

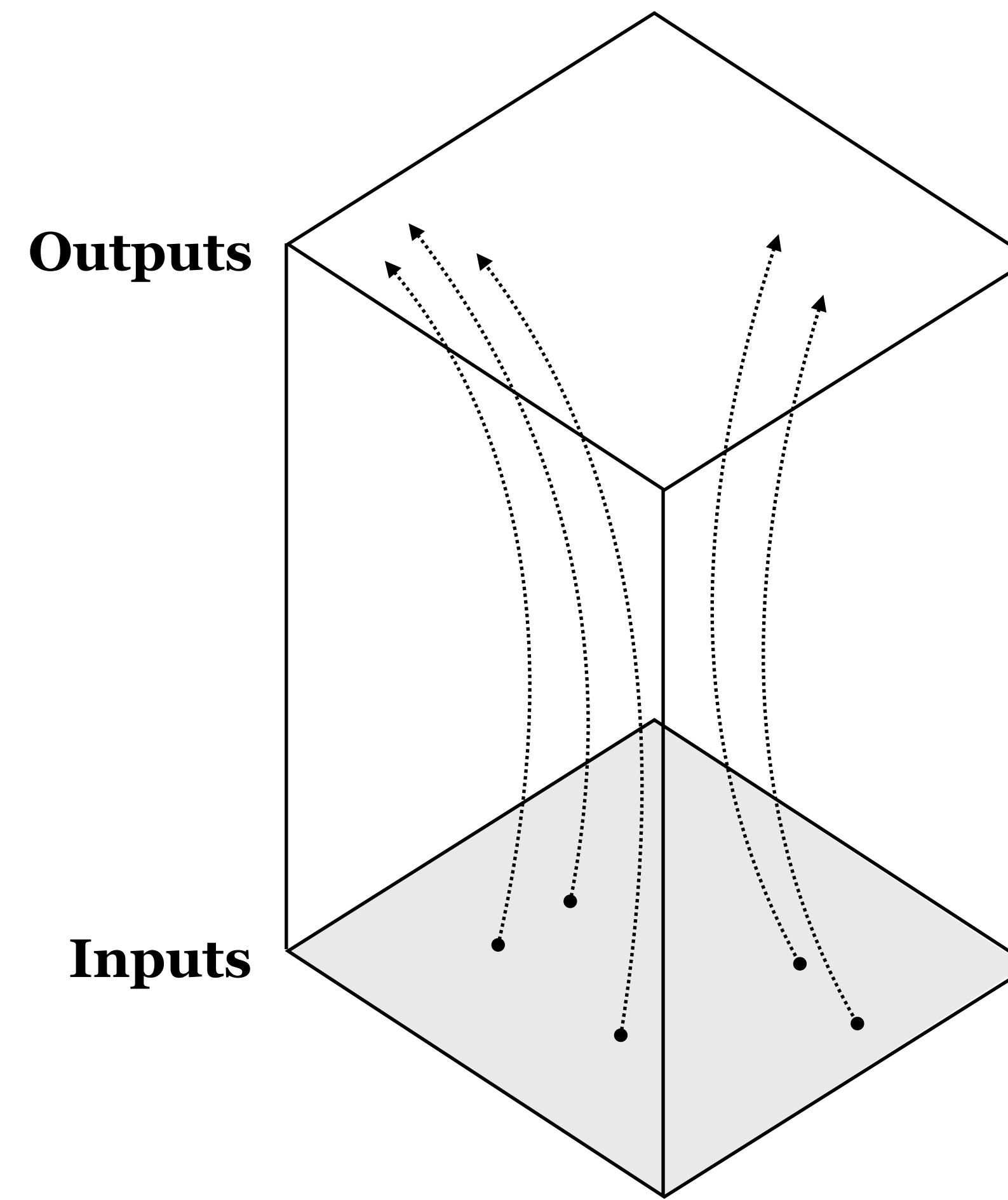
# Lecture 19: Transfer Learning II

Speaker: Sara Beery

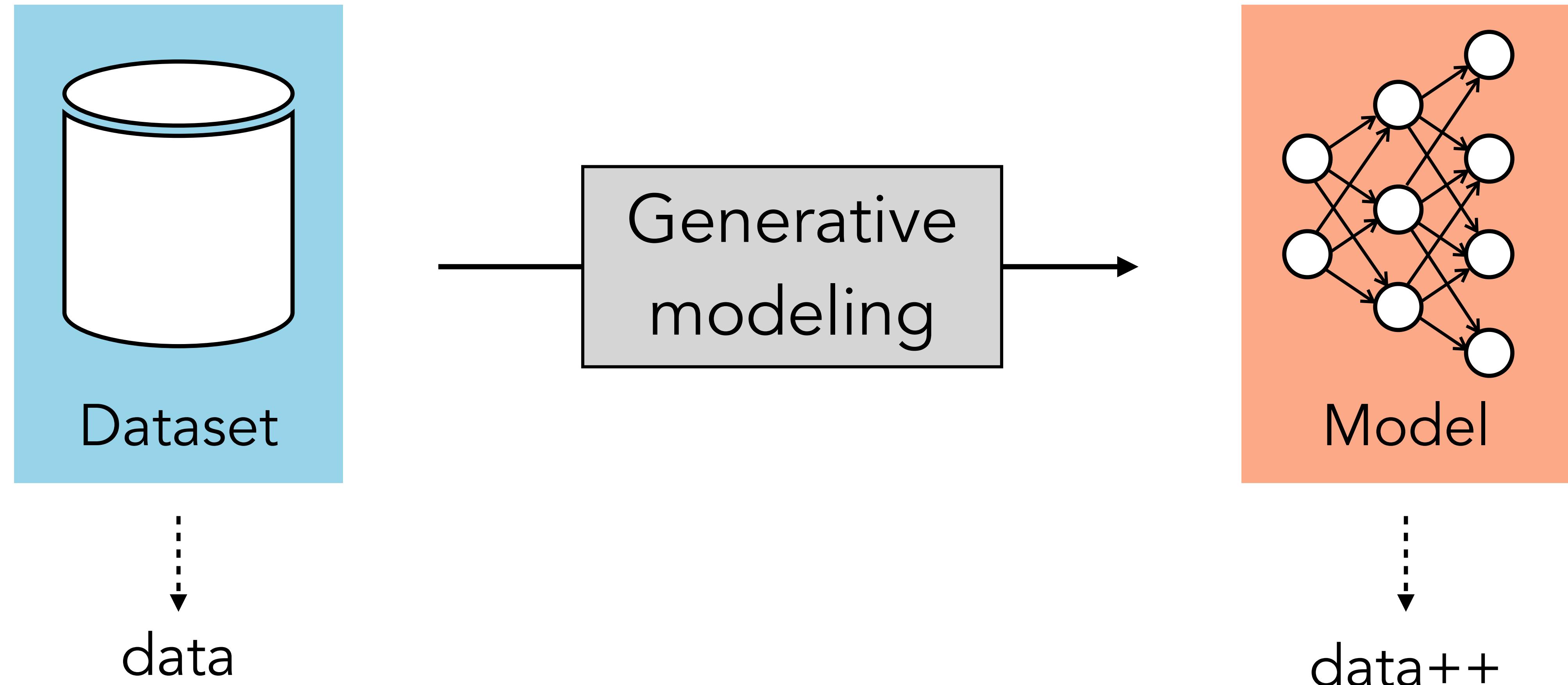
# Transfer Learning II

- Transferring knowledge about the inputs
  - Generative models as data++
- Meta-learning

1. Knowledge about the mapping
2. Knowledge about the outputs
3. **Knowledge about the inputs**



# Transfer Learning



“This release is the culmination of many hours of collective effort to create a single file that compresses the visual information of humanity into a few gigabytes.”

Emad Mostaque [<https://stability.ai/blog/stable-diffusion-public-release>]

# Data++: making data a first class object

---

$$\mathbb{X} = \{x, z, G, G^{-1}\}$$

Interpolation:  $\alpha \mathbb{X}_1 + (1 - \alpha) \mathbb{X}_2 \rightarrow \mathbb{X}_3$

Manipulation:  $\mathbb{X}_1 + w \rightarrow \mathbb{X}_2$

Composition:  $\mathbb{X}_1[m] + \mathbb{X}_2[1 - m] \rightarrow \mathbb{X}_3$

Optimization:  $\arg \min_{\mathbb{X}} f(\mathbb{X})$

[Goetschalckx\*, Andonian\*, Oliva, Isola, ICCV 2019]

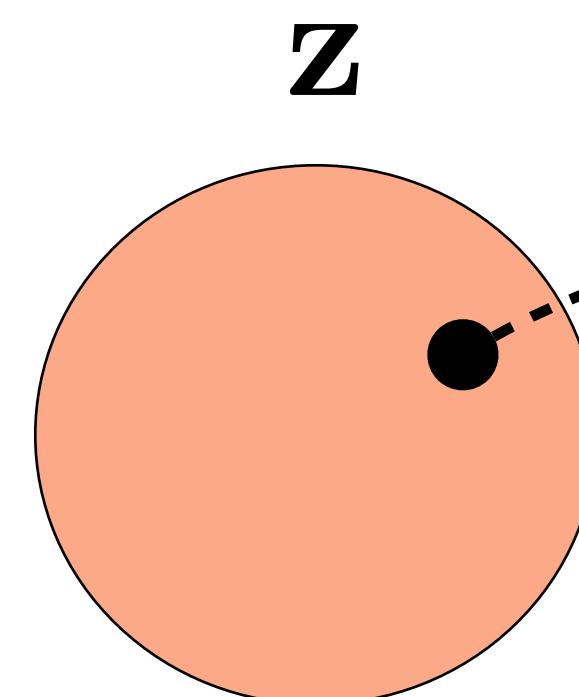
[Jahanian\*, Chai\*, Isola, ICLR 2020]

[Chai, Wulff, Isola, ICLR 2021]

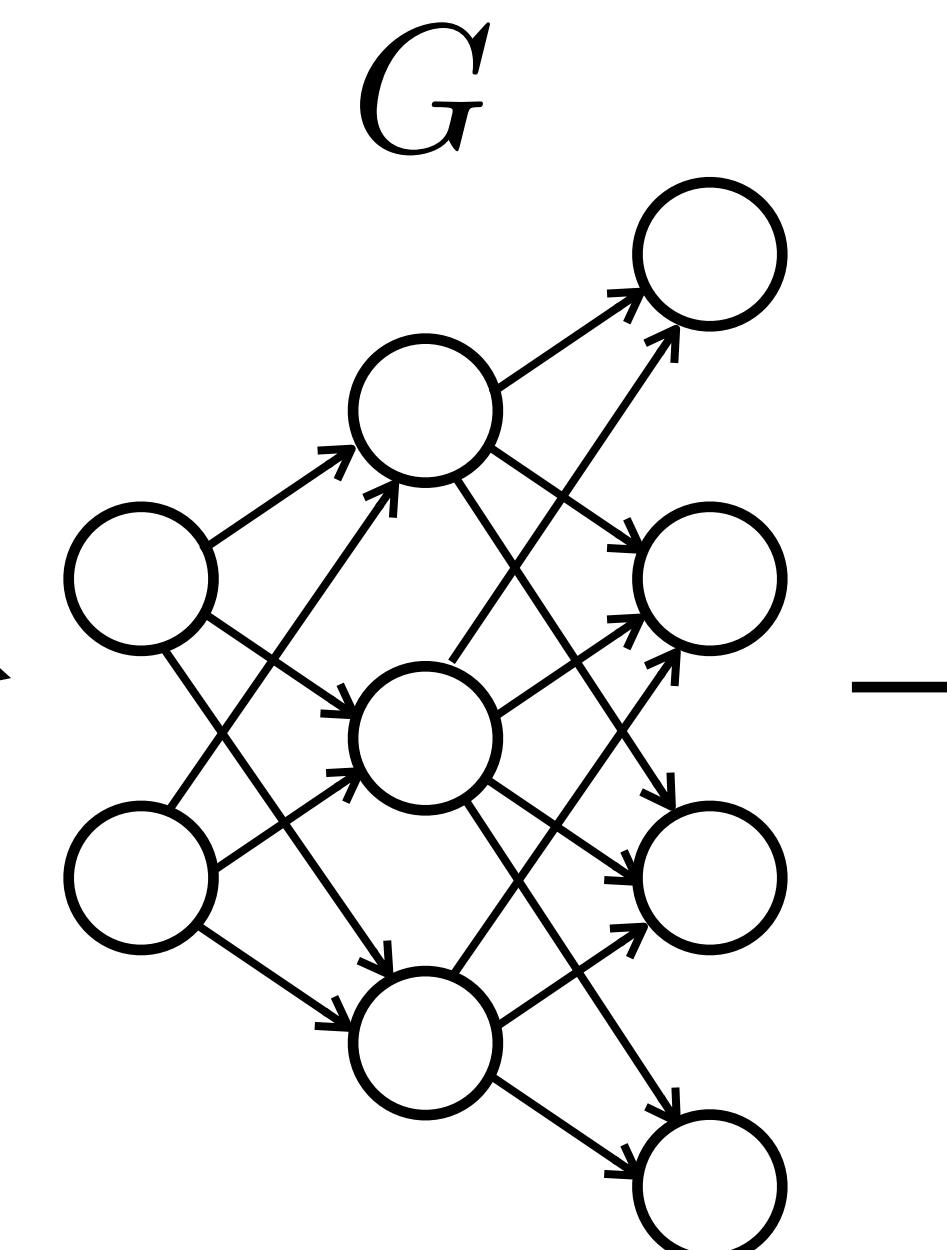
→ Graphics, visualization, data aug, counterfactual reasoning, ...

# Generative Models

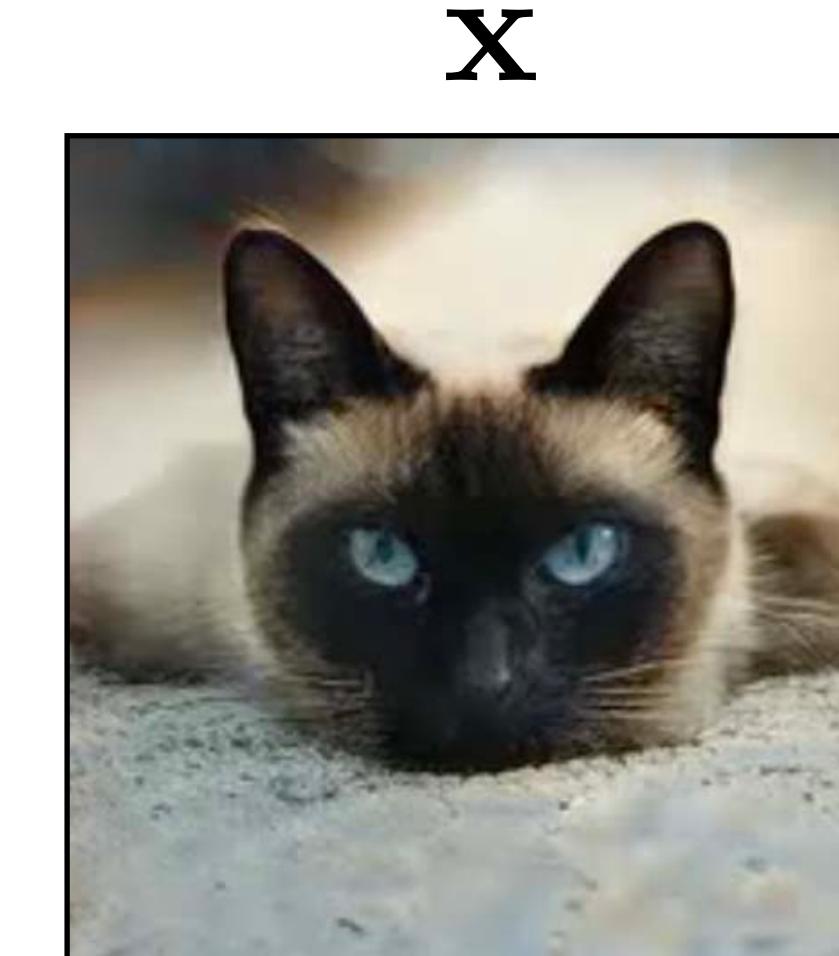
Latent variables  
(controls)



$$\mathbf{z} \sim \mathcal{N}(0, 1)$$



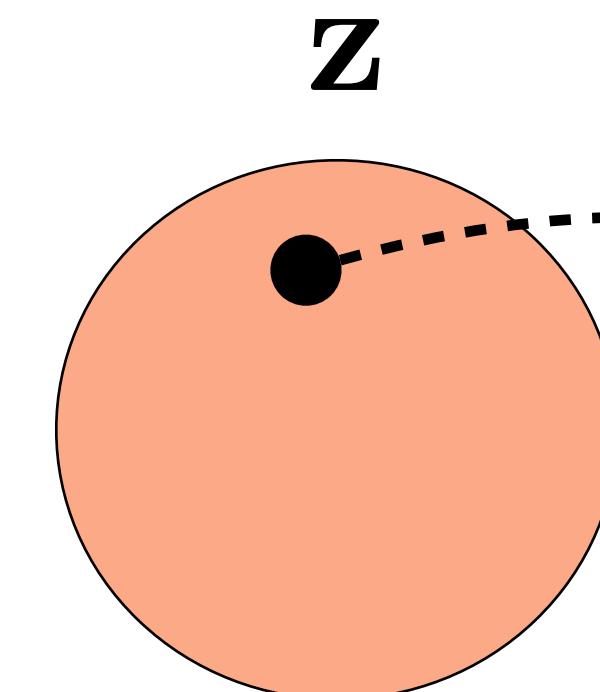
Synthesized Image



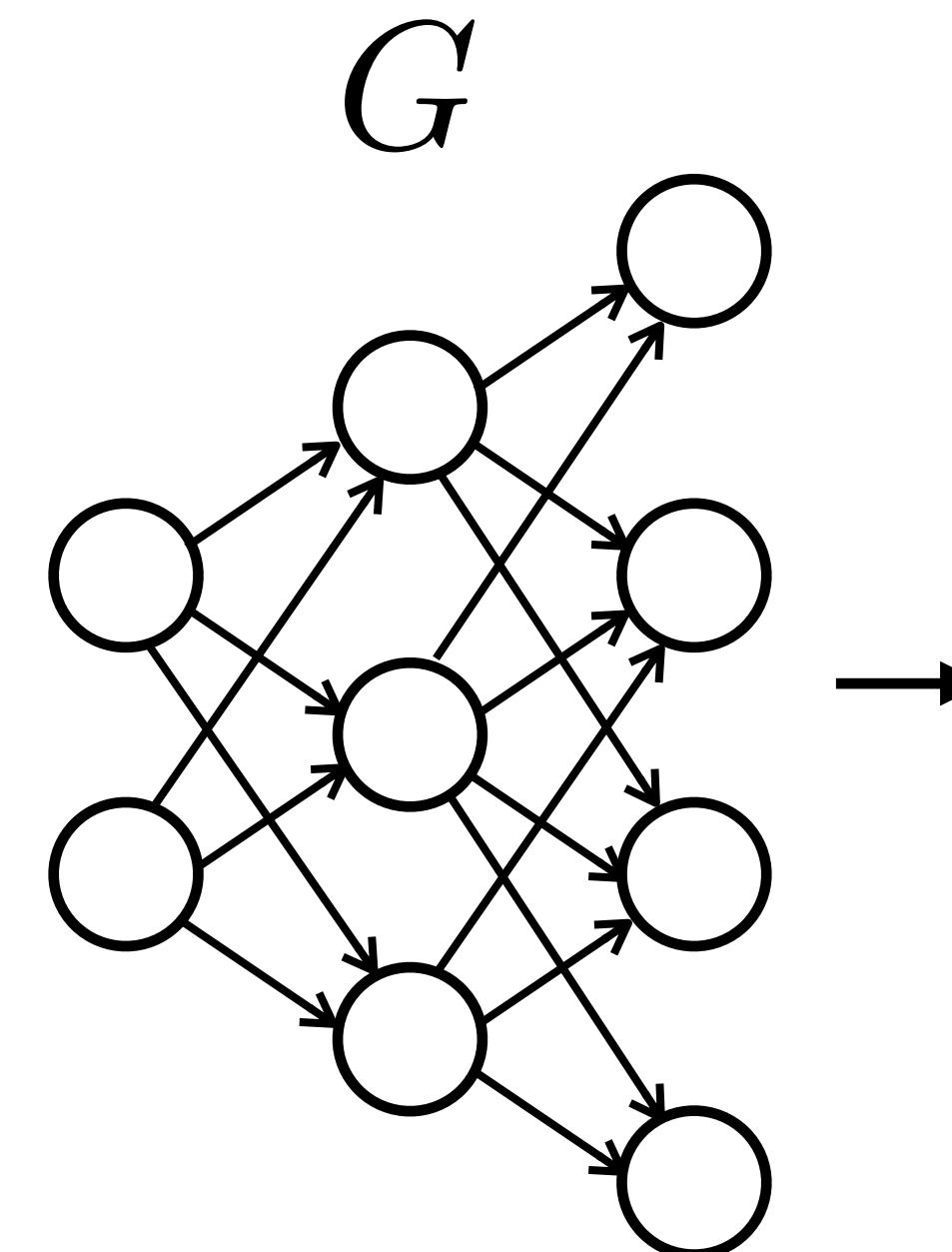
Cat photo from "StyleGAN2 — Official TensorFlow Implementation - Analyzing and Improving the Image Quality of StyleGAN", by Tero Karras, Samuli Laine, Miika Aittala, Janne Hellsten, Jaakko Lehtinen, Timo Aila (<https://github.com/NVlabs/stylegan2>). Made available under the Nvidia Source Code License-NC (<https://nvlabs.github.io/stylegan2/license.html>).

