Vision and Language

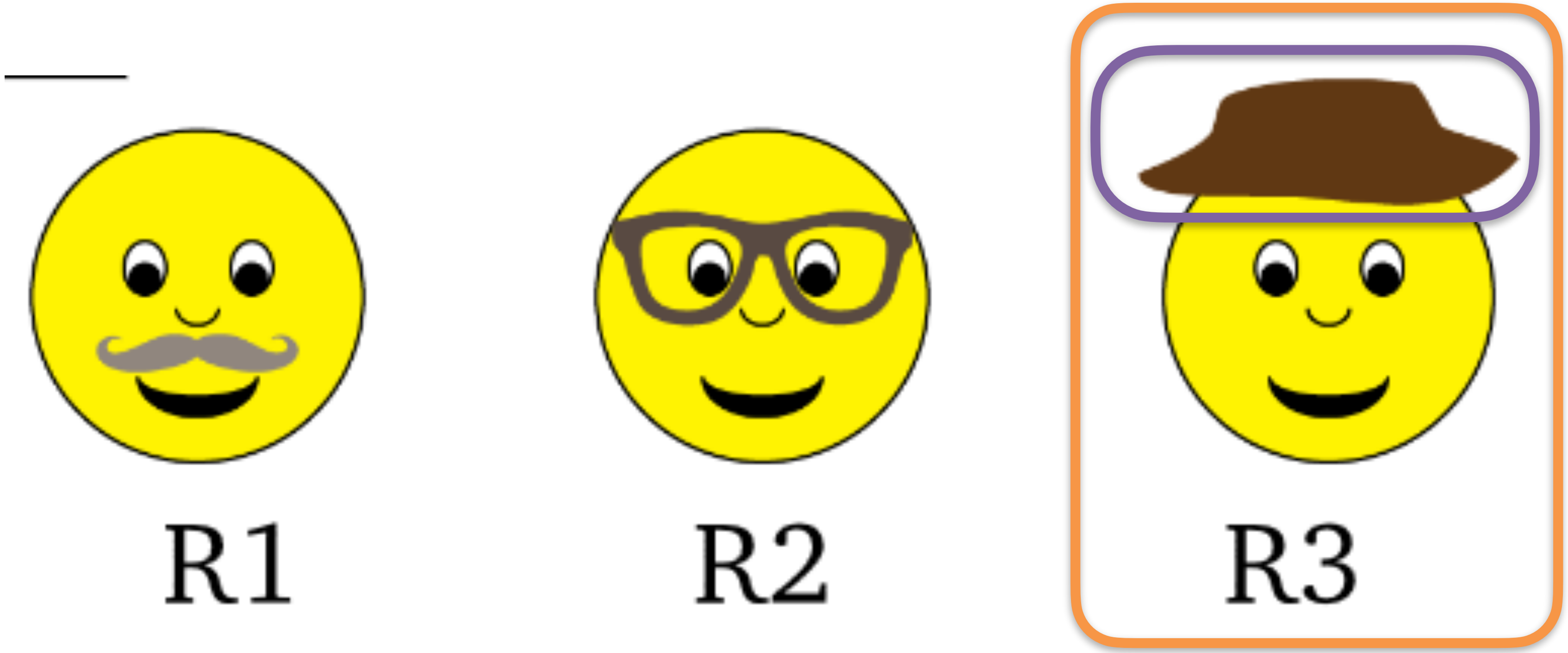
Berkeley

N L P

slides from: Daniel Fried, Yonatan Bisk, L-P Morency

Language Grounding

"Bob is wearing a hat" ⟶ $\exists\, x\,.\ \mathrm{hat}(x) \wedge \mathrm{wears}(bob, x)$



Language Grounding

"Bob is wearing a hat" $\longrightarrow$ $\exists\, x\, .\, \mathrm{hat}(x) \wedge \mathrm{wears}(\mathrm{bob}, x)$

x

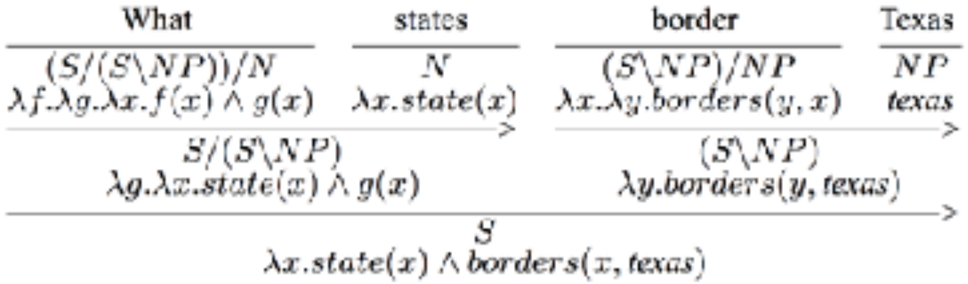
bob

Representation Learning

Representing language $\phi_l(x)$

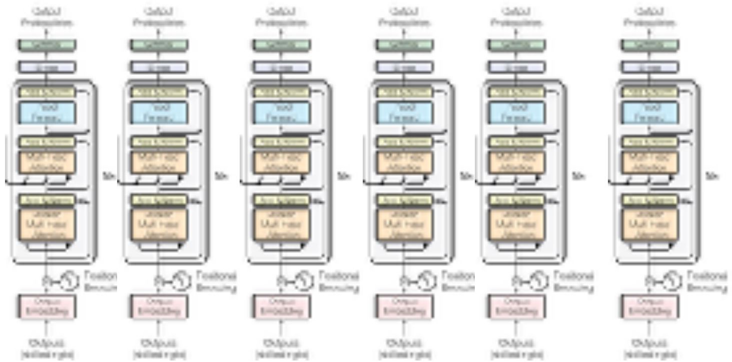
"Bob is wearing a hat"

↓

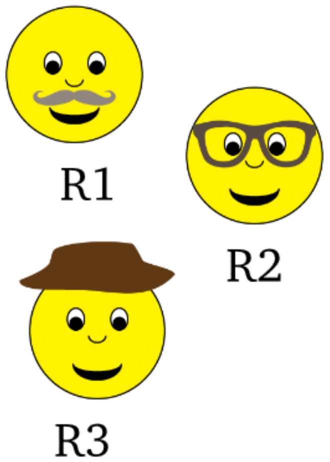


↓

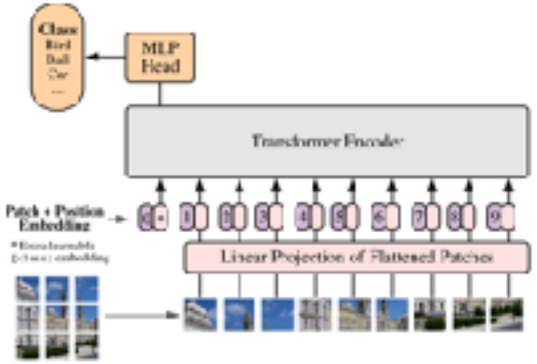
∃ x . hat(x) ∧ wears(bob, x)



Representing the world $\phi_w(i)$



	mustache?	glasses?	hat?
R1	yes	no	no
R2	no	yes	no
R3	no	no	yes

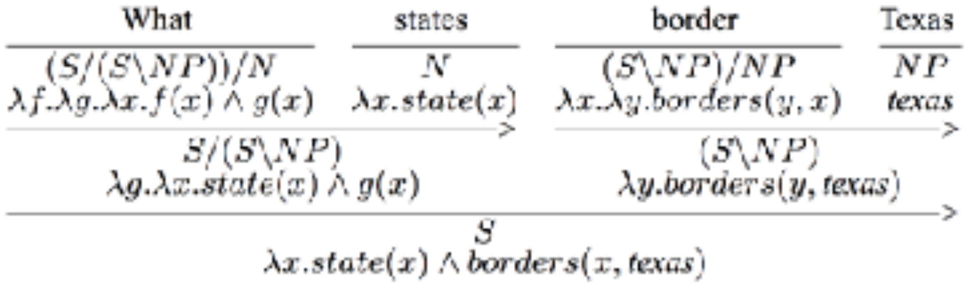


Grounding

Representing language $\phi_l(x)$

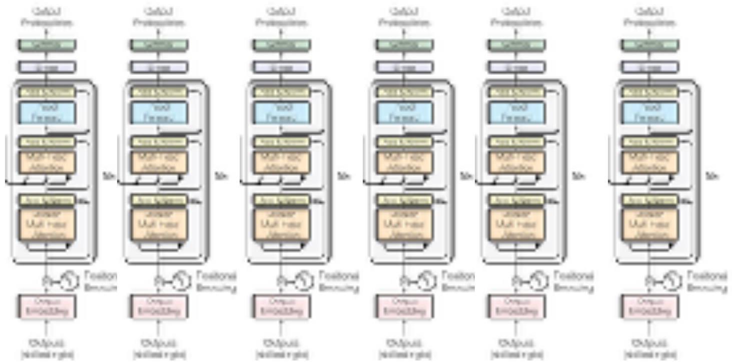
"Bob is wearing a hat"

↓



↓

$\exists$ x . hat(x) $\wedge$ wears(bob, x)



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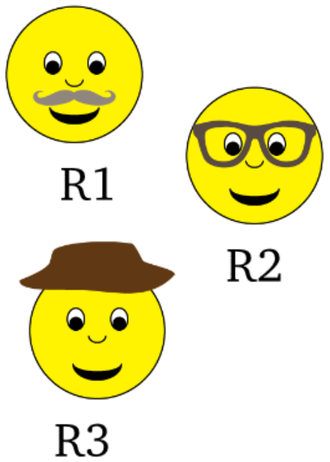

	mustache?	glasses?	hat?
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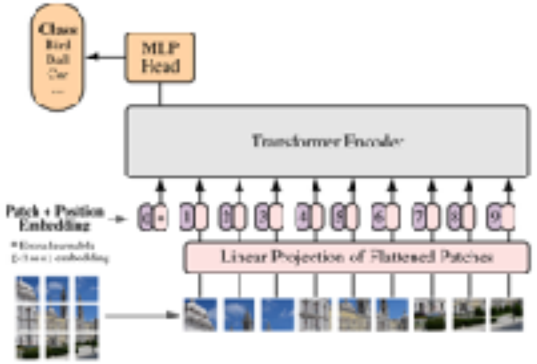


Vision-Language Tasks

- Image-text entailment

$$\phi_l(x) \stackrel{?}{=} \phi_w(i)$$

The left image contains twice the number of dogs as the right image, and at least two dogs in total are standing.

