No Training?
Towards Adapting Zero-Shot Models to Robotics Tasks

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CVPR 2022 tutorial on vision-based robot learning

Motivation

- Large, pre-trained models have made a splash in:

  📚 NLP

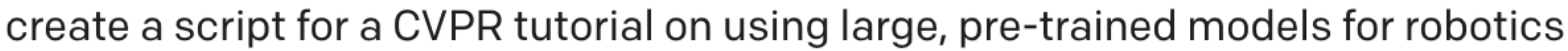
  👀 Vision

- Many such models show *zero-shot* capabilities

- Ideally we can leverage these existing models in other domains:

  🤖 Robotics!

Overview (According to GPT-3)



create a script for a CVPR tutorial on using large, pre-trained models for robotics

https://beta.openai.com/playground

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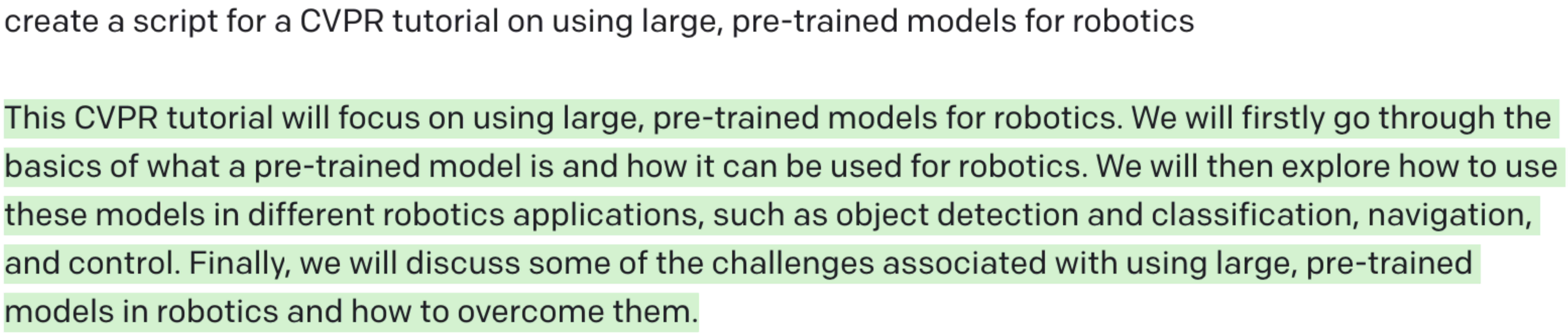

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This CVPR tutorial will focus on using large, pre-trained models for robotics. We will firstly go through the basics of what a pre-trained model is and how it can be used for robotics. We will then explore how to use these models in different robotics applications, such as object detection and classification, navigation, and control. Finally, we will discuss some of the challenges associated with using large, pre-trained models in robotics and how to overcome them.

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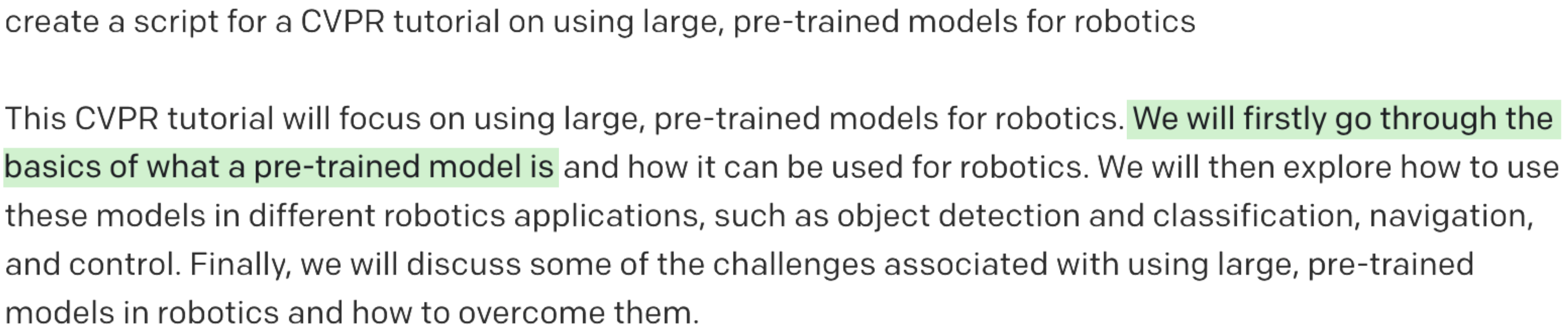

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- ✅ Pre-training at a high-level and success stories
- ✅ Language Modeling
- ✅ Vision-Language Modeling
- ❌ How to pre-train a robot with robot data

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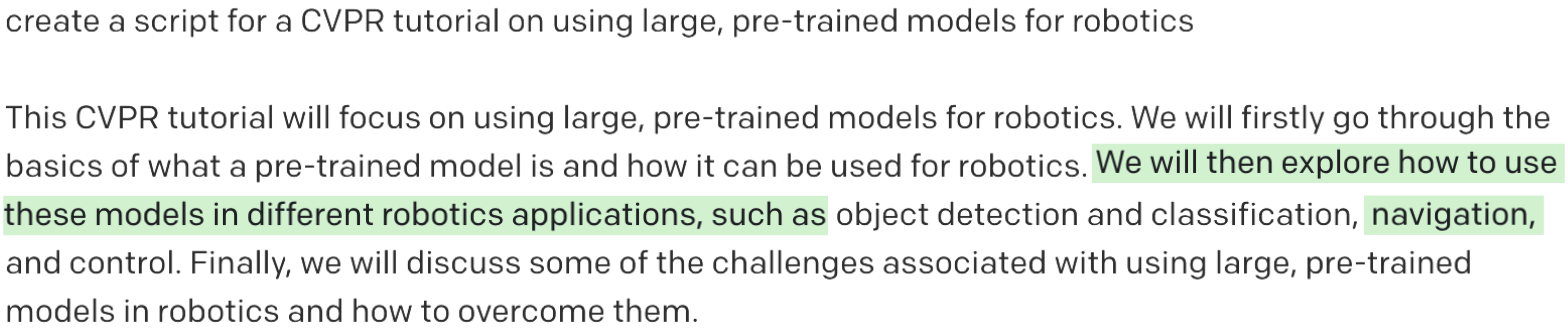

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- ✅ Manipulation
- ✅ Planning
- ✅ Navigation
- ❌ Object detection

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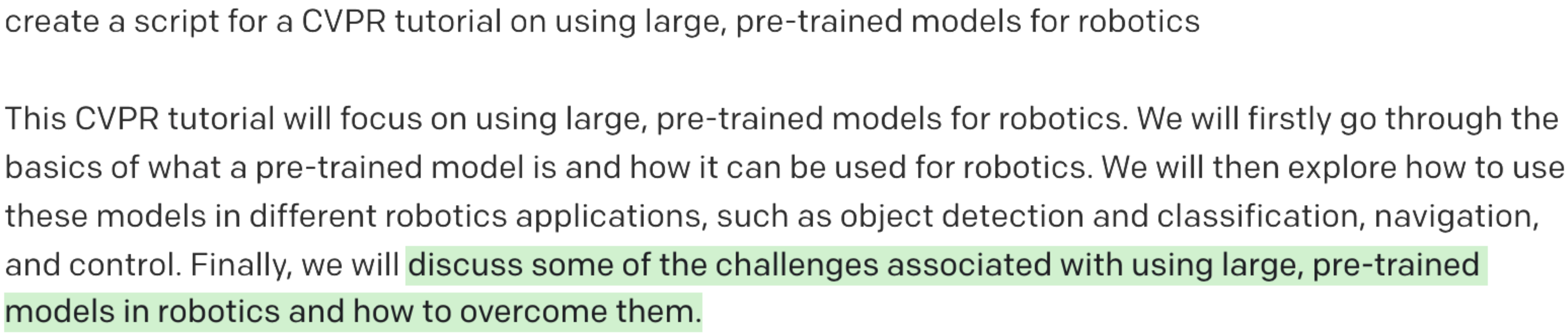

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✅ Limitations
✅ Exciting future directions!