# Generative Models

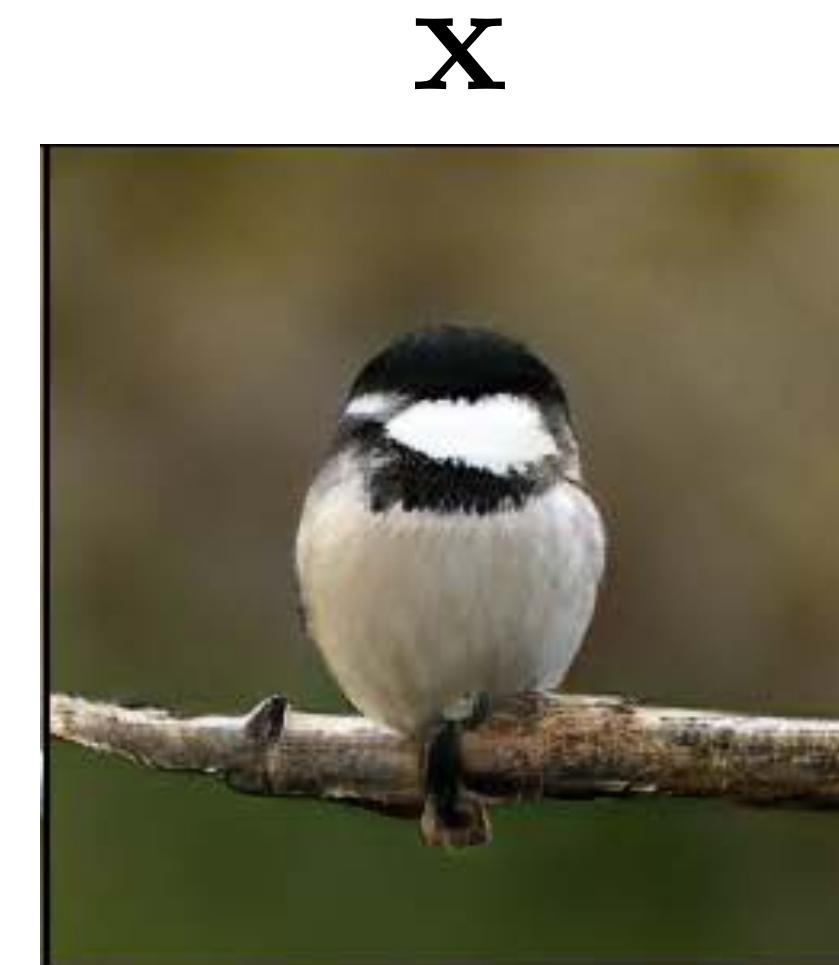
Latent variables  
(controls)



$$\mathbf{z} \sim \mathcal{N}(0, 1)$$

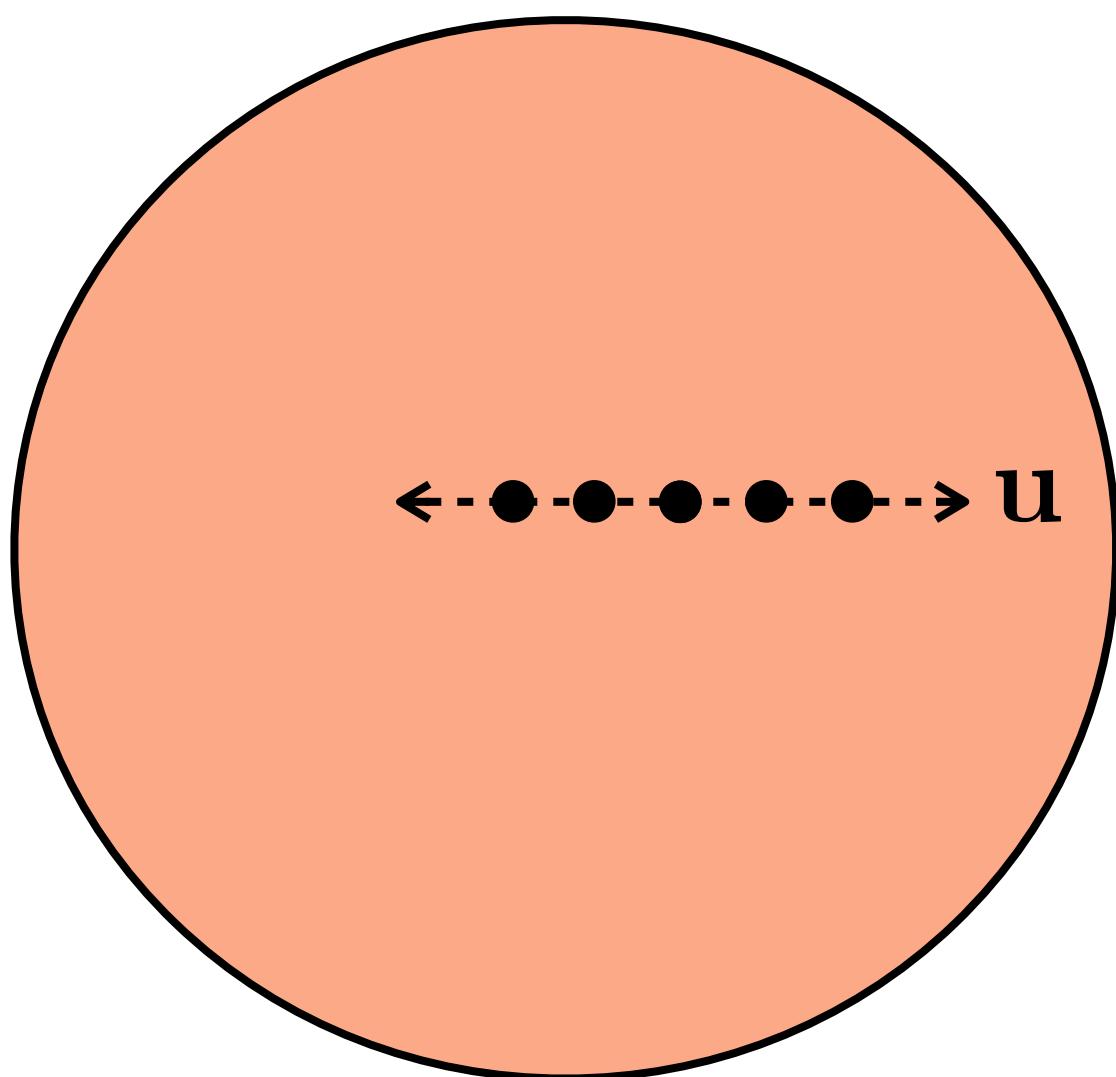


Synthesized Image



# Synthesized Images

Latent variables  
(controls)



v



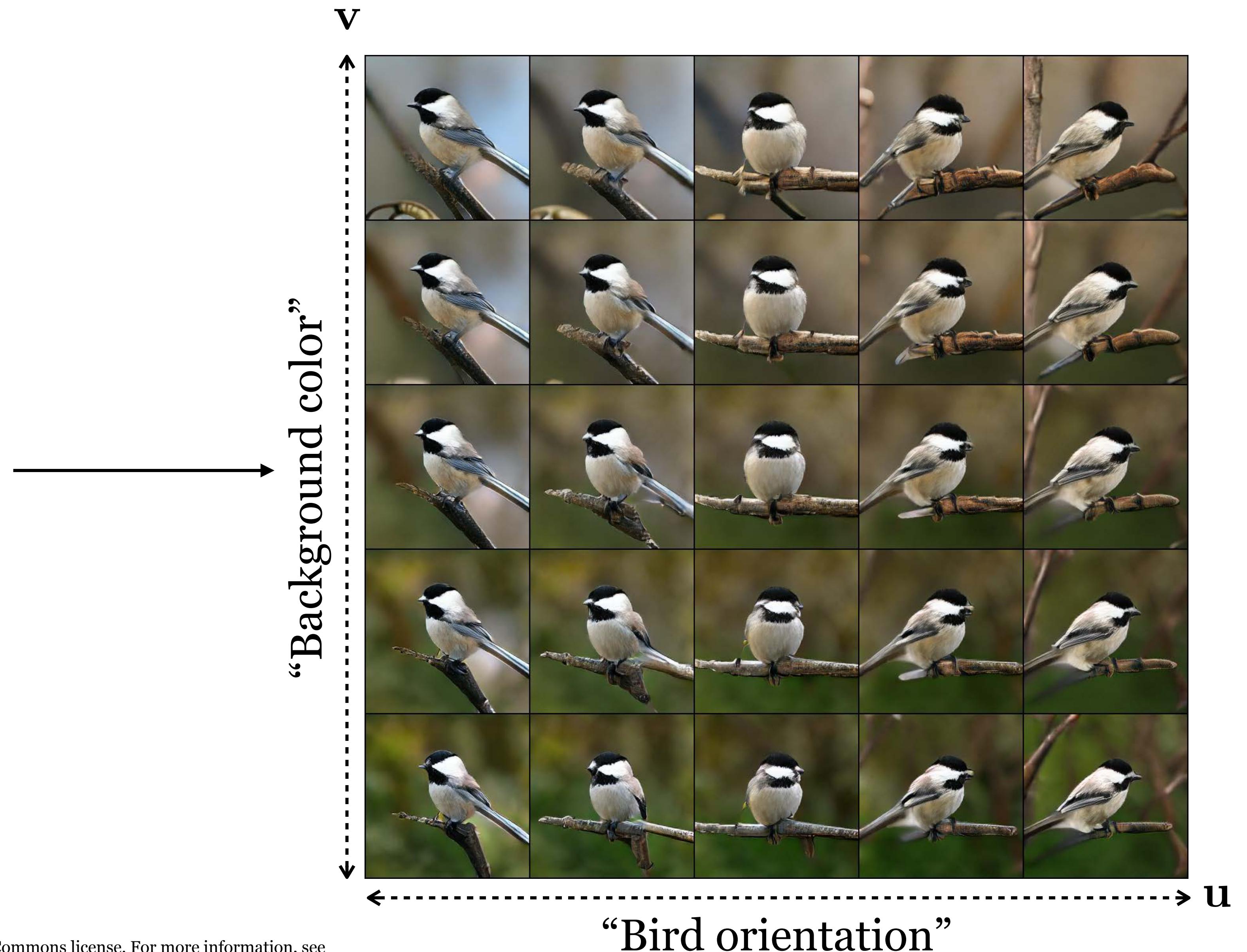
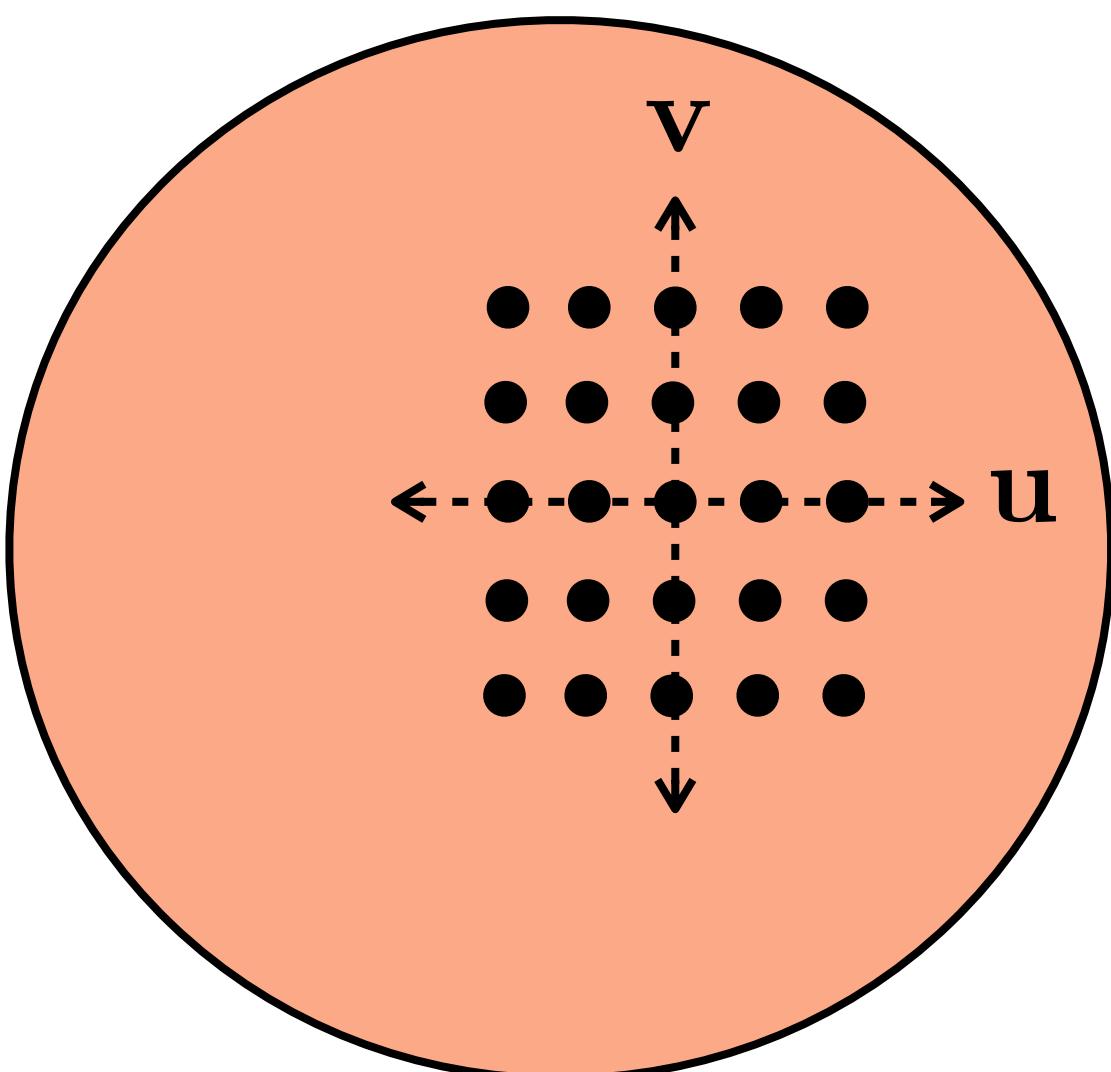
→ u

“Bird orientation”



# Synthesized Images

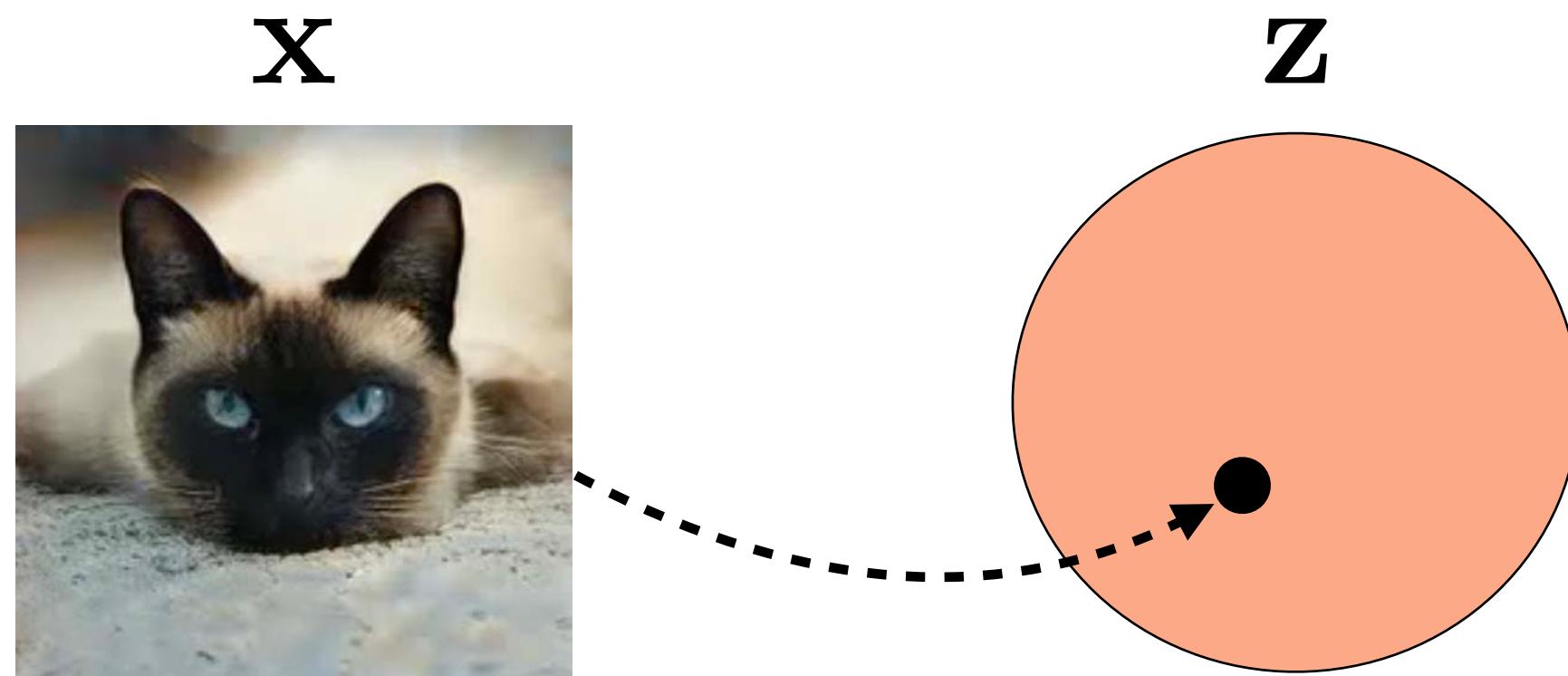
Latent variables  
(controls)



# Data++ supports counterfactual reasoning

“What would it look like if...”