[NLVR2, Suhr et al. 2019]

右图中的人在发球，左图中的人在接球。

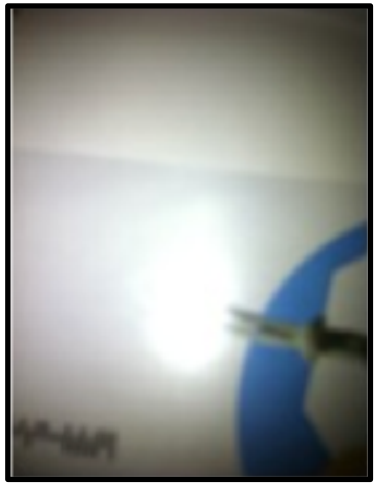
[MaRVL, Liu Fangyu et al. 2021]

Vision-Language Tasks

- Image-text entailment
- Question answering

$$\text{ask}(\phi_l(x), \phi_w(i))$$

Is this a vegetarian pizza?
[VQA, Antol et al. 2015]



Who is this mail for?
[VizWiz, Gurari et al. 2018]

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning $\arg\max_x \mathrm{sim}(\phi_l(x), \phi_w(i))$

Concadia, Kreiss et al. 2023

How would you describe this image to someone who can't see it?

"Grocery store photo of several bunches of bananas."

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning $\arg\max_{x} \mathrm{sim}(\phi_l(x), \phi_w(i))$

Concadia, Kreiss et al. 2023

What text should accompany this photo in a Wikipedia article about bananas?

"Grocery store photo of several bunches of bananas."

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning $\arg\max_x \mathrm{sim}(\phi_l(x), \phi_w(i))$

Concadia, Kreiss et al. 2023

What text should accompany this photo in a Wikipedia article about bananas?

“Grocery store photo of several bunches of bananas.”

“Cavendish bananas are the main commercial banana cultivars sold in the world market.”

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning
- Referring expression resolution

$$\arg\max_{i' \in i} \mathrm{sim}(\phi_l(x), \phi_w(i'))$$

“The guy with the hat”

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning
- Referring expression resolution

$$\arg\max_{i' \in i} \mathrm{sim}(\phi_l(x), \phi_w(i'))$$

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- Image-text entailment
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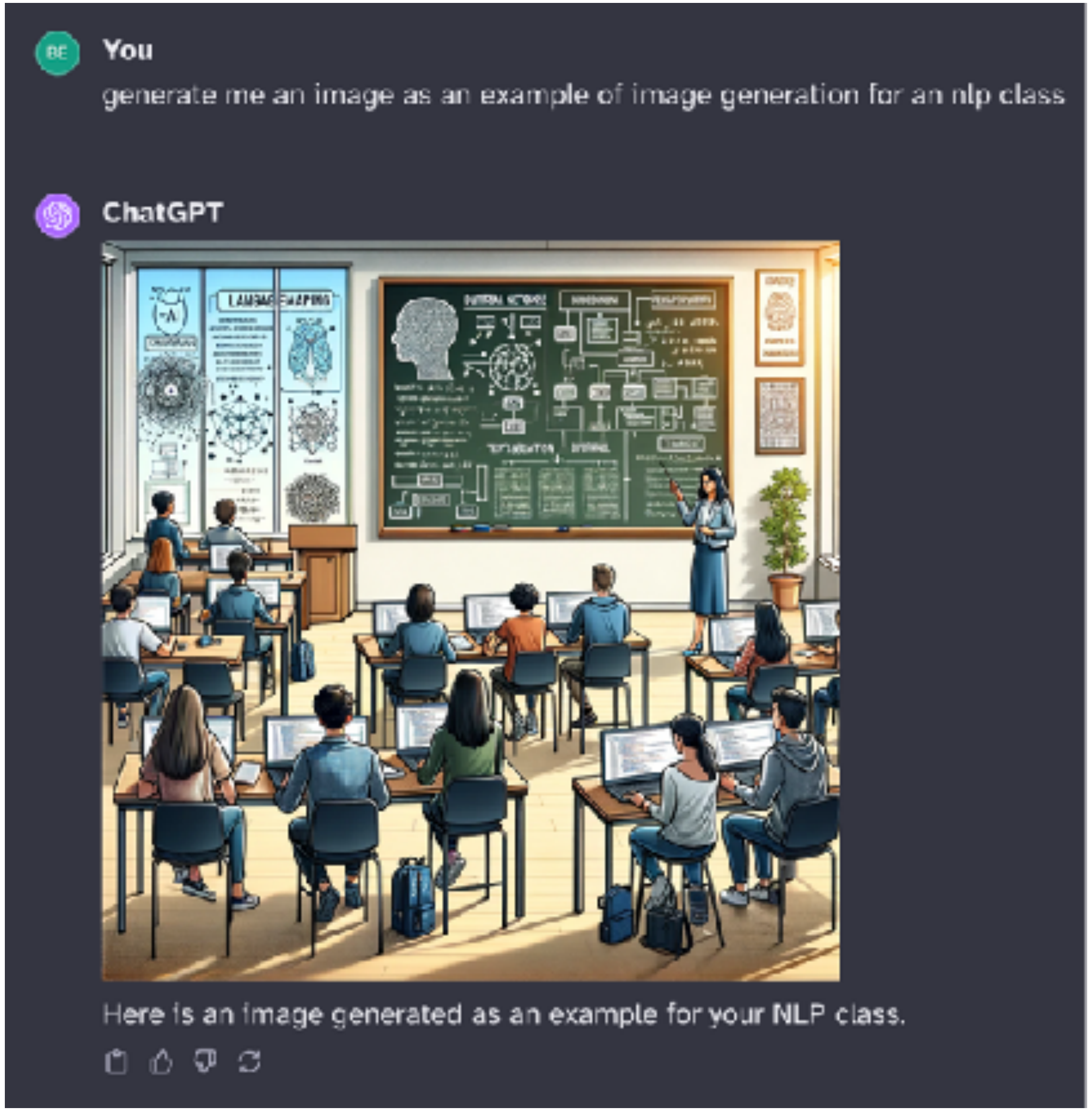
"The guy with the hat"

Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning
- Referring expression resolution
- Image generation

$$\arg\max_i \mathrm{sim}(\phi_l(x), \phi_w(i))$$

An illustrated scene in a classroom setting focused on Natural Language Processing (NLP). The classroom is modern with a large blackboard at the front, displaying diagrams of neural networks and examples of NLP tasks like text classification and machine translation. There are students of various descents sitting at desks with laptops open, showing code and language statistics. A professor, a Middle-Eastern woman, stands at the front with a pointer, gesturing towards the blackboard. Some of the students are taking notes, while others are discussing amongst themselves. The room has large windows with sunlight streaming in, and posters on the wall about AI and linguistics.



Vision-Language Tasks

- Image-text entailment
- Question answering
- Image captioning
- Referring expression resolution
- Image generation
- Conversational question answering
- Video question answering, captioning
- Instruction following

Methods

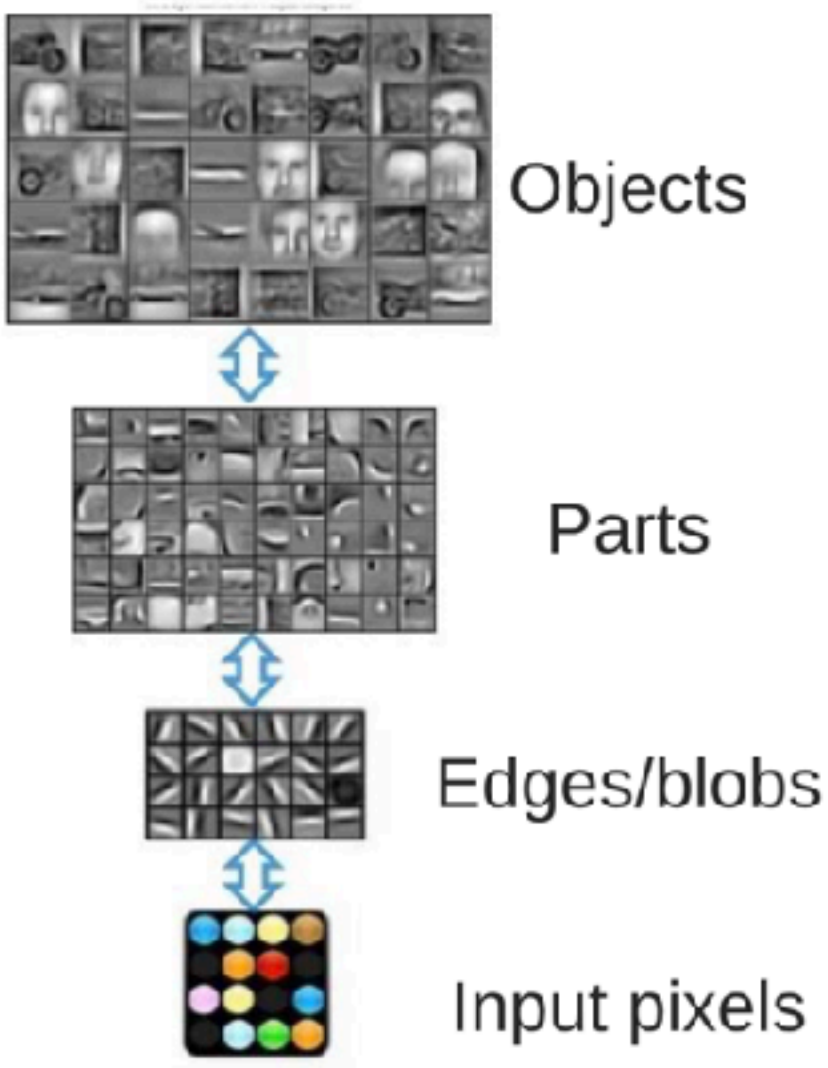
- Language representations
- Image representations
- Joint embedding spaces
- Multimodal transformers
- Neurosymbolic / code as a bottleneck

Image Representation: CNNs

Goal: building more abstract, hierarchical visual representations

Key advantages:

1) Inspired from visual cortex
2) Encourages visual abstraction
3) Exploits *translation invariance*
4) Kernels/templates are learned
5) Fewer parameters than MLP



Slides from LP Morency

Image Representation: CNNs

2 Data Points – Which one is up?

- MLP can easily learn this task (possibly with only 1 neuron!)