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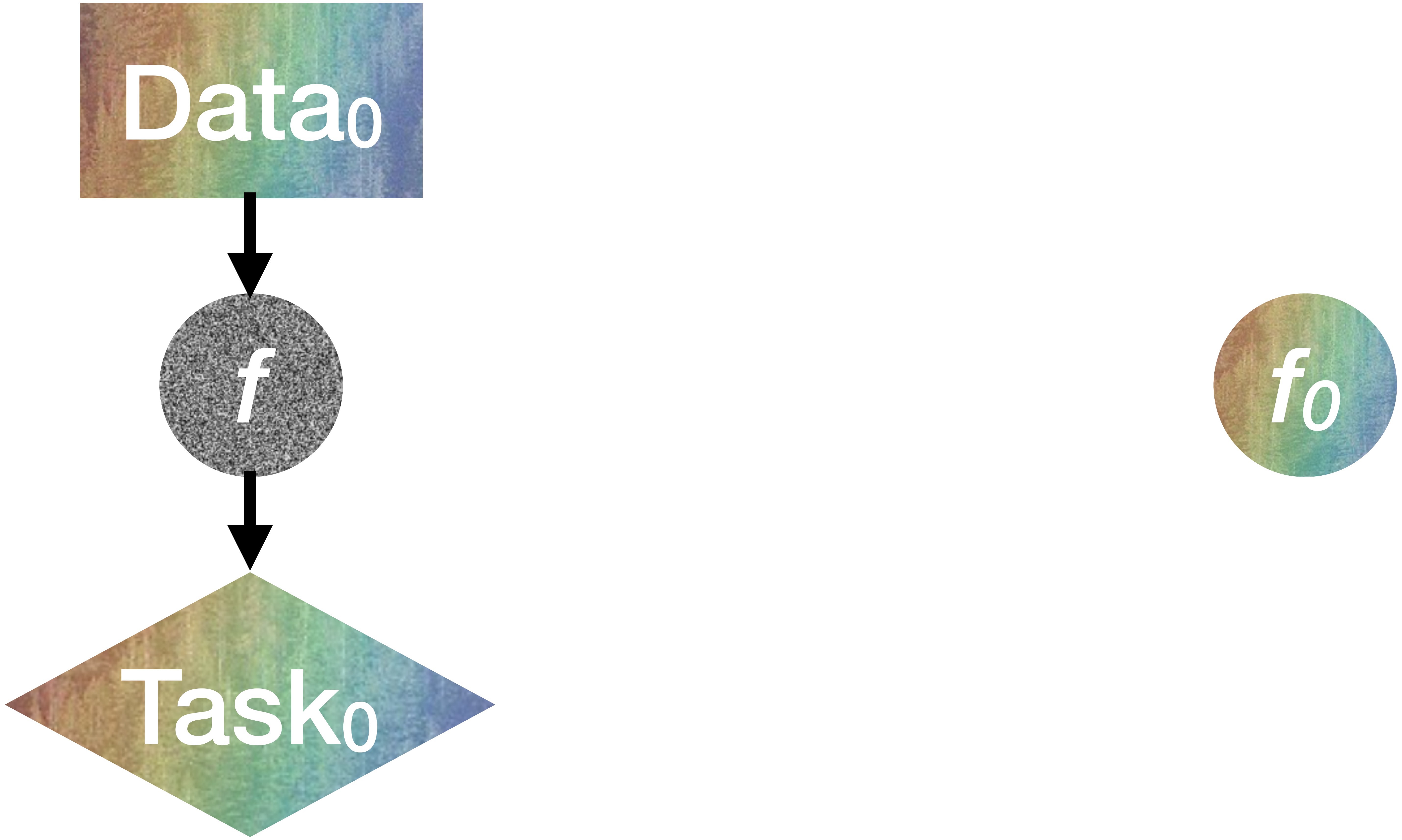
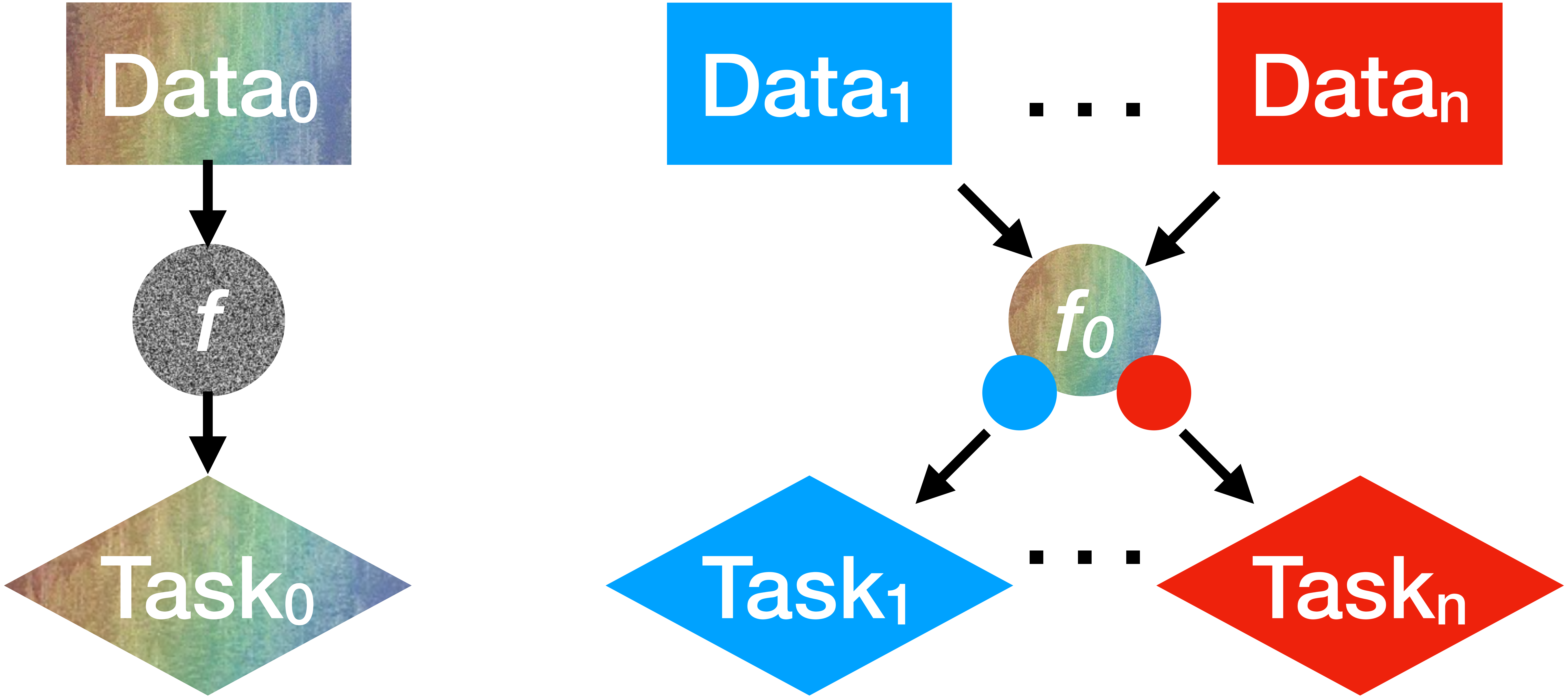
Pre-Training

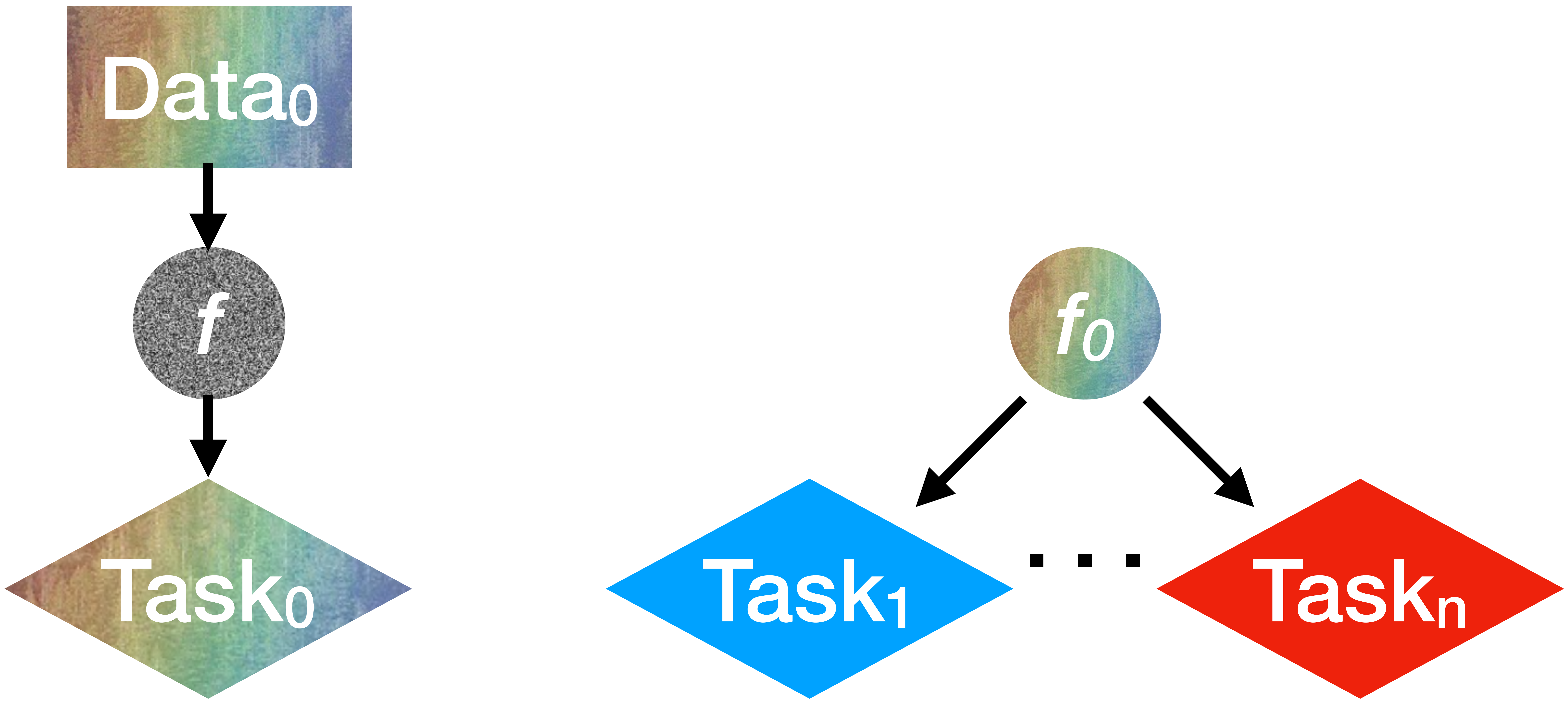


Fine-Tuning



Data_0
f
Task_0
Data_1
. . .
Data_n
f_0
Task_1
. . .
Task_n

Zero-Shot Inference



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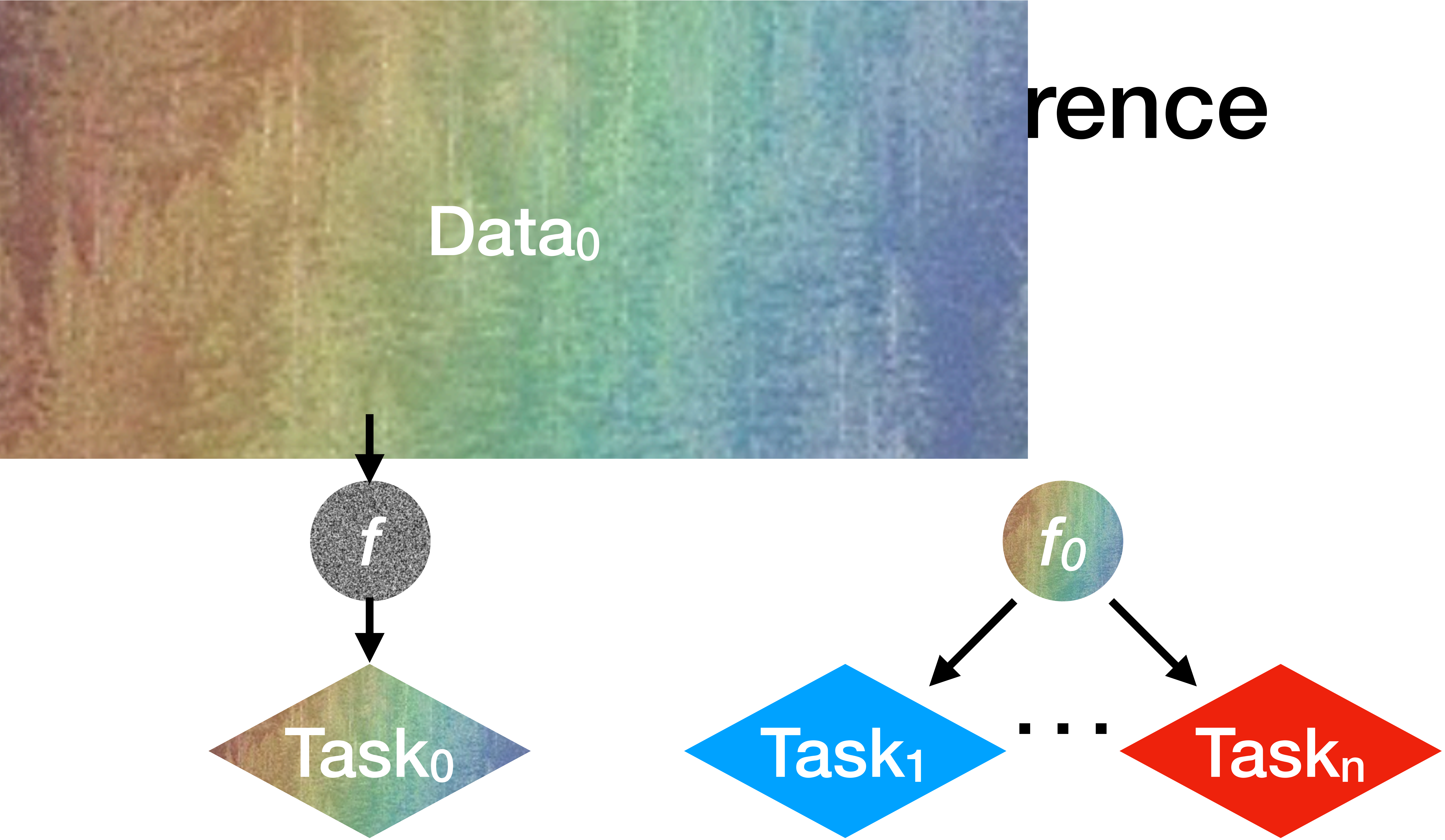