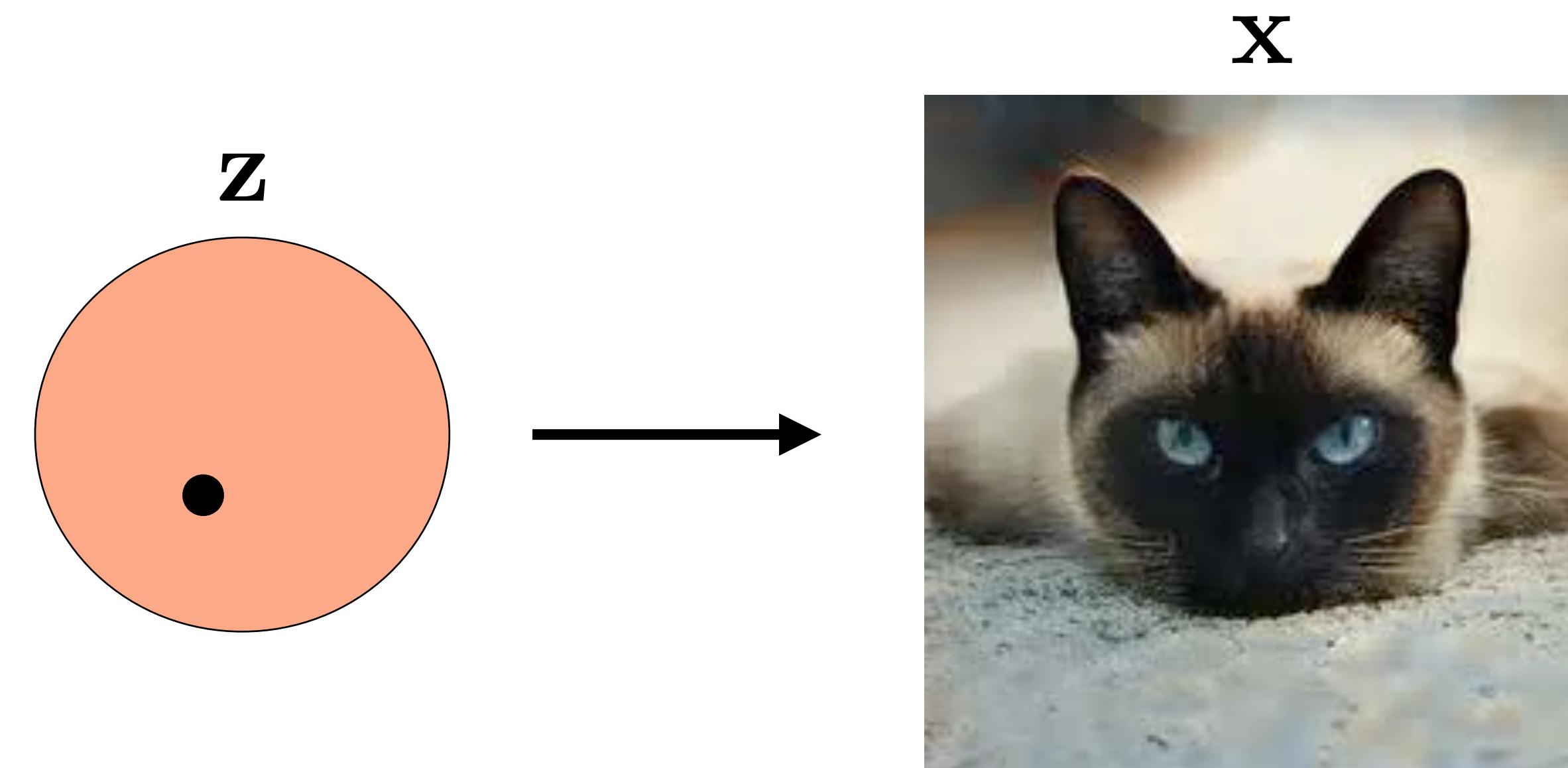
Data2Data++



Cat photo from "StyleGAN2 — Official TensorFlow Implementation - Analyzing and Improving the Image Quality of StyleGAN", by Tero Karras, Samuli Laine, Miika Aittala, Janne Hellsten, Jaakko Lehtinen, Timo Aila (<https://github.com/NVlabs/stylegan2>). Made available under the Nvidia Source Code License-NC (<https://nvlabs.github.io/stylegan2/license.html>).

# Data++ supports counterfactual reasoning

“What would it look like if...”

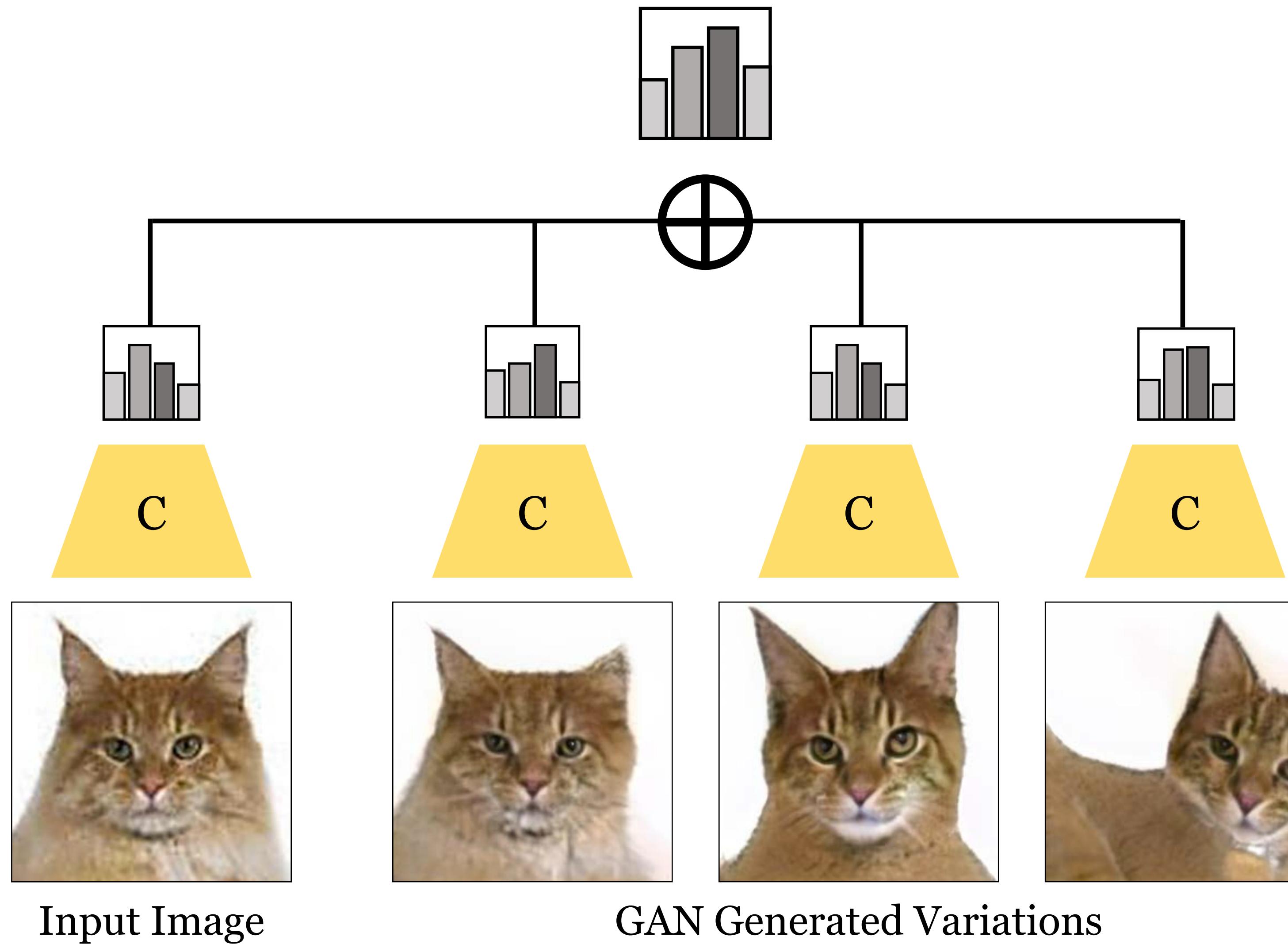


Cat photo from "StyleGAN2 — Official TensorFlow Implementation - Analyzing and Improving the Image Quality of StyleGAN", by Tero Karras, Samuli Laine, Miika Aittala, Janne Hellsten, Jaakko Lehtinen, Timo Aila (<https://github.com/NVlabs/stylegan2>). Made available under the Nvidia Source Code License-NC (<https://nvlabs.github.io/stylegan2/license.html>).

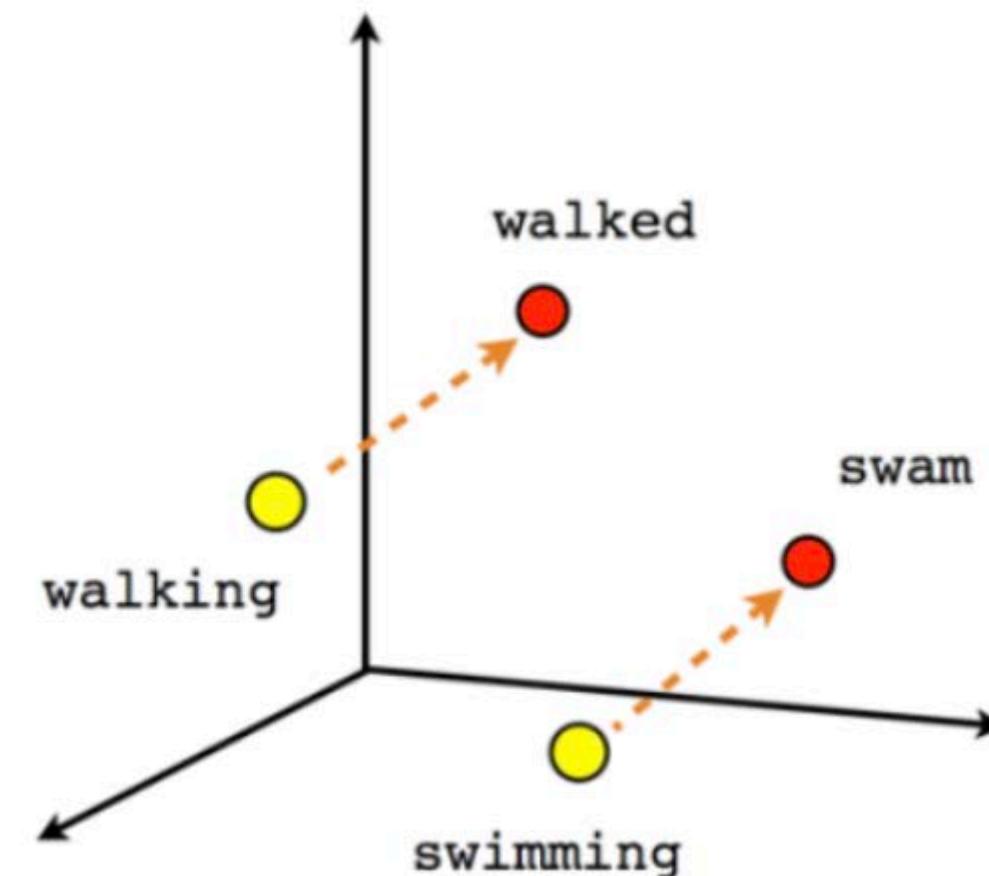
# Ensembling with Deep Generative Views

Chai, Zhu, Shechtman, Isola, Zhang

CVPR 2021

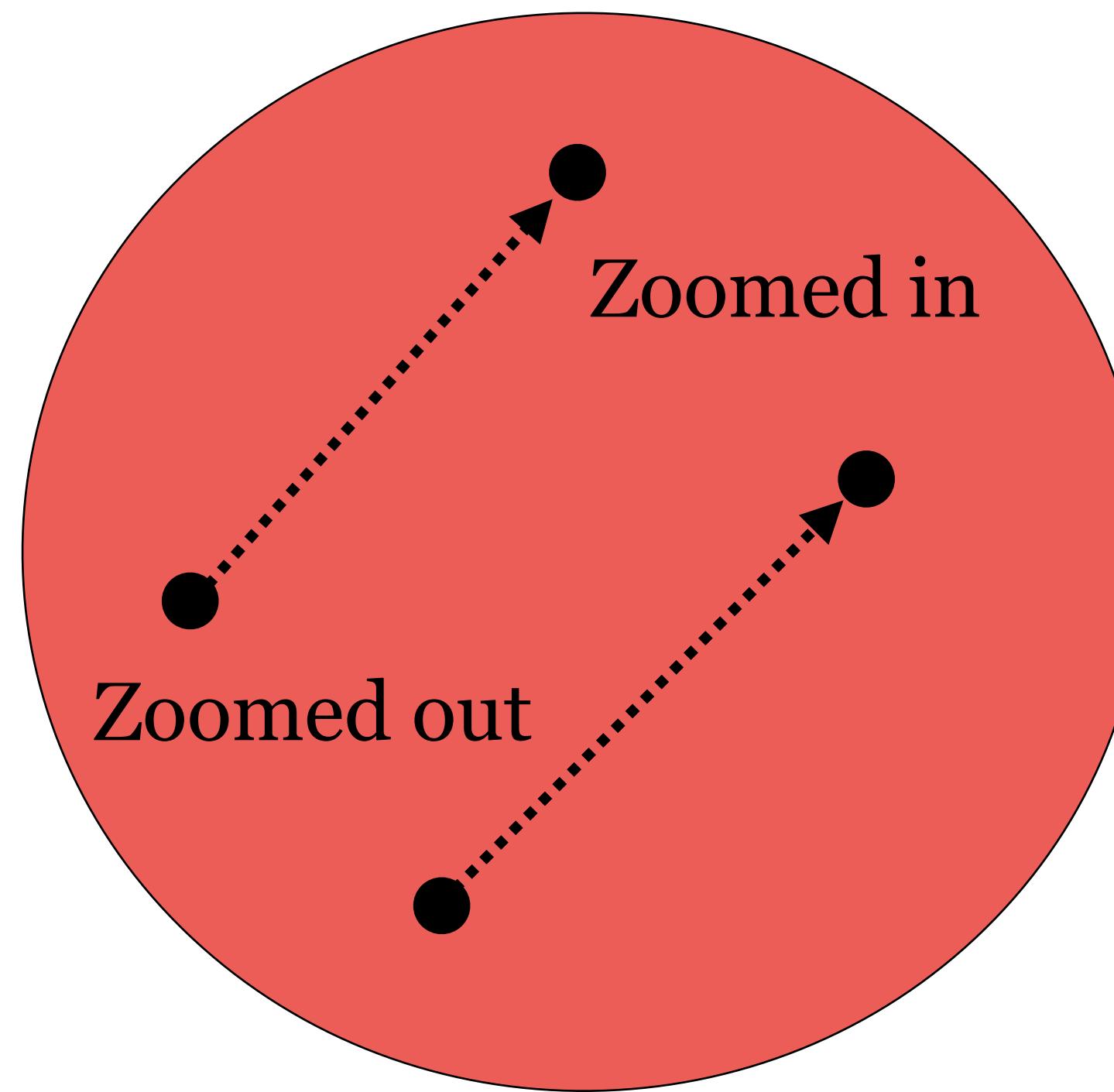


Improved  
accuracy and  
robustness

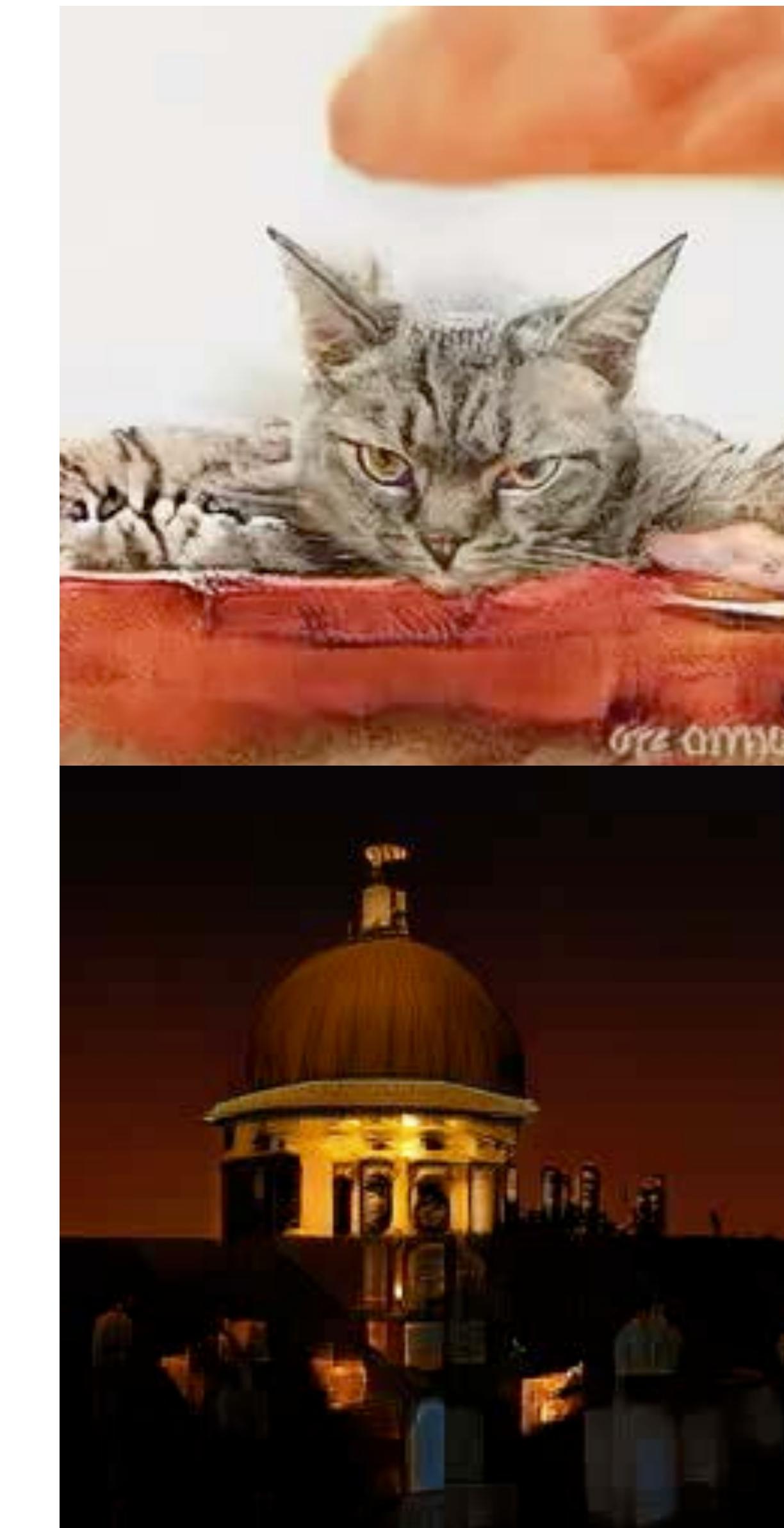


[word2vec, Mikolov et al., 2013]