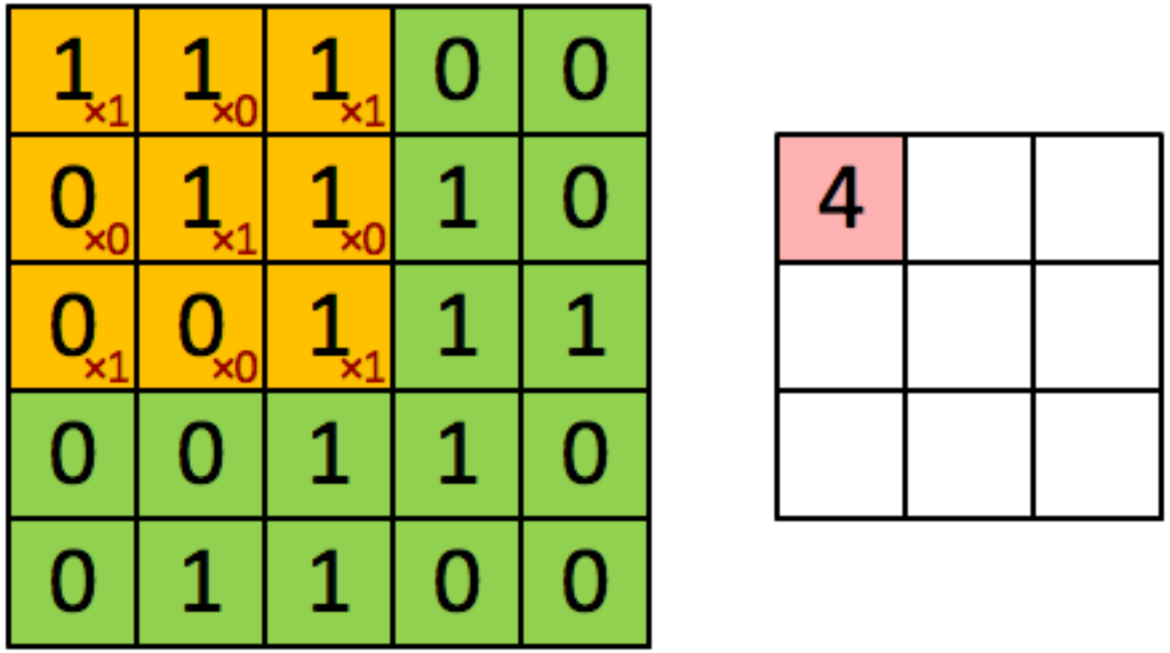
What happens if the face is slightly translated?

- The model should still be able to classify it

Conventional MLP models are not translation invariant!

- But CNNs are kernel-based, which helps with translation invariance and reduce number of parameters

CNNs: Convolution



Image

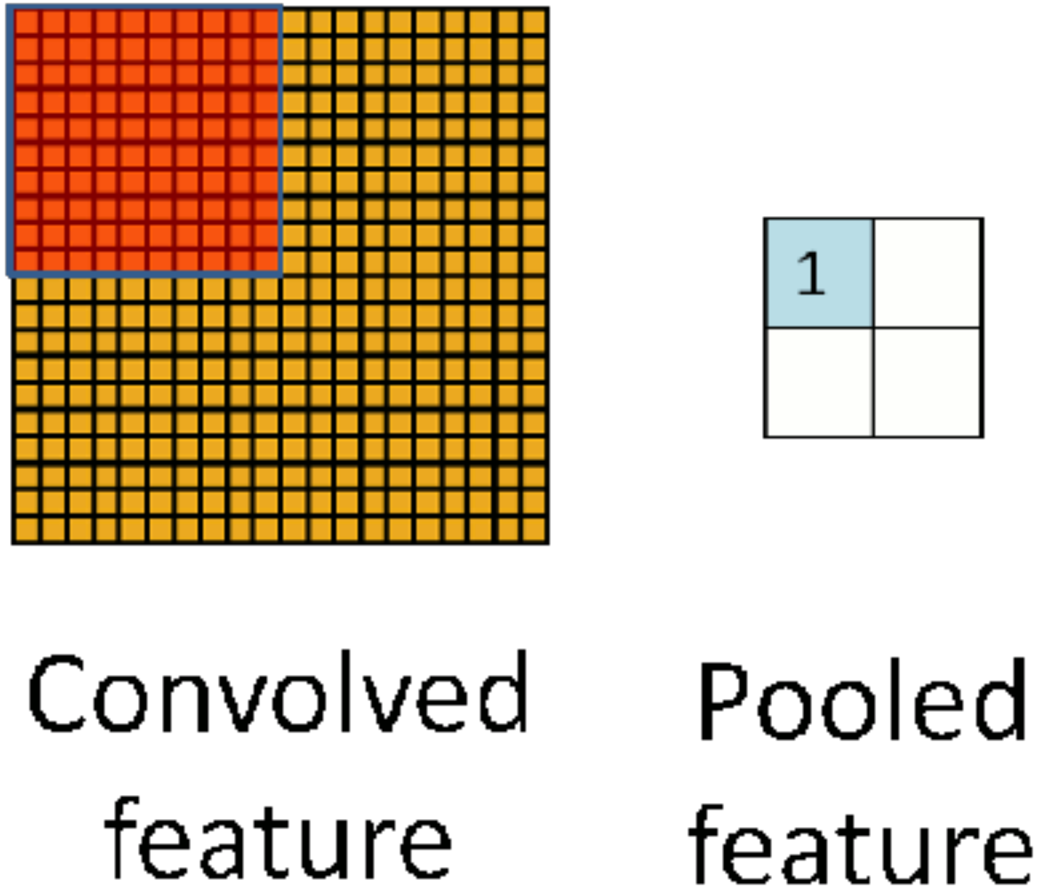
Convolved Feature

Filter:

$$\begin{matrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{matrix}$$

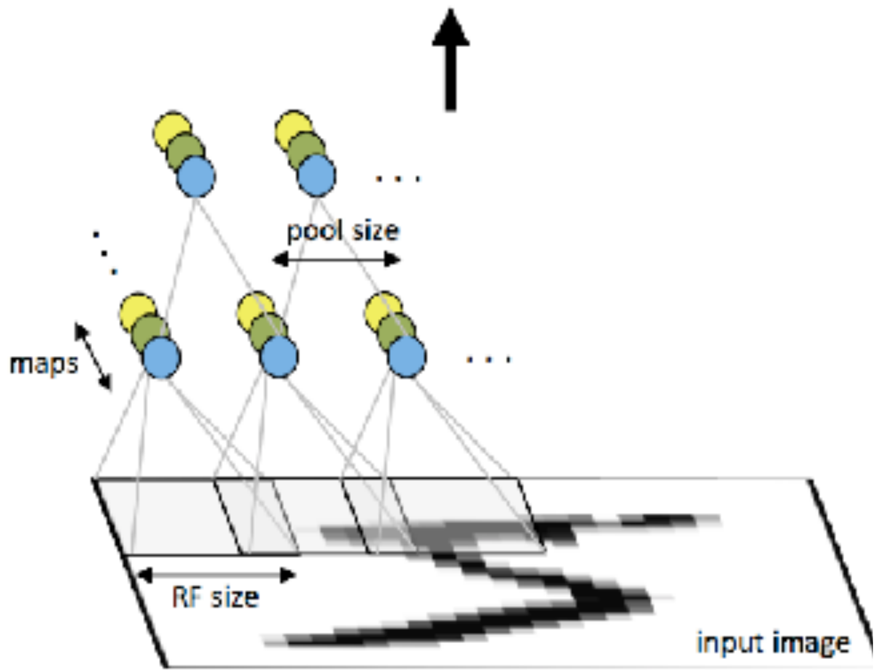
http://ufldl.stanford.edu/tutorial/

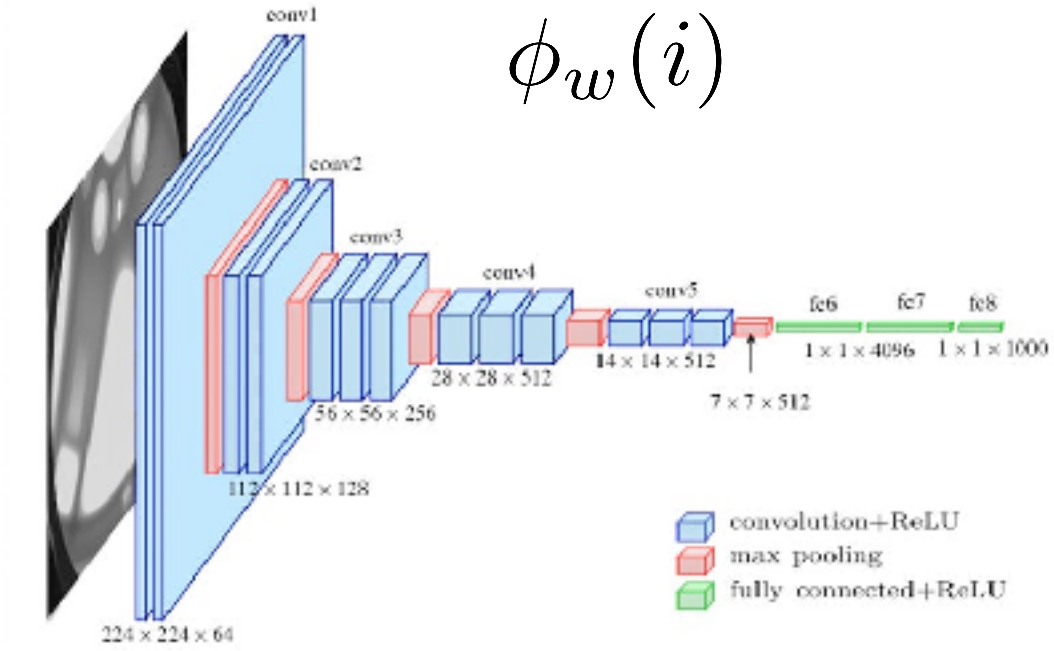
CNNs: Pooling



http://ufldl.stanford.edu/tutorial/

Multilayer CNNs





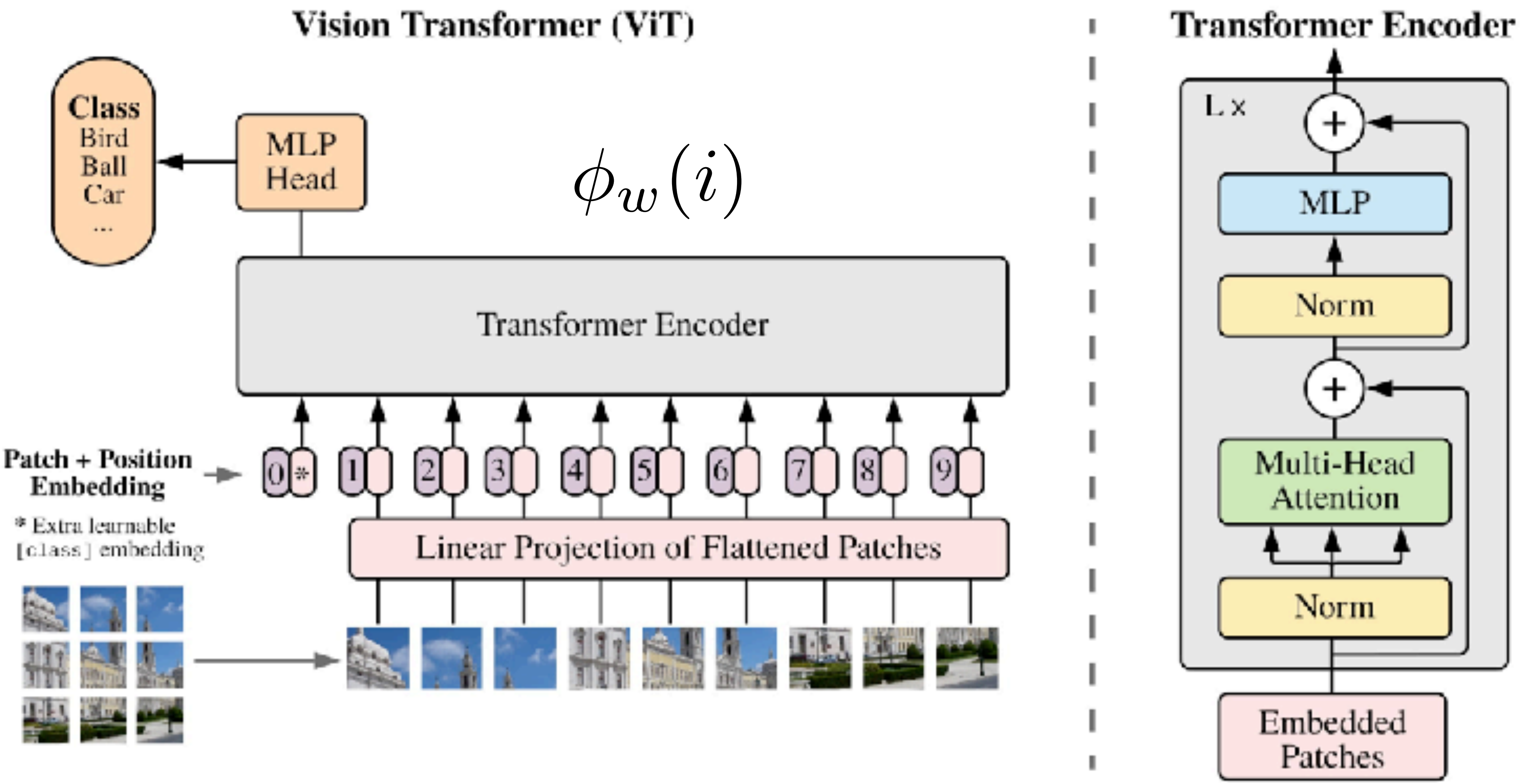
$$\phi_w(i)$$

http://ufldl.stanford.edu/tutorial/ , VGGNet (Simonyan et al. 2014)

CNN Explainer

https://poloclub.github.io/cnn-explainer/

Vision Transformer

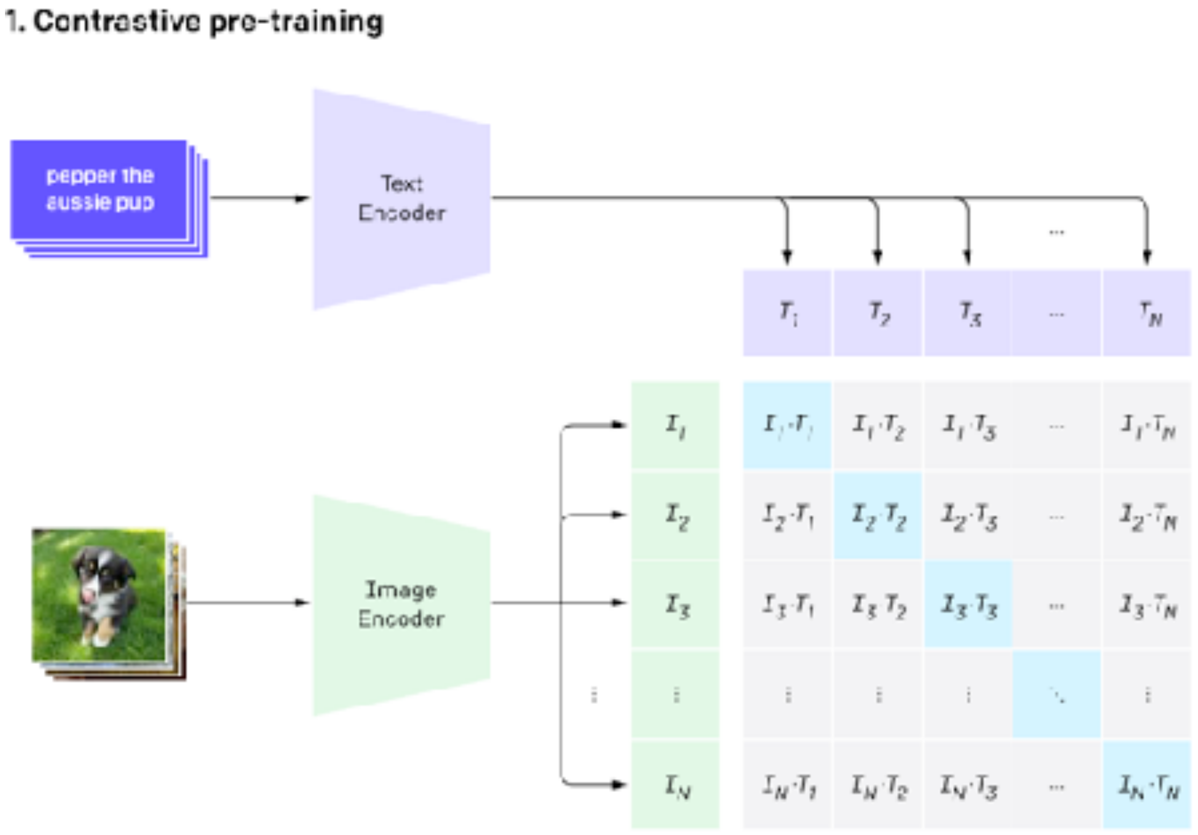


ViT, Dosovitskiy et al. 2021

Image-Text Matching

- Idea: learn a shared representational space of images and text
- I.e., representation of sentence *x* paired with image *i* should be similar to one another $\phi_l(x) \approx \phi_w(i)$
- CLIP (Contrastive Language-Image Pre-Training), Radford et al. 2021

