

# Transfer learning and self-supervised learning

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# Why use transfer/self-supervised learning?

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- ▶ It is often easier to obtain unlabeled data - from a lab instrument or a computer - than labeled data, which can require human intervention
  - ▶ Prepare labeling manuals, categories, hiring humans, creating GUIs, storage pipelines, etc.
- ▶ Sometimes it is also hard to label the data. For example it is difficult to automatically assess the overall sentiment of a movie review: is it favorable or not?
- ▶ Cognitive motivation: How animals / babies learn

“The brain has about  $10^{14}$  synapses and we only live for about  $10^9$  seconds. So we have a lot more parameters than data. This motivates the idea that we must do a lot of unsupervised learning” - Geoffrey Hinton

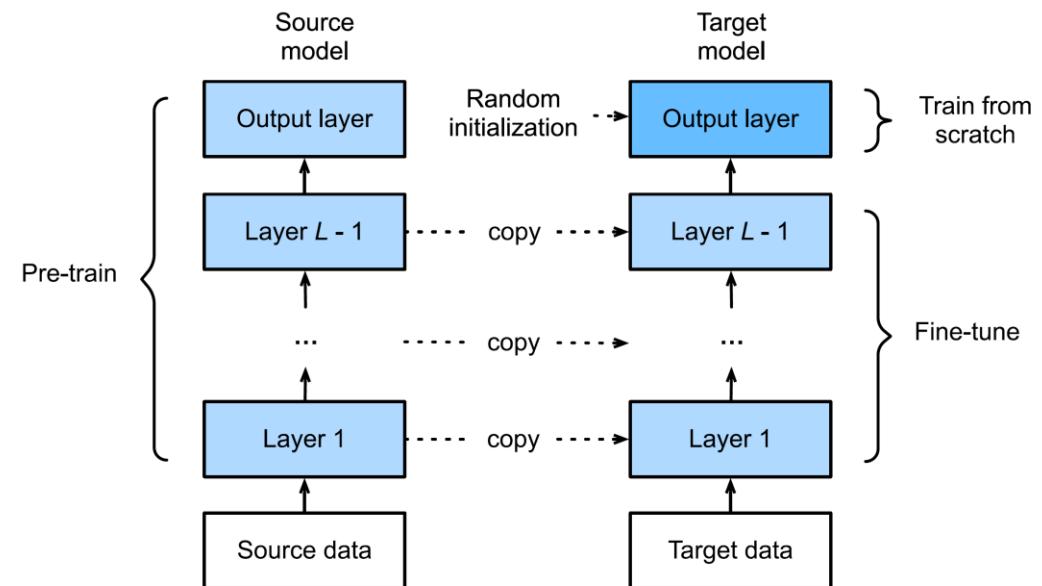
# 1. Transfer learning

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- ▶ It is generally not a good idea to train a very large DNN from scratch: instead, you should always try to find an existing neural network that accomplishes a *similar task* to the one you are trying to tackle, then reuse the lower layers of this network. This technique is called *transfer learning*
  - ▶ It will not only speed up training considerably, but also require significantly less labeled training data
- ▶ Suppose you have access to a DNN that was trained to classify pictures into 100 different categories, including animals, plants, vehicles, and everyday objects. You now want to train a DNN to classify specific types of vehicles. These tasks are very similar, even partly overlapping, so you should try to reuse parts of the first network

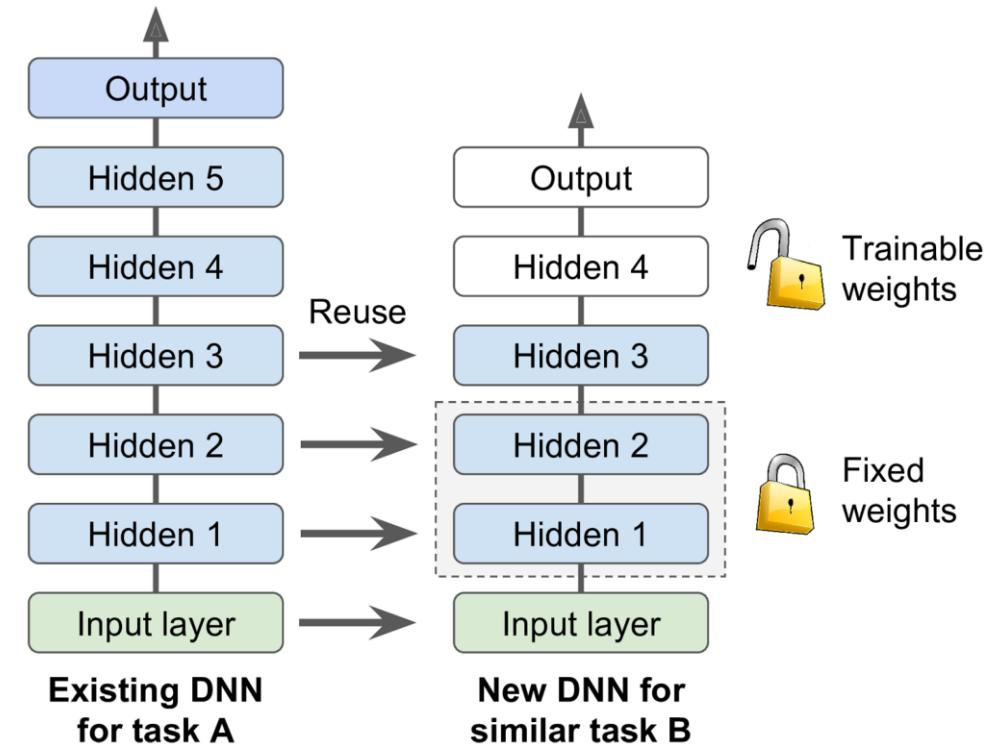
# Transfer learning

- ▶ Transfer learning work best when the inputs have similar low-level features
  - ▶ The output layer of the original model should be replaced because it is most likely not useful for the new task, and it may not have the right number of outputs for the new task
  - ▶ Similarly, the upper hidden layers of the model are less likely to be as useful as the lower layers since the high-level features that are most useful for the new task may differ significantly from the ones that were most useful for the original task
  - ▶ If we treat the lower layer frozen, we can often speed up training while still obtaining good performance
    - ▶ There exist complex variants such as adapter



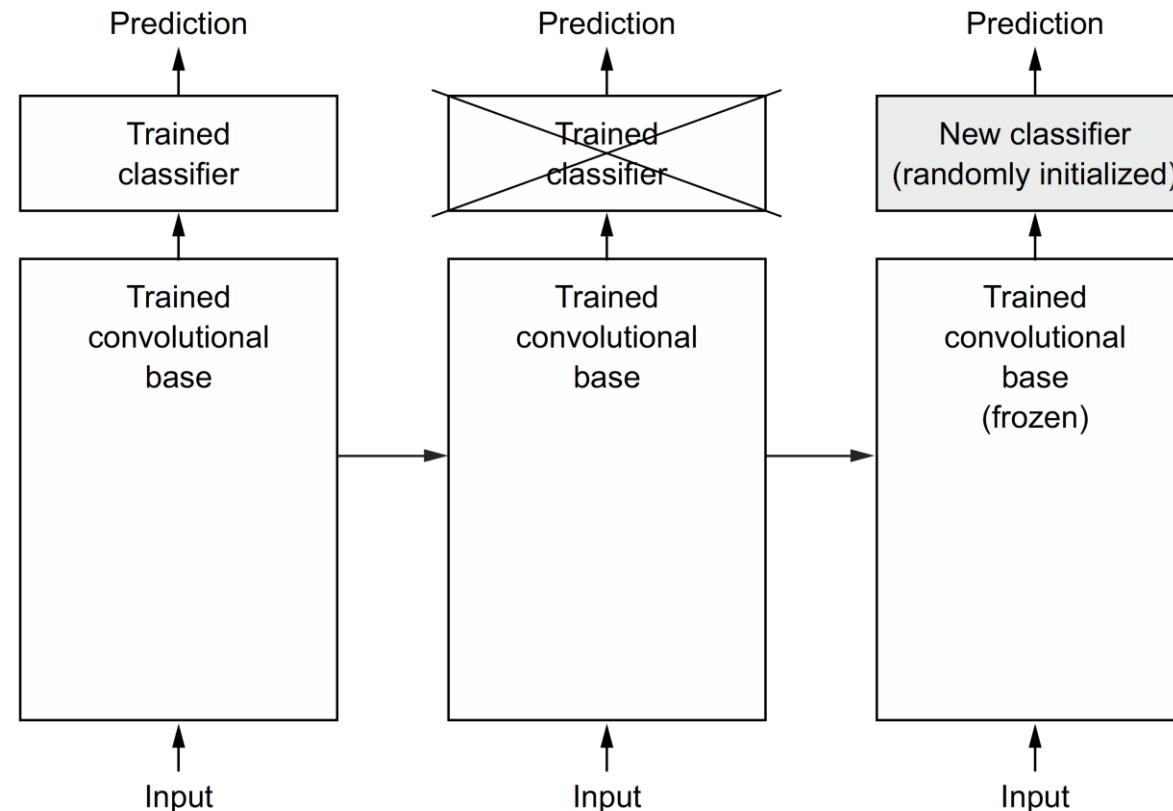
# Transfer learning

- ▶ You want to find the right number of layers to reuse
  1. Try freezing all the reused layers first, then train your model and see how it performs. Then try unfreezing one or two of the top hidden layers to let backpropagation tweak them and see if performance improves
  2. The more labeled training data you have, the more layers you can unfreeze. It is also useful to reduce the learning rate when you unfreeze reused layers
    - ▶ If you have plenty of training data, you may even try to add more hidden layers
  3. If you still cannot get good performance, and you have little training data, try dropping the top hidden layer(s) and freezing all the remaining hidden layers again. You can iterate until you find the right number of layers to reuse



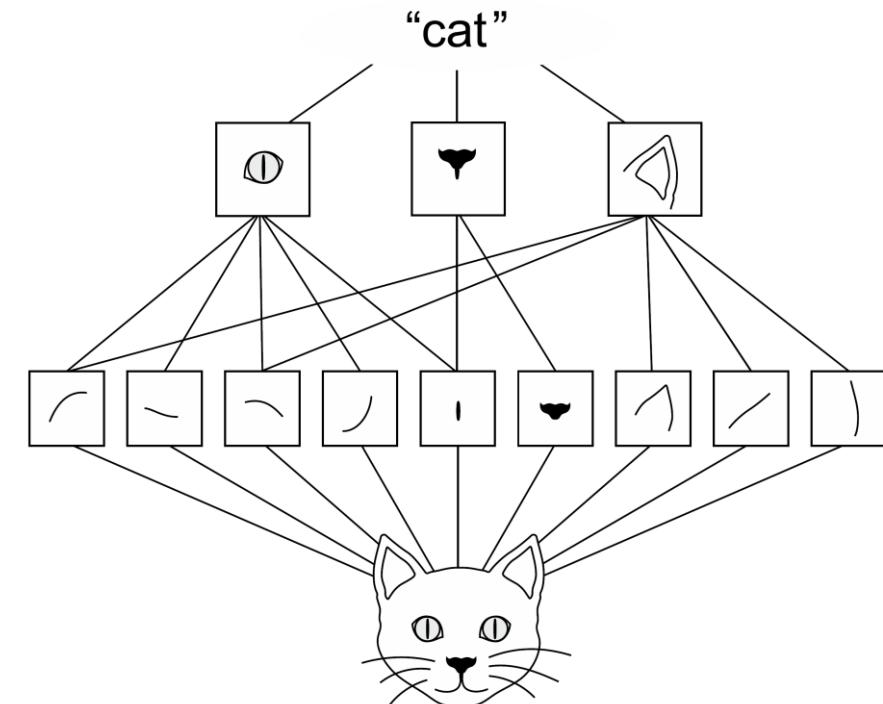
## 2. Using pretrained model – feature extraction

- ▶ *Feature extraction* with a pretrained model is often useful in the visual task
  - ▶ Such portability of learned features across different problems is an advantage of deep learning compared to traditional approaches and is effective for small-data problems



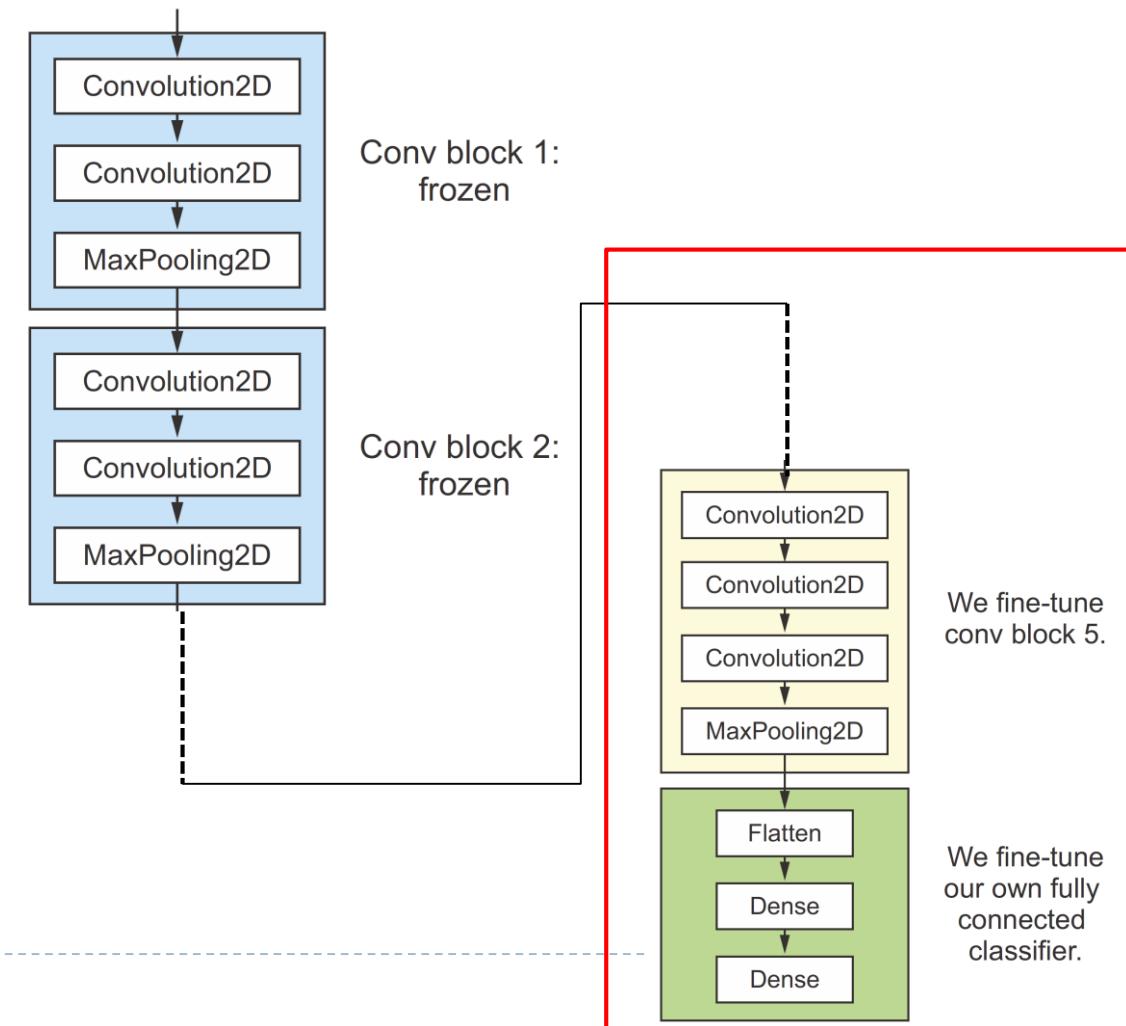
# Using pretrained model – feature extraction

- ▶ Convnets start with a series of pooling and convolution layers, and they end with a densely connected classifier. The first part is called the *convolutional base* of the model
  - ▶ In the case of convnets, feature extraction consists of taking the convolutional base of a previously trained network, and training a new classifier on top of the output
- ▶ Note that the level of generality of the representations extracted by specific convolution layers depends on the depth of the layer
  - ▶ Layers that come earlier in the model extract local, highly generic feature maps (such as visual edges, colors, and textures), whereas layers that are higher up extract more-abstract concepts (such as “cat ear” or “dog eye”)