[DCGAN, Radford, Metz, Chintala, 2015]



Zoom



Shift



Brighten

13

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Darken



# Color transformation vectors

**Winter to spring**



input

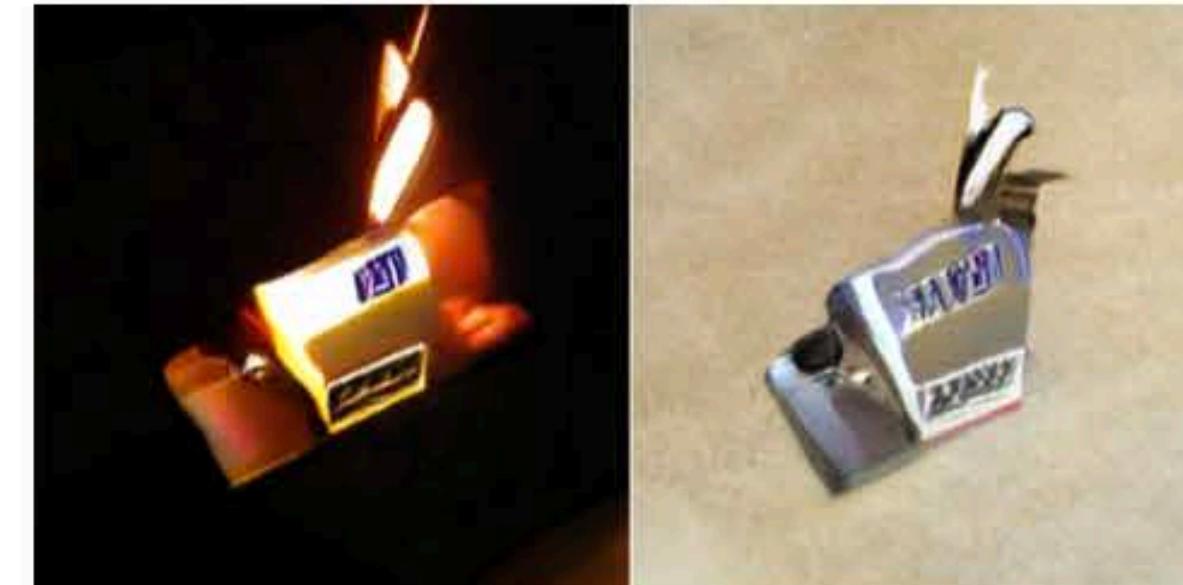


output

**Turning on the lights**

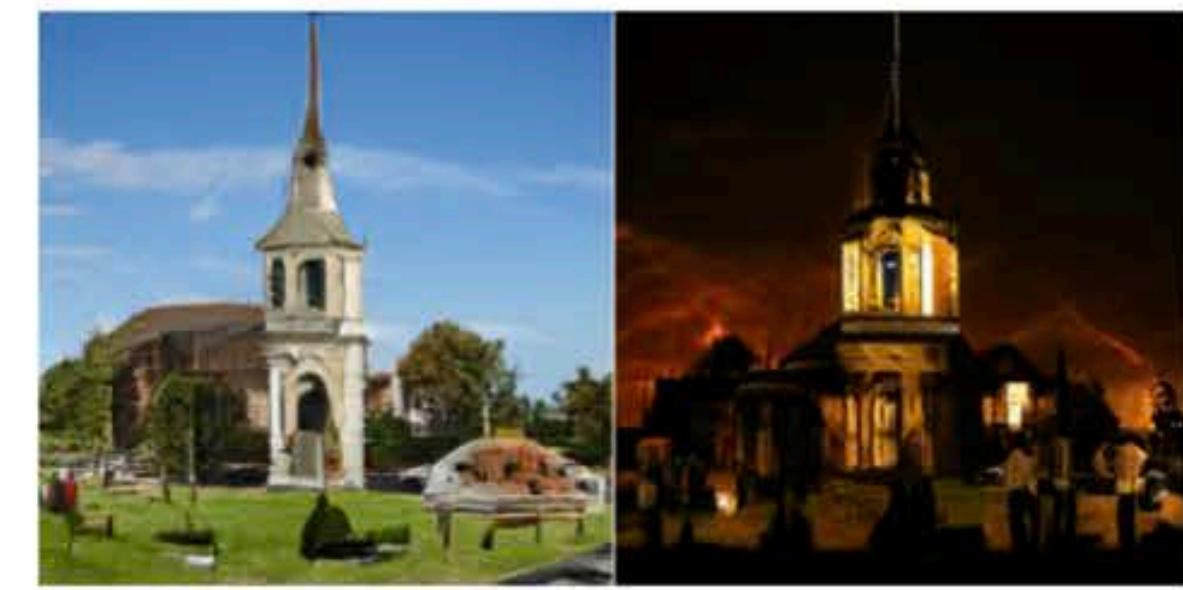


input



output

**Day to night**



input



output

**Volcano!**



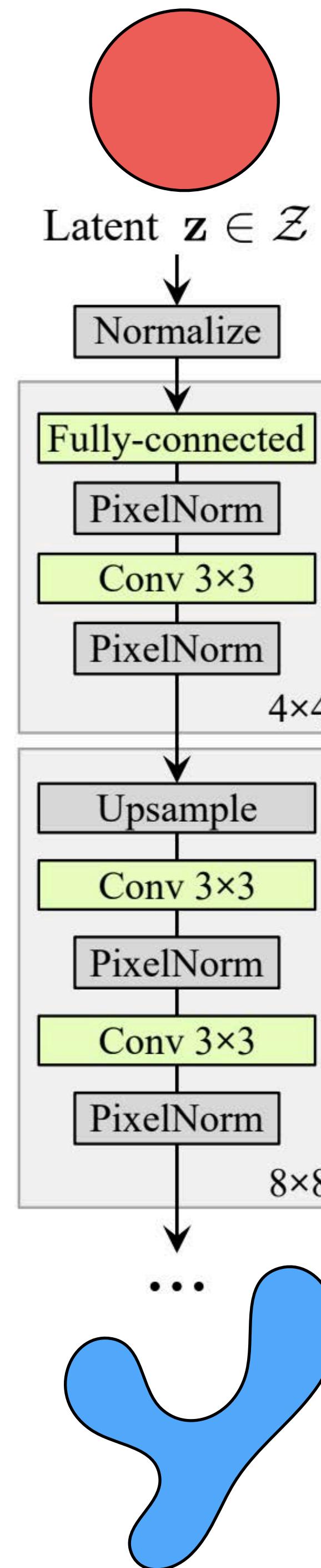
input



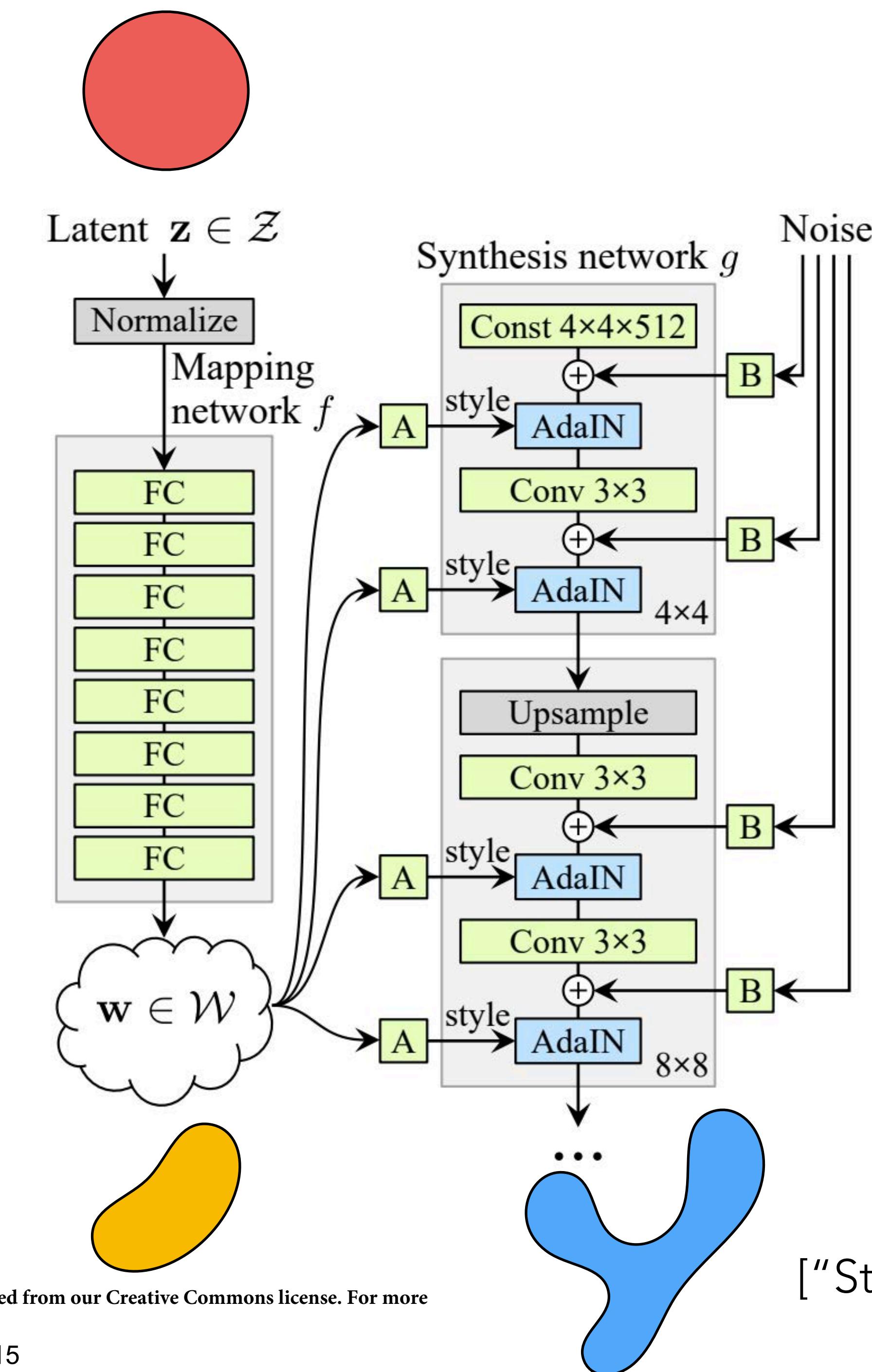
output

There is a latent space “vector” for each of these transformations – the “spring vector”, the “volcano exploding vector”

# Traditional GAN



# StyleGAN

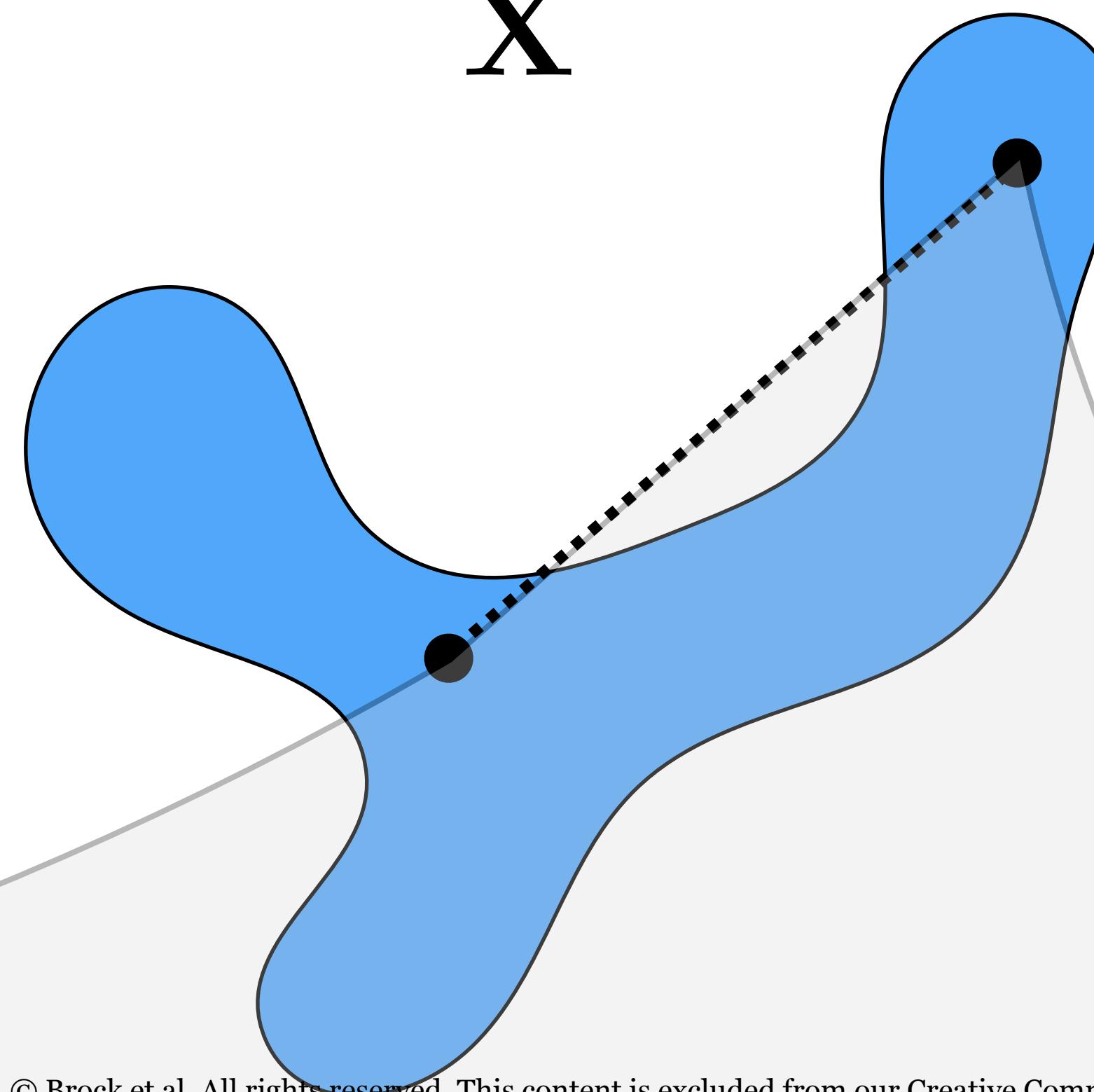


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# Interpolation in data space

Data space  
(Natural image manifold)

$\mathbf{X}$



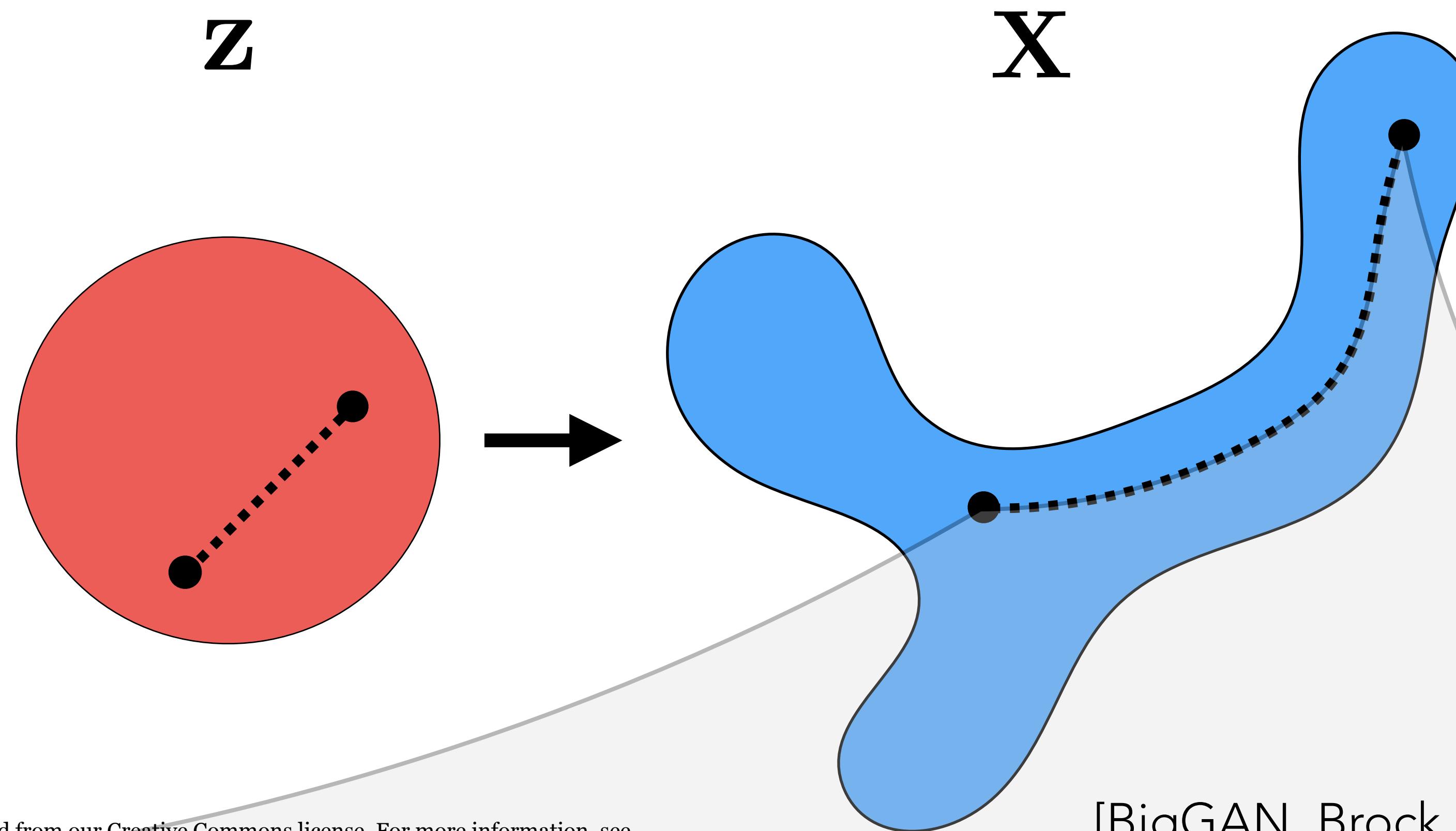
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# Interpolation in latent space

Latent space  
(Gaussian)