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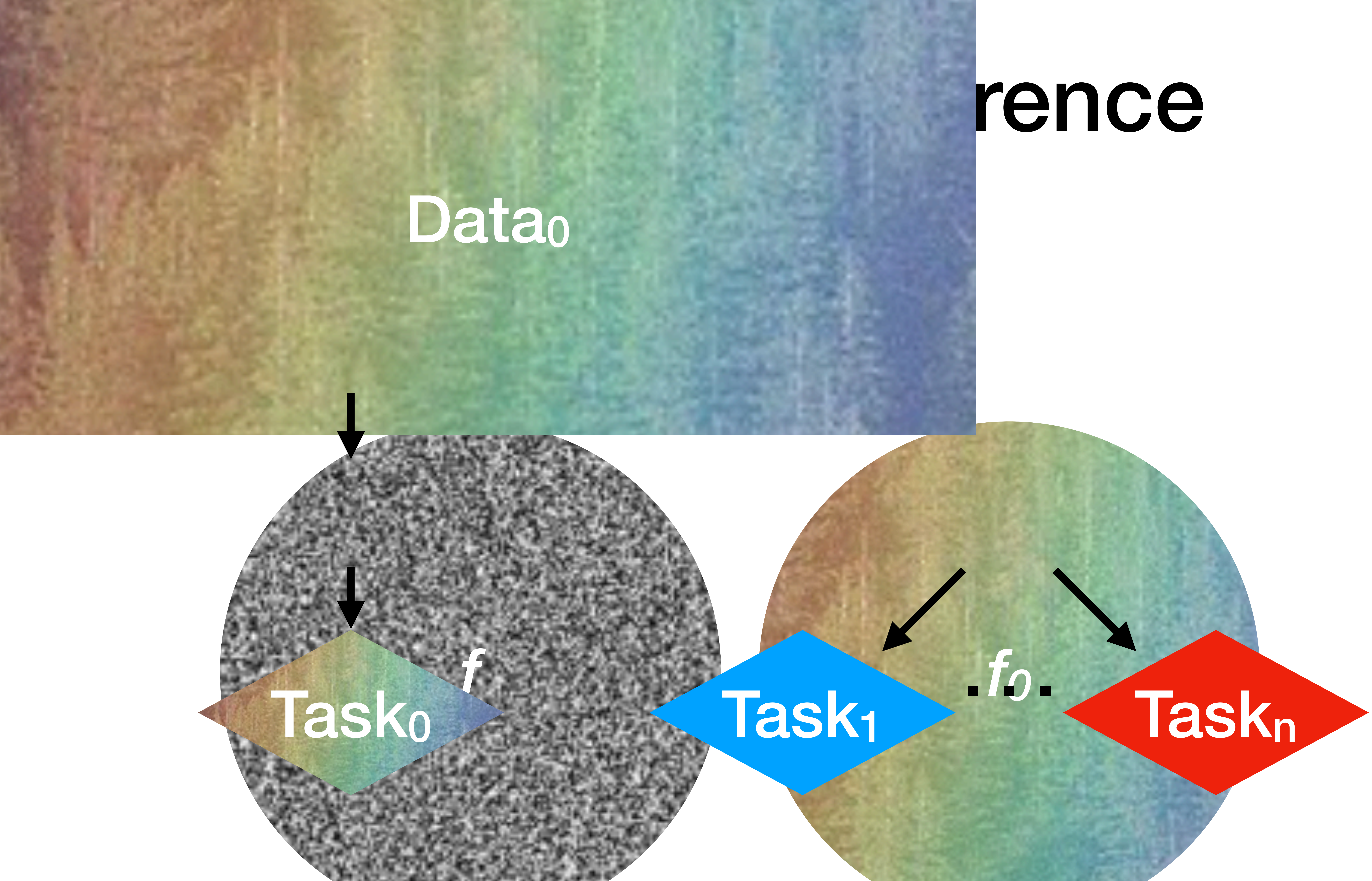
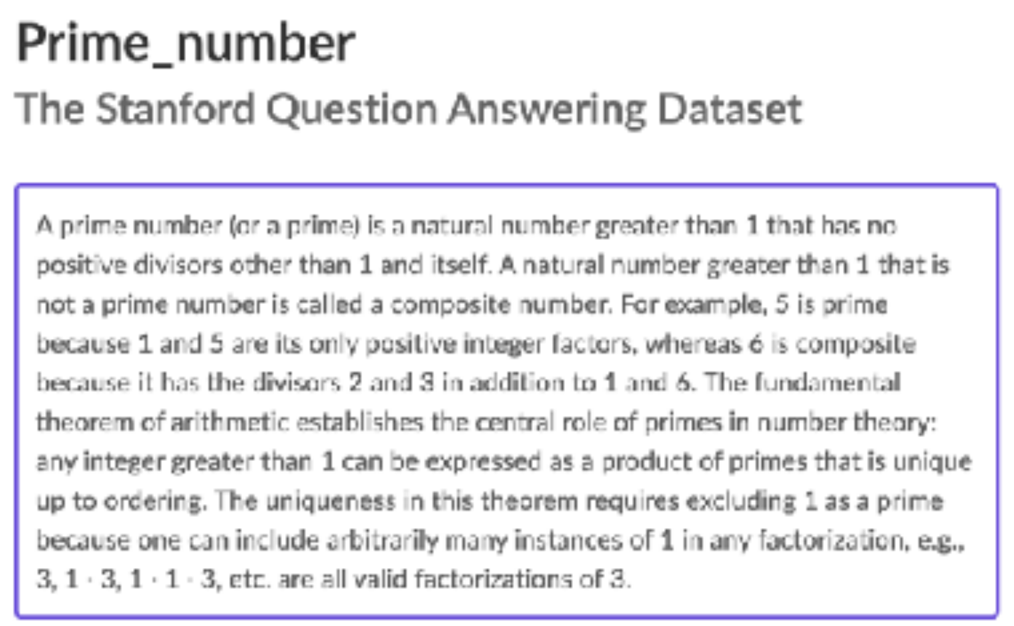


Where is zero-shot doing “ok”?

Question Answering

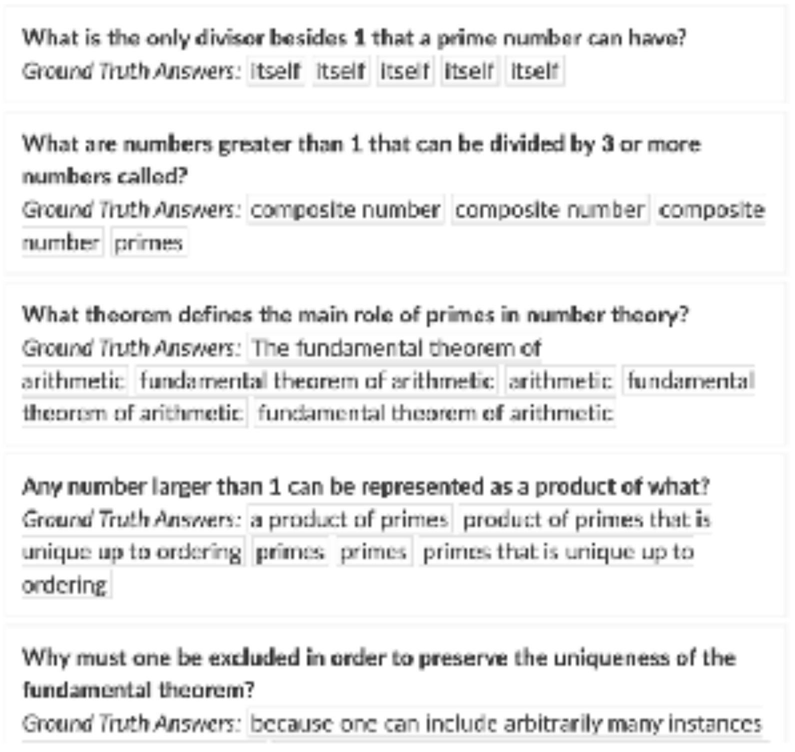
SQuADv2.0 [1]



Prime_number

The Stanford Question Answering Dataset

A prime number (or a prime) is a natural number greater than 1 that has no positive divisors other than 1 and itself. A natural number greater than 1 that is not a prime number is called a composite number. For example, 5 is prime because 1 and 5 are its only positive integer factors, whereas 6 is composite because it has the divisors 2 and 3 in addition to 1 and 6. The fundamental theorem of arithmetic establishes the central role of primes in number theory: any integer greater than 1 can be expressed as a product of primes that is unique up to ordering. The uniqueness in this theorem requires excluding 1 as a prime because one can include arbitrarily many instances of 1 in any factorization, e.g., 3, 1 · 3, 1 · 1 · 3, etc. are all valid factorizations of 3.