CLIP




```
# image_encoder - ResNet or Vision Transformer
# text_encoder - CBOW or Text Transformer
# I[n, h, w, c] - minibatch of aligned images
# T[n, l] - minibatch of aligned texts
# W_i[d_i, d_e] - learned proj of image to embed
# W_t[d_t, d_e] - learned proj of text to embed
# t - learned temperature parameter

# extract feature representations of each modality
I_f = image_encoder(I) #[n, d_i]
T_f = text_encoder(T) #[n, d_t]

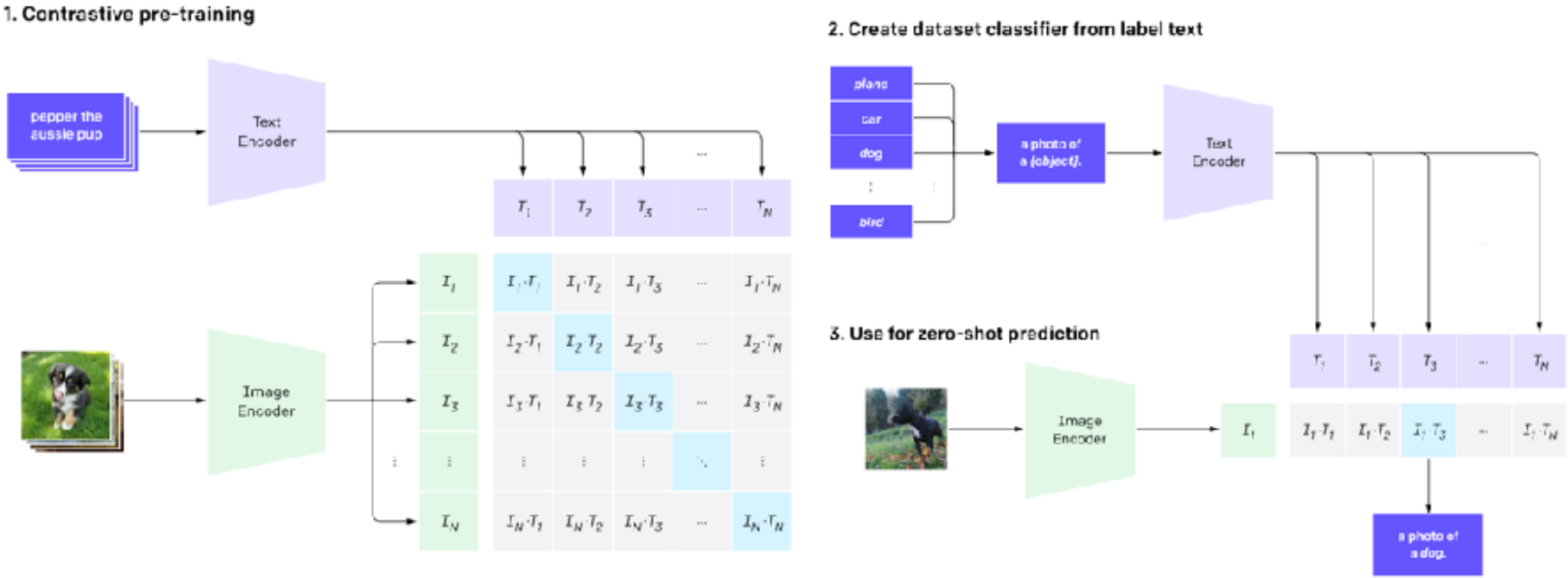
# joint multimodal embedding [n, d_e]
I_e = l2_normalize(np.dot(I_f, W_i), axis=1)
T_e = l2_normalize(np.dot(T_f, W_t), axis=1)

# scaled pairwise cosine similarities [n, n]
logits = np.dot(I_e, T_e.T) * np.exp(t)

# symmetric loss function
labels = np.arange(n)
loss_i = cross_entropy_loss(logits, labels, axis=0)
loss_t = cross_entropy_loss(logits, labels, axis=1)
loss = (loss_i + loss_t) / 2
```

Radford et al. 2021

CLIP



Radford et al. 2021

CLIP Applied: Image-Text Retrieval

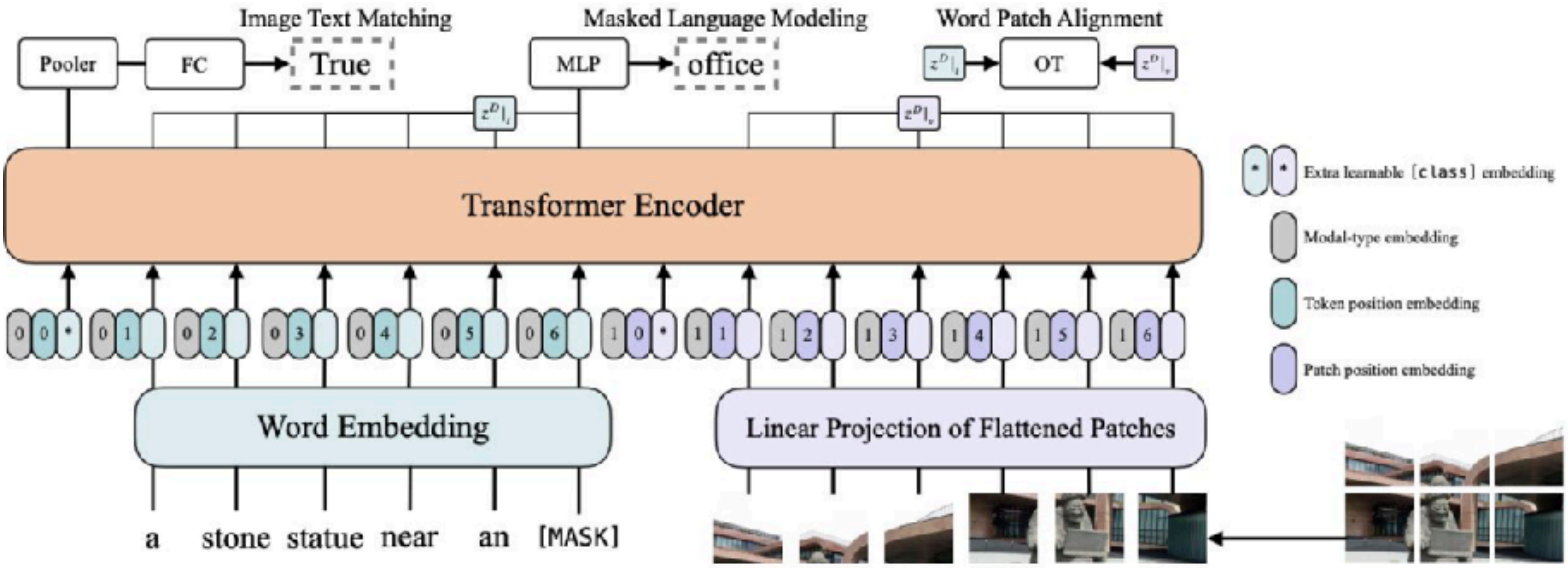
E.g., retrieve an image given a piece of text:

$$\arg\max_{i \in \mathcal{I}} \phi_l(x) \cdot \phi_w(i)$$

https://rom1504.github.io/clip-retrieval/

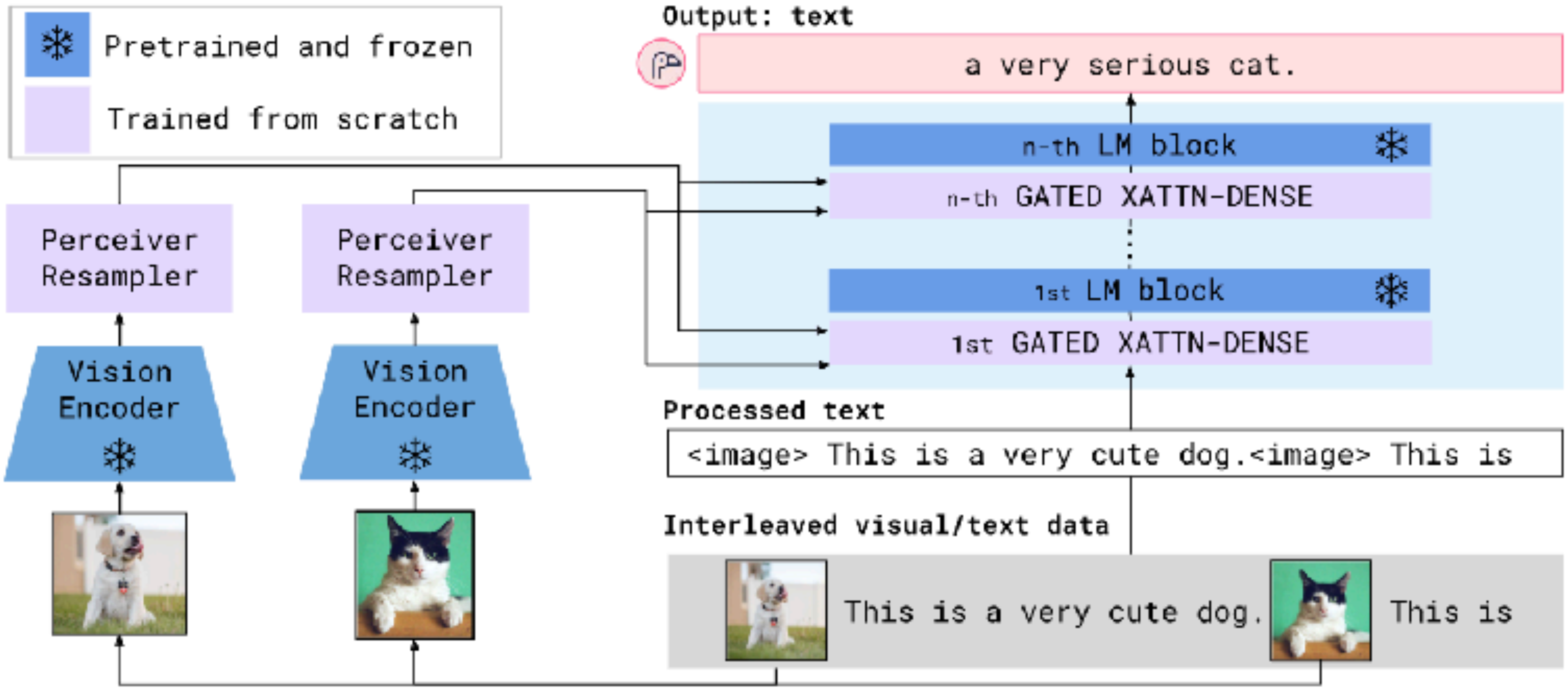
Joint Encoding: Multimodal Transformers

ViLT (Kim et al. 2021), encoder-only model (like BERT)