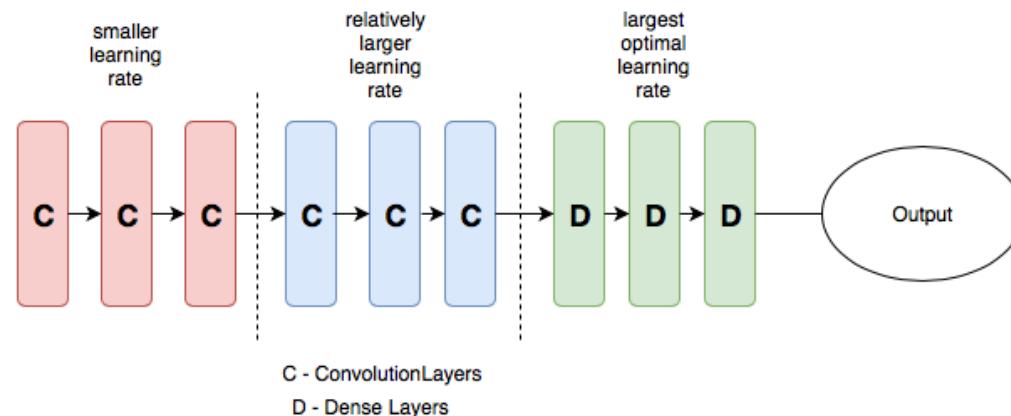
# Using pretrained model – fine-tuning

- ▶ Another widely used technique for model reuse, complementary to feature extraction, is *fine-tuning*
- ▶ Fine-tuning consists of unfreezing a few of the top layers of a frozen model base used for feature extraction, and jointly training both the newly added fully connected classifier and these top layers
- ▶ When fine-tuning a model that includes BatchNormalization layers, it is sometimes recommended leaving these layers frozen



# Discriminative learning rate

- ▶ Even after we unfreeze, we still care a lot about the quality of those pretrained weights
  1. We would not expect that the best learning rate for those pretrained parameters would be as high as for the randomly added parameters
  2. It often makes sense to let the later layers fine-tune more quickly than earlier layers
  3. Use a lower learning rate for the early layers of the neural network, and a higher learning rate for the later layers (and especially the randomly added layers)



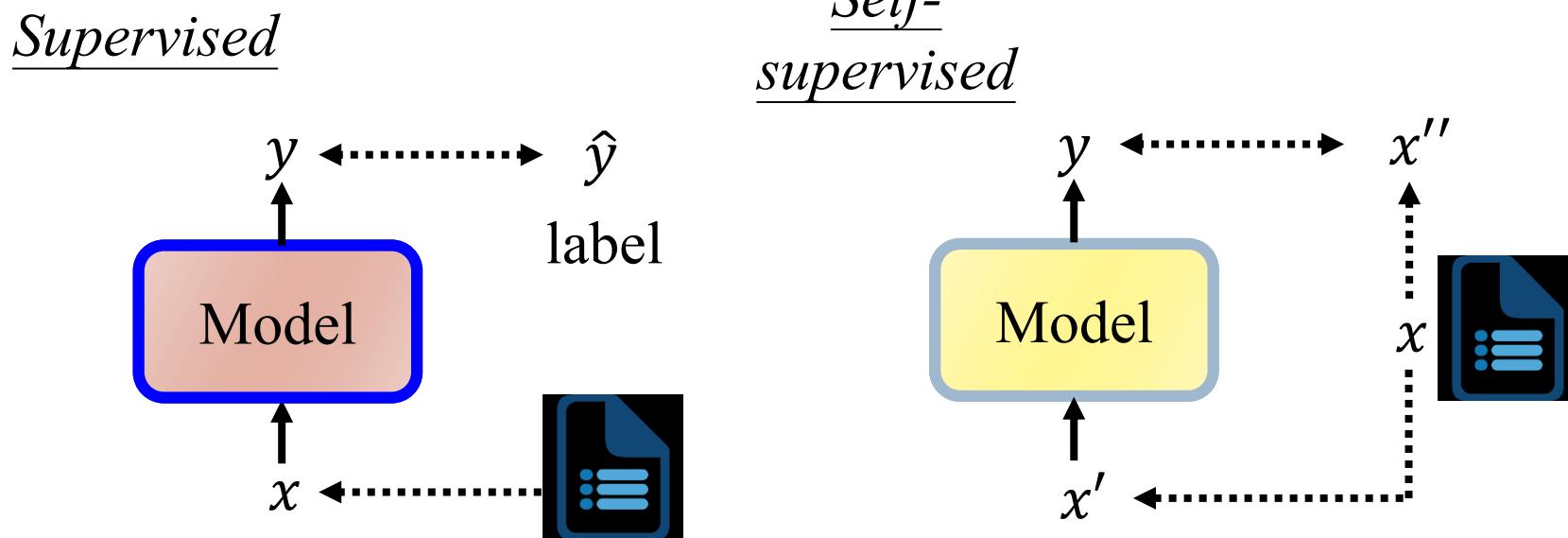
# Supervised pre-training

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- ▶ The pre-training task may be supervised or unsupervised; the main requirements are that it can teach the model's basic structure about the problem domain and that it is sufficiently similar to the downstream fine-tuning task
  - ▶ The notion of task similarity is not rigorously defined, but in practice, the domain of the pre-training task is often broader than that of the fine-tuning task
  - ▶ For example, it is very common to use the ImageNet dataset to pretrain CNNs, which can then be used for a variety of downstream tasks. [ImageNet](#) has 1.28 million natural images, each associated with a label from one of 1,000 classes. The classes constitute a wide variety of different concepts, including animals, foods, buildings, musical instruments, clothing, and so on
  - ▶ For NLP, we could pre-train a model on a large English-labeled corpus before fine-tuning on low-resource languages

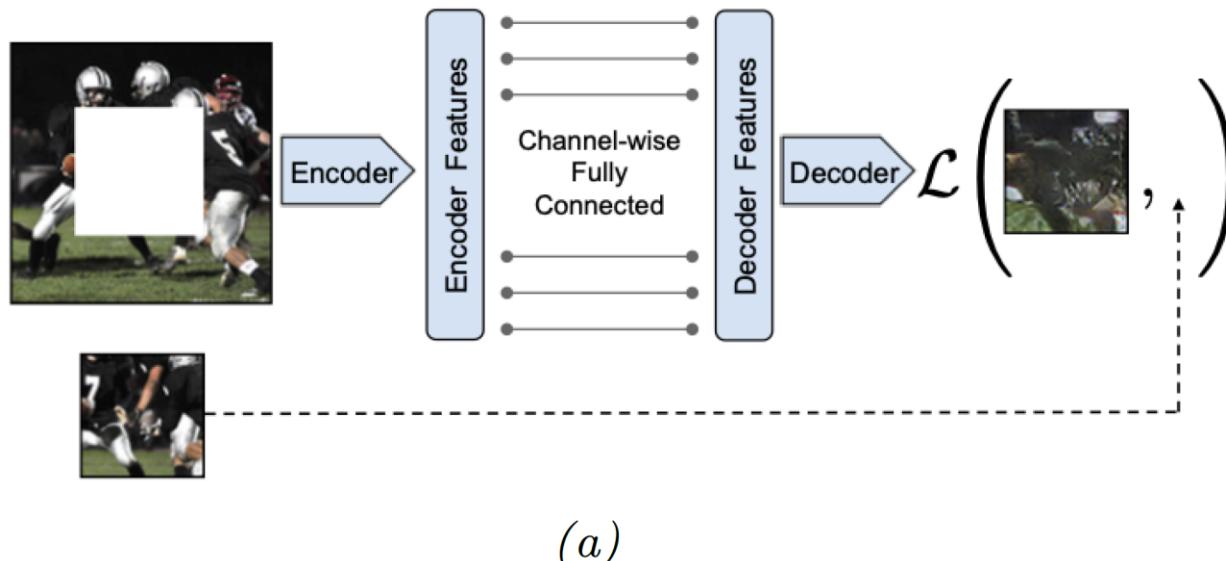
### 3. Self-supervised learning

- ▶ Self-supervised learning is an active research field. Self-supervised learning is an approach to pre-training models using unlabeled data
- ▶ This term is used because the labels are created by the algorithm, rather than being provided externally by a human, as in standard supervised learning. Both supervised and self-supervised learning are discriminative tasks, since they require predicting outputs given inputs

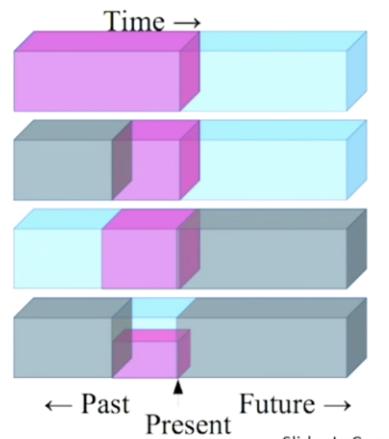


# Self-supervised learning - Pretrained using imputation tasks

- One approach to self-supervised learning is to solve imputation tasks. In this approach, we partition the input vector  $x$  into two parts,  $x = (x_h, x_v)$ , and then try to predict the hidden part  $x_h$  given the remaining visible part,  $x_v$ , using a model of the form  $\hat{x}_h = f(x_h = 0, x_v)$ . We can think of this as a “fill-in-the-blank” task; in the NLP community, this is called a cloze task



- Predict any part of the input from any other part.
- Predict the future from the past.
- Predict the future from the recent past.
- Predict the past from the present.
- Predict the top from the bottom.
- Predict the occluded from the visible
- Pretend there is a part of the input you don't know and predict that.



# Self-supervised learning - Pretrained using imputation tasks

- For more information see [here](#)

(special token)

= MASK

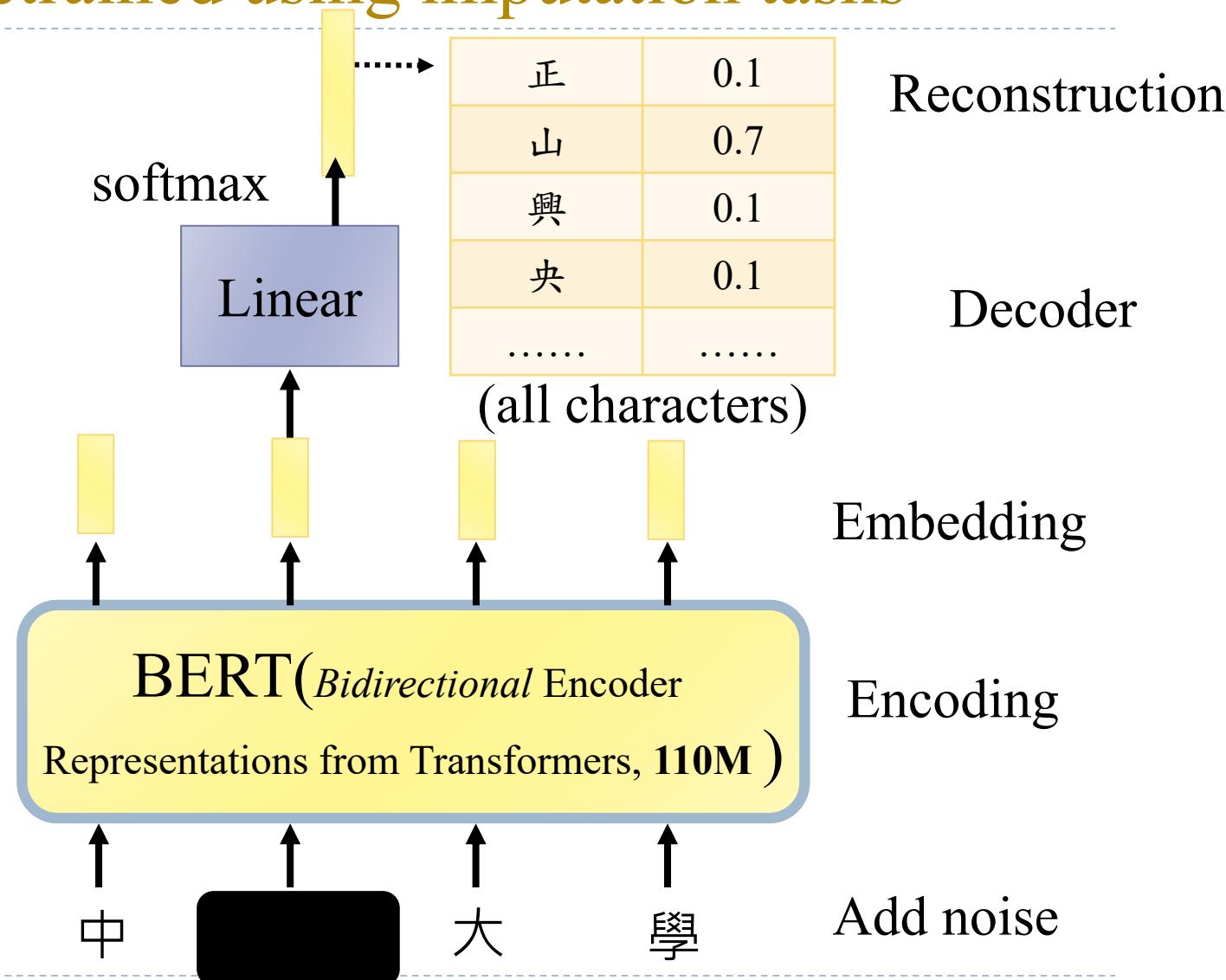
or

= Random

—、天、大、小 ...