What is the only divisor besides 1 that a prime number can have?
Ground Truth Answers: itself itself itself itself itself

What are numbers greater than 1 that can be divided by 3 or more numbers called?
Ground Truth Answers: composite number composite number composite number primes

What theorem defines the main role of primes in number theory?
Ground Truth Answers: The fundamental theorem of arithmetic fundamental theorem of arithmetic arithmetic fundamental theorem of arithmetic fundamental theorem of arithmetic

Any number larger than 1 can be represented as a product of what?
Ground Truth Answers: a product of primes product of primes that is unique up to ordering primes primes primes that is unique up to ordering

Why must one be excluded in order to preserve the uniqueness of the fundamental theorem?
Ground Truth Answers: because one can include arbitrarily many instances

[1] Rajpurkar et al. SQuAD: 100,000+ Questions for Machine Comprehension of Text. EMNLP 2016.

Where is zero-shot doing “ok”?

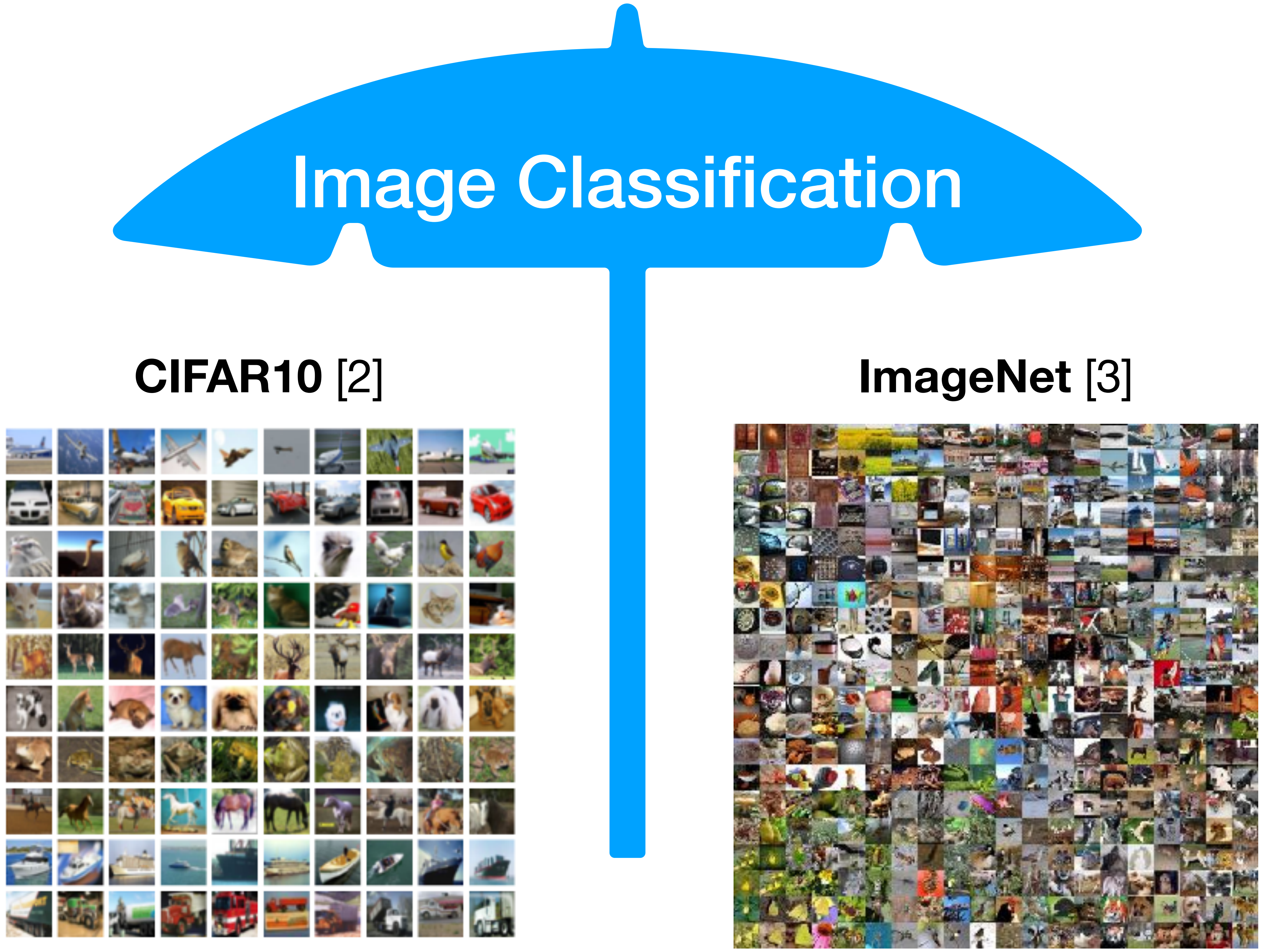


Image Classification

CIFAR10 [2]

ImageNet [3]

[2] Krizhevsky. Learning multiple layers of features from tiny images. 2009.

[3] Russakovsky et al. Imagenet large scale visual recognition challenge. IJCV 2015.

What seems to be getting us there?

- In NLP?
    - Large Language Models (LLM) i.a., GPT-3 [4]
- In Vision?
    - Vision-Language Models (VLM) i.a., CLIP [5]

[4] Brown et al. *Language Models are Few-Shot Learners*. NeurIPS 2020.

[5] Radford et al. Learning Transferable Vision Models From Natural Language Supervision. ICML 2021.

Language Model Pre-Training

Predict the next word in the ______

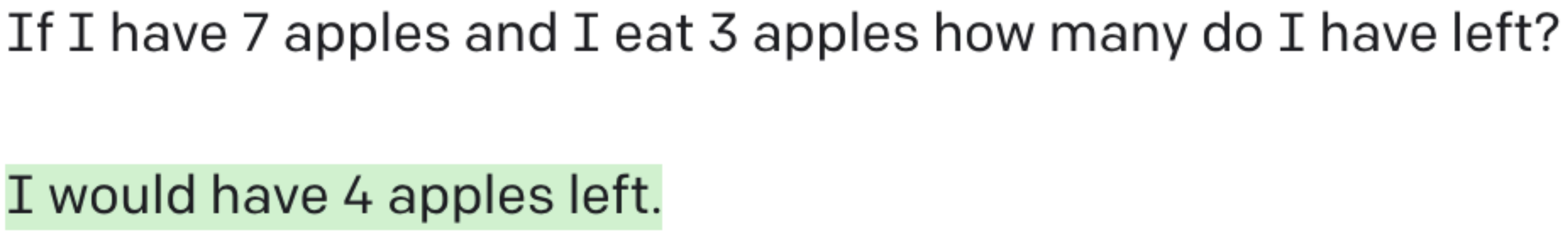
i.a., [5] Brown et al. *Language Models are Few-Shot Learners*. NeurIPS 2020.

Language Model Pre-Training

Predict the next word in the sentence.

i.a., [5] Brown et al. *Language Models are Few-Shot Learners*. NeurIPS 2020.

Zero-shot Inference (NLP)

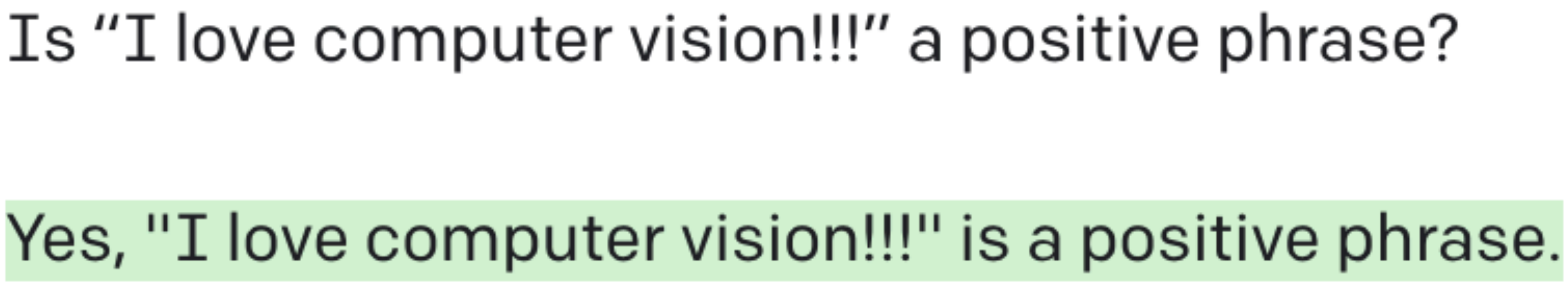


If I have 7 apples and I eat 3 apples how many do I have left?

I would have 4 apples left.

https://beta.openai.com/playground

Zero-shot Inference (NLP)

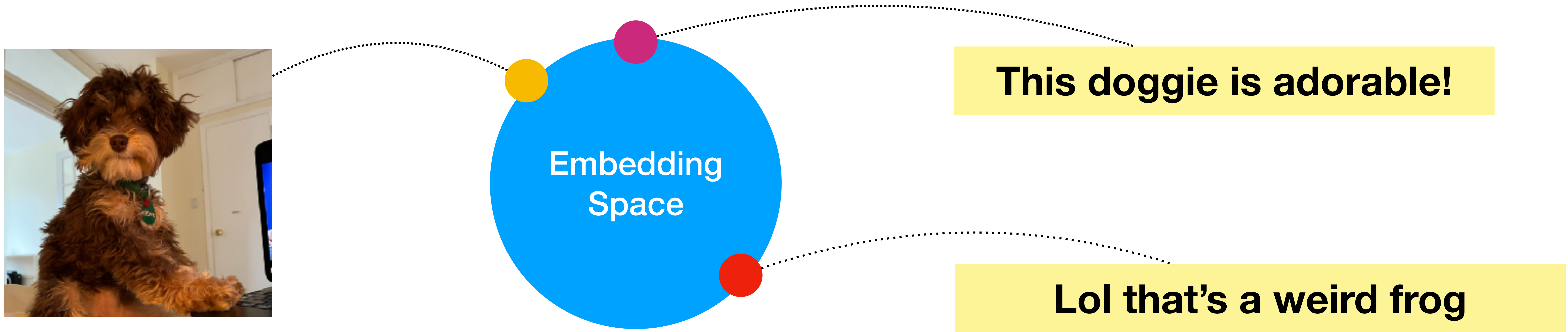


Is “I love computer vision!!!” a positive phrase?

