\text{LARGE}}$ (Zhang et al. 2021)	5.7M	ResNeXt-152	76.52	92.04	61.50	66.68	76.63
SimVLM$_{\text{LARGE}}$ (Wang et al. 2021c)	1.8B	ResNet-152	79.32	-	-	-	79.56
VLMO$_{\text{LARGE}}$ (Wang et al. 2021a)	4M	BEiT-L-224/16	79.94	-	-	-	79.98
OFA$_{\text{LARGE}}$ (Wang et al. 2022b) $*\star$	54M	ResNet-152	80.43	93.32	**67.31**	72.71	80.67
BRIDGETOWER$_{\text{LARGE}}$ **(Ours)**	**4M**	CLIP-ViT-L-224/14	**81.25**	**94.69**	64.58	**73.16**	**81.15**
BRIDGETOWER$_{\text{LARGE}}$ **(Ours)** $*$	**4M**	CLIP-ViT-L-224/14	**81.52**	**94.80**	66.01	**73.45**	**81.49**
Huge or even Larger Size Models							
SimVLM$_{\text{HUGE}}$ (Wang et al. 2021c)	1.8B	ResNet-101	80.03	93.29	66.54	72.23	80.34
METER$_{\text{HUGE}}$ (Dou et al. 2022)	14M	Florence-CoSwin-H	80.33	94.25	64.37	72.30	80.54
mPLUG (Li et al. 2022a) $*$	14M	CLIP-ViT-L-224/14	81.27	-	-	-	81.26
GIT2 (Wang et al. 2022a) $*$	10.5B	DaViT(4.8B)	81.74	92.90	67.06	75.77	81.92
OFA$_{\text{HUGE}}$ (Wang et al. 2022b) $*\star$	54M	ResNet-152	82.0	94.66	71.44	73.35	81.98
Flamingo (Alayrac et al. 2022) $\star$	2.3B	NFNet-F6	82.0	-	-	-	82.1
CoCa (Yu et al. 2022) $\star$	4.8B	ViT-G-288/18	82.3	94.55	70.25	74.46	82.33
BEiT-3 (Wang et al. 2022c)	28M	BEiT-3	84.19	**96.43**	**73.63**	75.92	84.18
PaLI (Chen et al. 2022)	1.6B	ViT-E-224	**84.3**	96.13	69.07	**77.58**	**84.34**

Results on SNLI-VE and Flickr30K Dataset

Model	# Pre-train Images	SNLI-VE dev	SNLI-VE test	Flickr30K (1K test set) IR@1	IR@5	IR@10	TR@1	TR@5	TR@10	RSUM
Pre-trained on More Data										
$\text{ALIGN}_{\text{BASE}}$ (Jia et al. 2021)	1.8B	-	-	84.9	97.4	98.6	95.3	99.8	100.0	576.0
$\text{ALBEF}_{\text{BASE}}$ (Li et al. 2021a)	14M	80.80	80.91	85.6	97.5	98.9	95.9	99.8	100.0	577.7
Pre-trained on CC, SBU, MSCOCO and VG datasets										
$\text{ViLT}_{\text{BASE}}$ (Kim, Son, and Kim 2021)	4M	-	-	64.4	88.7	93.8	83.5	96.7	98.6	525.7
$\text{UNITER}_{\text{LARGE}}$ (Chen et al. 2020)	4M	79.30	79.38	75.6	94.1	96.8	87.3	98.0	99.2	550.9
$\text{VILLA}_{\text{LARGE}}$ (Gan et al. 2020)	4M	80.18	80.02	76.3	94.2	96.8	87.9	97.5	98.8	551.5
$\text{UNIMO}_{\text{LARGE}}$ (Li et al. 2021b)	4M	**81.11**	80.63	78.0	94.2	97.1	89.4	98.9	99.8	557.5
$\text{ALBEF}_{\text{BASE}}$ (Li et al. 2021a)	4M	80.14	80.30	82.8	96.7	98.4	94.3	99.4	99.8	571.4
$\text{METER-CLIP-ViT}_{\text{BASE}}$ (Dou et al. 2022)	4M	80.86	**81.19**	82.2	96.3	98.4	94.3	**99.6**	99.9	570.7
$\text{BRIDGETOWER}_{\text{BASE}}$ (Ours)	**4M**	**81.11**	**81.19**	**85.8**	**97.6**	**98.9**	**94.7**	**99.6**	**100.0**	**576.6**