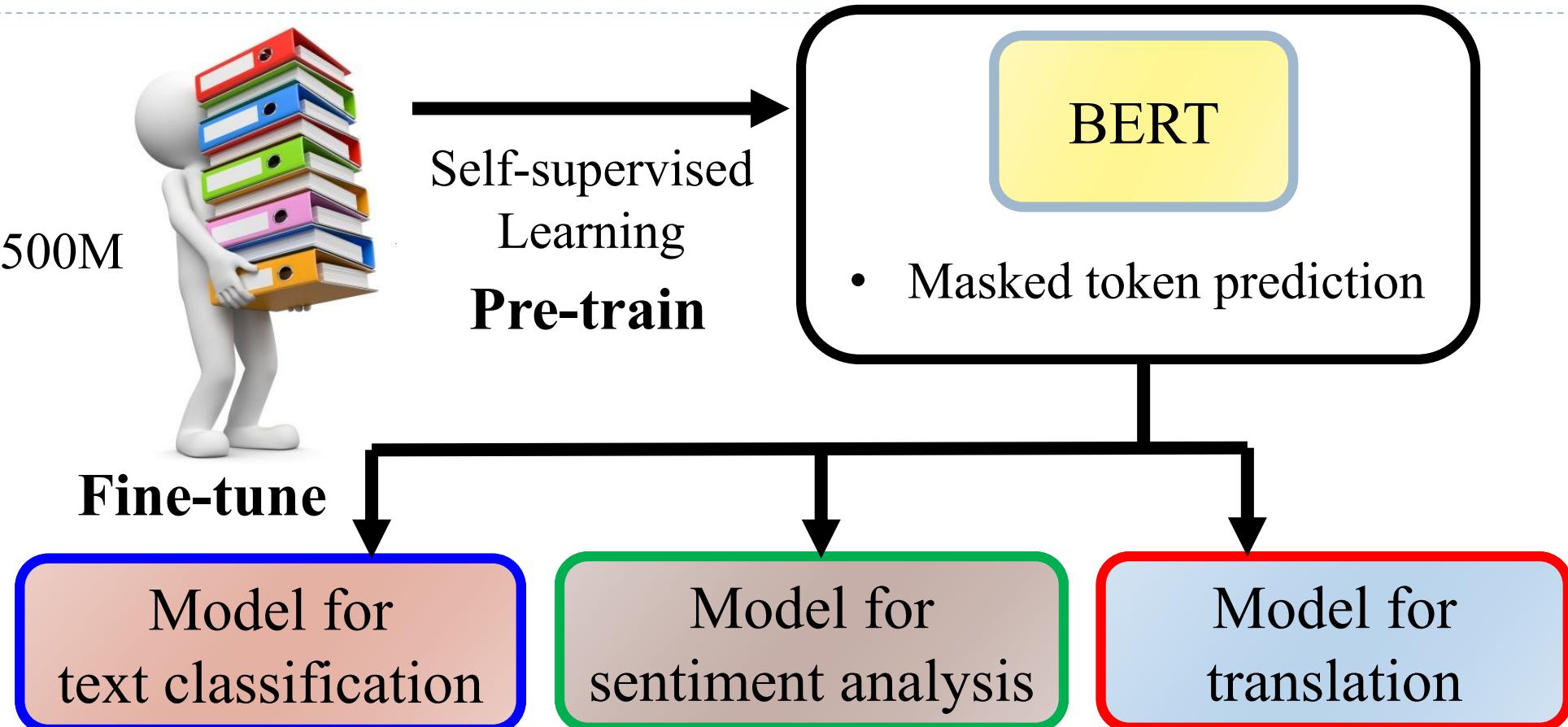
Transformer  
Encoder

Randomly masking some tokens



# Downstream task - NLP

Data:  
800M+2500M

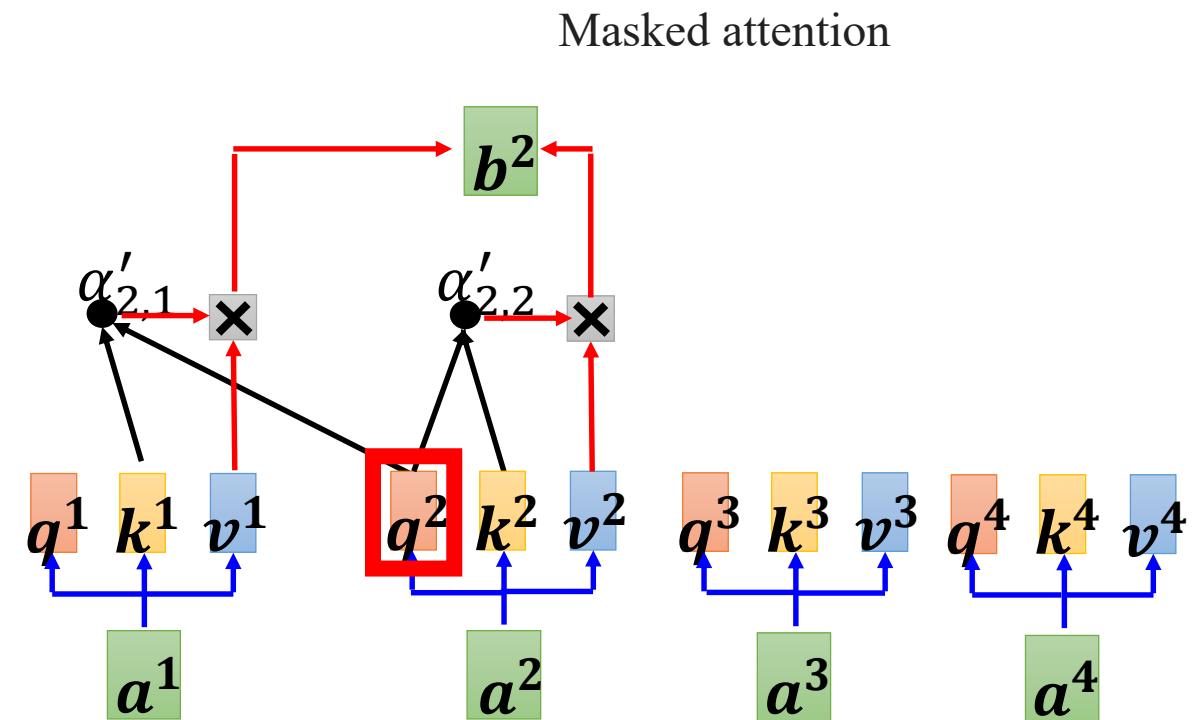
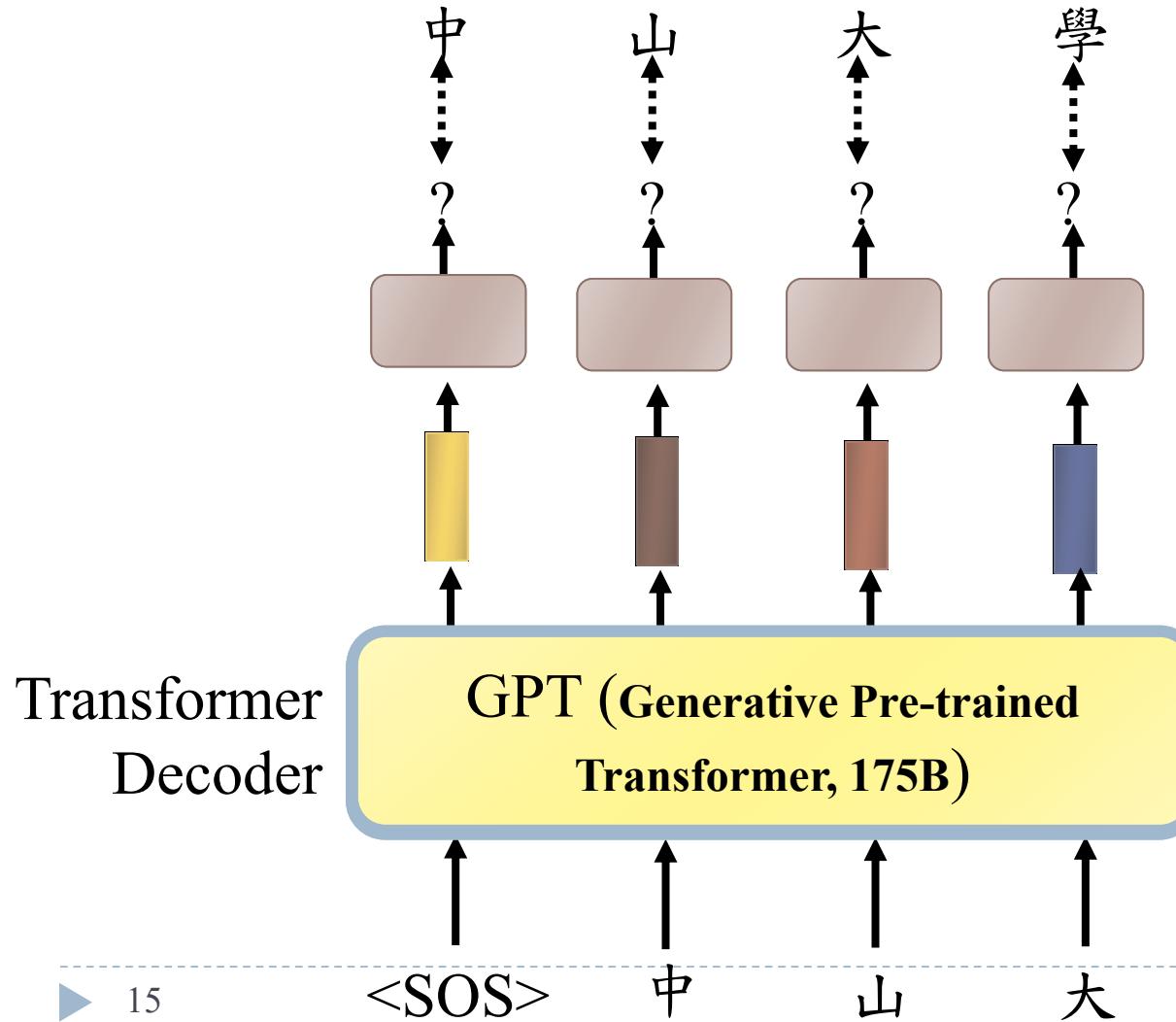


## Downstream Tasks

- The tasks we care
- We have a little bit labeled data.

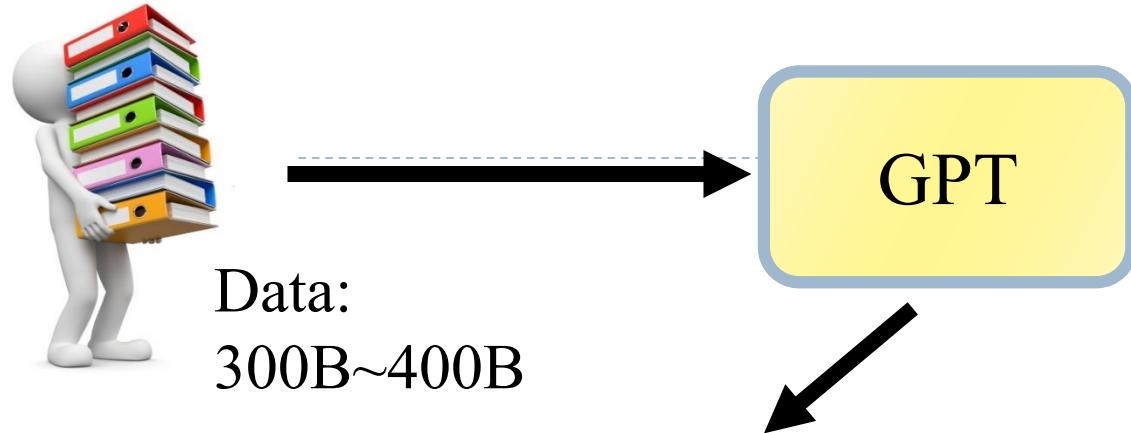
# Self-supervised learning - Pretrained using imputation tasks

## Predict Next Token



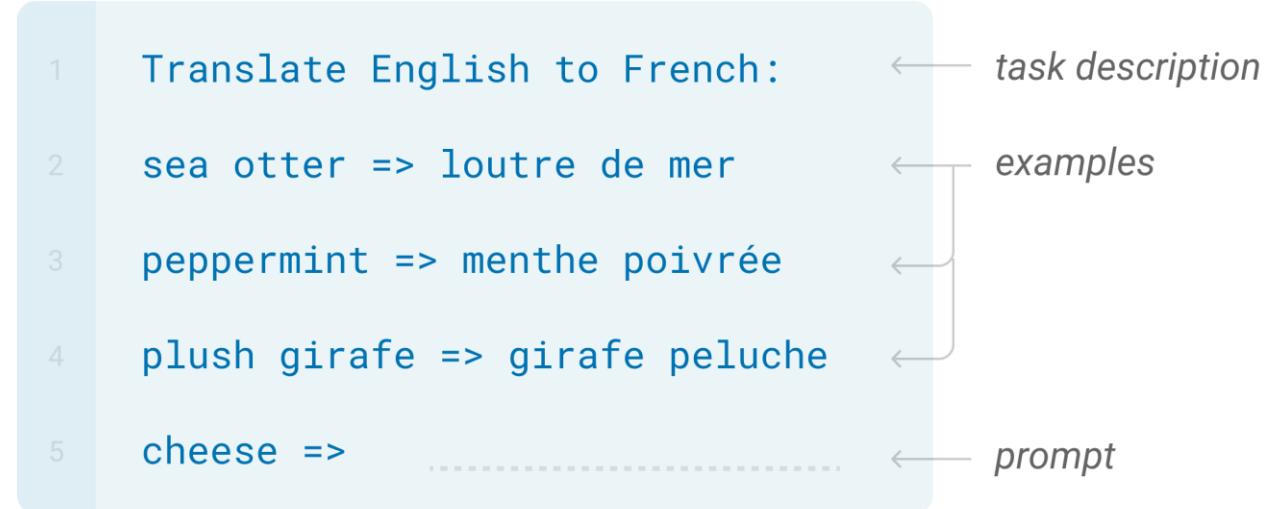
# Downstream task - NLP

- ▶ In-context learning



## "Few-shot" Learning

(no gradient  
descent)

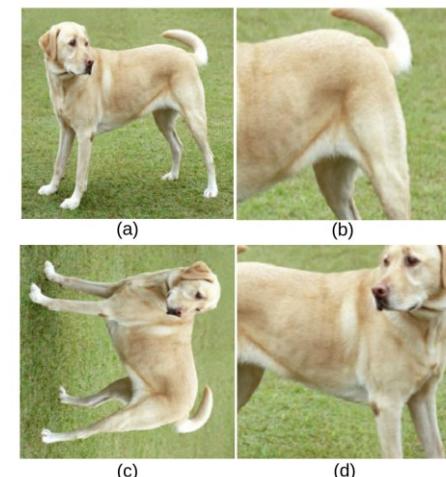
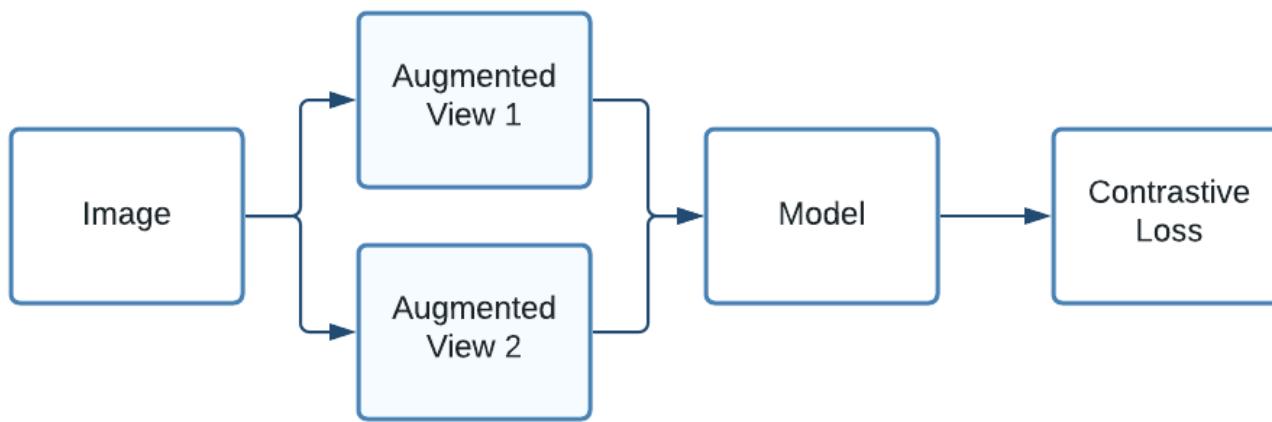


## "zero-shot" Learning



# Self-supervised learning - contrastive tasks

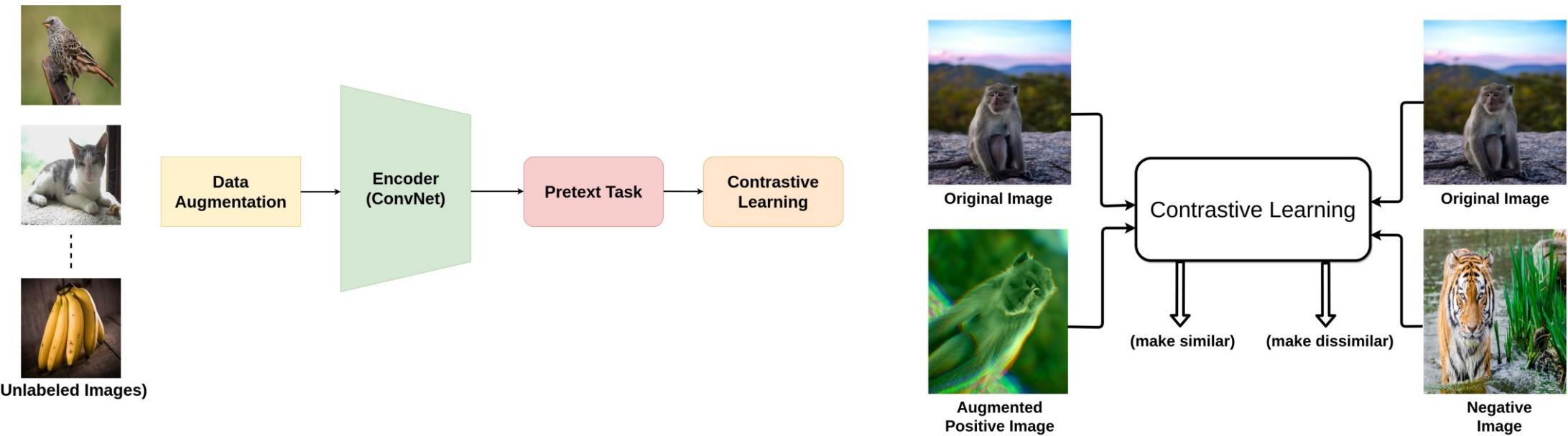
- ▶ Solve proxy tasks, also called pretext tasks
  - ▶ The basic idea is to create pairs of examples that are semantically similar to each other, using data augmentation methods
  - ▶ Train a self-supervised model to learn data representations by contrasting multiple augmented views of the same example. These learned representations capture data invariants, e.g., object translation, color jitter, noise, etc