Yes, "I love computer vision!!!" is a positive phrase.

https://beta.openai.com/playground

CLIP Pre-Training



Embedding Space

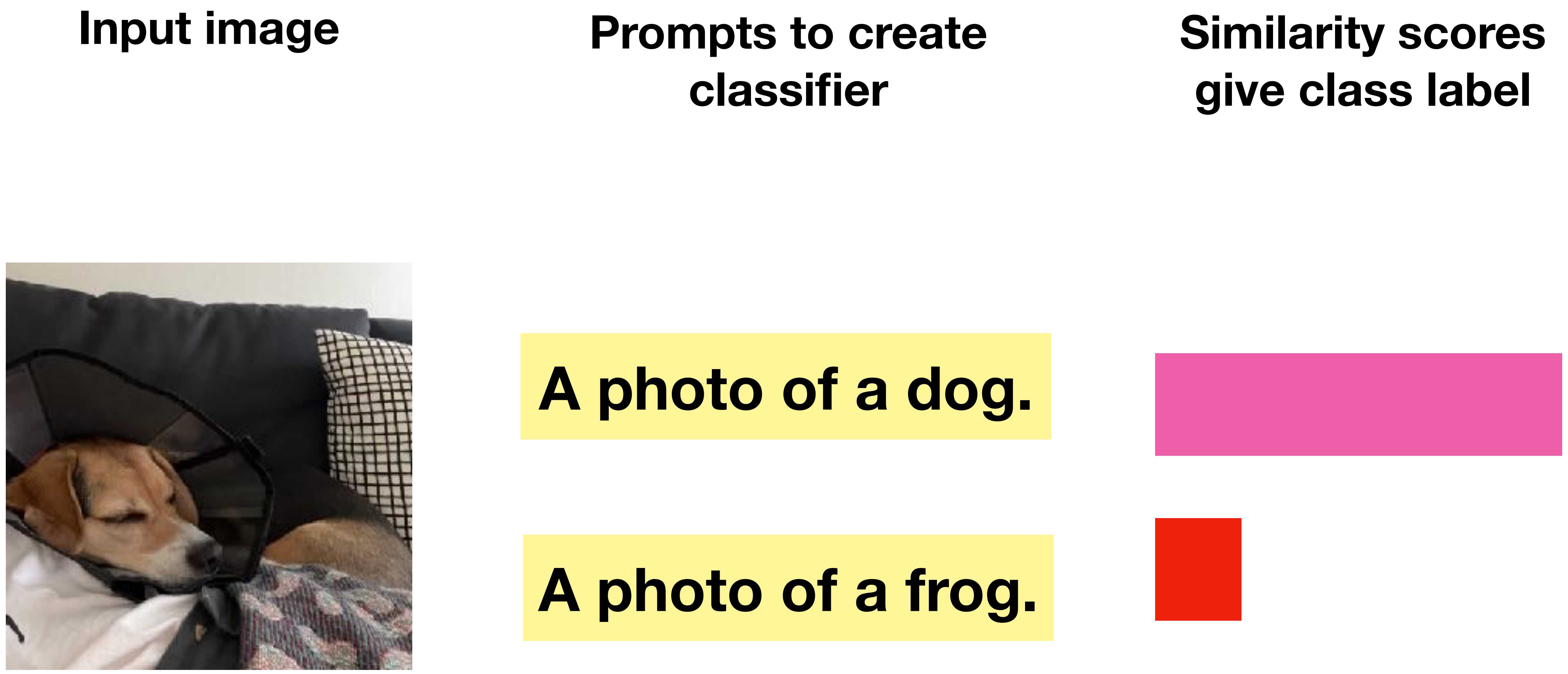
This doggie is adorable!

Lol that’s a weird frog

i.a., [6] Radford et al. Learning Transferable Vision Models From Natural Language Supervision. ICML 2021.

Zero-shot Inference (Vision)

- With vision-language features we can create *arbitrary* image classifiers.



Input image

Prompts to create classifier

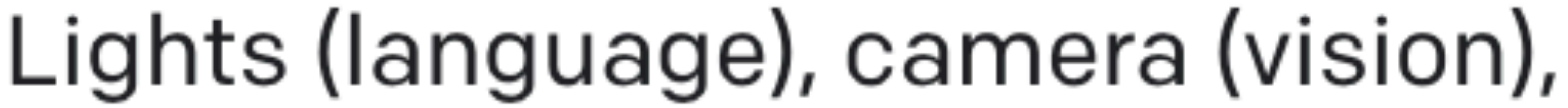
Similarity scores give class label

A photo of a dog.

A photo of a frog.

i.a., [6] Radford et al. Learning Transferable Vision Models From Natural Language Supervision. ICML 2021.

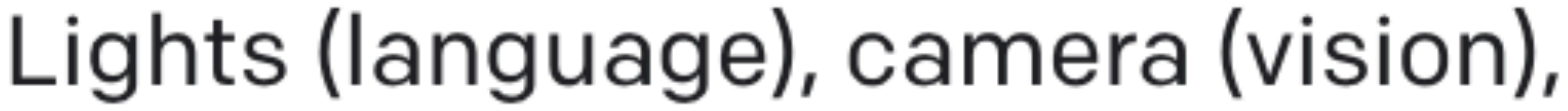
We’ve got some zero-shot capabilities



Lights (language), camera (vision),

https://beta.openai.com/playground

What’s missing for robotics?



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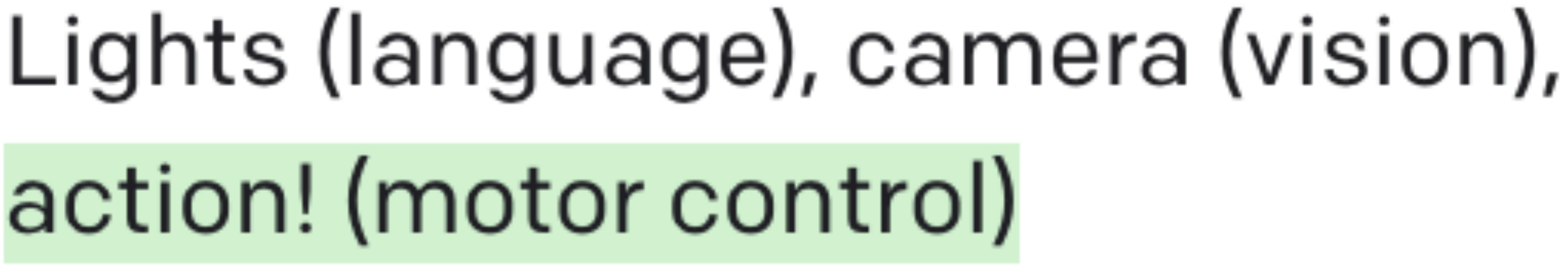

Lights (language), camera (vision),
action! (motor control)

https://beta.openai.com/playground

Pre-train like we do in NLP and Vision?

I want pre-training too!

Pre-train like we do in NLP and Vision?

- People have definitely been up to cool things! For example, with datasets [7,8,9,10]
- Maybe, but it seems pretty hard at the present moment
  - Data scale?
  - Data diversity?
  - Scaling Reinforcement Learning (RL)?
  - Pre-training objective?

[7] Sharma et al. *Multiple Interactions Made Easy (MIME): Large Scale Demonstrations Data for Imitation*. CoRL 2018.
[8] Dasari et al. *RoboNet: Large-Scale Multi-Robot Learning*. arXiv 2019.
[9] Song et al. *Grasping in the Wild: Learning 6DoF Closed-Loop Grasping from Low-Cost Demonstrations*. RA-L 2020.
[10] Yen-Chen et al. *Learning to See before Learning to Act: Visual Pre-training for Manipulation.* ICRA 2020.

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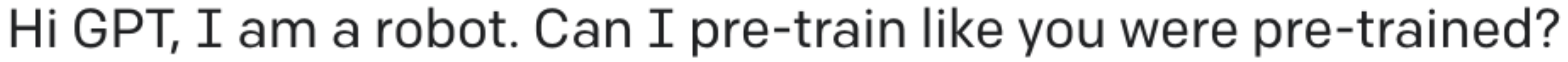

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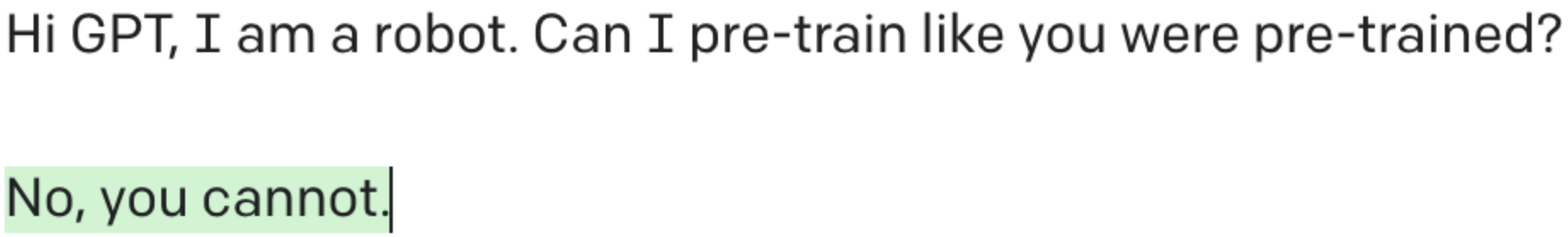
Pre-train like we do in NLP and Vision?



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No, you cannot.

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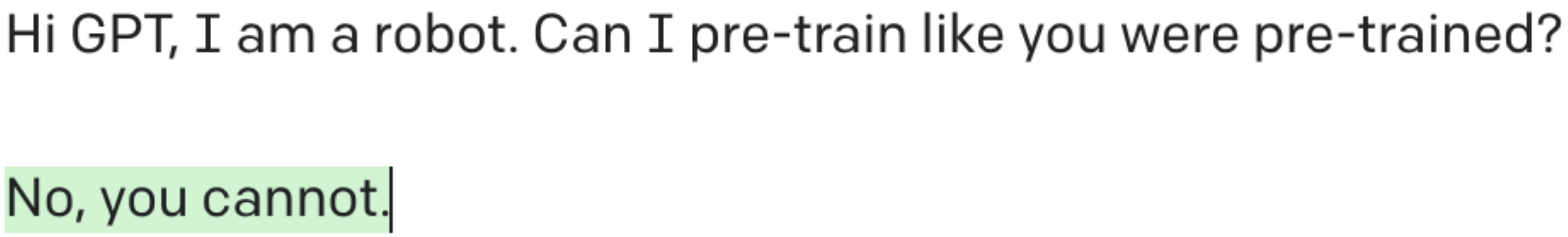
What now?