Joint Encoding: Multimodal Transformers

Flamingo, Alayrac et al. 2022



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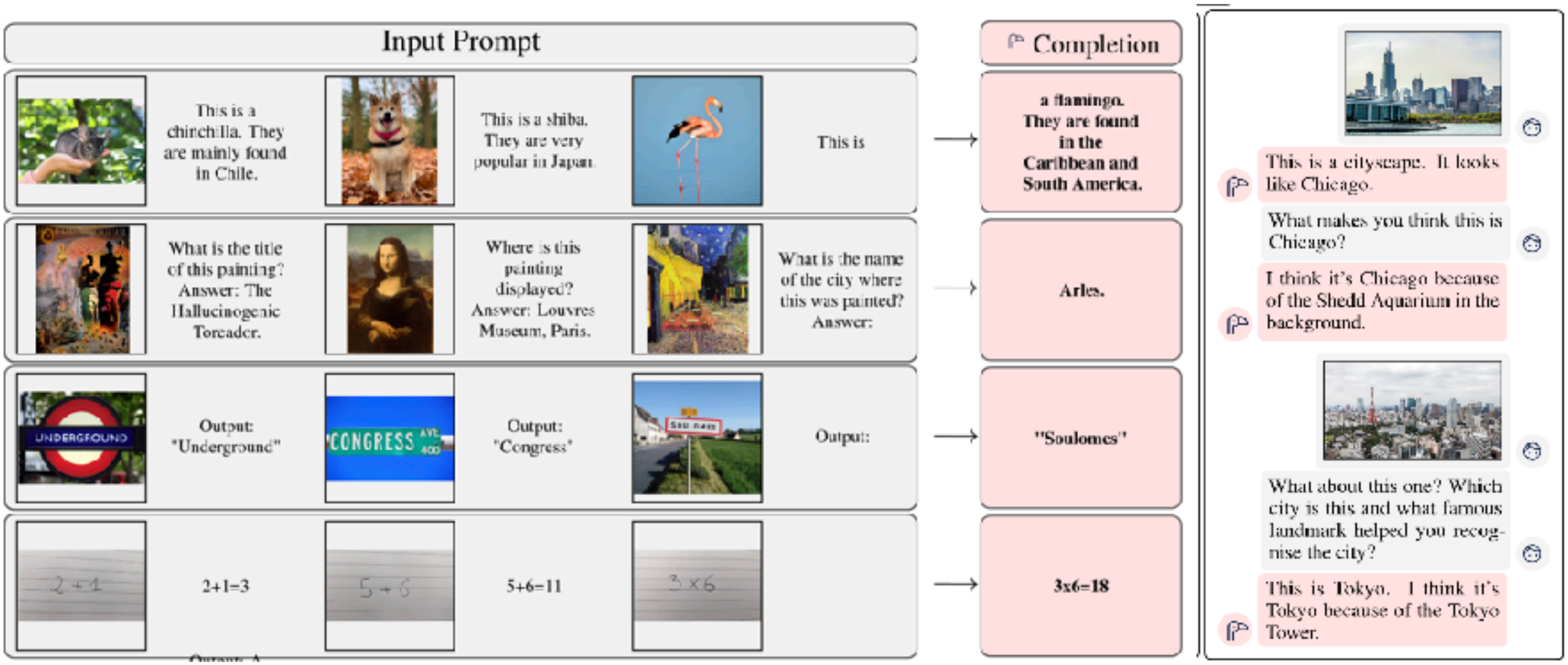
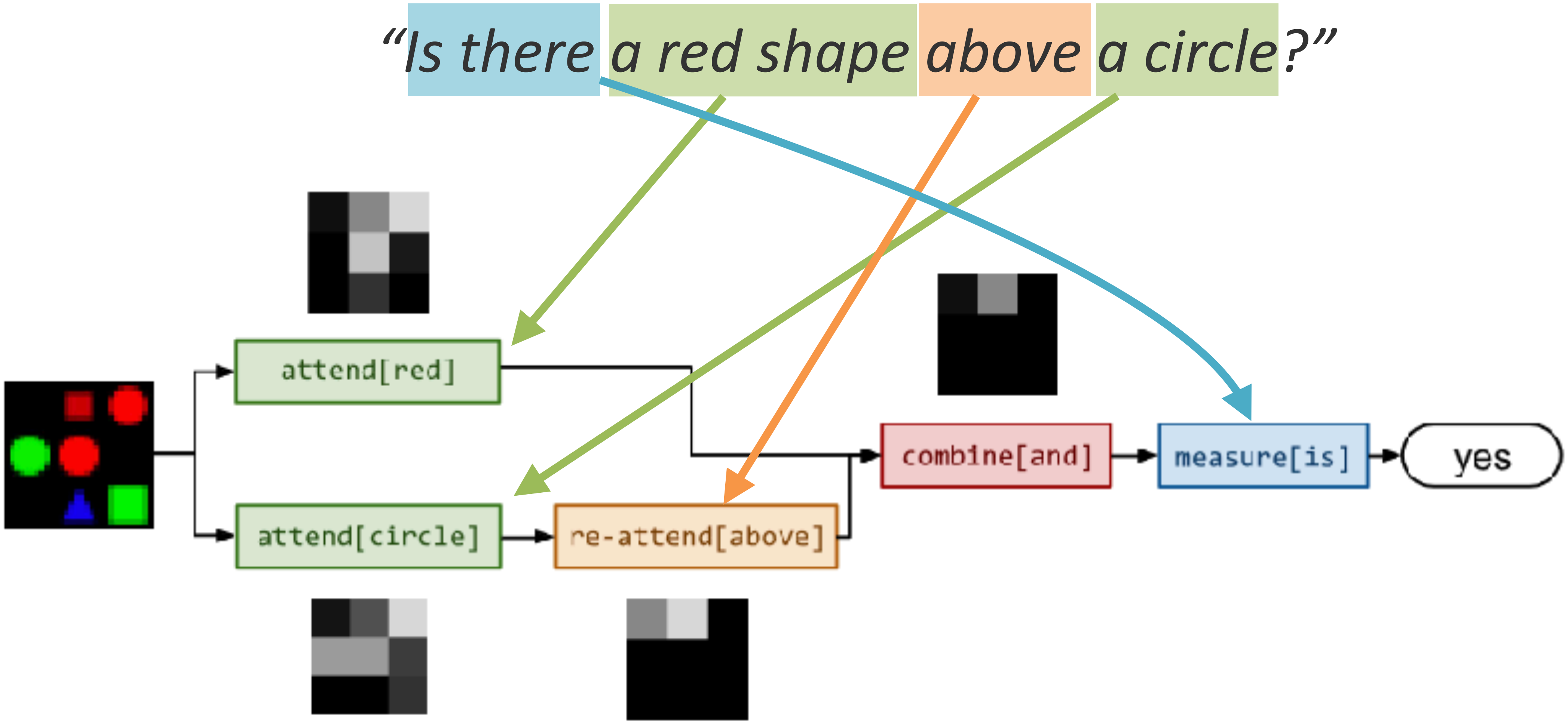


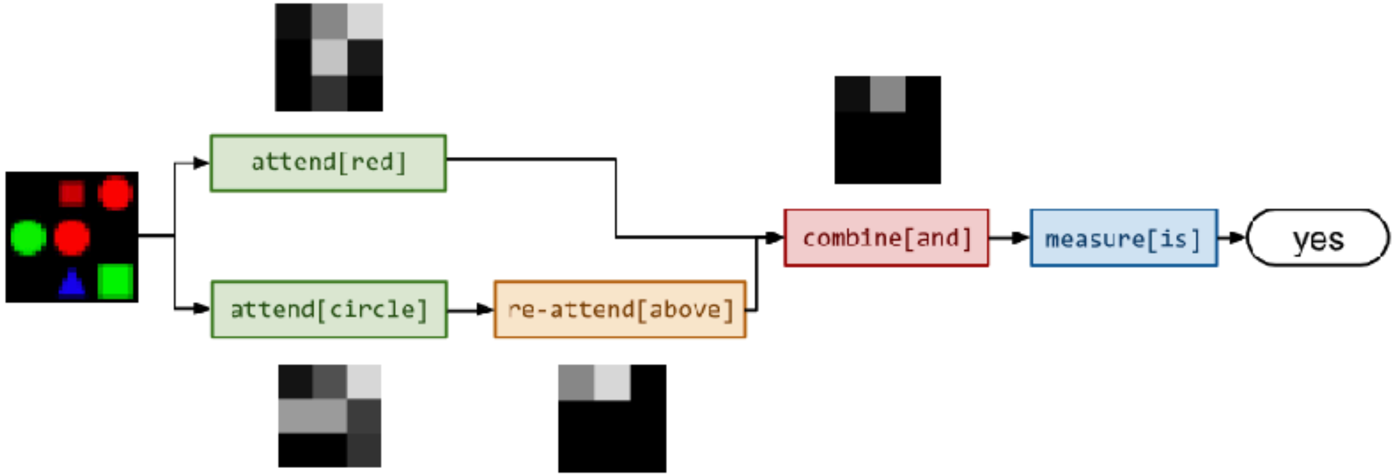
Neuromodular Approaches



Neural Module Networks, Andreas et al. 2017

Neuromodular Approaches

"Is there a red shape above a circle?"