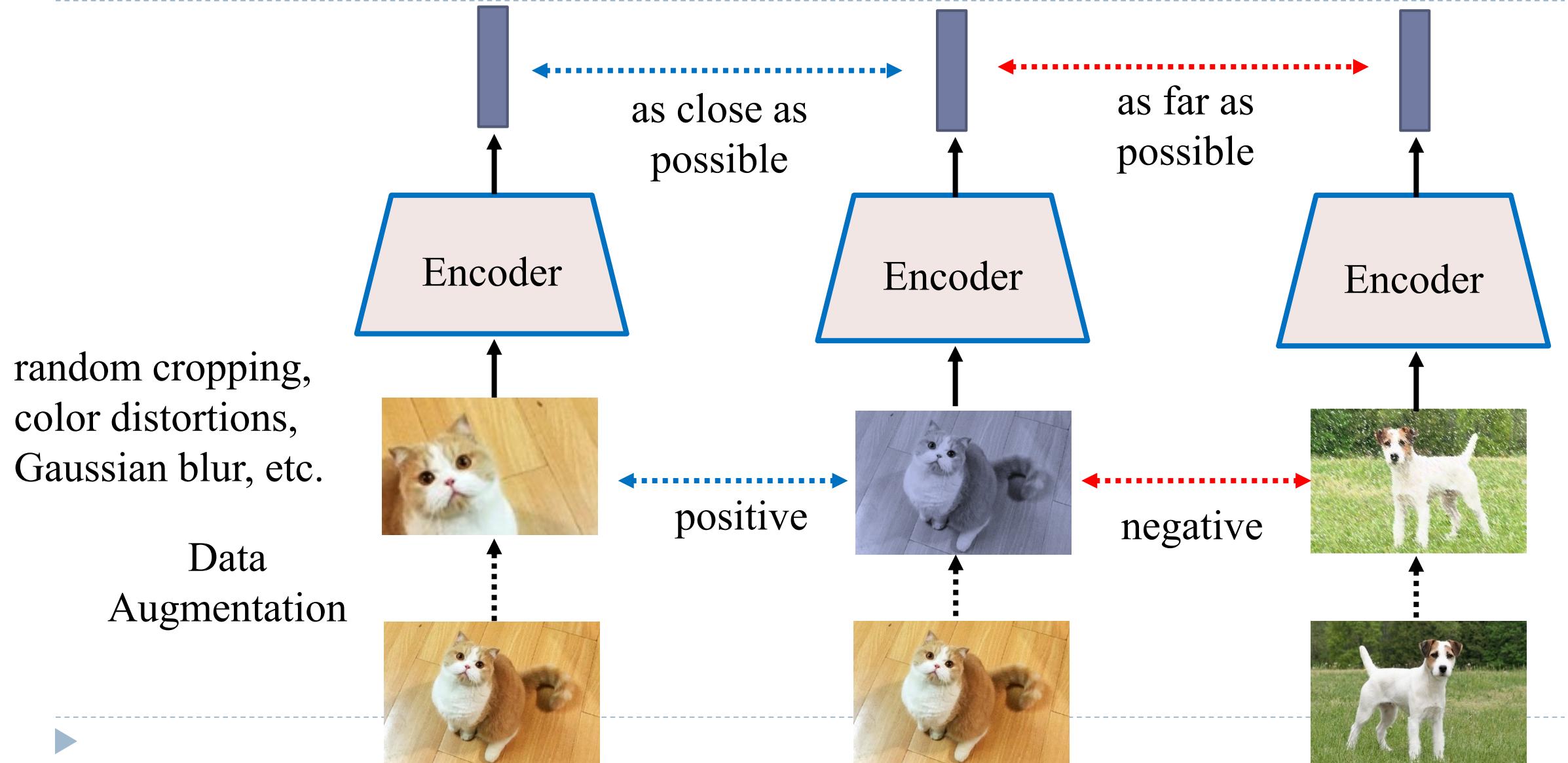
<https://arxiv.org/abs/2011.00362>

# Self-supervised learning - contrastive tasks

- ▶ Pretext tasks are self-supervised tasks that act as an important strategy to learn representations of the data
- ▶ The original image acts as an anchor, its augmented version acts as a positive sample, and the rest of the images in the batch or in the training data act as negative samples



# Self-supervised learning - contrastive tasks - SimCLR



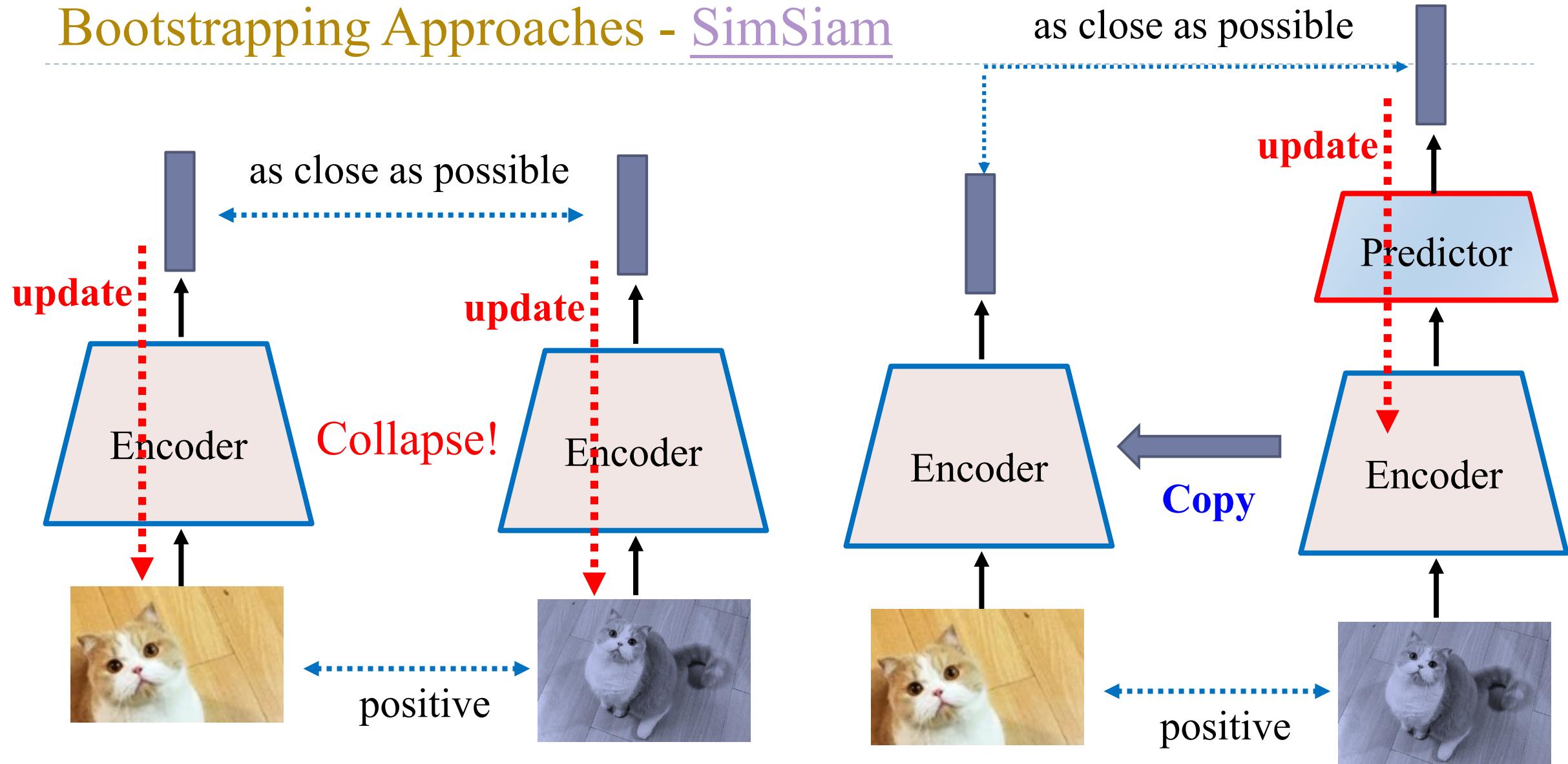
# Selecting Negative Examples is not trivial

- ▶ The negative examples should be hard enough

But cannot be too hard ...

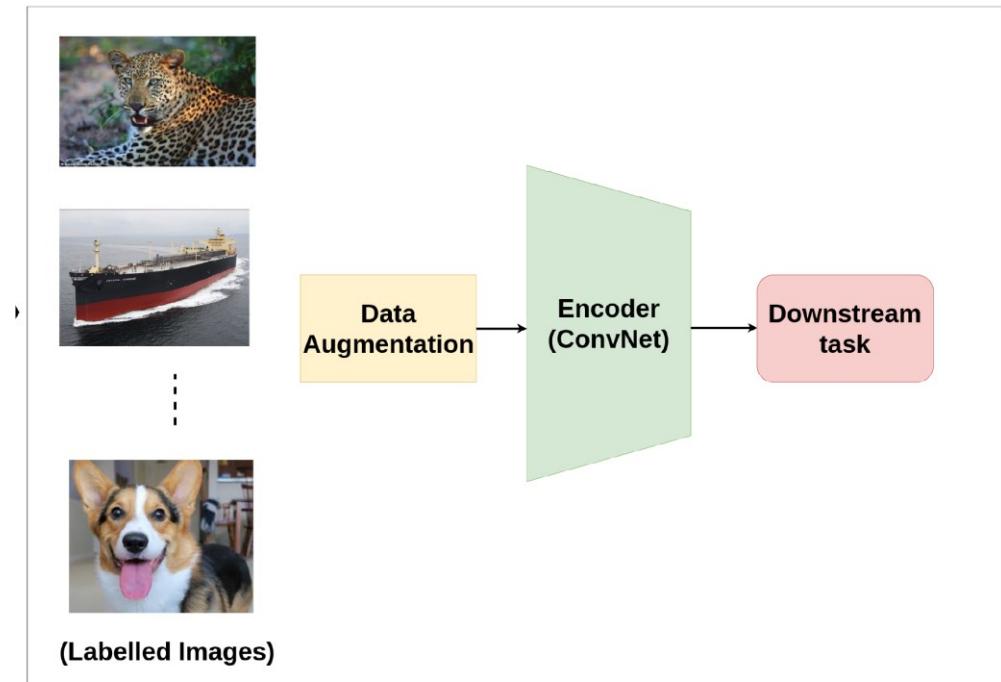


## Bootstrapping Approaches - SimSiam



# Downstream task – computer vision

- ▶ Downstream tasks are application-specific tasks that utilize the knowledge that was learned during the contrastive task
  - ▶ Training a classifier on top of the frozen representations
  - ▶ The learned parameters serve as a pretrained model and are transferred to other downstream computer vision tasks by fine-tuning
  - ▶ The encoder can then be used to produce embedding or latent space

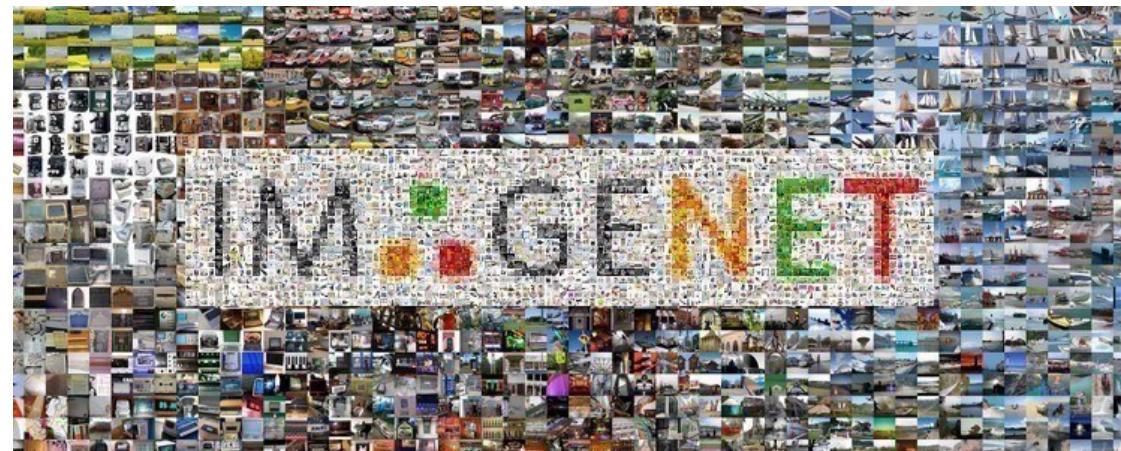


# Multimodal -CLIP (Contrastive Language–Image Pre-training)

- ▶ Text
  - ▶ Self-supervised (LLM)
  - ▶ Large training data
- ▶ Images
  - ▶ Supervised learning
  - ▶ Not that large training data

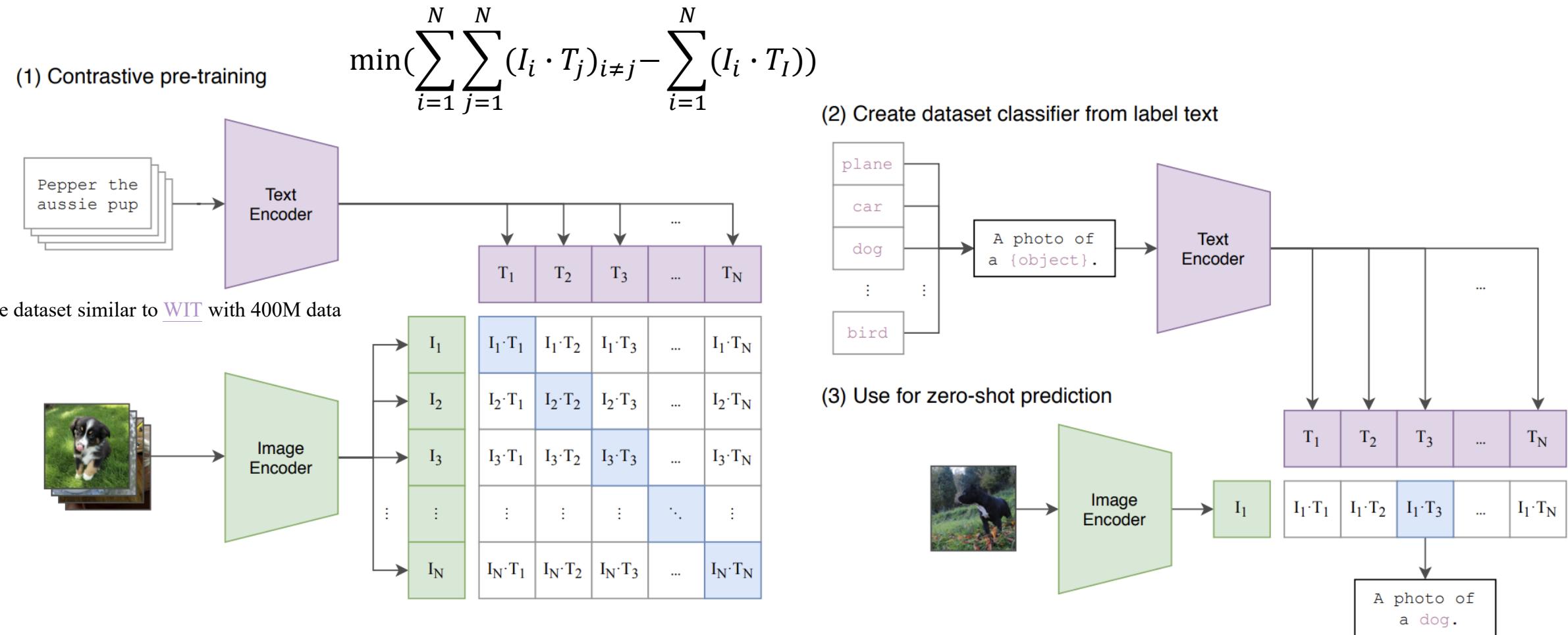
Model	Size (# Parameters)	Training Tokens
LaMDA (Thoppilan et al., 2022)	137 Billion	168 Billion
GPT-3 (Brown et al., 2020)	175 Billion	300 Billion
Jurassic (Lieber et al., 2021)	178 Billion	300 Billion
Gopher (Rae et al., 2021)	280 Billion	300 Billion
MT-NLG 530B (Smith et al., 2022)	530 Billion	270 Billion