KL Divergence Visualization



(a) METER, visual self-attention

(c) METER, textual self-attention

(e) METER, visual cross-attention

(g) METER, textual cross-attention

(b) BRIDGETOWER, visual self-attention

(d) BRIDGETOWER, textual self-attention

(f) BRIDGETOWER, visual cross-attention

(h) BRIDGETOWER, textual cross-attention

Higher/lower KL divergence means that different attention heads pay attention to different/similar tokens.

Conclusion & Future

- Conclusion:
  - We introduced BridgeTower, a simple but effective architecture for VL pre-training.
  - We studied different design choices for bridges.
  - We show that BridgeTower achieves SOTA results on multiple downstream tasks.
- Future:
  - More Pre-training Objectives (currently we only use two)
  - Larger-Scale Pre-training (currently only 4M data)
  - More Modalities (currently only two modalities)

Integrated into Hugging Face – Transformers

Transformers

Search documentation ⌘K

MAIN EN 78,811

Image Processor

MODELS

TEXT MODELS

VISION MODELS

AUDIO MODELS

MULTIMODAL MODELS

AltCLIP
BLIP
BridgeTower
Chinese-CLIP
CLIP
CLIPSeg
Data2Vec
Donut
FLAVA
GIT
GroupViT
LayoutLMV2
LayoutLMV3
LayoutXLM
LXMERT
OneFormer
OWL-ViT
Perceiver
Speech Encoder Decoder Models
TrOCR
OWL-ViT
Perceiver
Speech Encoder Decoder Models
TrOCR

BridgeTower

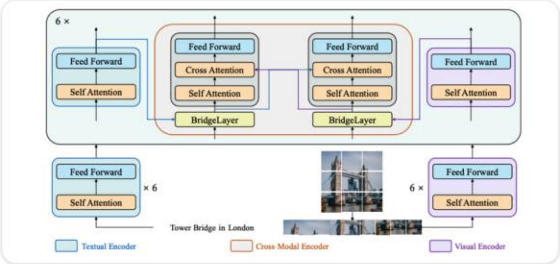
Overview

The BridgeTower model was proposed in BridgeTower: Building Bridges Between Encoders in Vision-Language Representative Learning by Xiao Xu, Chenfei Wu, Shachar Rosenman, Vasudev Lal, Wanxiang Che, Nan Duan. The goal of this model is to build a bridge between each uni-modal encoder and the cross-modal encoder to enable comprehensive and detailed interaction at each layer of the cross-modal encoder thus achieving remarkable performance on various downstream tasks with almost negligible additional performance and computational costs.

This paper has been accepted to the AAAI'23 conference.

The abstract from the paper is the following:

Vision-Language (VL) models with the TWO-TOWER architecture have dominated visual-language representation learning in recent years. Current VL models either use lightweight uni-modal encoders and learn to extract, align and fuse both modalities simultaneously in a deep cross-modal encoder, or feed the last-layer uni-modal representations from the deep pre-trained uni-modal encoders into the top cross-modal encoder. Both approaches potentially restrict vision-language representation learning and limit model performance. In this paper, we propose BRIDGETOWER, which introduces multiple bridge layers that build a connection between the top layers of uni-modal encoders and each layer of the crossmodal encoder. This enables effective bottom-up cross-modal alignment and fusion between visual and textual representations of different semantic levels of pre-trained uni-modal encoders in the cross-modal encoder. Pre-trained with only 4M images, BRIDGETOWER achieves state-of-the-art performance on various downstream vision-language tasks. In particular, on the VQAv2 test-std set, BRIDGETOWER achieves an accuracy of 78.73%, outperforming the previous state-of-the-art model METER by 1.09% with the same pre-training data and almost negligible additional parameters and computational costs. Notably, when further scaling the model, BRIDGETOWER achieves an accuracy of 81.15%, surpassing models that are pre-trained on orders-of-magnitude larger datasets.