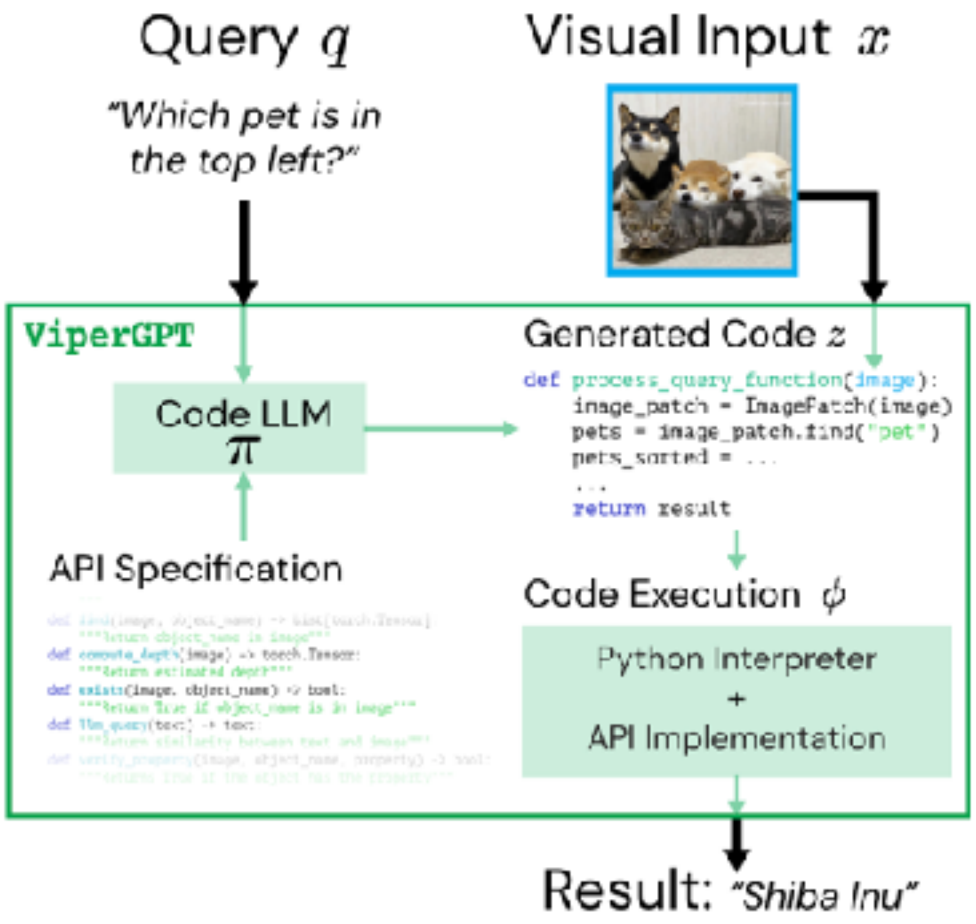


- Map x to some structured representation $\phi_l(x)$
- Manipulate image $\phi_w(i)$ according to components of this structured representation

Neural Module Networks, Andreas et al. 2017

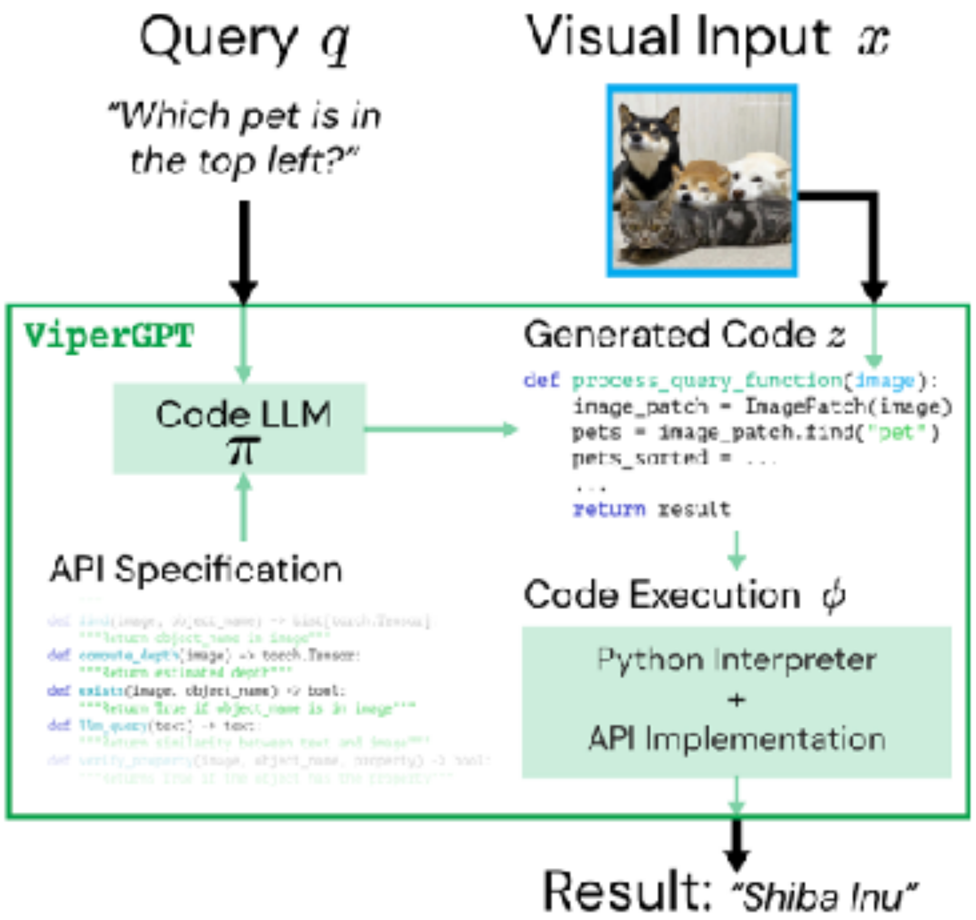
Neuromodular Approaches

- Text representation: executable python code
- Image representation: pixels (also assume access to some computer vision algorithms)
- Grounding: executing python code on image representations



Neuromodular Approaches

With sufficiently powerful code LLMs (e.g., Codex) and access to an API that can operate on top of images (or other modalities), no domain-specific or multimodal training is necessary



Neuromodular Approaches

Query: How many muffins can each kid have for it to be fair?

ViperGPT, Surís et al. 2023

Neuromodular Approaches

Query: How many muffins can each kid have for it to be fair?

Generated Code

```
def execute_command(image):
    image_patch = ImagePatch(image)
    muffin_patches = image_patch.find("muffin")
    kid_patches = image_patch.find("kid")
    return str(len(muffin_patches) // len(kid_patches))
```

ViperGPT, Surís et al. 2023

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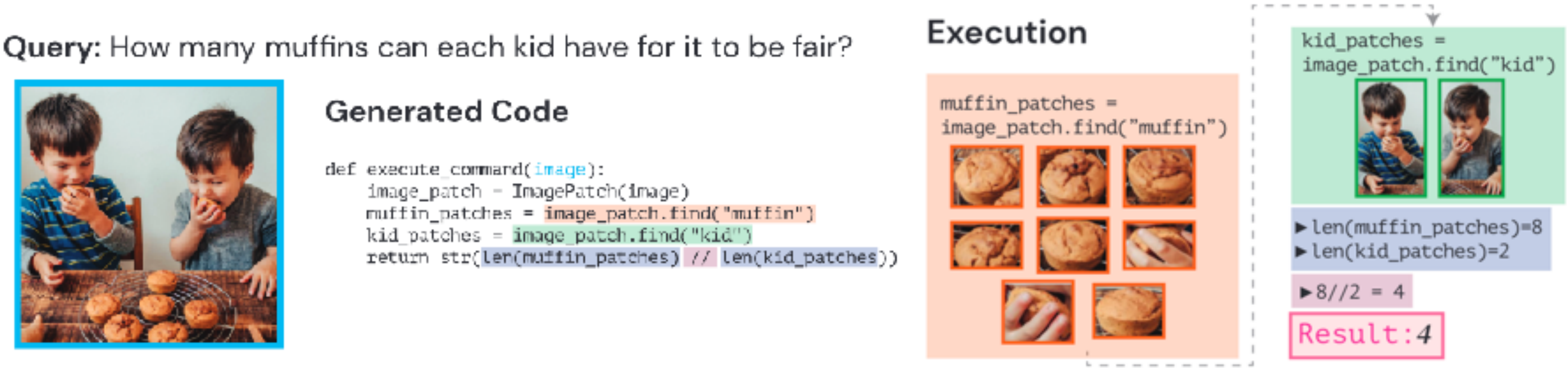