<https://arxiv.org/abs/2203.15556>



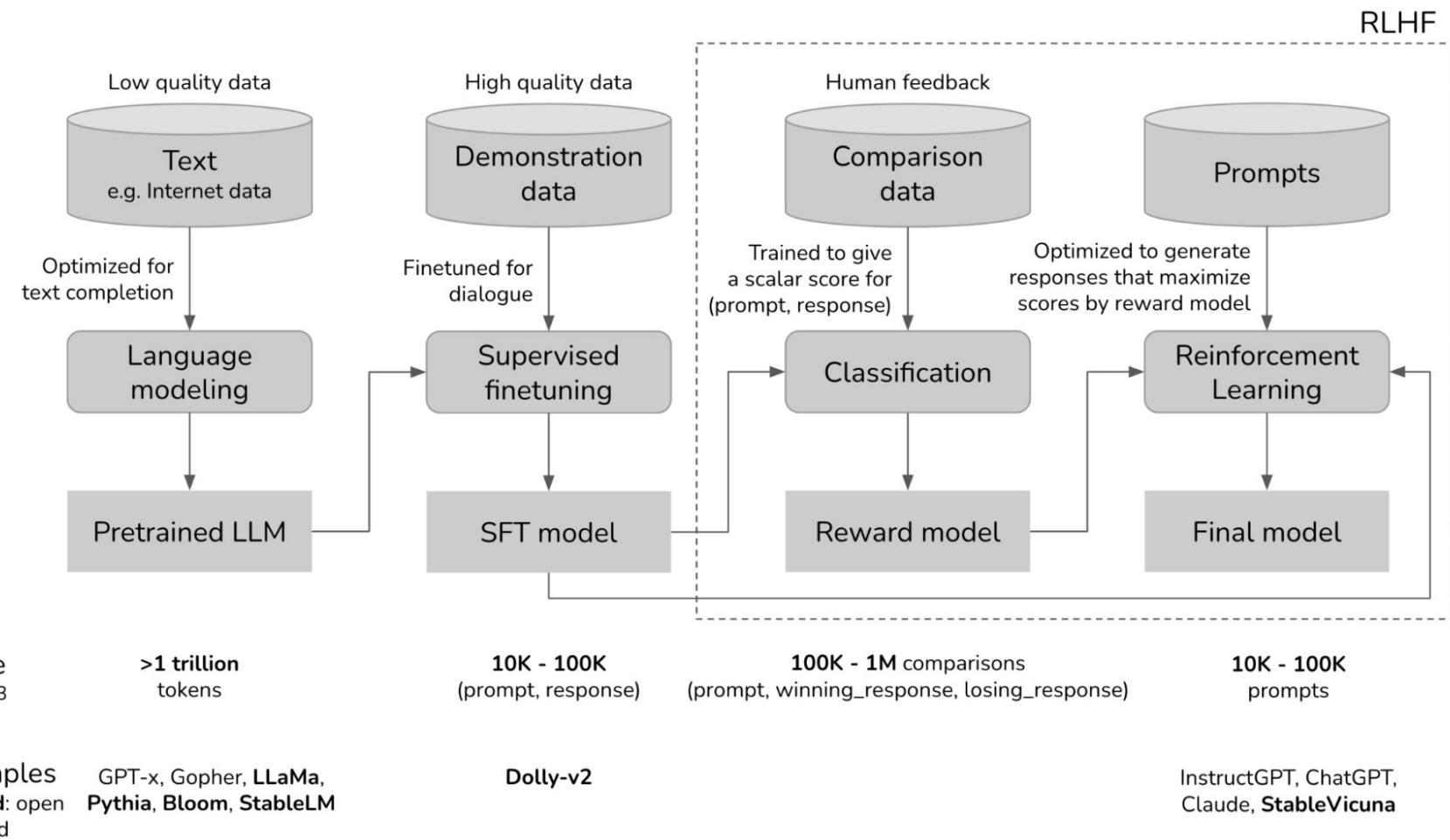
1.28M, 1000 classes

# CLIP (Contrastive Language–Image Pre-training)



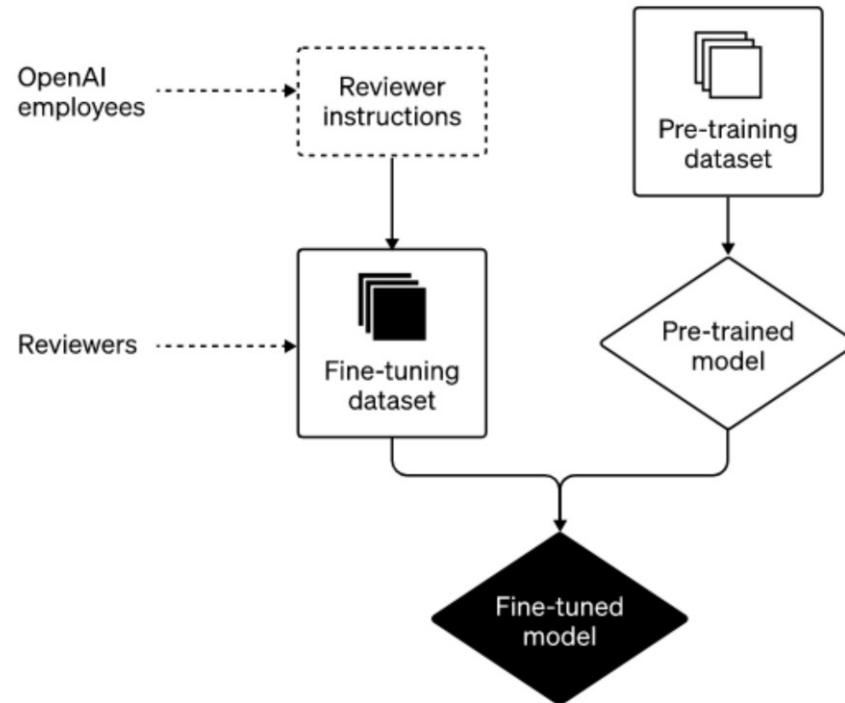
# 4. ChatGPT

## ▶ From GPT to ChatGPT



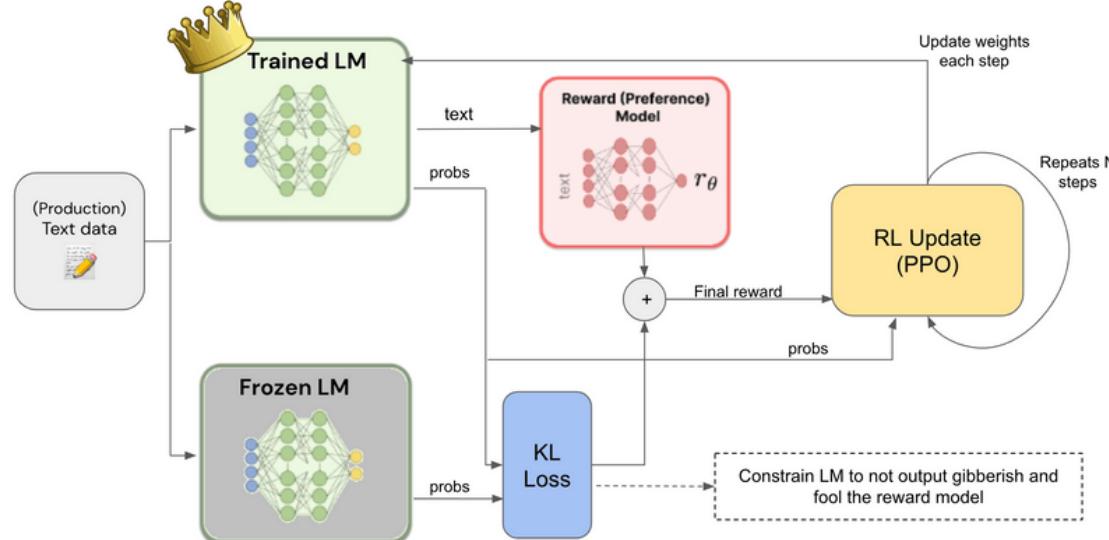
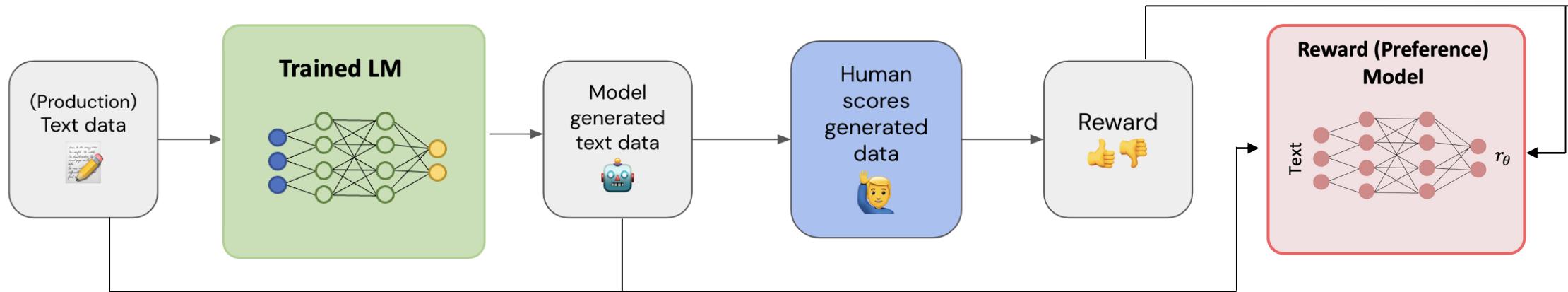
# Supervised Fine-tuning

- ▶ Very little text in the original GPT-3 dataset is of suitable zero-shot form
  - ▶ To improve performance on zero-shot inputs, fine-tuned on a smaller high-quality dataset of instructions-completions



<https://openai.com/blog/how-should-ai-systems-behave>

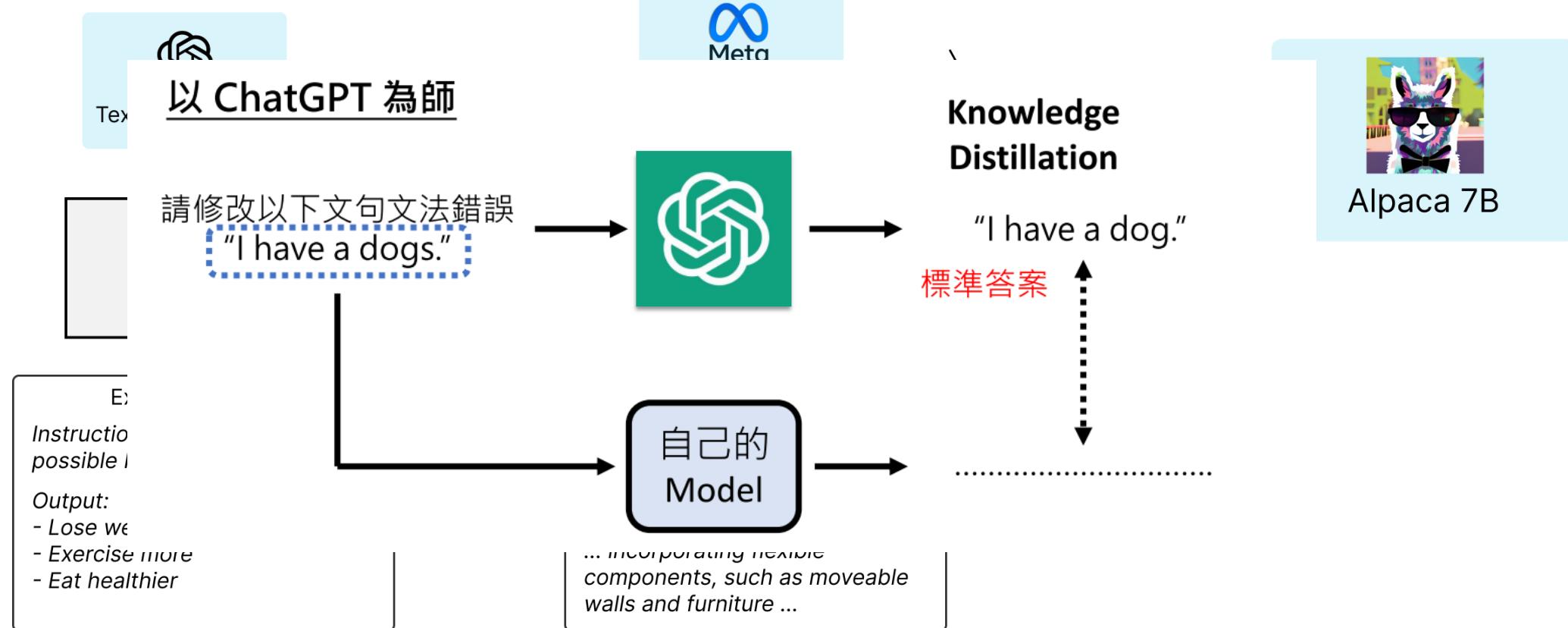
# Reinforcement Learning from Human Feedback (RLHF)



<https://www.nebulys.com/blog/reinforcement-learning-from-human-feedback-rlhf-a-simplified-explanation>

# Build your own ChaptGPT

## ► Alpaca



# Build your own ChaptGPT

## ▶ Hugging Chat

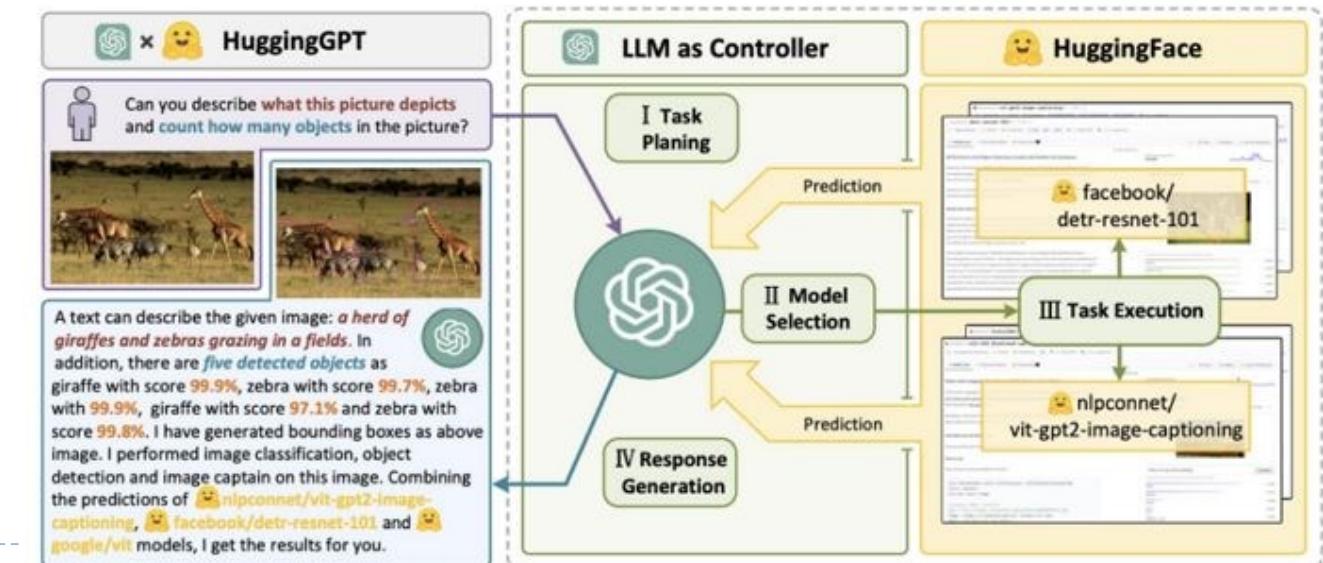
- ▶ Based on LLaMA and finetune on an open dataset provided by [OpenAssistant](#)

## ▶ Dolly 2.0

- ▶ Based on [Pythia](#) that can be used in commercial product
- ▶ The dataset was authored by more than 5,000 Databricks employees during March and April of 2023

## ▶ HuggingGPT

- ▶ Language serves as an interface for LLMs to connect numerous AI models for solving complicated AI tasks!