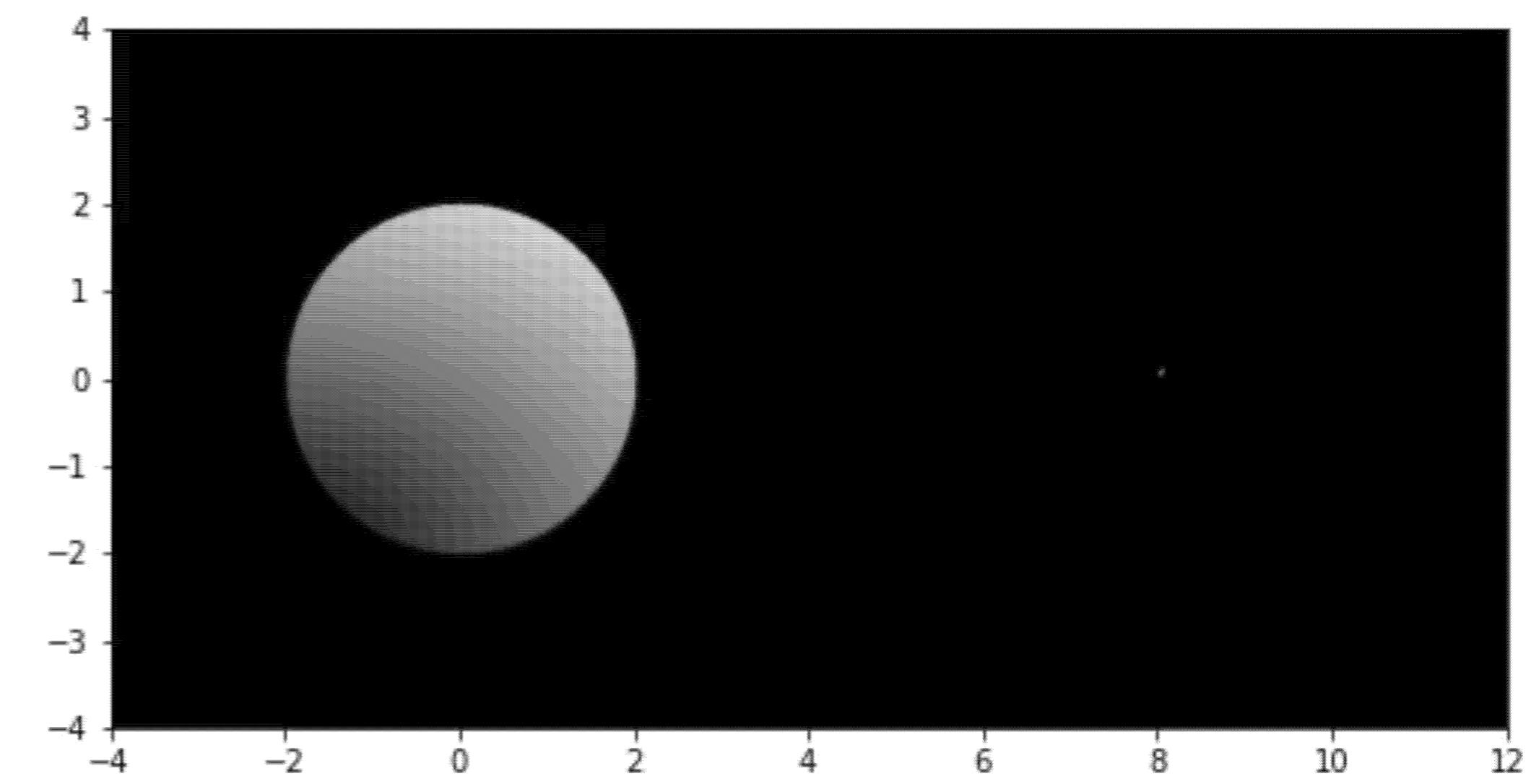
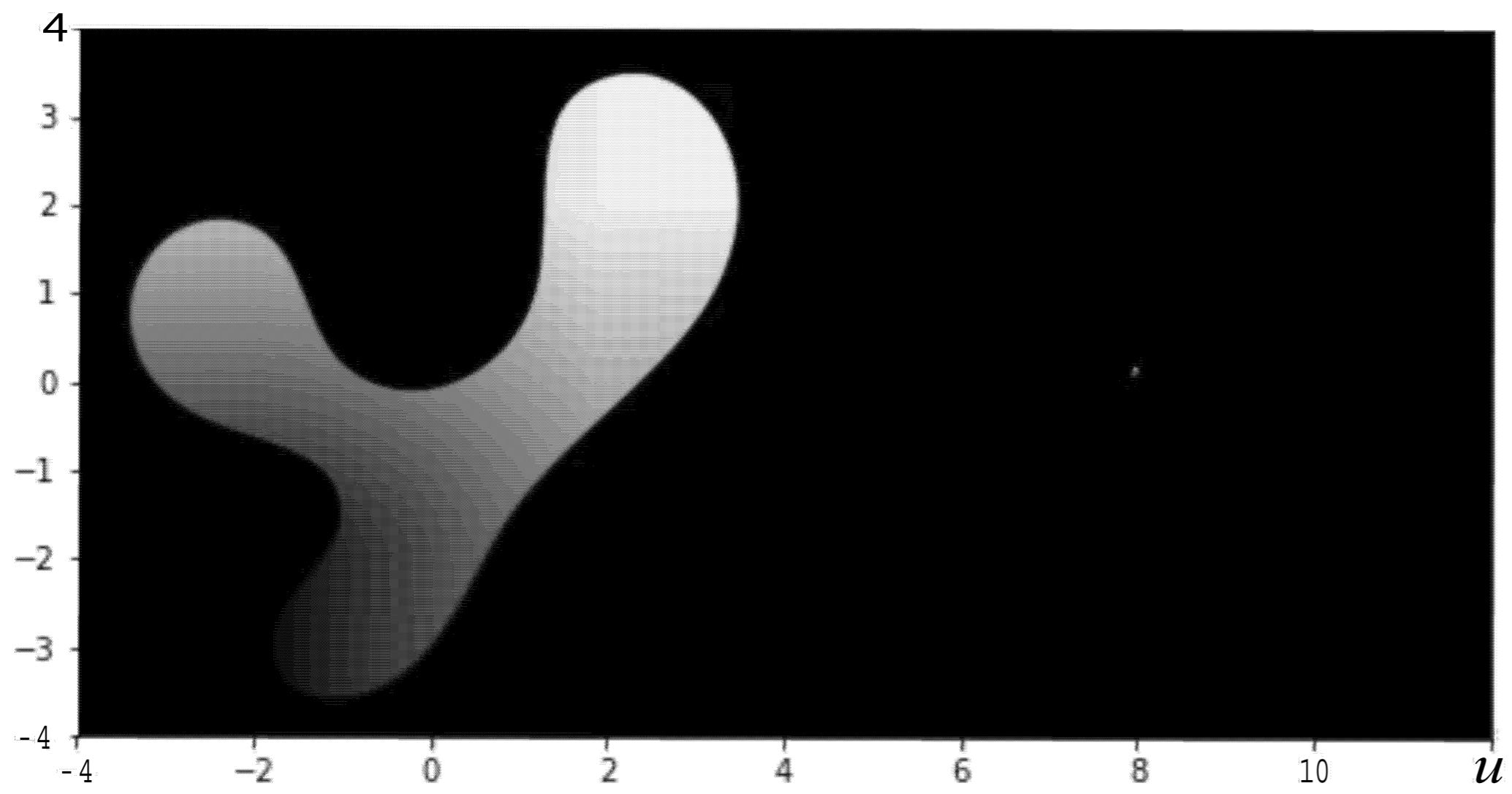
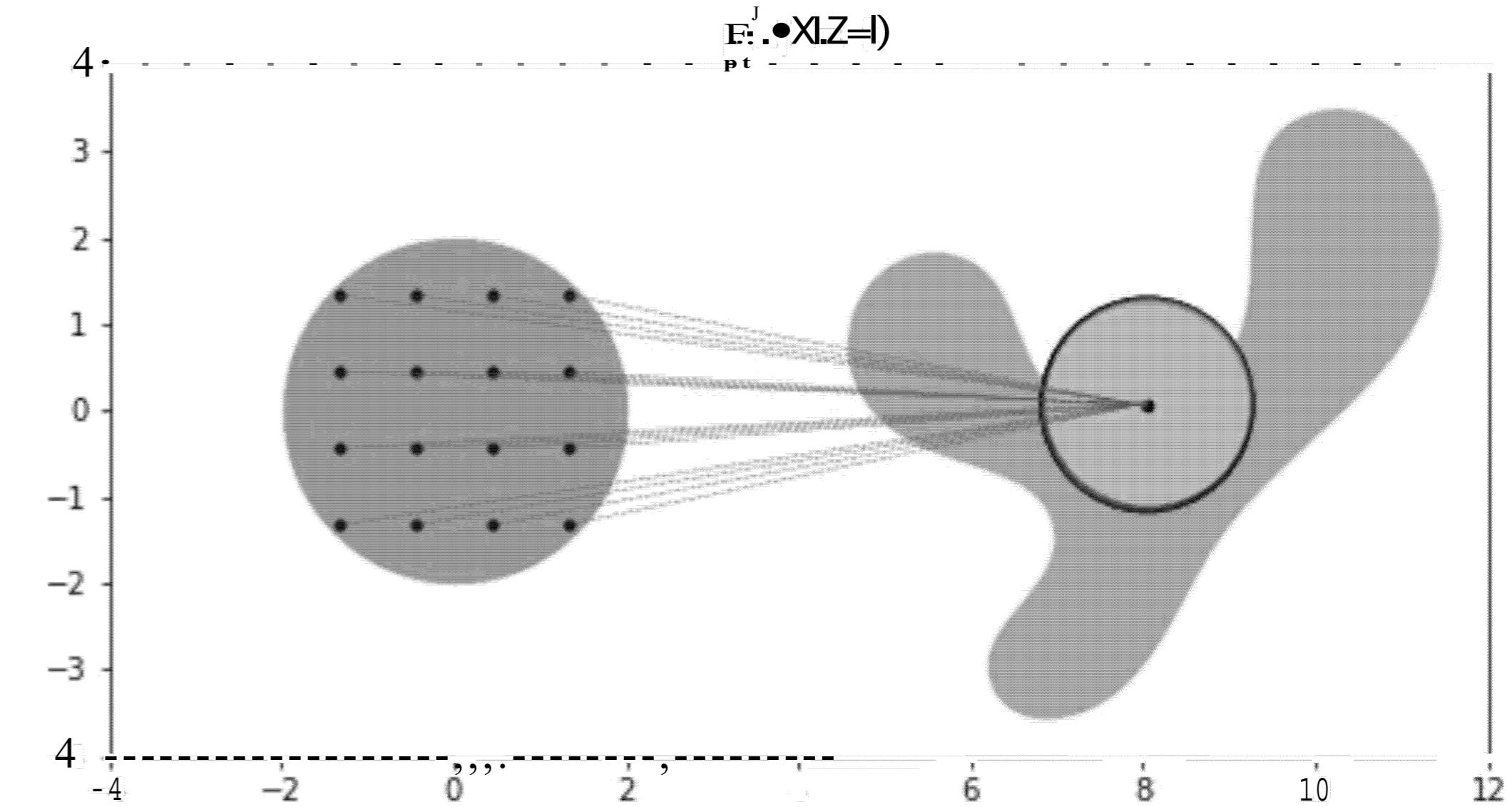
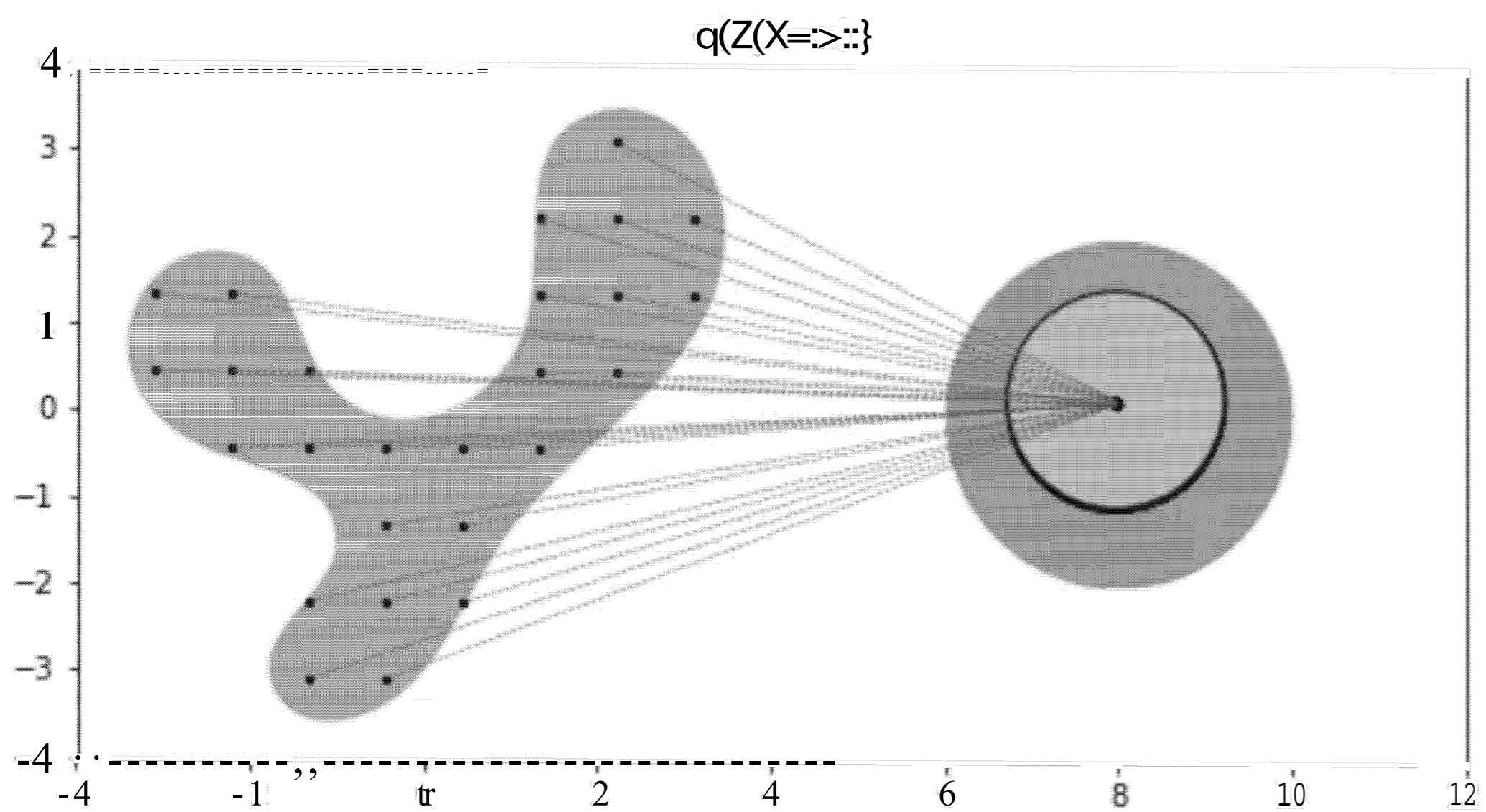
Data space  
(Natural image manifold)

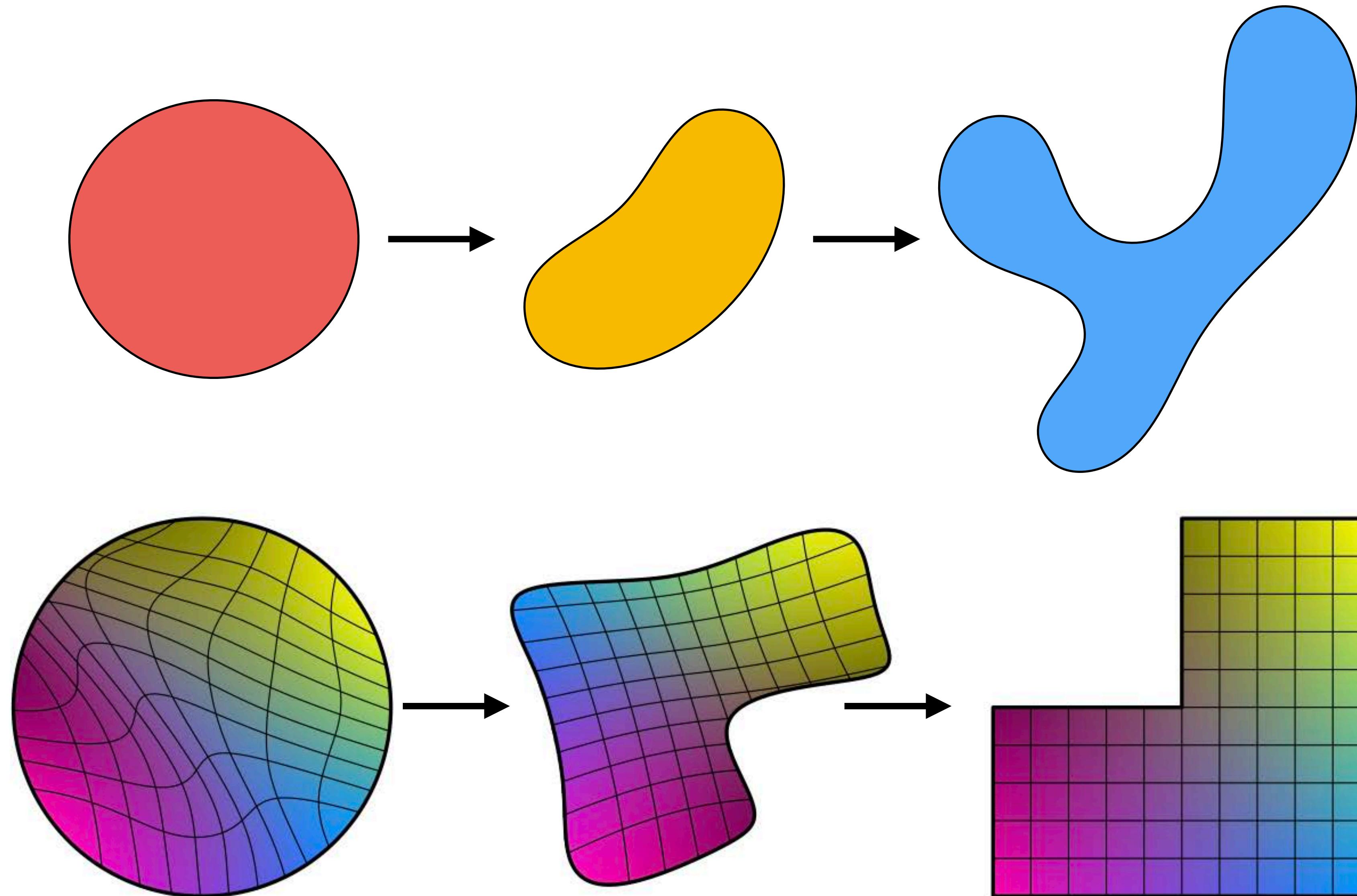


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[BigGAN, Brock et al. 2018]