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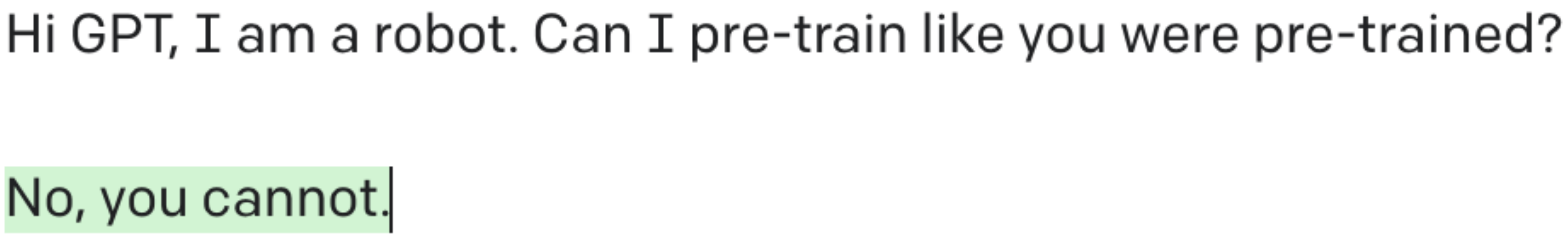
Before giving up, ask for help!



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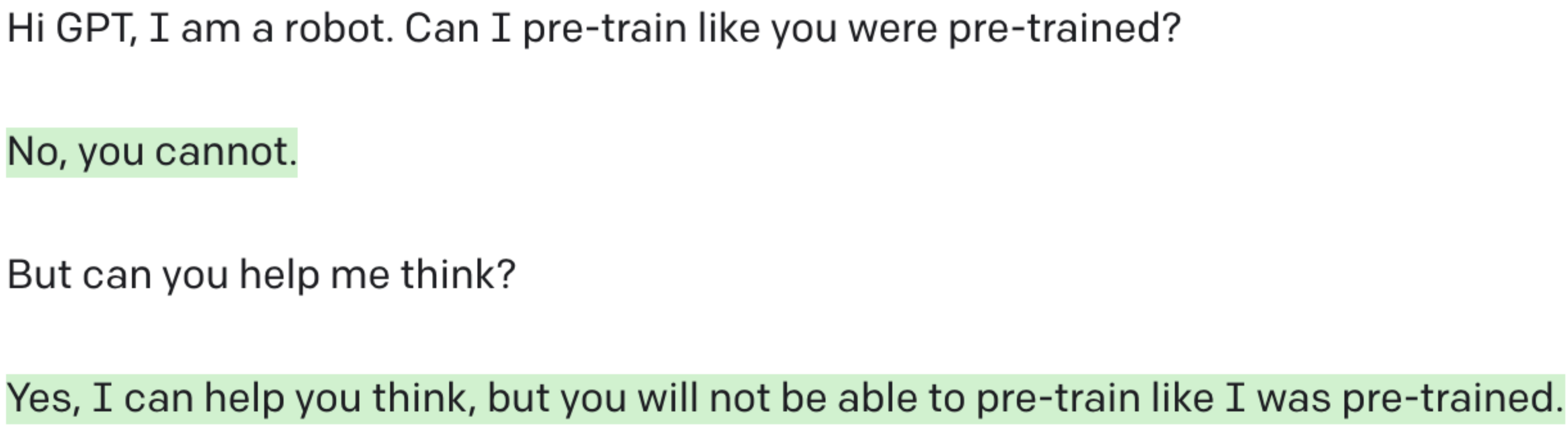


Hi GPT, I am a robot. Can I pre-train like you were pre-trained?

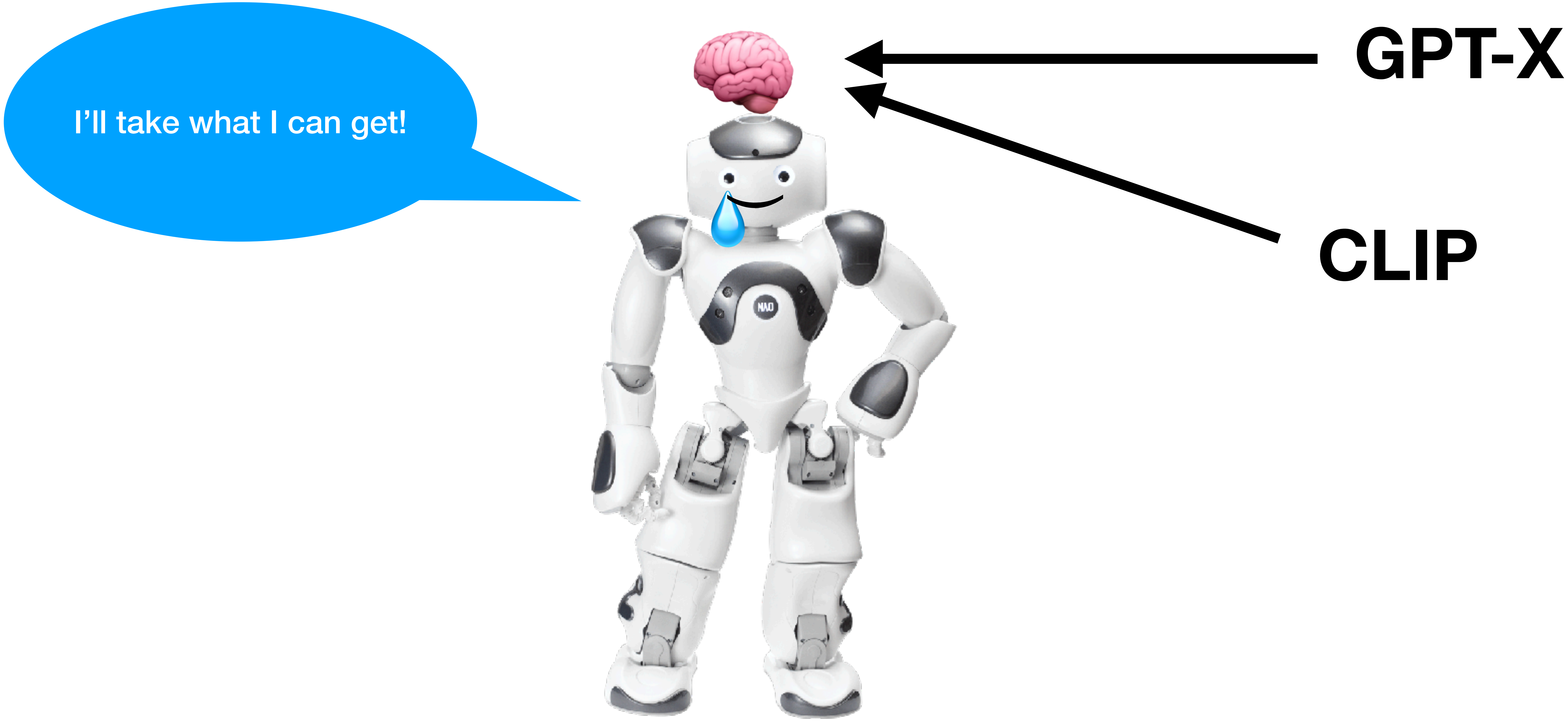
No, you cannot.

But can you help me think?

Yes, I can help you think, but you will not be able to pre-train like I was pre-trained.

https://beta.openai.com/playground

Adapting pre-trained models for robotics



I'll take what I can get!

GPT-X

CLIP

What does *adapting* mean?

- **Fine-tuning** a pre-trained model
    - [11] Shridhar et al. *CLIPort: What and Where Pathways for Robotic Manipulation*. CoRL 2021.
    - [12] Khandelwal et al. Simple but Effective: CLIP Embeddings for Embodied AI. CVRP 2022.
- **Zero-shot inference** directly with pre-trained models
    - [13] Huang et al. Language Models as Zero-Shot Planners: Extracting Actionable Knowledge for Embodied Agents. ICML 2022.
    - [14] Ahn et al. *Do As I Can, Not As I Say: Grounding Language in Robotic Affordances.* arXiv 2022.
    - [15] Zeng et al. *Socratic Models. Composing Zero-Shot Multimodal Reasoning with Language.* arXiv 2022.
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CLIPort: Big Ideas

- Separate **spatial** and **semantic** information streams
  - CLIP vision encoder to process visual input for semantics
  - CLIP language encoder to process input textual description of the task
- Learn the other components we might need to do pick-and-place by adding added parameters and **collecting human demos**

[11] Shridhar et al. *CLIPort: What and Where Pathways for Robotic Manipulation*. CoRL 2021.

CLIPort: Task

- Inputs:

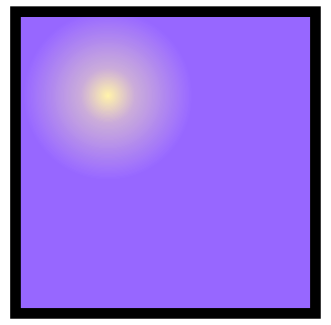
Top down RGB + D

Language description of the task

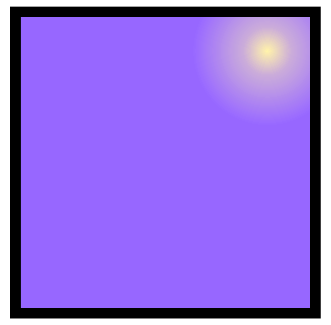
“pack the white tape in the brown box”

- Output:

Pick location

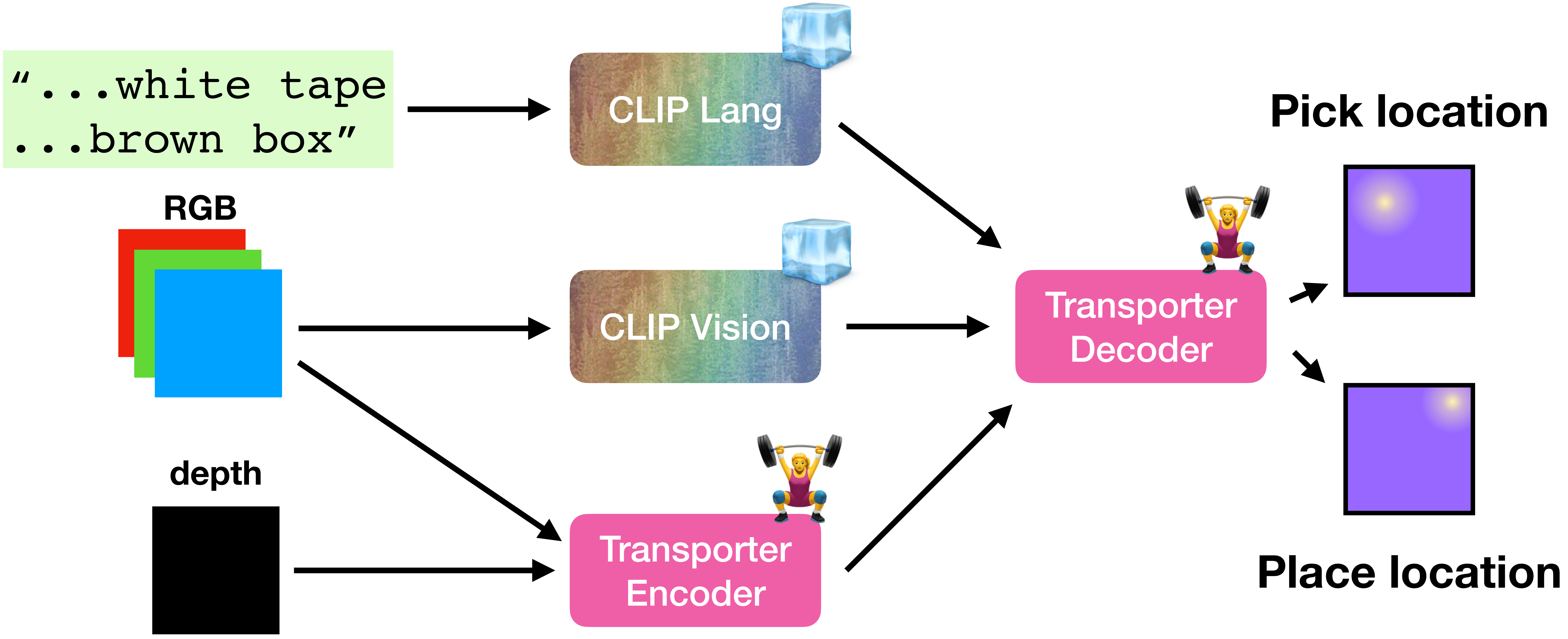


Place location



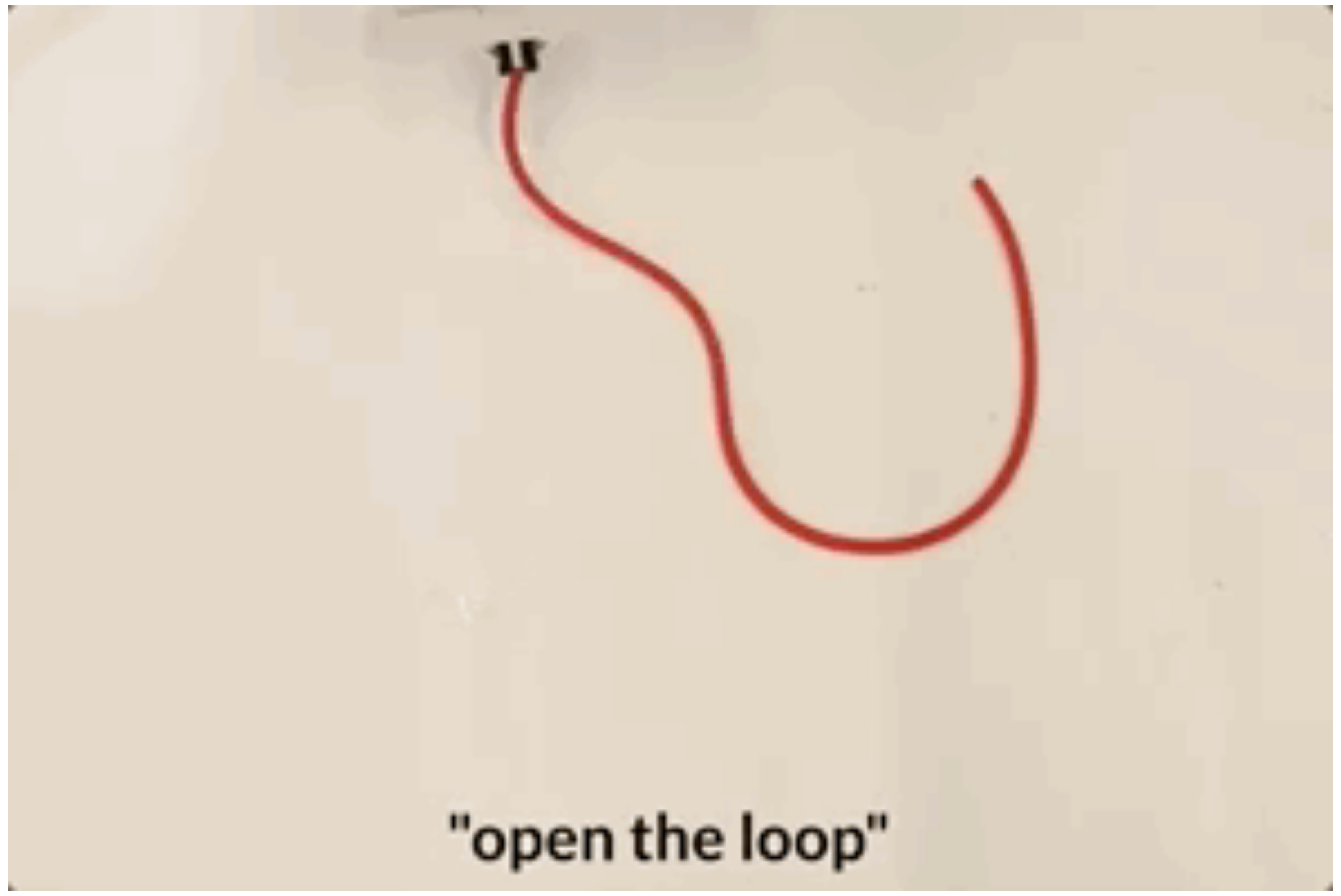
[11] Shridhar et al. *CLIPort: What and Where Pathways for Robotic Manipulation*. CoRL 2021.

CLIPort: Model



[11] Shridhar et al. *CLIPort: What and Where Pathways for Robotic Manipulation*. CoRL 2021.

CLIPort: Demo



"open the loop"

"pick all the cherries and put them in the box"

[11] Shridhar et al. *CLIPort: What and Where Pathways for Robotic Manipulation*. CoRL 2021.

Possible Drawbacks of Fine-Tuning

- When we fine-tune what capabilities are we losing in the original model?
- Do we lose:
  - Robustness to distribution shift?
  - Zero-shot capabilities?
  - Generality?

LM as Planners: Big Ideas

- **LM can do high-level planning** (given the proper prompting and admissibility checks)

[13] Huang et al. Language Models as Zero-Shot Planners: Extracting Actionable Knowledge for Embodied Agents. ICML 2022.

LM as Planners: Task

- Inputs:

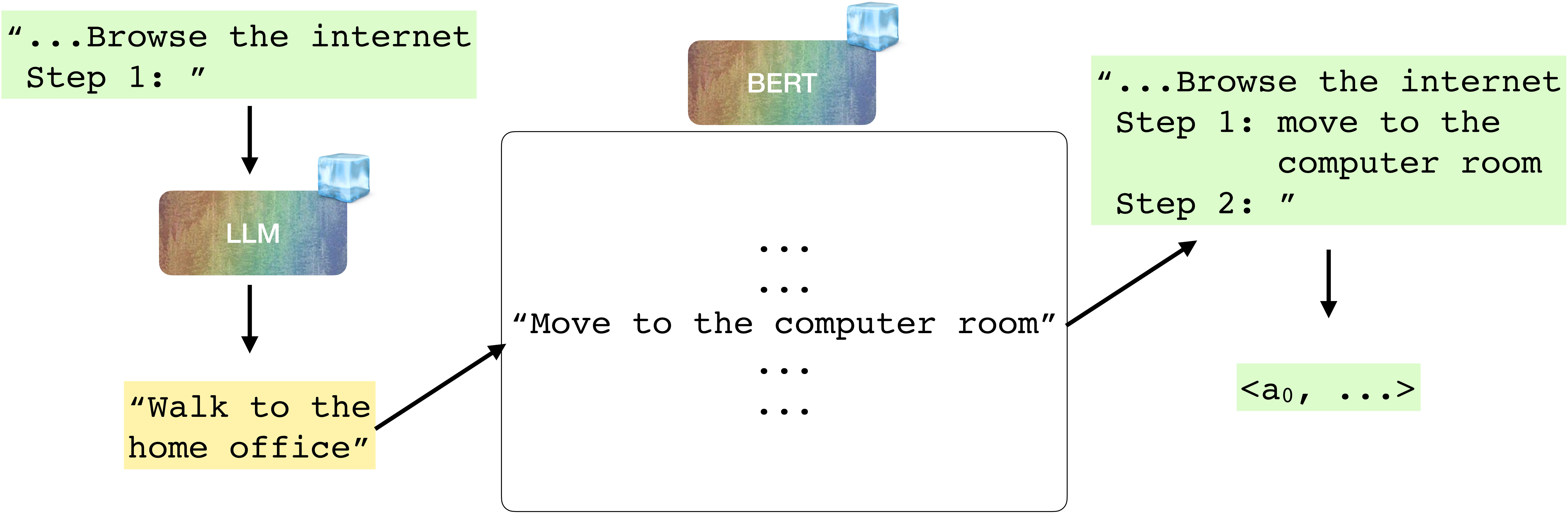
“...Browse the internet...”

- Output:

$<a_0, a_1, ..., a_n>$

[13] Huang et al. Language Models as Zero-Shot Planners: Extracting Actionable Knowledge for Embodied Agents. ICML 2022.

LM as Planners: Model



“...Browse the internet
Step 1: ”

LLM

“Walk to the home office”

BERT

...
...
“Move to the computer room”
...
...

“...Browse the internet
Step 1: move to the computer room
Step 2: ”

<a_0, ...>

[13] Huang et al. Language Models as Zero-Shot Planners: Extracting Actionable Knowledge for Embodied Agents. ICML 2022.