# Conclusion

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- ▶ Many ML models, especially neural networks, often have many more parameters than we have labeled training examples
- ▶ Of course these parameters are highly correlated, so they are not independent “degrees of freedom”. Nevertheless, such big models are slow to train and, more importantly, they may easily overfit. This is particularly a problem when you do not have a large labeled training set
- ▶ Pretraining using supervised, unsupervised or self-supervised way can greatly benefit the downstream tasks by transferring knowledge from one task to another

# References

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- [1] Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 3rd Edition  
Chapter 11,14
- [2] Deep learning with Python, 2nd Edition Chapter 8
- [3] <https://speech.ee.ntu.edu.tw/~hylee/ml/2022-spring.php> Lecture 7 and Lecture 11
- [4] A Survey on Contrastive Self-supervised Learning

# Appendix

# Resources

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- ▶ **Model repositories**
  - ▶ <https://huggingface.co/models>
  - ▶ <https://tfhub.dev/>
  - ▶ <https://huggingface.co/ckiplab>
- ▶ **Tutorial on transfer learning**
  - ▶ [https://www.tensorflow.org/tutorials/images/transfer\\_learning](https://www.tensorflow.org/tutorials/images/transfer_learning)
  - ▶ <https://github.com/jindongwang/transferlearning/tree/master/code/DeepDA>
- ▶ **Self-supervised learning**
  - ▶ <https://github.com/tensorflow/similarity>
  - ▶ <https://github.com/lightly-ai/lightly>
  - ▶ [https://github.com/KeremTurgutlu/self\\_supervised/tree/main](https://github.com/KeremTurgutlu/self_supervised/tree/main)
  - ▶ <https://github.com/nlp-with-transformers/notebooks/tree/main>
  - ▶ [https://huggingface.co/docs/transformers/tasks/zero\\_shot\\_image\\_classification](https://huggingface.co/docs/transformers/tasks/zero_shot_image_classification)

# Resources

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- ▶ Foundation model
  - ▶ <https://snorkel.ai/foundation-models/>
  - ▶ <https://github.com/facebookresearch/dinov2>
- ▶ Prompt engineering
  - ▶ <https://www.deeplearning.ai/short-courses/chatgpt-prompt-engineering-for-developers/>
  - ▶ <https://blog.o-w-o.cc/archives/chatgpt-prompt-guideline>
- ▶ Tutorials on other related topics
  - ▶ [https://d2l.ai/chapter\\_natural-language-processing-pretraining/index.html](https://d2l.ai/chapter_natural-language-processing-pretraining/index.html)
  - ▶ [Multi-Task Learning](#)
  - ▶ [Zero-Shot Learning](#)
  - ▶ [A Survey on Contrastive Self-supervised Learning](#)
  - ▶ [Curriculum Learning](#)

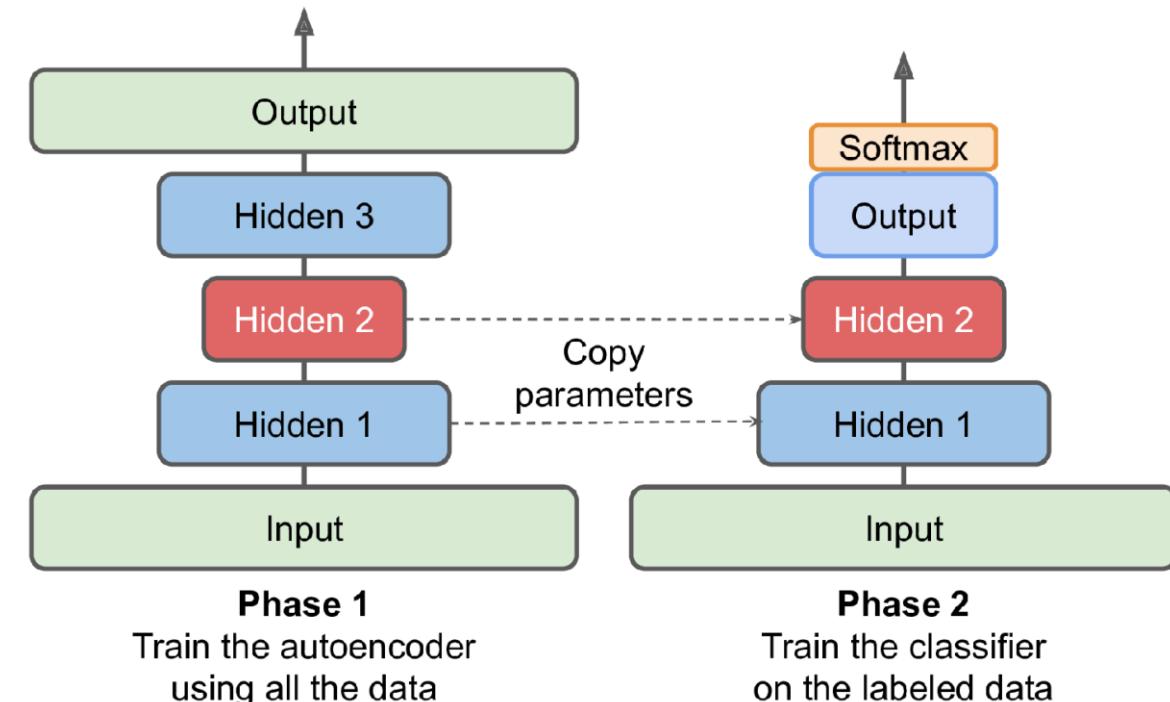
# Unsupervised pretraining

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- ▶ In case you want to tackle a complex task for which you don't have much labeled data, but unfortunately you can't find a model trained on a similar task
  - ▶ If you can gather plenty of unlabeled training data, you can try to use it to train an unsupervised model, such as an autoencoder or a generative adversarial network
  - ▶ You can then reuse the lower layers of the autoencoder or GAN's discriminator, add the output layer for your task on top, and finetune the final network with the labeled training examples

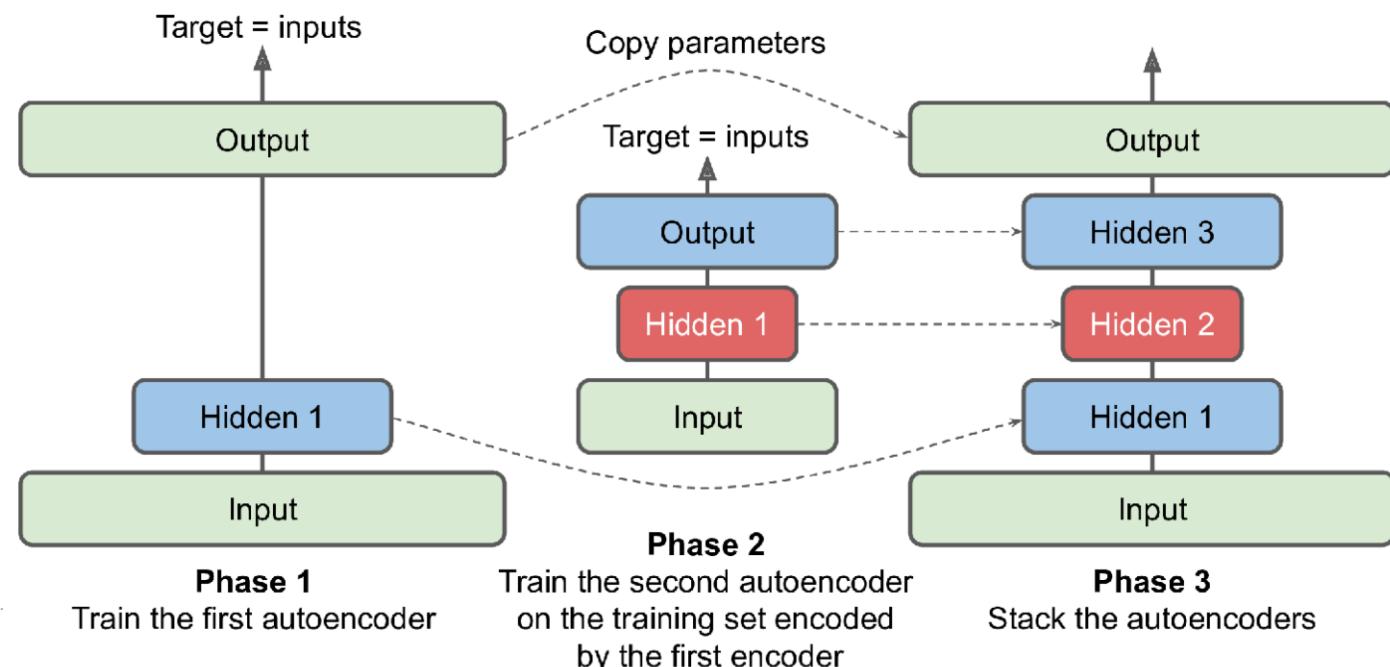
# Unsupervised pretrained

- ▶ If you have a large dataset but most of it is unlabeled, you can first train a stacked autoencoder using all the data
  - ▶ Then reuse the lower layers to create a neural network for your actual task and train it using the labeled data, you may also want to freeze the pretrained layers
  - ▶ When an autoencoder is neatly symmetrical, a common technique is to tie the weights of the decoder layers to the weights of the encoder layers. This halves the number of weights in the model, speeding up training and limiting the risk of overfitting



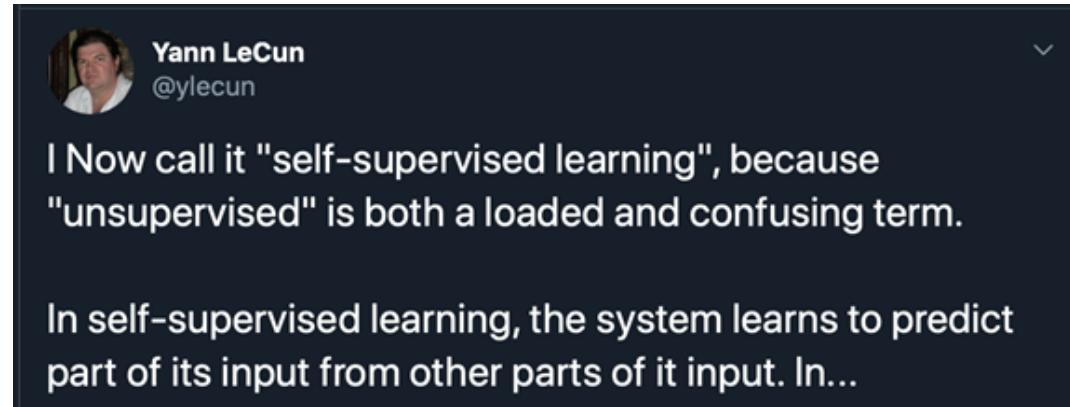
# Training one autoencoder at a time

- ▶ It is possible to train one shallow autoencoder at a time, then stack all of them into a single stacked autoencoder called “greedy layerwise training”
- ▶ During the first phase of training, the first autoencoder learns to reconstruct the inputs. Then we encode the whole training set using this first autoencoder, and this gives us a new (compressed) training set. We then train a second autoencoder on this new dataset. This is the second phase of training
- ▶ Finally, we build a big sandwich using all these autoencoders, This gives us the final stacked autoencoder



# What is Self-Supervised Learning?

- ▶ A version of unsupervised learning where data provides the supervision.



- ▶ In general, withhold some part of the data and the task a neural network to predict it from the remaining parts.
- ▶ Goal: Learning to represent the world before learning tasks.

# Self-supervised learning

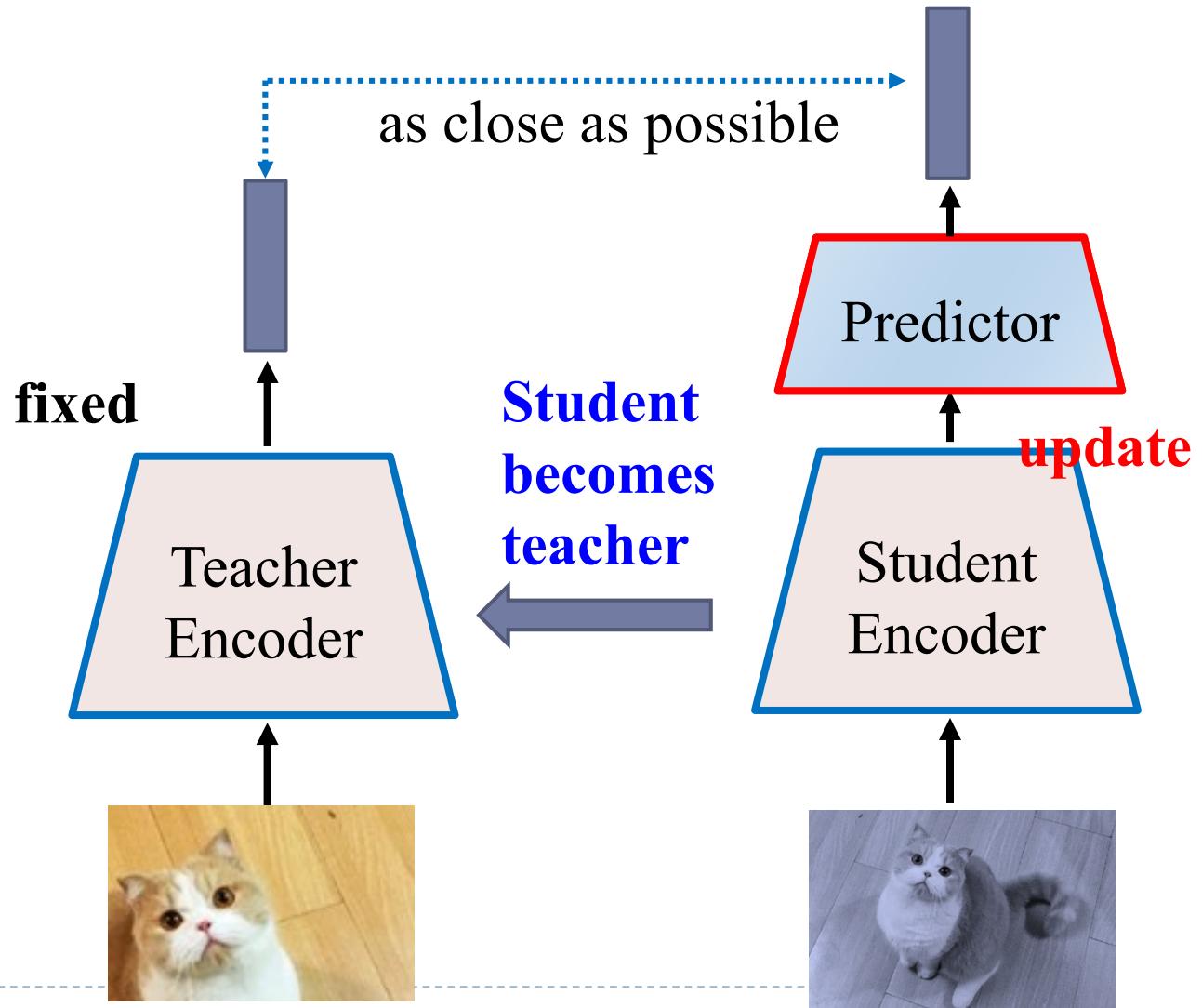
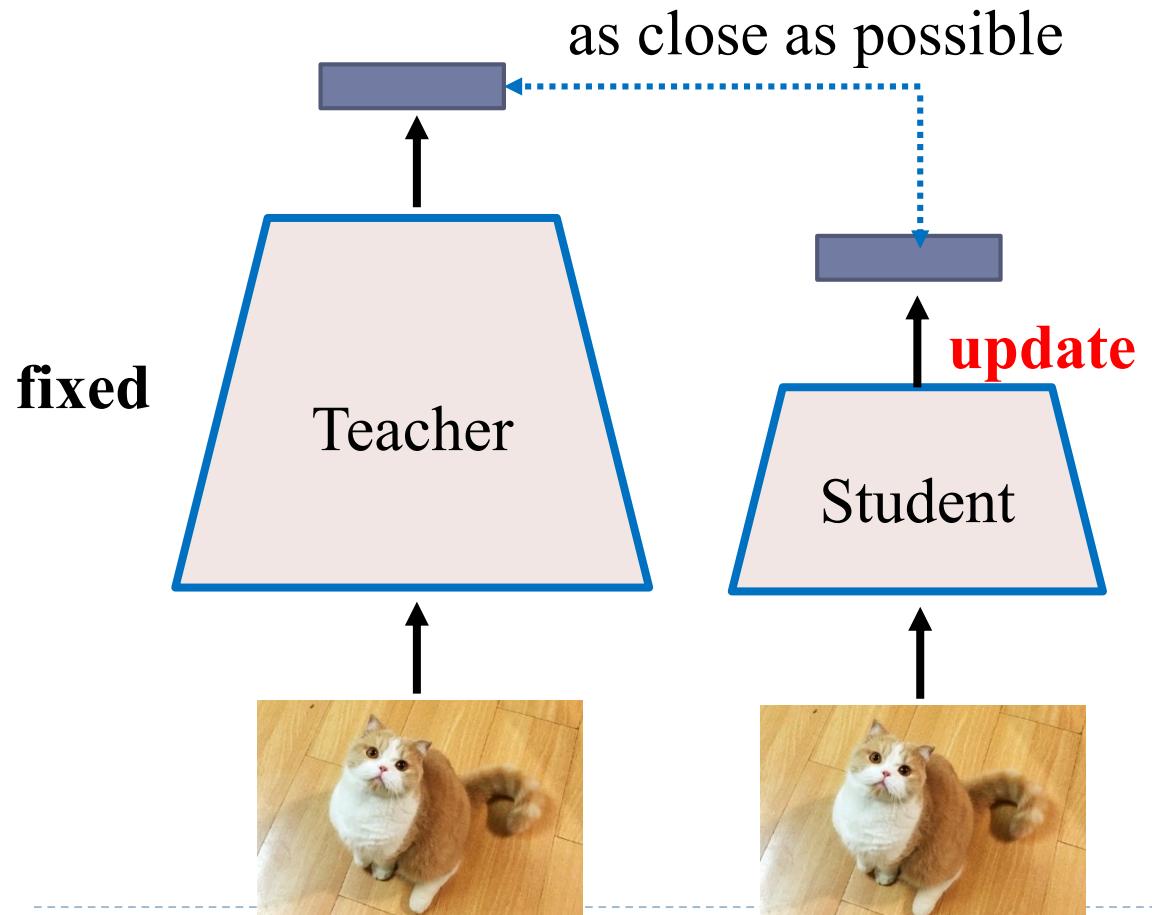
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- ▶ Identifying the right pre-text task
  - ▶ The choice of pretext task relies on the type of problem being solved
  - ▶ The main aim of a pre-text task is to compel the model to be *invariant* to these transformations while remaining discriminative to other data points
  - ▶ For instance, colorization-based pretext tasks might not work out in a fine-grain classification represented in figure