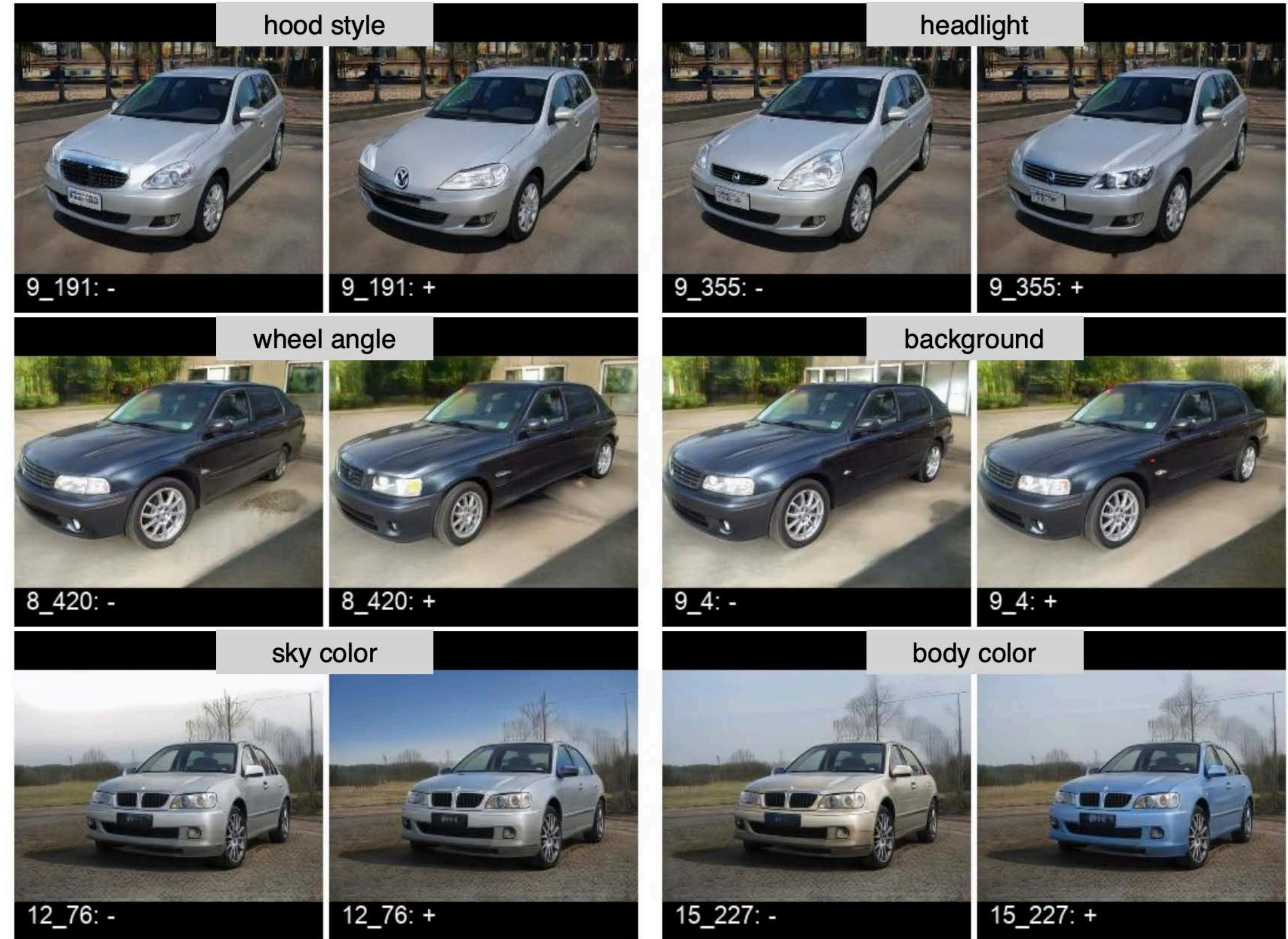
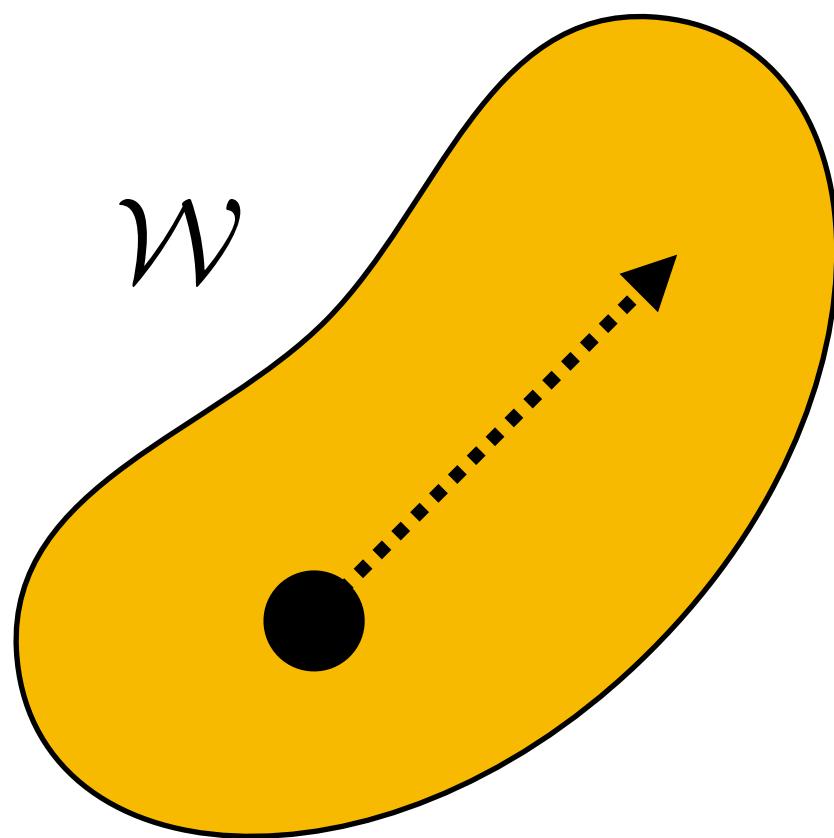


**(b) Mapping from  $\mathcal{Z}$  to features**

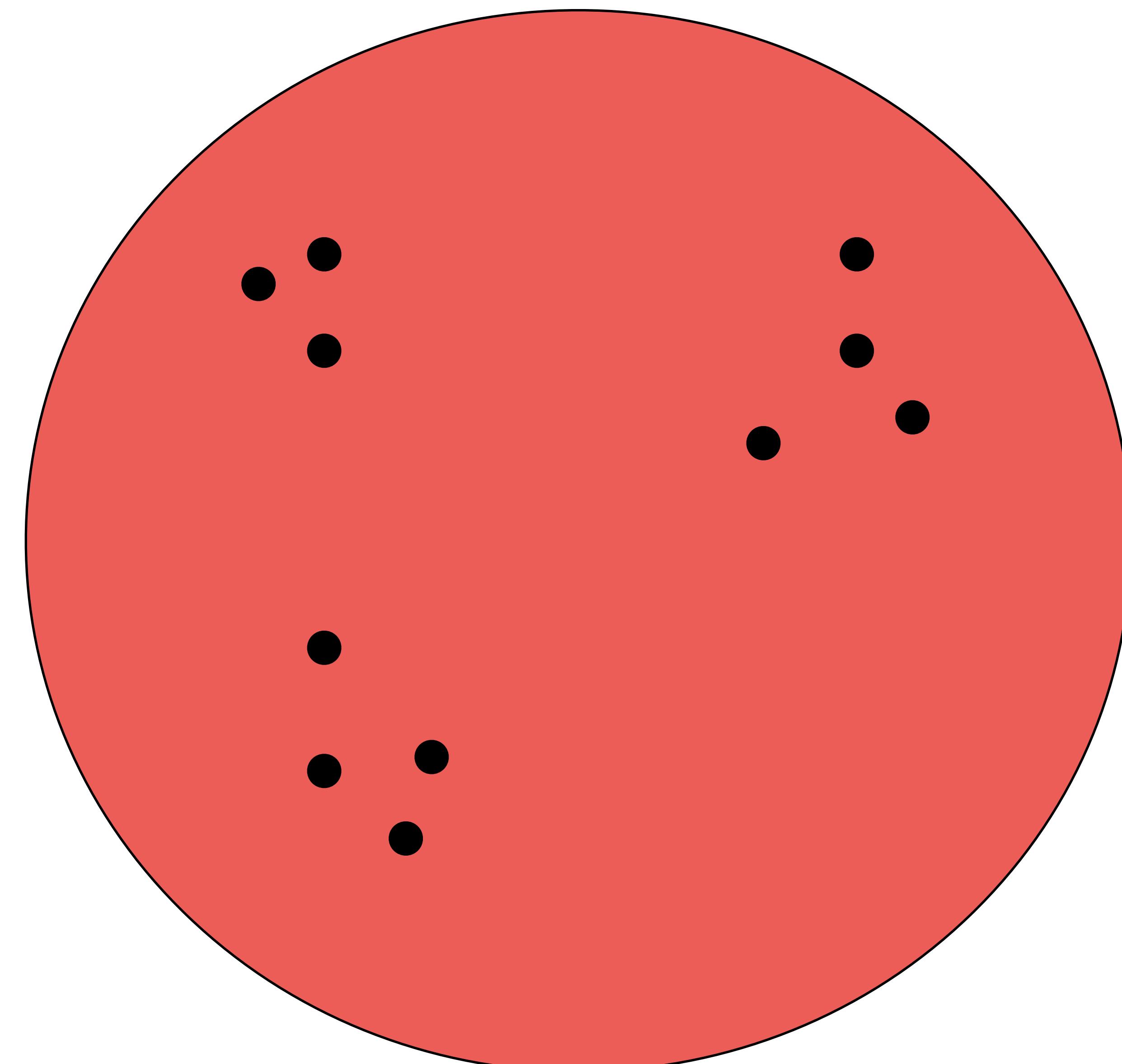
**(c) Mapping from  $\mathcal{W}$  to features**

**(a) Distribution of features in training set**

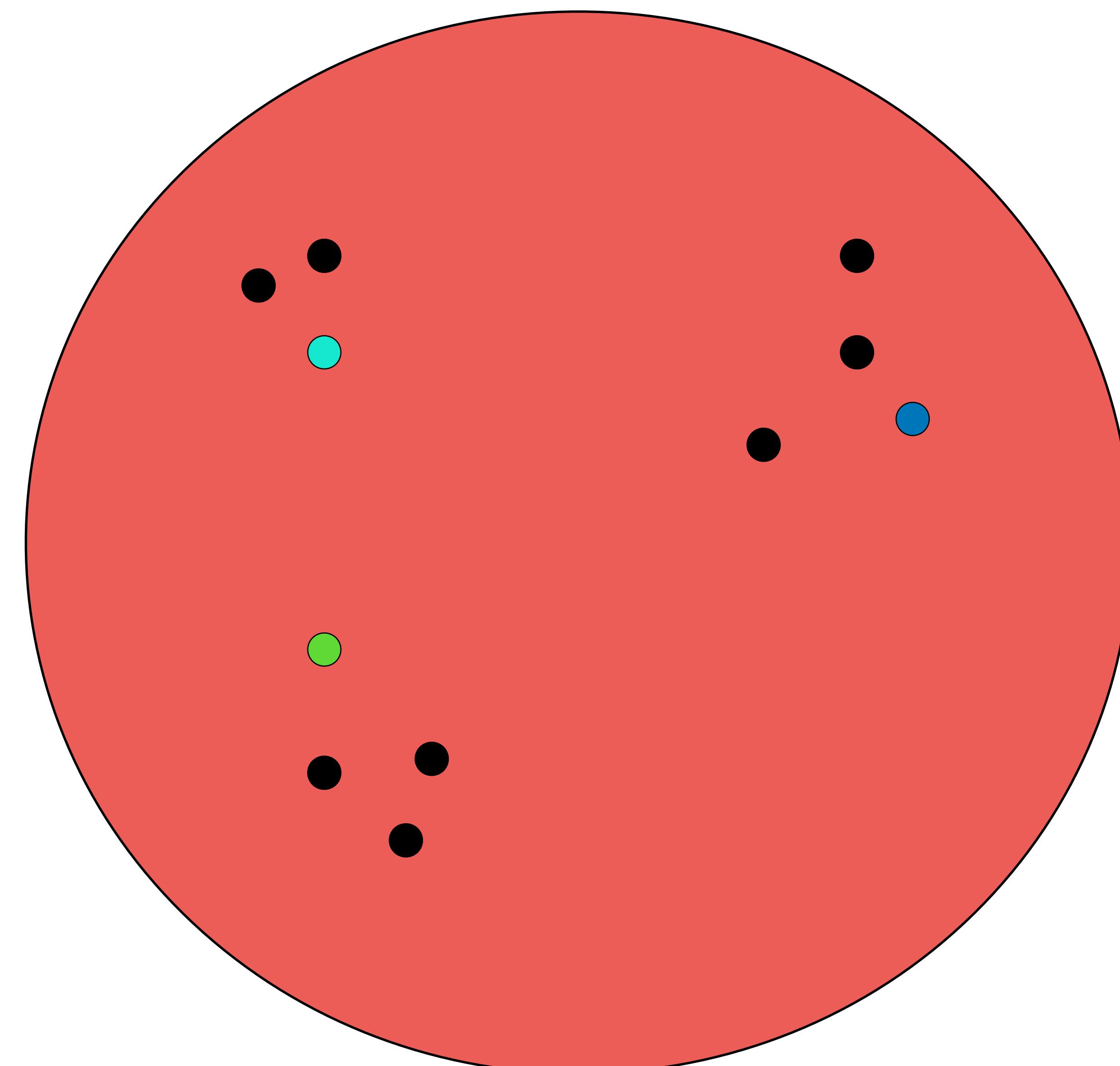
# Different ways to navigate latent space