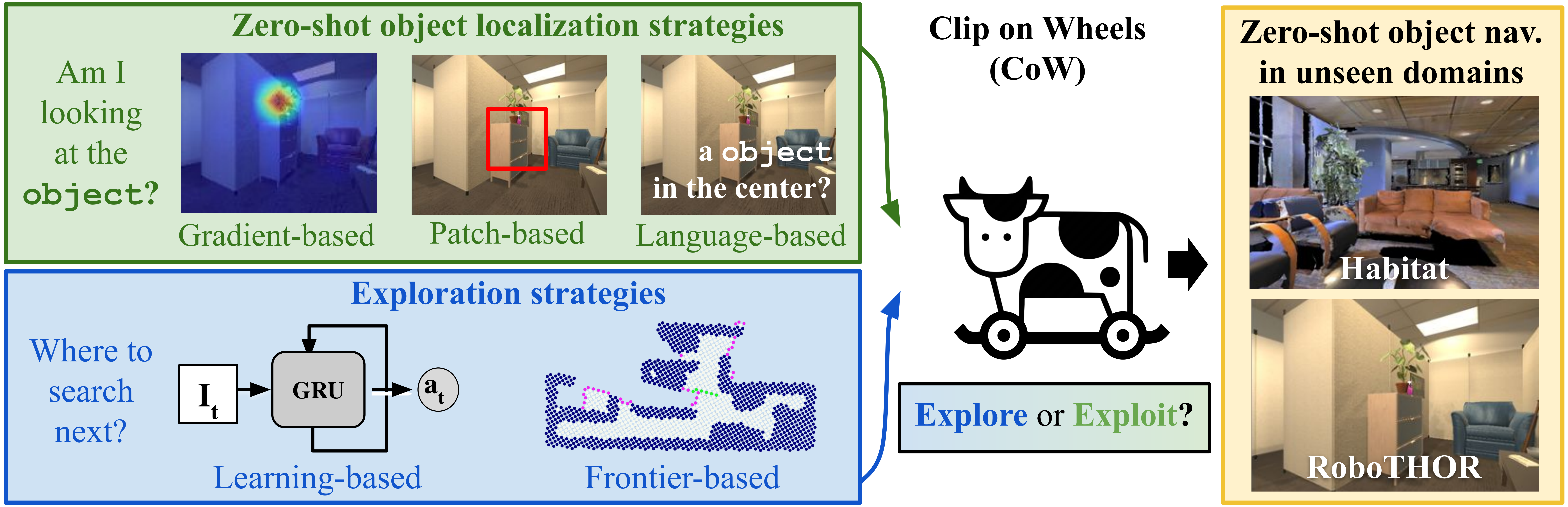
LM as Planners: Demo

[13] Huang et al. Language Models as Zero-Shot Planners: Extracting Actionable Knowledge for Embodied Agents. ICML 2022.

We ideally want vision in the mix

- Language models seem to be capable high level planners
- Can we use vision-language models to translate perception into action?

CLIP on Wheels (CoW): Big Ideas



Zero-shot object localization strategies

Am I looking at the object?

a object in the center?

Gradient-based

Patch-based

Language-based

Exploration strategies

Where to search next?

Learning-based

Frontier-based

Clip on Wheels (CoW)

Explore or Exploit?

Zero-shot object nav. in unseen domains

[16] Gadre et al. *CLIP on Wheels: Open-Vocabulary Models are (Almost) Zero-Shot Object Navigators*. arXiv 2022.

CoW: Task

- Inputs:

Egocentric RGB + D

Language for the target object

`“A photo of a plant.”`

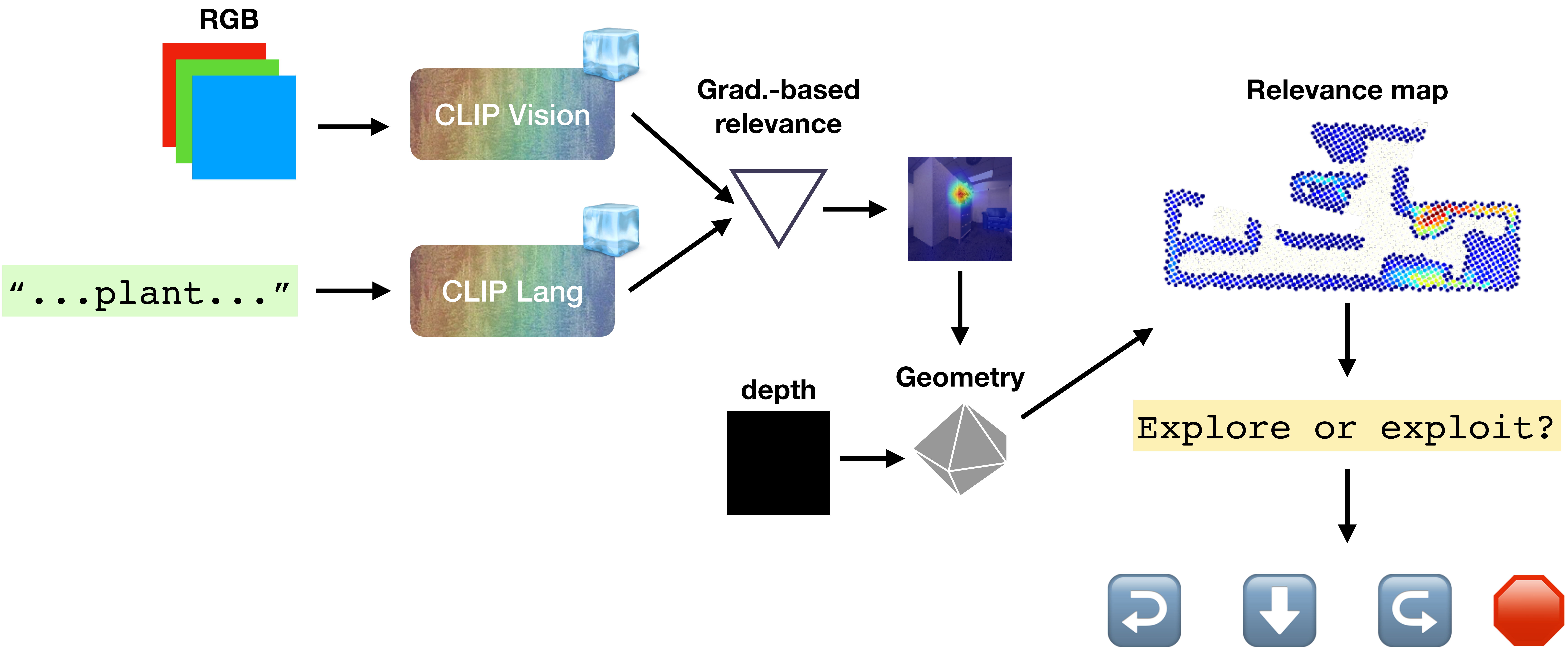
- Output:

Action: direction to move (or stop)

↩ ⬇ ↪ 🛑

[16] Gadre et al. *CLIP on Wheels: Open-Vocabulary Models are (Almost) Zero-Shot Object Navigators*. arXiv 2022.

CLIP on Wheels (CoW): Model



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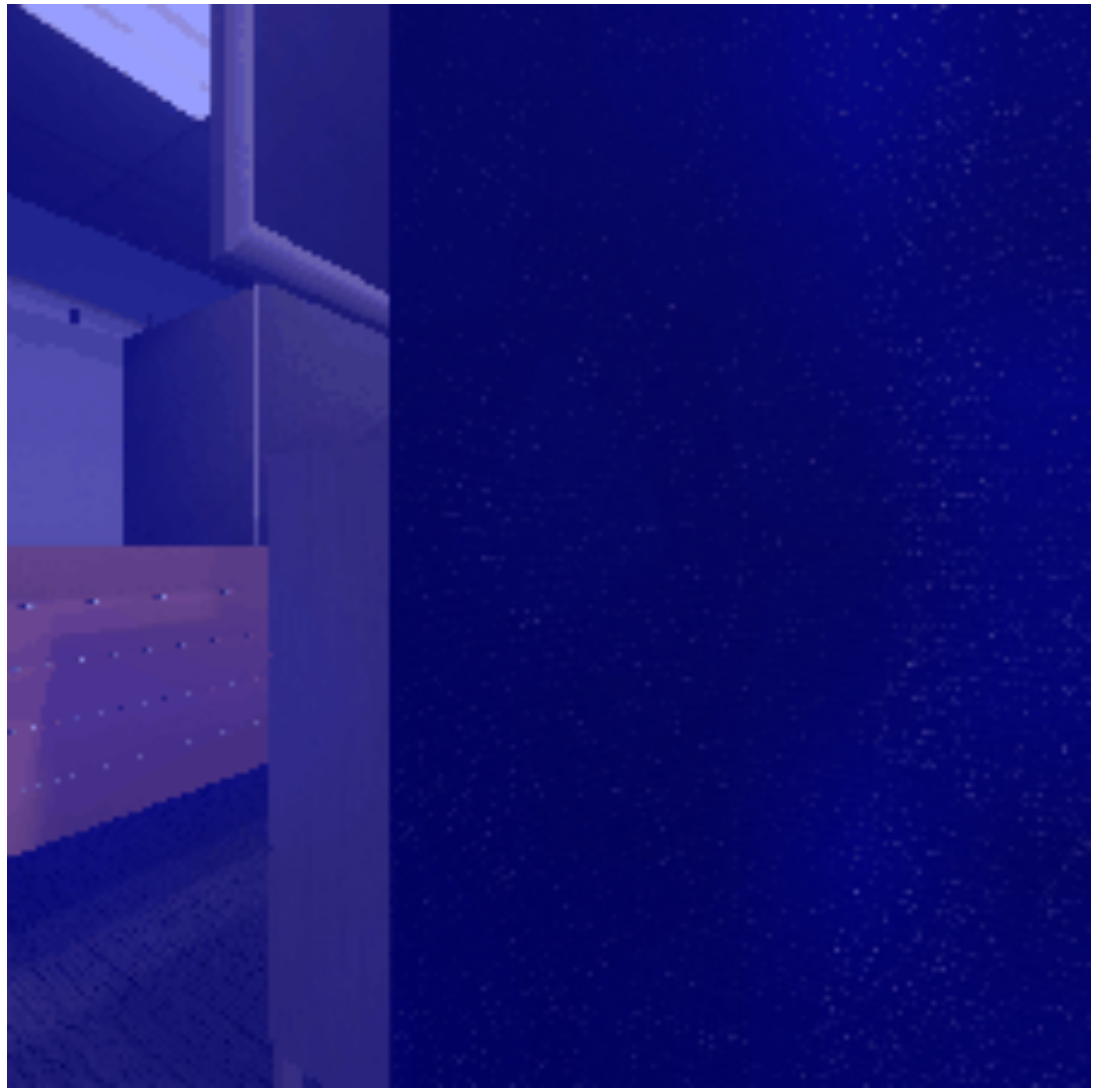
CoW: Demo



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Limitations

- We are still beginning to understand the biases and failure modes of large models. Mitigating against these biases should be taken seriously for downstream robotics
- Usually still a gap between zero-shot and fine-tuned performance
- Pay walls

Future Directions

- Pre-trained Vision-Language models are really powerful, we should think of new ways of using them (for robotics) without more training

- How can other vision techniques be used in conjunction with zero-shot models