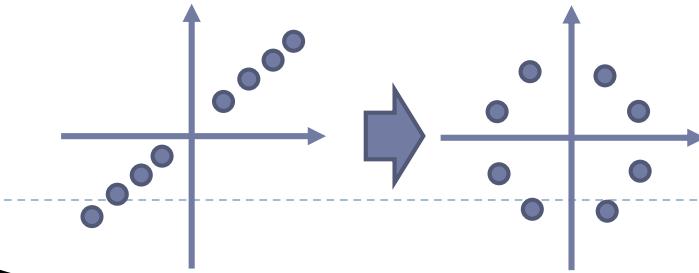
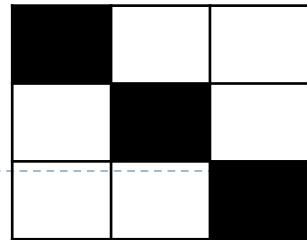
# Alternative view of Bootstrapping

## Typical Knowledge Distillation



## Covariance

Off-diagonal elements close to 0



**Audio: DeLoRes**

<https://arxiv.org/abs/2203.13628>

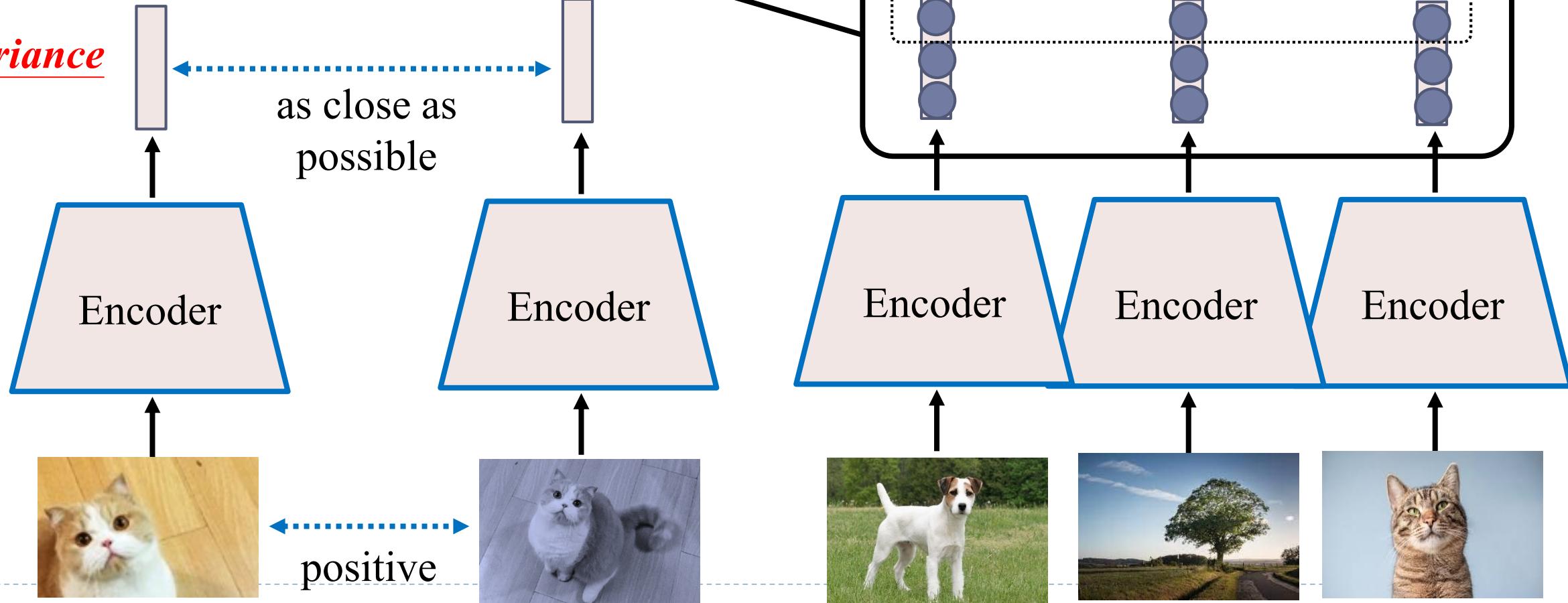
## Variance

Variance larger than a threshold

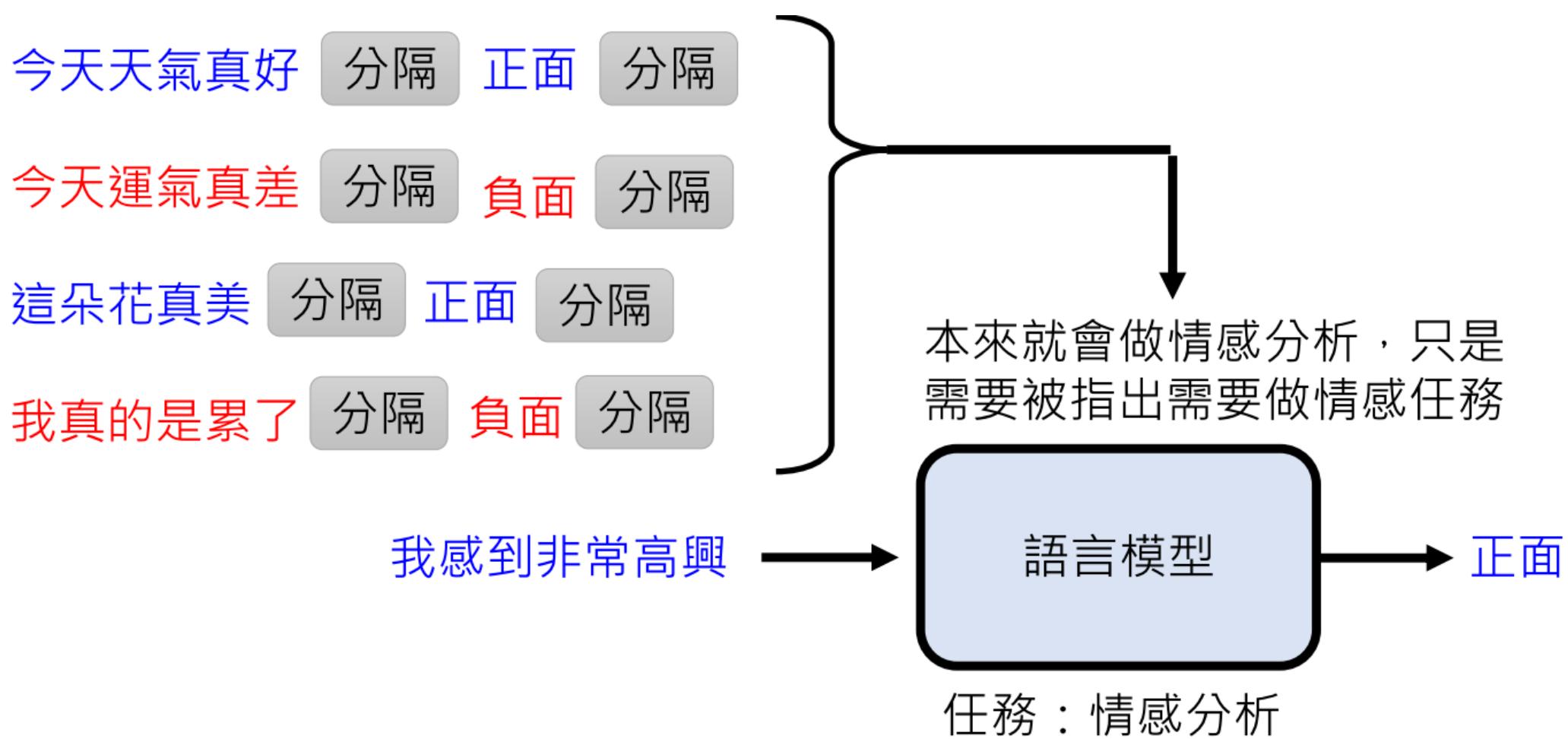
**Prevent collapse**

## Invariance

as close as possible



# In-context learning (Standard prompting)

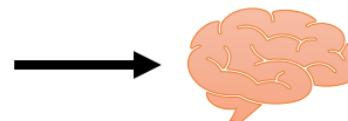


# Instruction tuning and Chain of Thought

## Instruction-tuning

Training

對以下文句做翻譯：這堂課我們  
要講如何駕馭大型語言模型 .....



This course  
is about .....

對以下文句做摘要：這堂課我們  
要講如何駕馭大型語言模型 .....

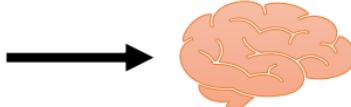


本課程重點  
為 .....

Testing

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請幫我編修以下文句："How is  
you?"

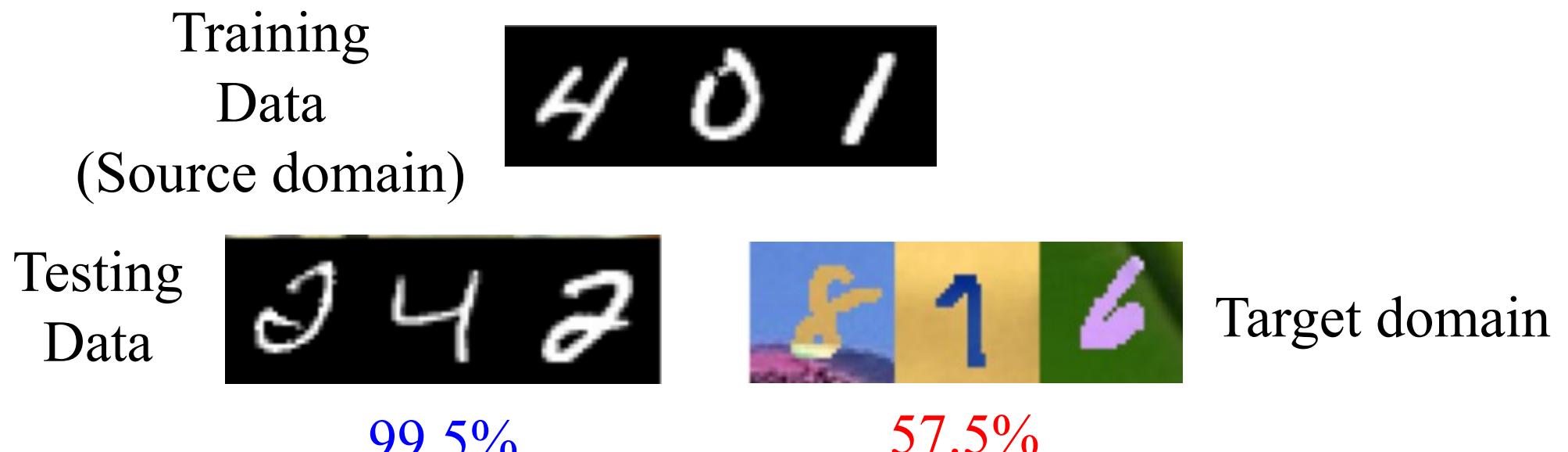


"How are  
you?"

# Taxonomy of Transfer learning

		Source Data (not directly related to the task)	
		labelled	unlabeled
Target Data	labelled	Fine-tuning Multitask Learning Few-shot learning	<b>Self-taught learning</b> “Transfer learning from unlabeled data”, ICML, 2007 <b>Self-supervised learning</b>
	unlabeled	Domain-adversarial training Zero-shot learning	<b>Self-taught Clustering</b> “Self-taught clustering”, ICML 2008

# Domain adaptation



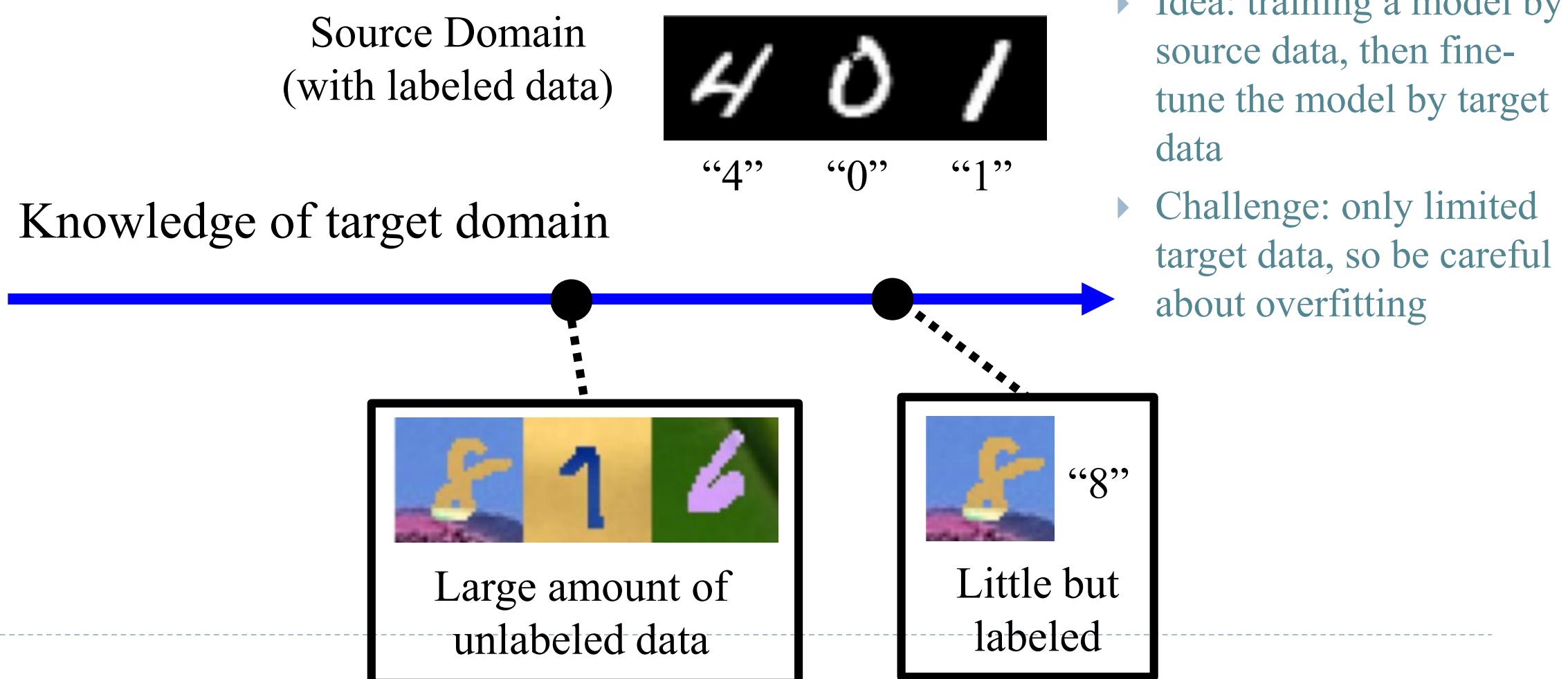
Domain shift: Training and testing data have different distributions.