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```

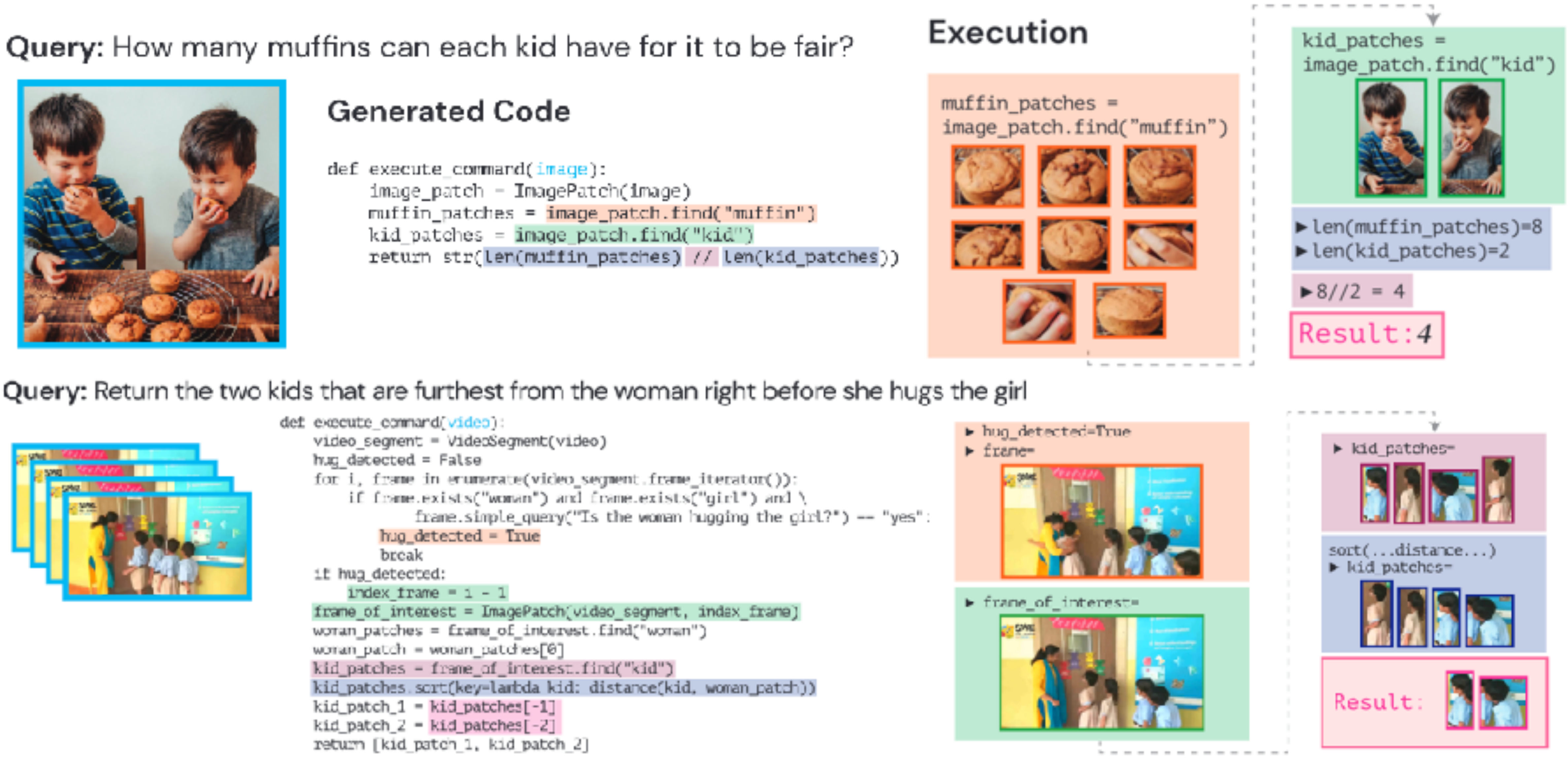
Execution

Query: Return the two kids that are furthest from the woman right before she hugs the girl

```
def execute_command(video):
    video_segment = VideoSegment(video)
    hug_detected = False
    for i, frame in enumerate(video_segment.frame_iterator()):
        if frame.exists("woman") and frame.exists("girl") and \
                frame.simple_query("Is the woman hugging the girl?") == "yes":
            hug_detected = True
            break
    if hug_detected:
        index_frame = i - 1
    frame_of_interest = ImagePatch(video_segment, index_frame)
    woman_patches = frame_of_interest.find("woman")
    woman_patch = woman_patches[0]
    kid_patches = frame_of_interest.find("kid")
    kid_patches.sort(key=lambda kid: distance(kid, woman_patch))
    kid_patch_1 = kid_patches[-1]
    kid_patch_2 = kid_patches[-2]
    return [kid_patch_1, kid_patch_2]
```

ViperGPT, Surís et al. 2023

Neuromodular Approaches



ViperGPT, Surís et al. 2023

Neuromodular Approaches

Query: What color do you get if you combine the colors of the viper and the flower?

```
def execute_command(image):
    image_patch = ImagePatch(image)
    viper_patches = image_patch.find("viper")
    flower_patches = image_patch.find("flower")
    viper_patch = viper_patches[0]
    flower_patch = flower_patches[0]
    viper_color = viper_patch.simple_query("What color is the viper?")
    flower_color = flower_patch.simple_query("What color is the flower?")
    color = llm_query(f"What color do you get if you combine the colors
                        {viper_color} and {flower_color}?")
    return color
```

▶ viper_patch= 

▶ flower_patch= 

▶ viper_color='blue'

▶ flower_color='red'

▶ color='purple'

Result: *"purple"*

ViperGPT, Surís et al. 2023

Drawback: Context-Dependence

"Is the potted plant to the right of the bench?"

Visual Spatial Reasoning, Liu Fangyu et al. 2023

Drawback: Context-Dependence

"Is the potted plant to the right of the bench?"

```
bbox_plant = detect(image, "potted plant")
bbox_bench = detect(image, "bench")
return bbox_plant.x > bbox_bench.x
```

Visual Spatial Reasoning, Liu Fangyu et al. 2023

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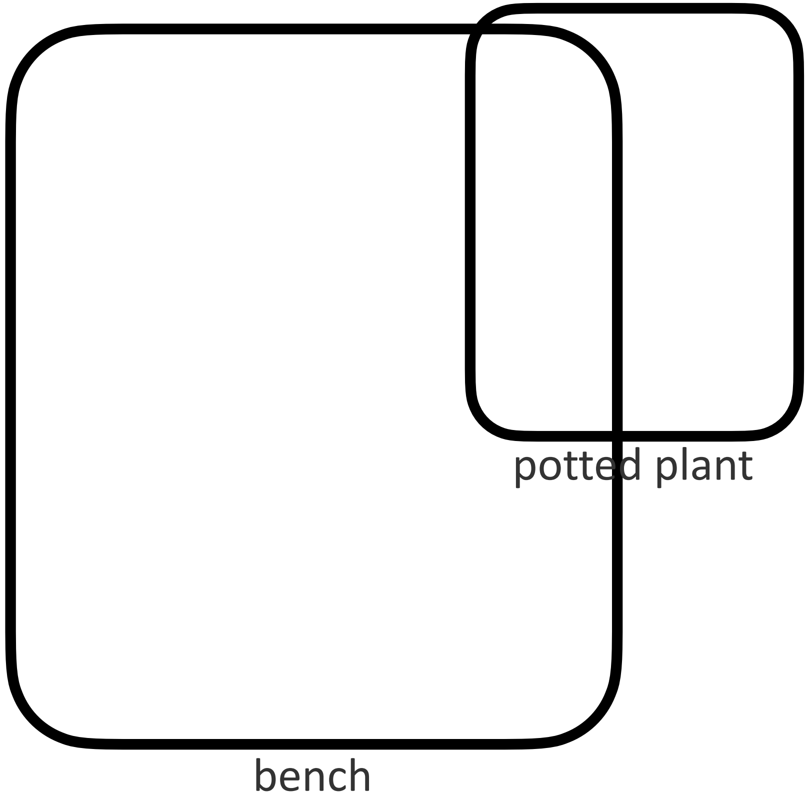

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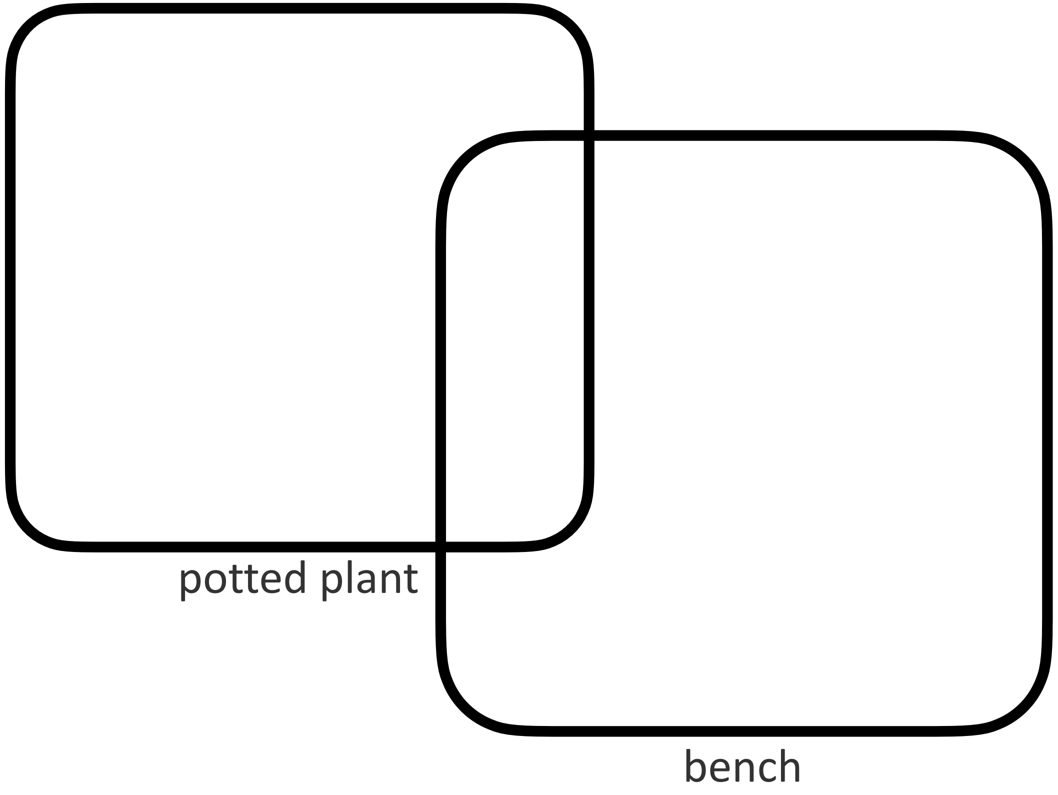

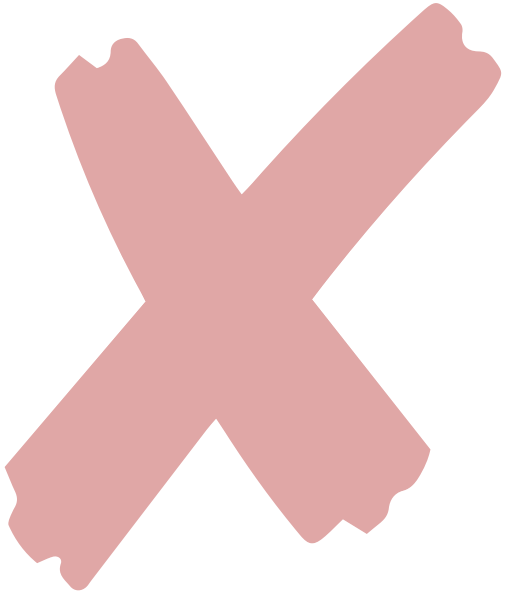

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