BridgeTower
Overview
Usage
BridgeTowerConfig
BridgeTowerTextConfig
BridgeTowerVisionConfig
BridgeTowerImageProcessor
BridgeTowerProcessor
BridgeTowerModel
BridgeTowerForMaskedLM
BridgeTowerForImageAndText Retrieval

- Source Code: https://github.com/huggingface/transformers/tree/main/src/transformers/models/bridgetower
- Documentation: https://huggingface.co/docs/transformers/main/en/model_doc/bridgetower

Integrated into Hugging Face – Transformers

- Pre-trained models released on Hugging Face – Model Hub
  - https://huggingface.co/BridgeTower

Models 4 — ⇅ Sort: Recently Updated

- BridgeTower/bridgetower-large-itm-mlm-gaudi — Updated about 8 hours ago
- BridgeTower/bridgetower-base — Updated about 8 hours ago • ↓ 550
- BridgeTower/bridgetower-large-itm-mlm — Updated about 8 hours ago • ↓ 366
- BridgeTower/bridgetower-base-itm-mlm — Updated about 8 hours ago • ↓ 300

- Model Variants
  - Number of parameters:

	Textual Encoder	**Visual Encoder**	**Cross-Modal Encoder**	**Total**
$\text{BridgeTower}_{\text{Base}}$	124M	86M	113M	323M
$\text{BridgeTower}_{\text{Large}}$	355M	304M	200M	859M

Usage – Image-Text Matching

```python
from transformers import BridgeTowerProcessor, BridgeTowerForImageAndTextRetrieval
import requests
from PIL import Image

url = "http://images.cocodataset.org/val2017/000000039769.jpg"
image = Image.open(requests.get(url, stream=True).raw)
texts = ["An image of two cats chilling on a couch", "A football player scoring a goal"]

processor = BridgeTowerProcessor.from_pretrained("BridgeTower/bridgetower-base-itm-mlm")
model = BridgeTowerForImageAndTextRetrieval.from_pretrained("BridgeTower/bridgetower-base-itm-mlm")

# forward pass
scores = dict()
for text in texts:
    # prepare inputs
    encoding = processor(image, text, return_tensors="pt")
    outputs = model(**encoding)
    scores[text] = outputs.logits[0,1].item()
# {'An image of two cats chilling on a couch': 4.843737125396728,
#  'A football player scoring a goal': -6.8970479965209961}
```

Usage – Masked Language Modeling

```python
from transformers import BridgeTowerProcessor, BridgeTowerForMaskedLM
from PIL import Image
import requests

url = "http://images.cocodataset.org/val2017/000000360943.jpg"
image = Image.open(requests.get(url, stream=True).raw).convert("RGB")
text = "a <mask> looking out of the window"

processor = BridgeTowerProcessor.from_pretrained("BridgeTower/bridgetower-base-itm-mlm")
model = BridgeTowerForMaskedLM.from_pretrained("BridgeTower/bridgetower-base-itm-mlm")

# prepare inputs
encoding = processor(image, text, return_tensors="pt")

# forward pass
outputs = model(**encoding)

results = processor.decode(outputs.logits.argmax(dim=-1).squeeze(0).tolist())

print(results)
# a cat looking out of the window.
```

Next Steps

- ❑ Pre-training Scripts for BridgeTower
- ❑ Fine-tuning Scripts and Notebooks for More Downstream Tasks

Thanks & QA

Xiao Xu[1,2], Chenfei Wu[2], Shachar Rosenman[3], Vasudev Lal[3], Wanxiang Che[1], Nan Duan[2]

[1]Harbin Institute of Technology, [2]Microsoft Research Asia, [3]Intel Labs

Presenter: Xiao Xu

Slides and more in https://looperxx.github.io/.