**Domain  
adaptation**

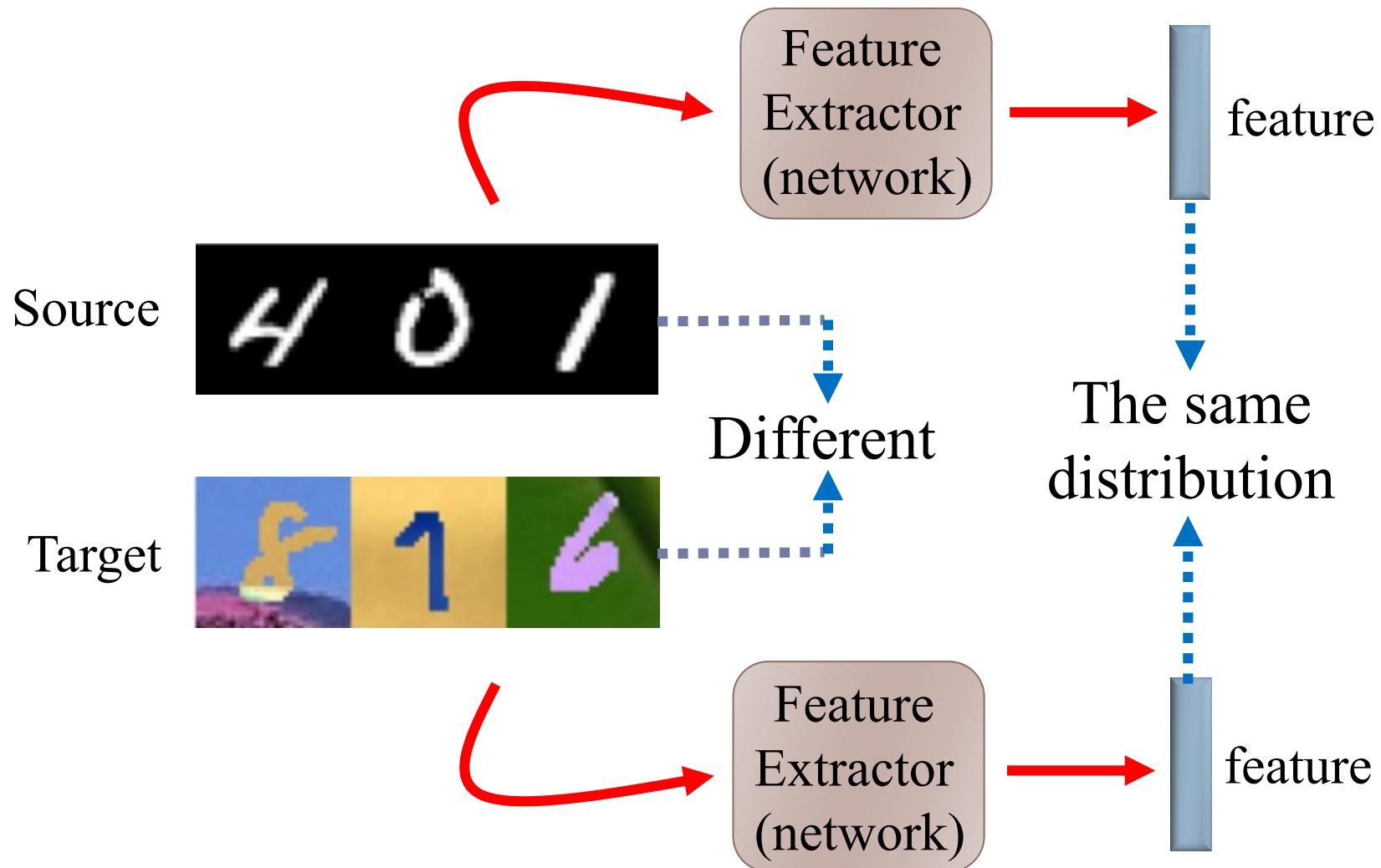
# Domain adaptation

- ▶ <https://paperswithcode.com/sota/domain-adaptation-on-gta5-to-cityscapes>

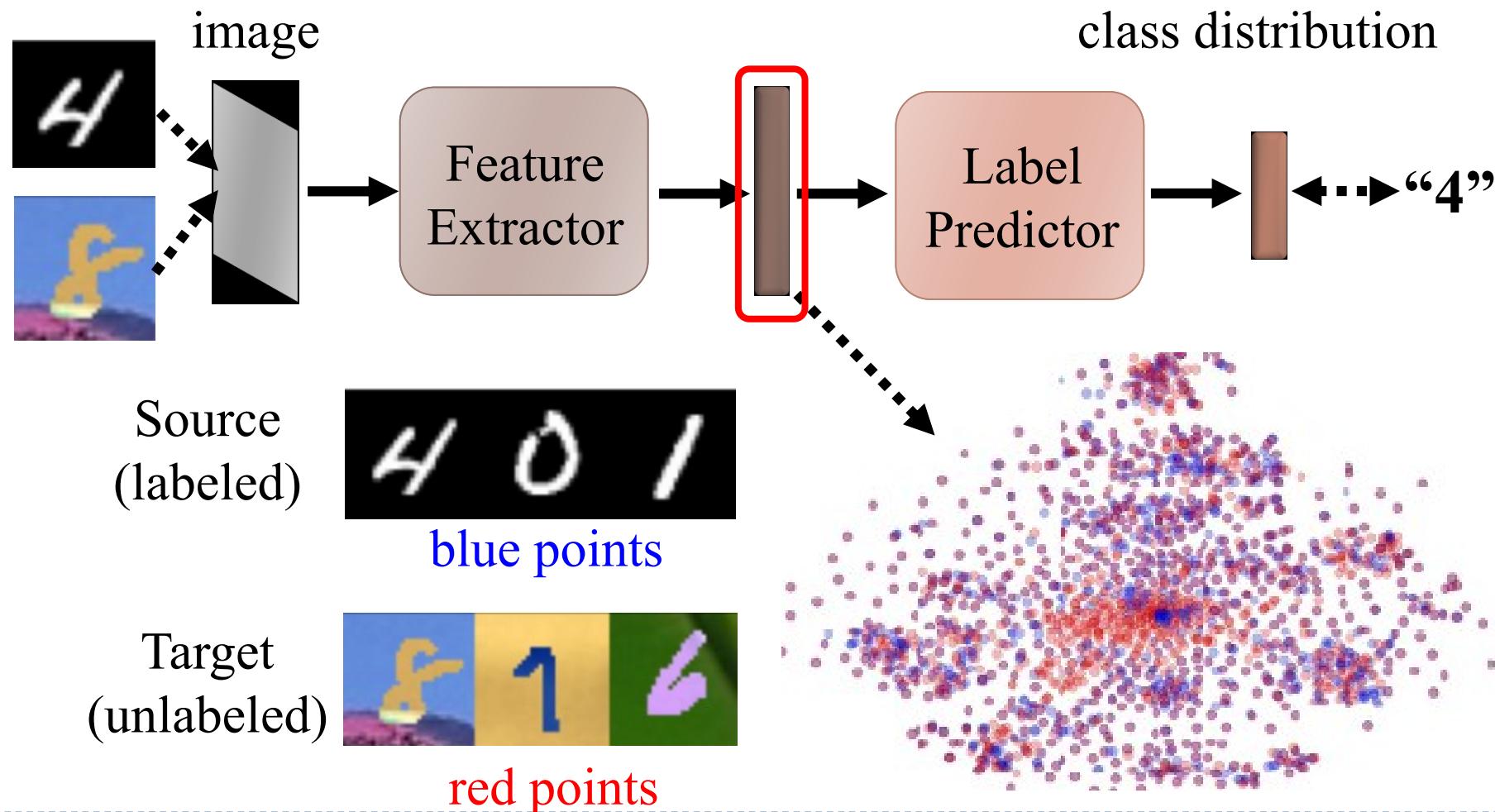


# Domain adaptation

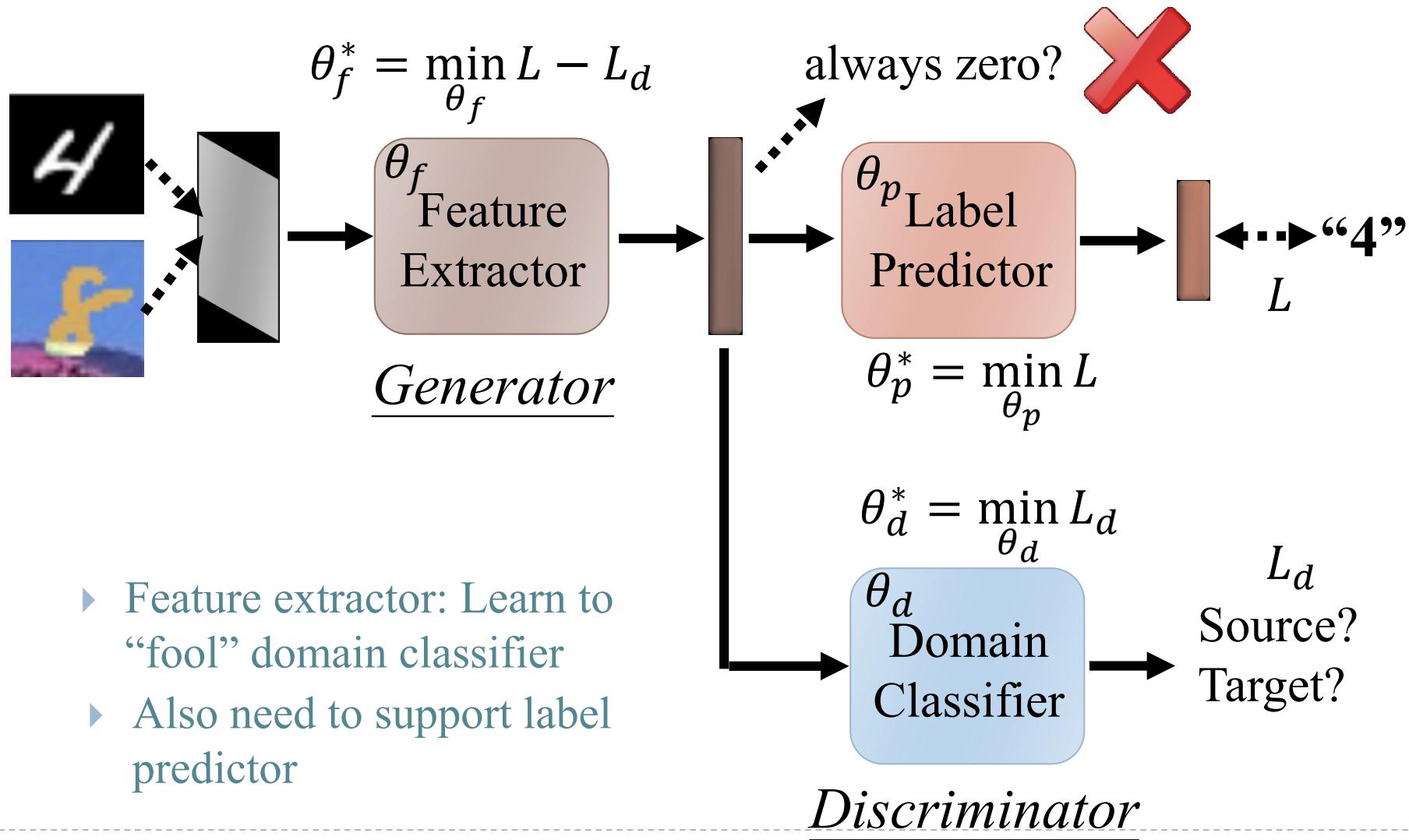
Learn to ignore colors



# Domain adversarial training



# Domain adversarial training



- ▶ Feature extractor: Learn to “fool” domain classifier
- ▶ Also need to support label predictor

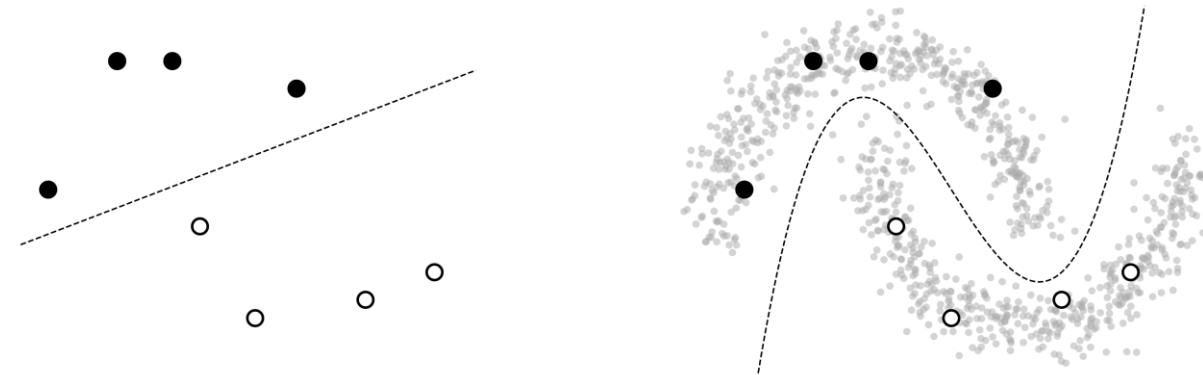
# Domain adversarial training



METHOD	SOURCE	MNIST	SYN NUMBERS	SVHN	SYN SIGNS
	TARGET	MNIST-M	SVHN	MNIST	GTSRB
SOURCE ONLY		.5749	.8665	.5919	.7400
PROPOSED APPROACH		<b>.8149</b> (57.9%)	<b>.9048</b> (66.1%)	<b>.7107</b> (29.3%)	<b>.8866</b> (56.7%)
TRAIN ON TARGET		.9891	.9244	.9951	.9987

# Semi-supervised learning

- ▶ Semi-supervised learning can alleviate the need for labeled data by taking advantage of unlabeled data
- ▶ The general goal of semi-supervised learning is to allow the model to learn the high-level structure of the data distribution from unlabeled data and only rely on the labeled data for learning the fine-grained details of a given task
- ▶ Whereas in standard supervised learning we assume that we have access to samples from the joint distribution of data and labels  $x, y \sim p(x, y)$ , semi-supervised learning assumes that we additionally have access to samples from the marginal distribution of  $x \sim p(x)$



# Semi-supervised learning: self-training and pseudo-labeling

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- ▶ A straightforward approach to *semi-supervised learning* is self-training
  - ▶ The basic idea behind self-training is to use the model itself to infer predictions on unlabeled data, and then treat these predictions as labels for subsequent training
  - ▶ Recently, it has become common to refer to this approach as “pseudo-labeling” because the inferred labels for unlabeled data are only “pseudo-correct” in comparison with the true, ground-truth targets used in supervised learning
  - ▶ A common strategy is to use a “selection metric” which tries to only retain pseudo-labels that are correct. For example, assuming that a model outputs probabilities for each possible class, a frequently-used selection metric is to only retain pseudo-labels whose largest class probability is above a threshold
  - ▶ Also refer to noisy student approach, some recent paper advocate self-training approach rather than supervised or self-supervised way, see [here](#)