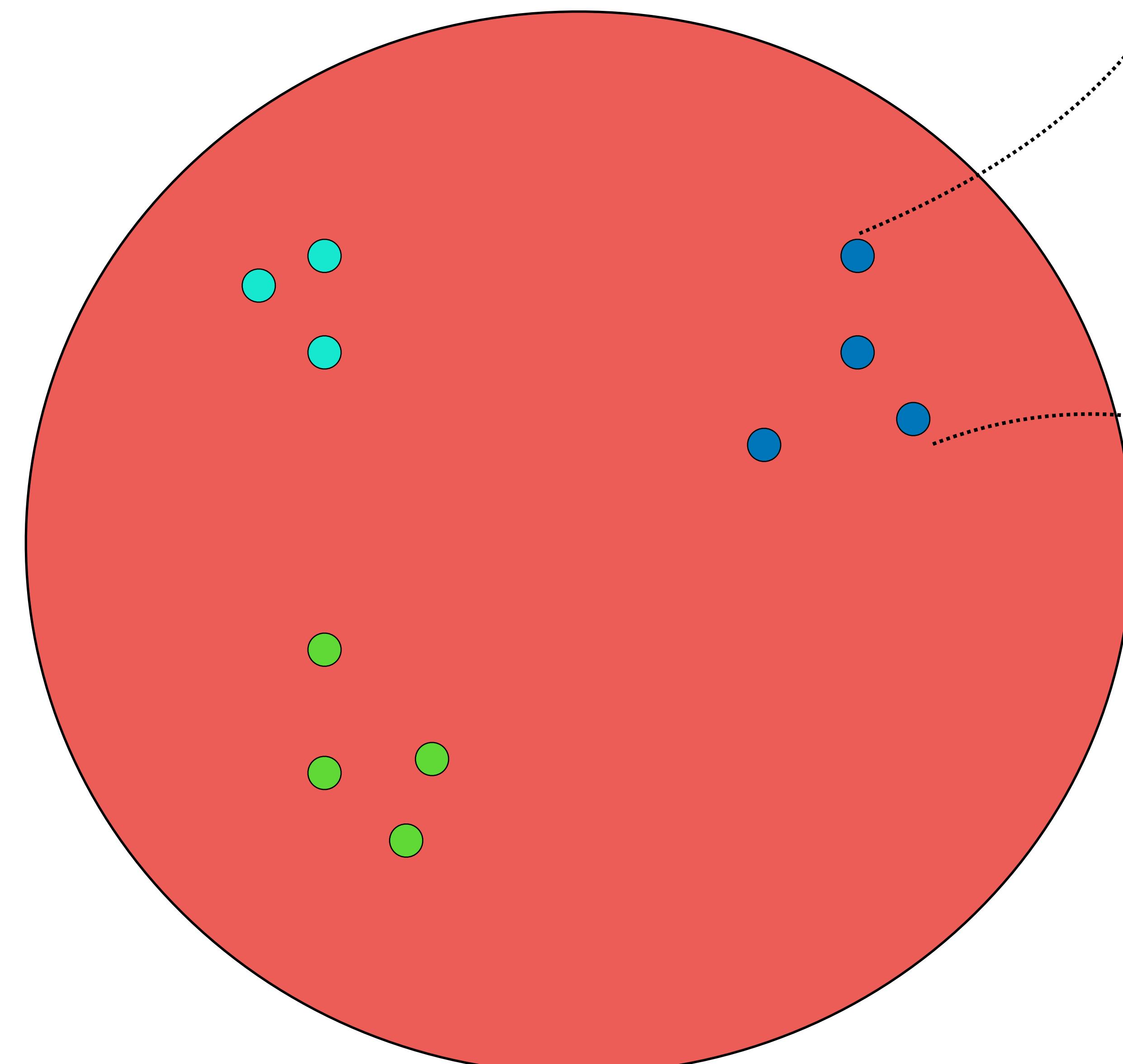
# Labeling Data++



# Labeling Data++

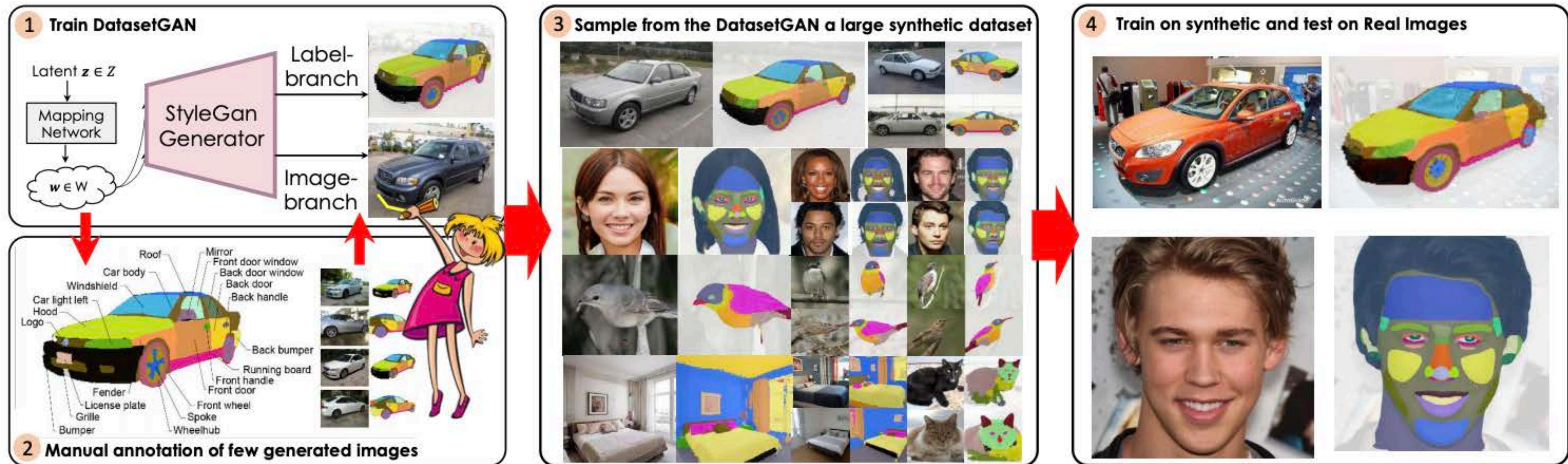


# Labeling Data++



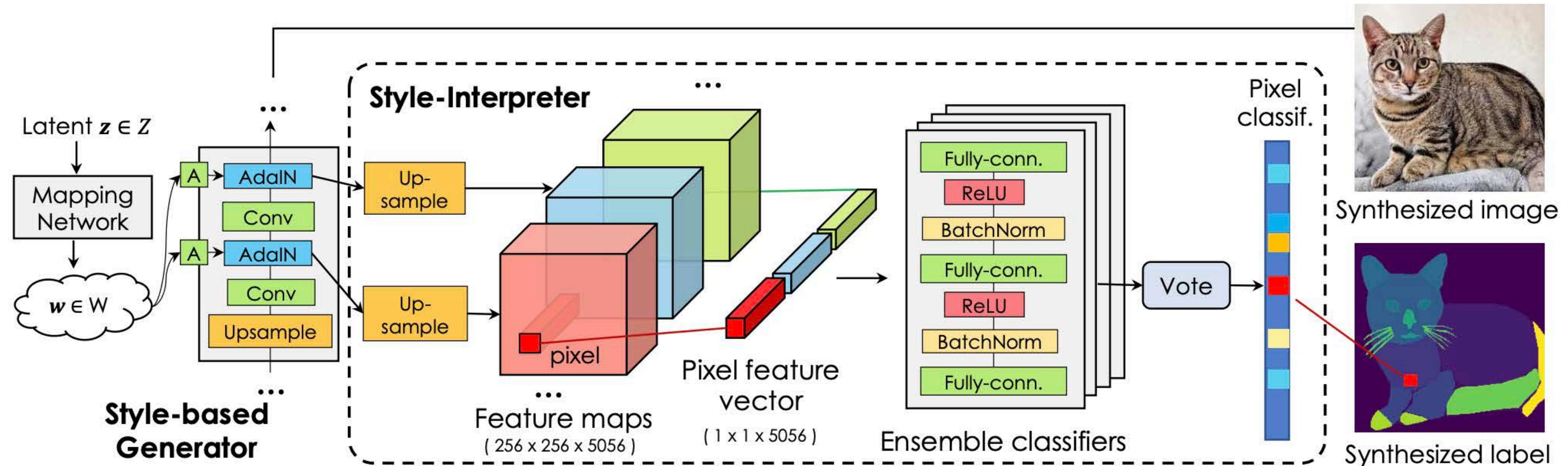
# DatasetGAN

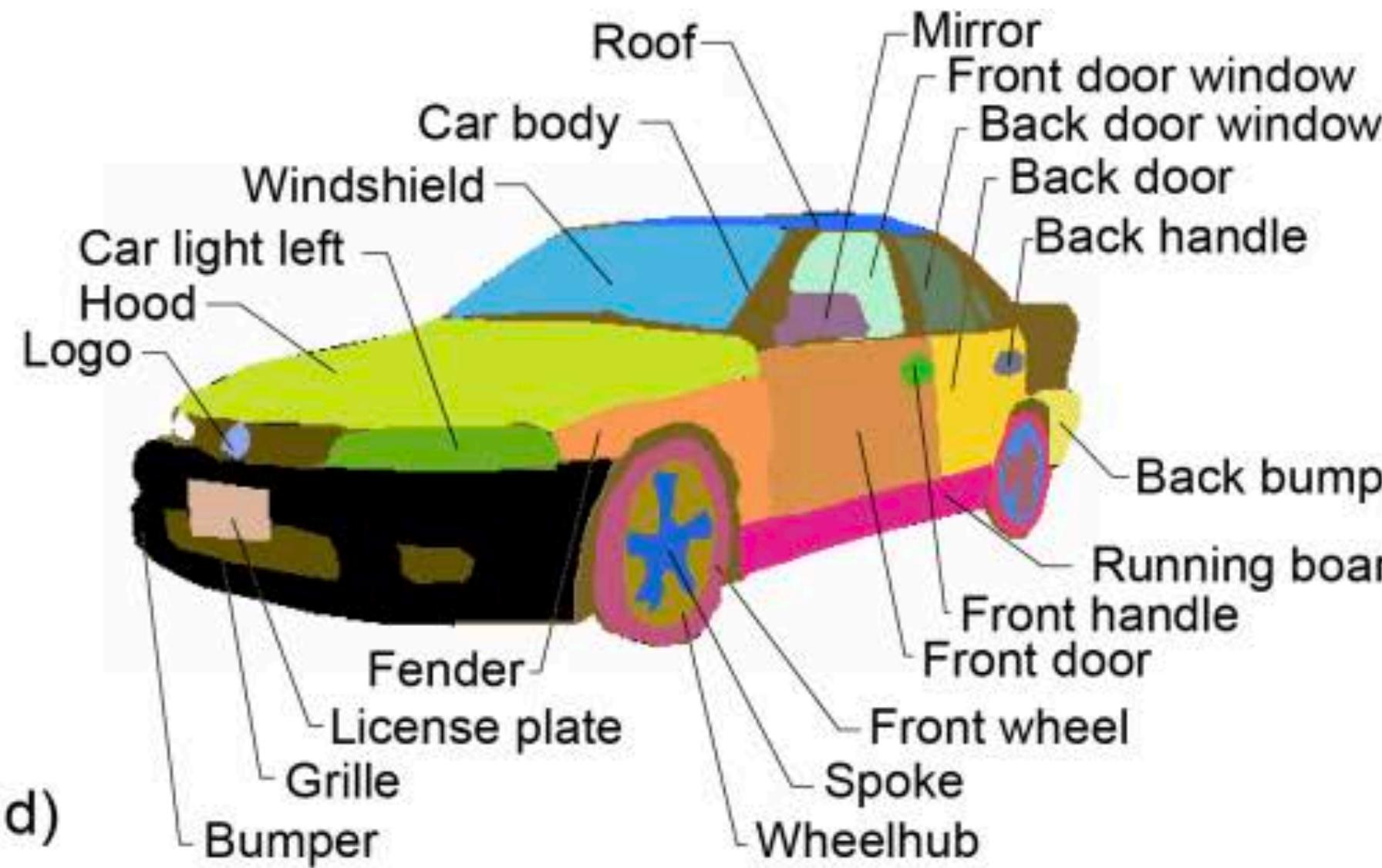
[Zhang\*, Ling\*, Gao, Yin, Lafleche, Barriuso, Torralba, Fidler 2021]



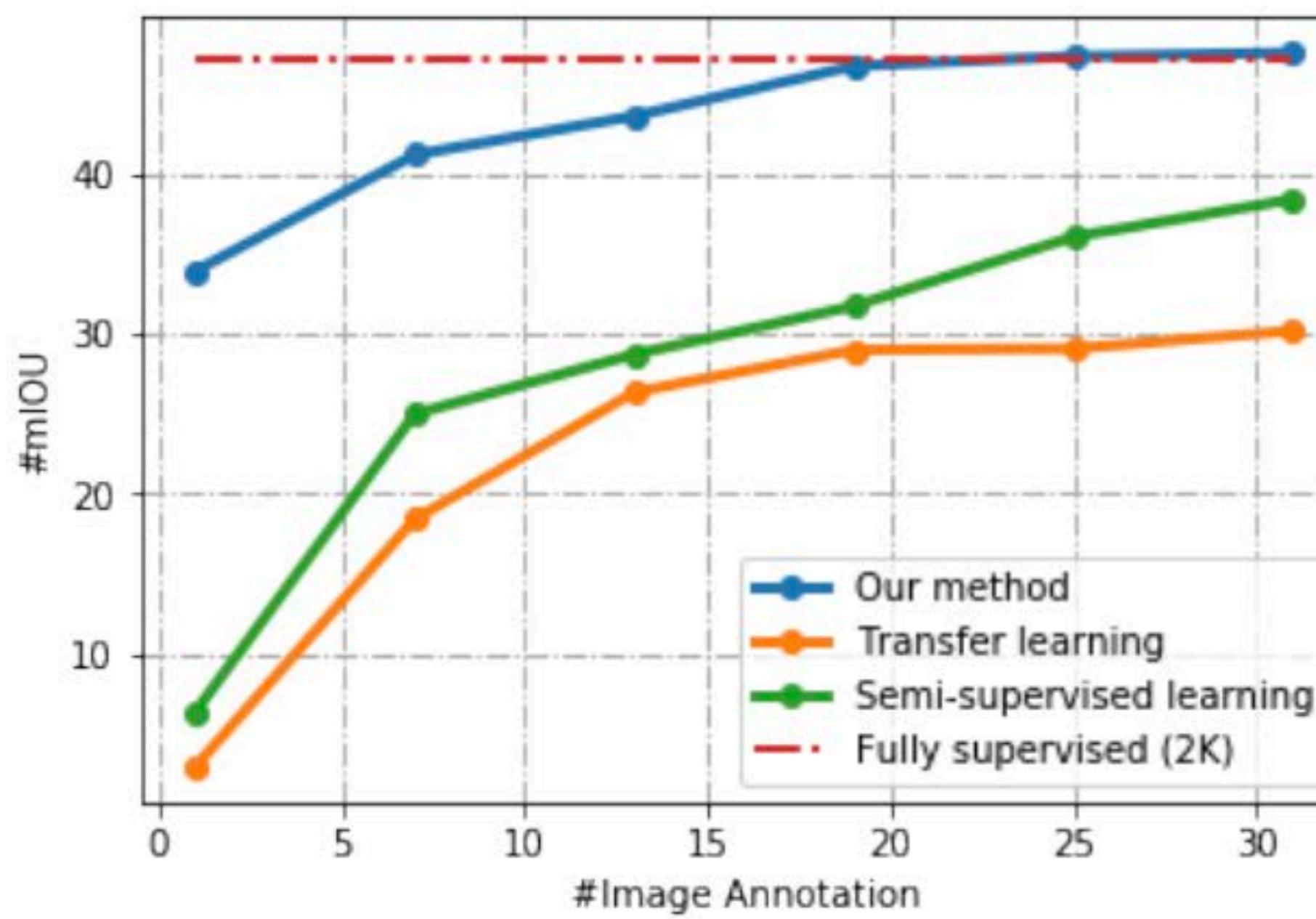
see also [Tritrong\*, Rewatbowornwong\*, Suwajanakorn, CVPR 2021]

[Li, Yang, Kries, Torralba, Fidler, CVPR 2021]

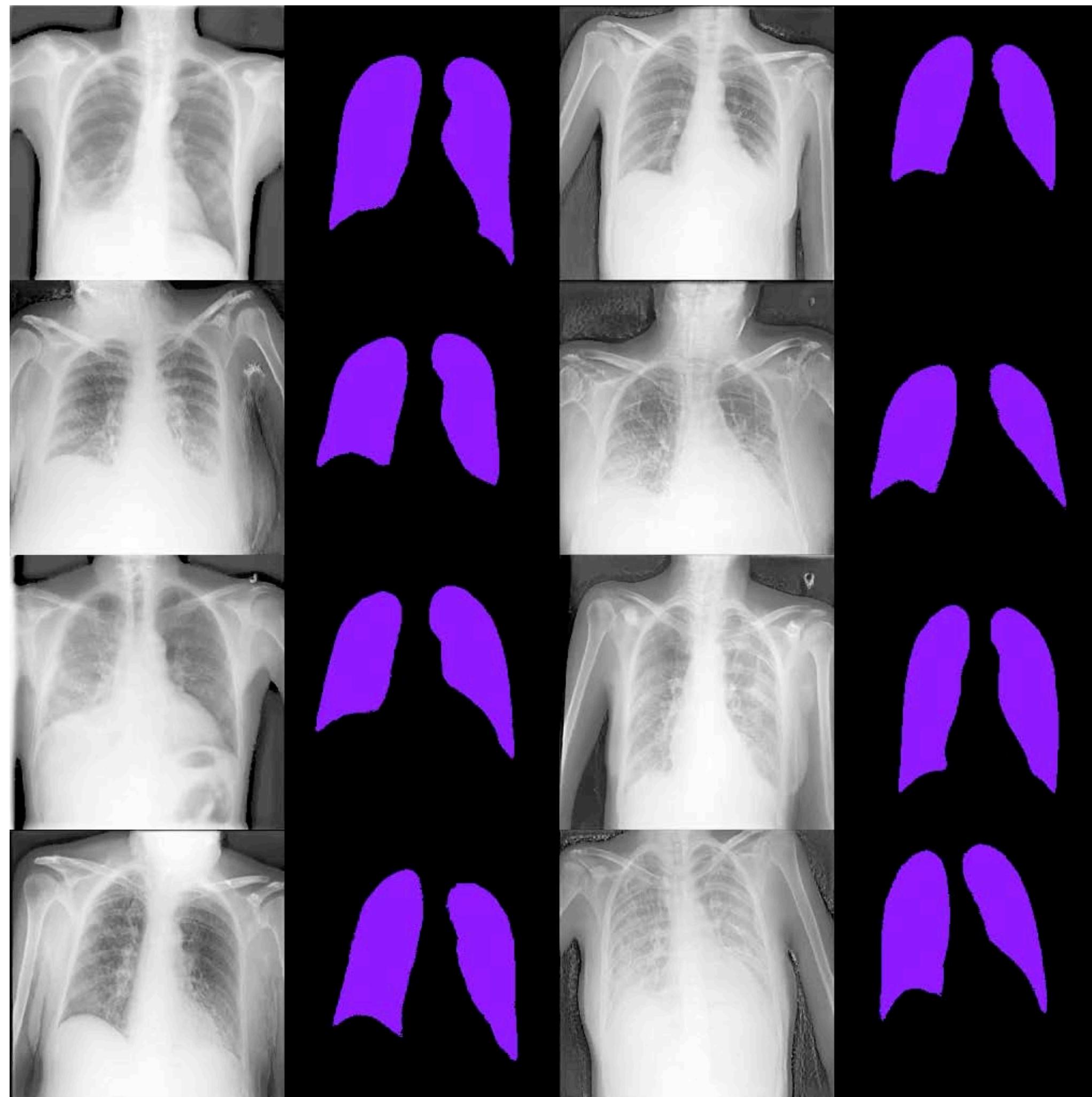




|                               | Method |
|-------------------------------|--------|
| Roof                          | 41     |
| Front door window             | 27     |
| Back door window              | 21     |
| Back door                     | 21     |
| Back handle                   | 21     |
| Car body                      | 19     |
| Windshield                    | 19     |
| Car light left                | 19     |
| Hood                          | 19     |
| Logo                          | 19     |
| Back bumper                   | 19     |
| Running board                 | 19     |
| Front handle                  | 19     |
| Front door                    | 19     |
| Front wheel                   | 19     |
| Spoke                         | 19     |
| Wheelhub                      | 19     |
| Fender                        | 18     |
| License plate                 | 18     |
| Grille                        | 18     |
| Bumper                        | 18     |
| Front left wheel              | 17     |
| Front right wheel             | 17     |
| Front left headlight          | 17     |
| Front right headlight         | 17     |
| Front left fog light          | 17     |
| Front right fog light         | 17     |
| Exhaust pipe                  | 17     |
| Left headlight                | 17     |
| Right headlight               | 17     |
| Front light                   | 17     |
| Front                         | 17     |
| Front bumper                  | 16     |
| Front ground back right wheel | 15     |
| Front left fog light          | 15     |
| Front left light              | 15     |
| Front right light             | 15     |
| Exterior pipe                 | 15     |
| Left headlight                | 15     |
| Right headlight               | 15     |
| Front light                   | 15     |
| Front                         | 15     |
| Front                         | 15     |
| Front bumper                  | 14     |
| Front ground back left wheel  | 14     |
| Front left fog light          | 14     |
| Front left light              | 14     |
| Front right light             | 14     |
| Exterior pipe                 | 14     |
| Left headlight                | 14     |
| Right headlight               | 14     |
| Front light                   | 14     |
| Front                         | 14     |
| Front                         | 14     |
| Front bumper                  | 13     |
| Front ground back right wheel | 13     |
| Front left fog light          | 13     |
| Front left light              | 13     |
| Front right light             | 13     |
| Exterior pipe                 | 13     |
| Left headlight                | 13     |
| Right headlight               | 13     |
| Front light                   | 13     |
| Front                         | 13     |
| Front                         | 13     |
| Front bumper                  | 12     |
| Front ground back left wheel  | 12     |
| Front left fog light          | 12     |
| Front left light              | 12     |
| Front right light             | 12     |
| Exterior pipe                 | 12     |
| Left headlight                | 12     |
| Right headlight               | 12     |
| Front light                   | 12     |
| Front                         | 12     |
| Front                         | 12     |
| Front bumper                  | 11     |
| Front ground back right wheel | 11     |
| Front left fog light          | 11     |
| Front left light              | 11     |
| Front right light             | 11     |
| Exterior pipe                 | 11     |
| Left headlight                | 11     |
| Right headlight               | 11     |
| Front light                   | 11     |
| Front                         | 11     |
| Front                         | 11     |
| Front bumper                  | 10     |
| Front ground back left wheel  | 10     |
| Front left fog light          | 10     |
| Front left light              | 10     |
| Front right light             | 10     |
| Exterior pipe                 | 10     |
| Left headlight                | 10     |
| Right headlight               | 10     |
| Front light                   | 10     |
| Front                         | 10     |
| Front                         | 10     |
| Front bumper                  | 9      |
| Front ground back right wheel | 9      |
| Front left fog light          | 9      |
| Front left light              | 9      |
| Front right light             | 9      |
| Exterior pipe                 | 9      |
| Left headlight                | 9      |
| Right headlight               | 9      |
| Front light                   | 9      |
| Front                         | 9      |
| Front                         | 9      |
| Front bumper                  | 8      |
| Front ground back left wheel  | 8      |
| Front left fog light          | 8      |
| Front left light              | 8      |
| Front right light             | 8      |
| Exterior pipe                 | 8      |
| Left headlight                | 8      |
| Right headlight               | 8      |
| Front light                   | 8      |
| Front                         | 8      |
| Front                         | 8      |
| Front bumper                  | 7      |
| Front ground back right wheel | 7      |
| Front left fog light          | 7      |
| Front left light              | 7      |
| Front right light             | 7      |
| Exterior pipe                 | 7      |
| Left headlight                | 7      |
| Right headlight               | 7      |
| Front light                   | 7      |
| Front                         | 7      |
| Front                         | 7      |
| Front bumper                  | 6      |
| Front ground back left wheel  | 6      |
| Front left fog light          | 6      |
| Front left light              | 6      |
| Front right light             | 6      |
| Exterior pipe                 | 6      |
| Left headlight                | 6      |
| Right headlight               | 6      |
| Front light                   | 6      |
| Front                         | 6      |
| Front                         | 6      |
| Front bumper                  | 5      |
| Front ground back right wheel | 5      |
| Front left fog light          | 5      |
| Front left light              | 5      |
| Front right light             | 5      |
| Exterior pipe                 | 5      |
| Left headlight                | 5      |
| Right headlight               | 5      |
| Front light                   | 5      |
| Front                         | 5      |
| Front                         | 5      |
| Front bumper                  | 4      |
| Front ground back left wheel  | 4      |
| Front left fog light          | 4      |
| Front left light              | 4      |
| Front right light             | 4      |
| Exterior pipe                 | 4      |
| Left headlight                | 4      |
| Right headlight               | 4      |
| Front light                   | 4      |
| Front                         | 4      |
| Front                         | 4      |
| Front bumper                  | 3      |
| Front ground back right wheel | 3      |
| Front left fog light          | 3      |
| Front left light              | 3      |
| Front right light             | 3      |
| Exterior pipe                 | 3      |
| Left headlight                | 3      |
| Right headlight               | 3      |
| Front light                   | 3      |
| Front                         | 3      |
| Front                         | 3      |
| Front bumper                  | 2      |
| Front ground back left wheel  | 2      |
| Front left fog light          | 2      |
| Front left light              | 2      |
| Front right light             | 2      |
| Exterior pipe                 | 2      |
| Left headlight                | 2      |
| Right headlight               | 2      |
| Front light                   | 2      |
| Front                         | 2      |
| Front                         | 2      |
| Front bumper                  | 1      |
| Front ground back right wheel | 1      |
| Front left fog light          | 1      |
| Front left light              | 1      |
| Front right light             | 1      |
| Exterior pipe                 | 1      |
| Left headlight                | 1      |
| Right headlight               | 1      |
| Front light                   | 1      |
| Front                         | 1      |
| Front                         | 1      |

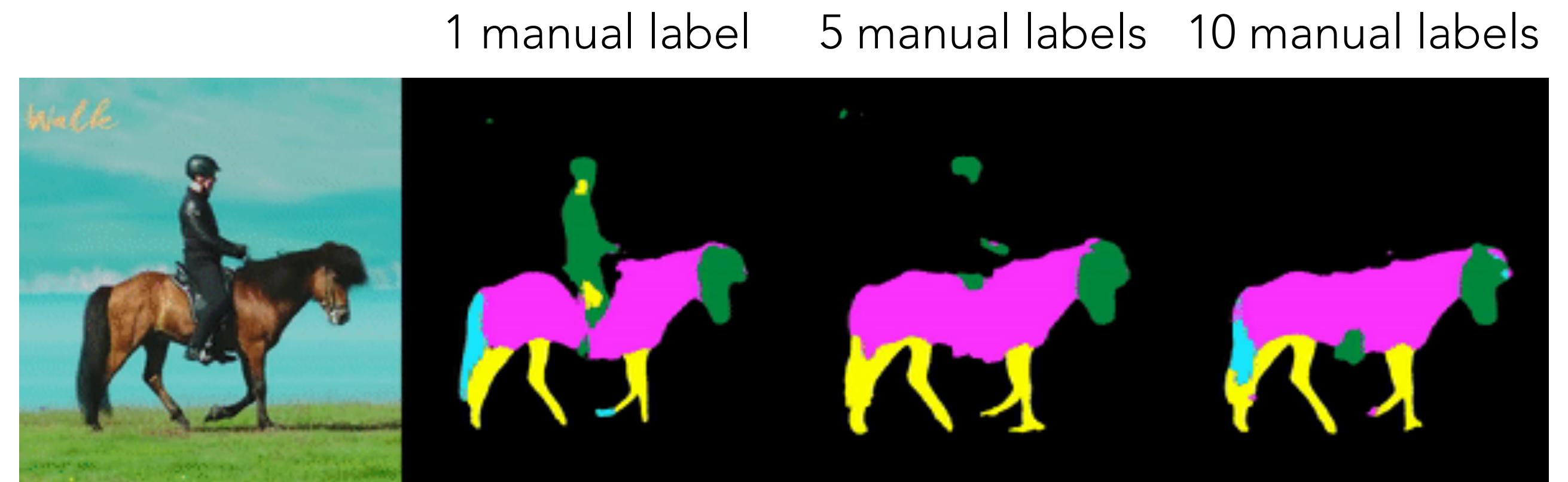


1 labeled GAN image is worth  
~100 labeled regular images!



[Li, Yang, Kries, Torralba, Fidler, CVPR 2021]

Courtesy of Li et al. Used under CC BY.



[Tritrong\*, Rewatbowornwong\*, Suwajanakorn, CVPR 2021]

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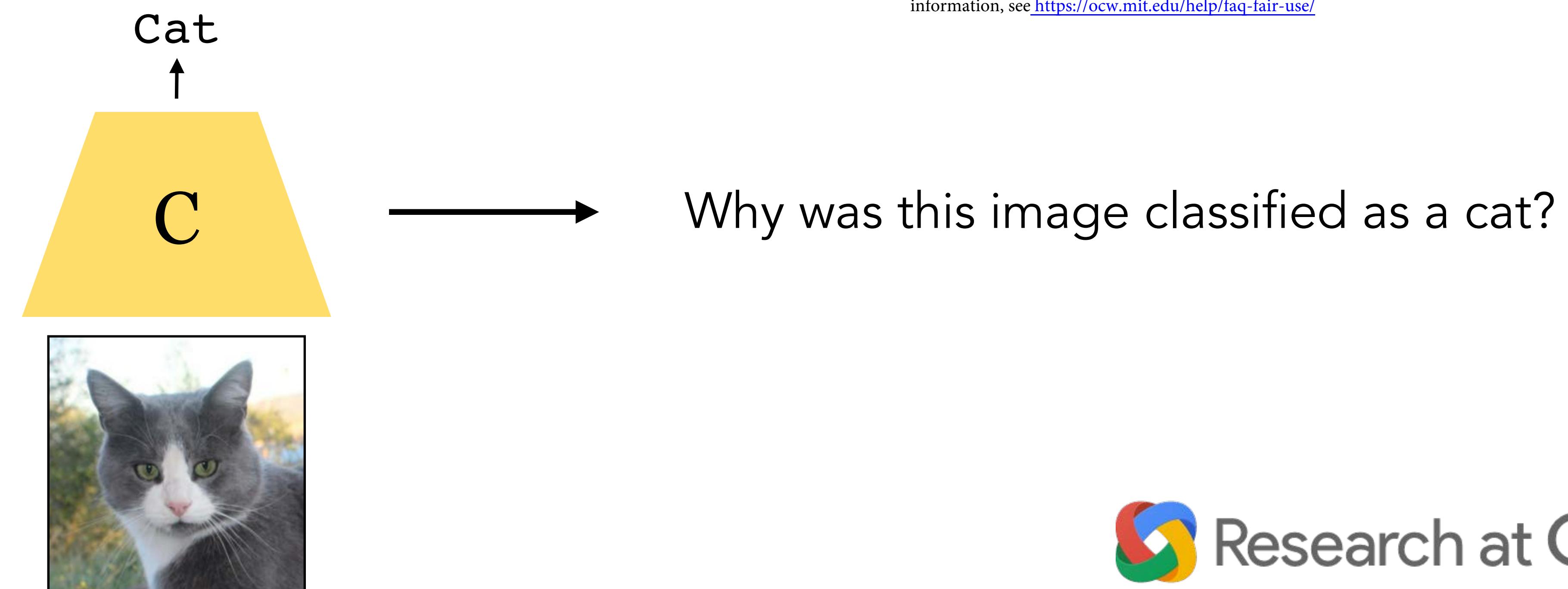
# Explaining in Style: Training a GAN to Explain a Classifier

Oran Lang\*, Yossi Gandelsman\*, Michal Yarom\*, Yoav Wald\*, Gal Elidan, Avinatan Hassidim, William T. Freeman, Phillip Isola, Amir Globerson, Michal Irani, Inbar Mosseri

ICCV 2021



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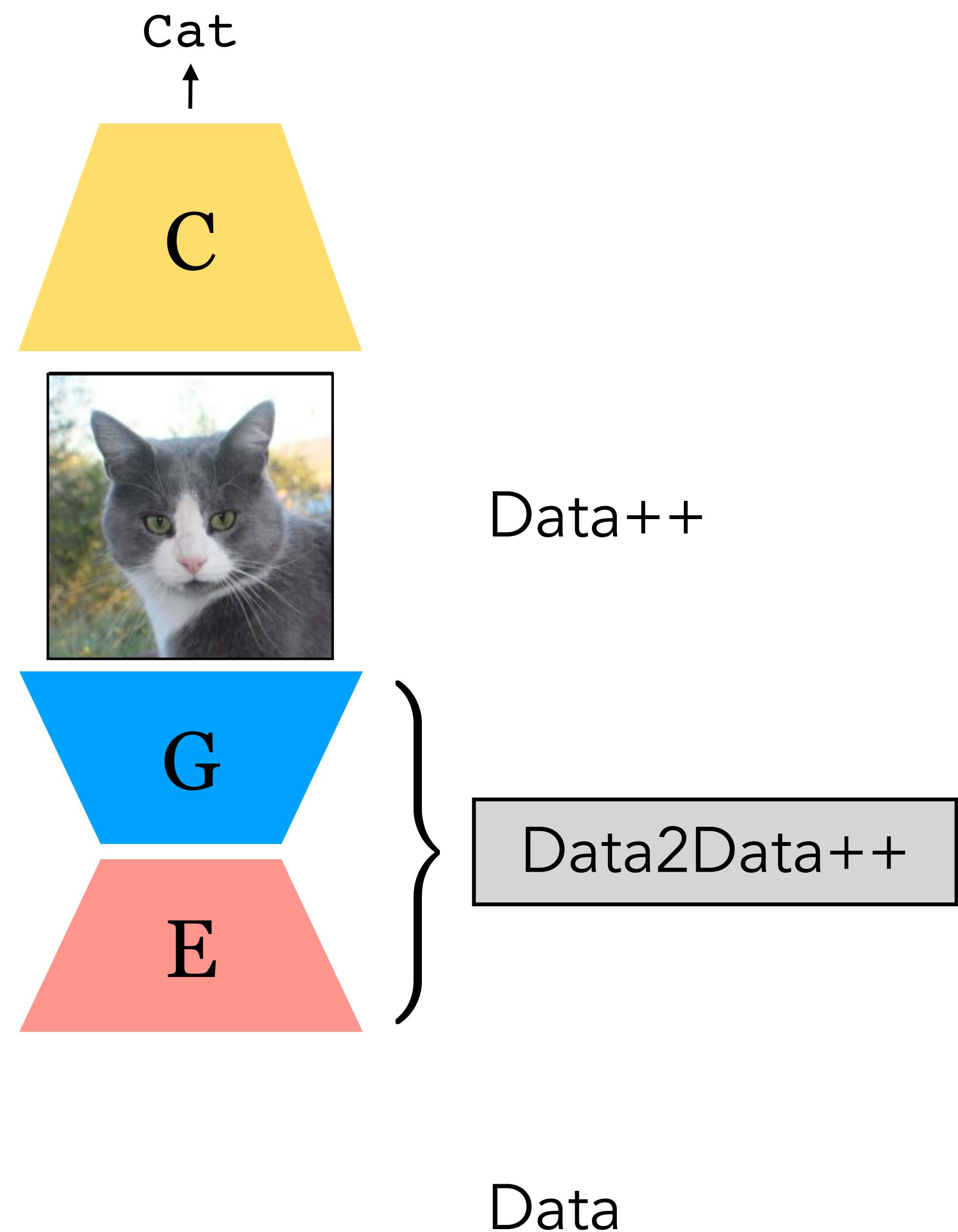


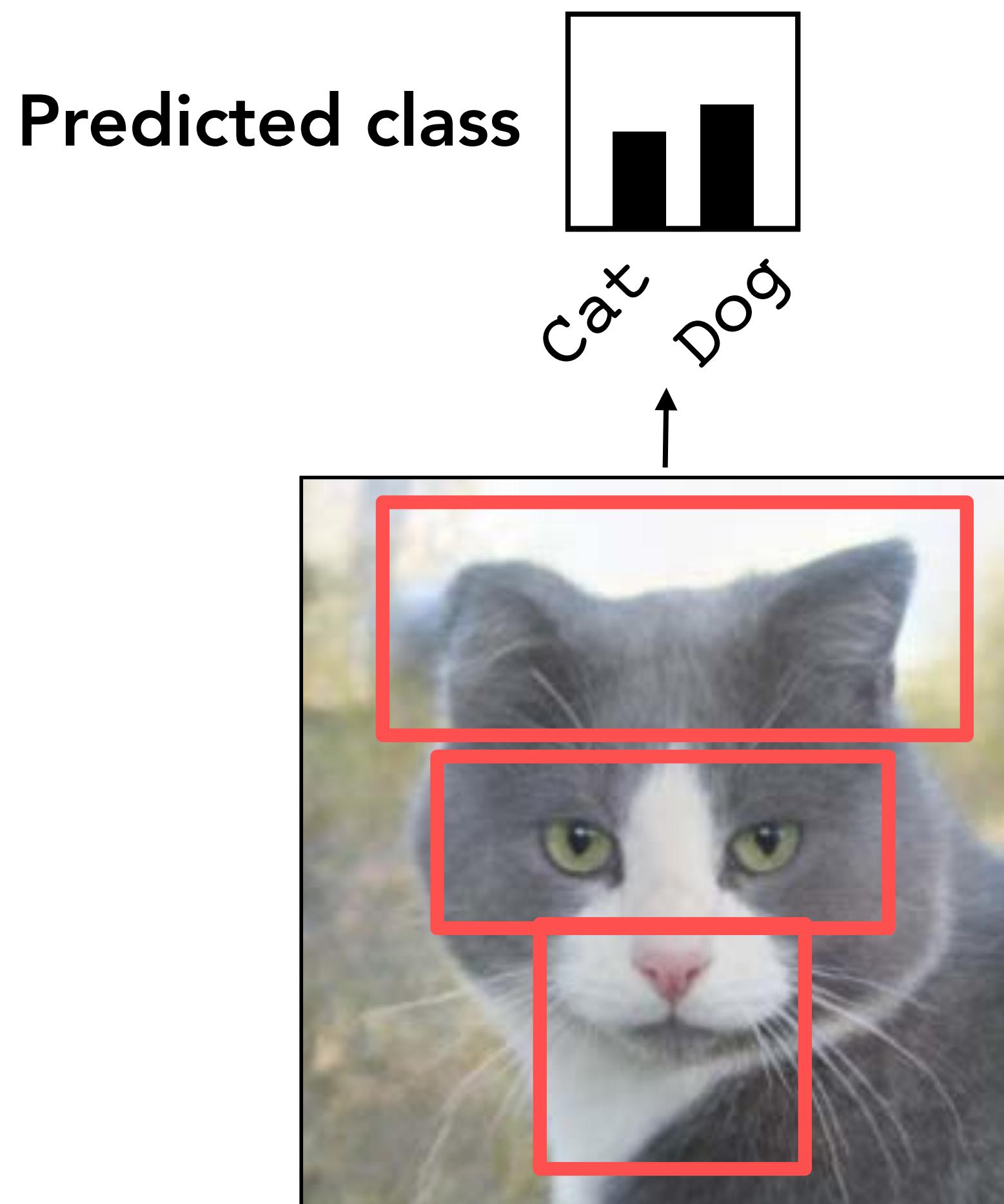
Cat



C







## StylEx

Find top-K StyleSpace directions that most affect predicted class



← Manipulate latent variables  
[“StyleSpace”: Wu, Lischinski, Shechtman 2020]

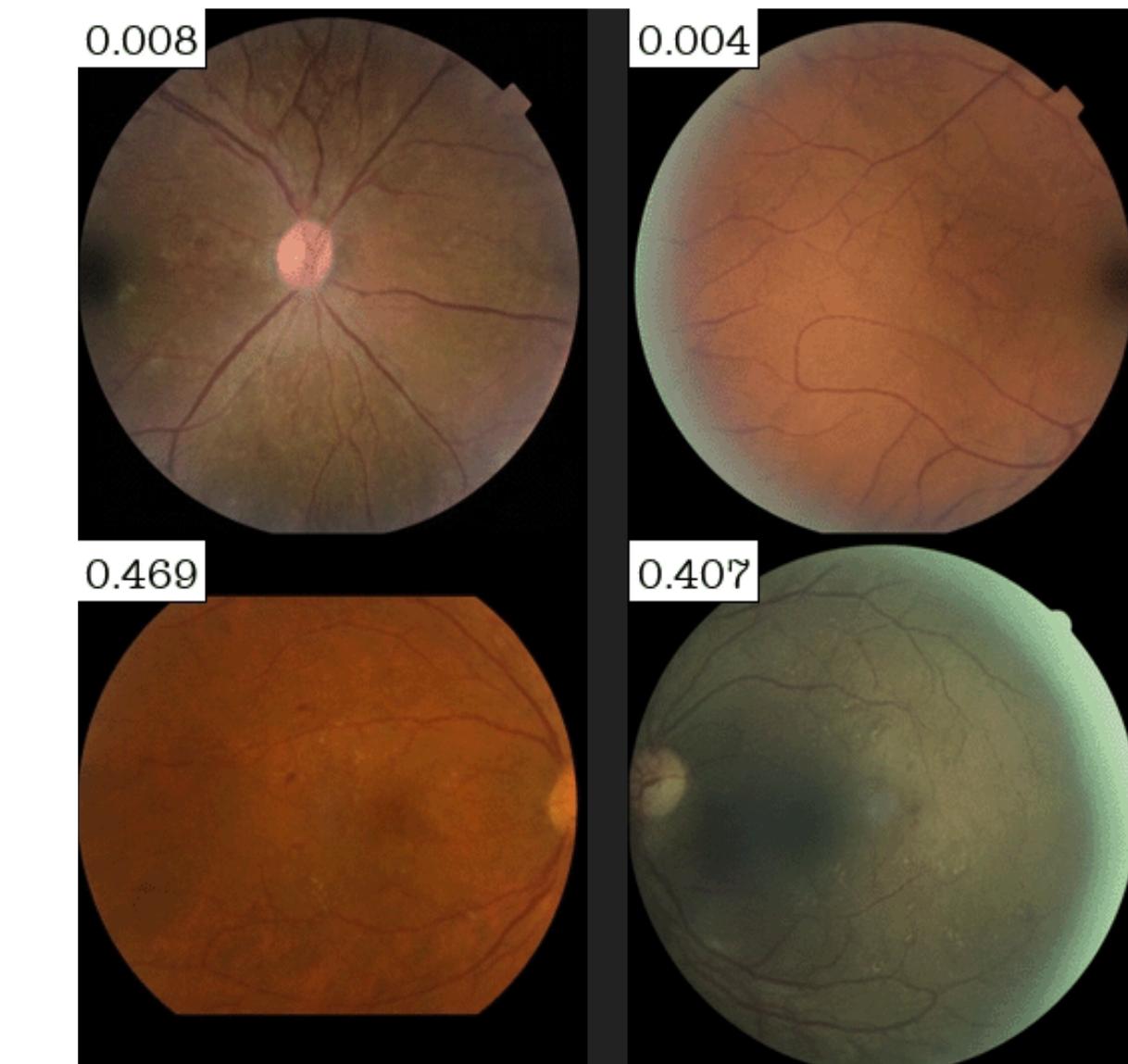
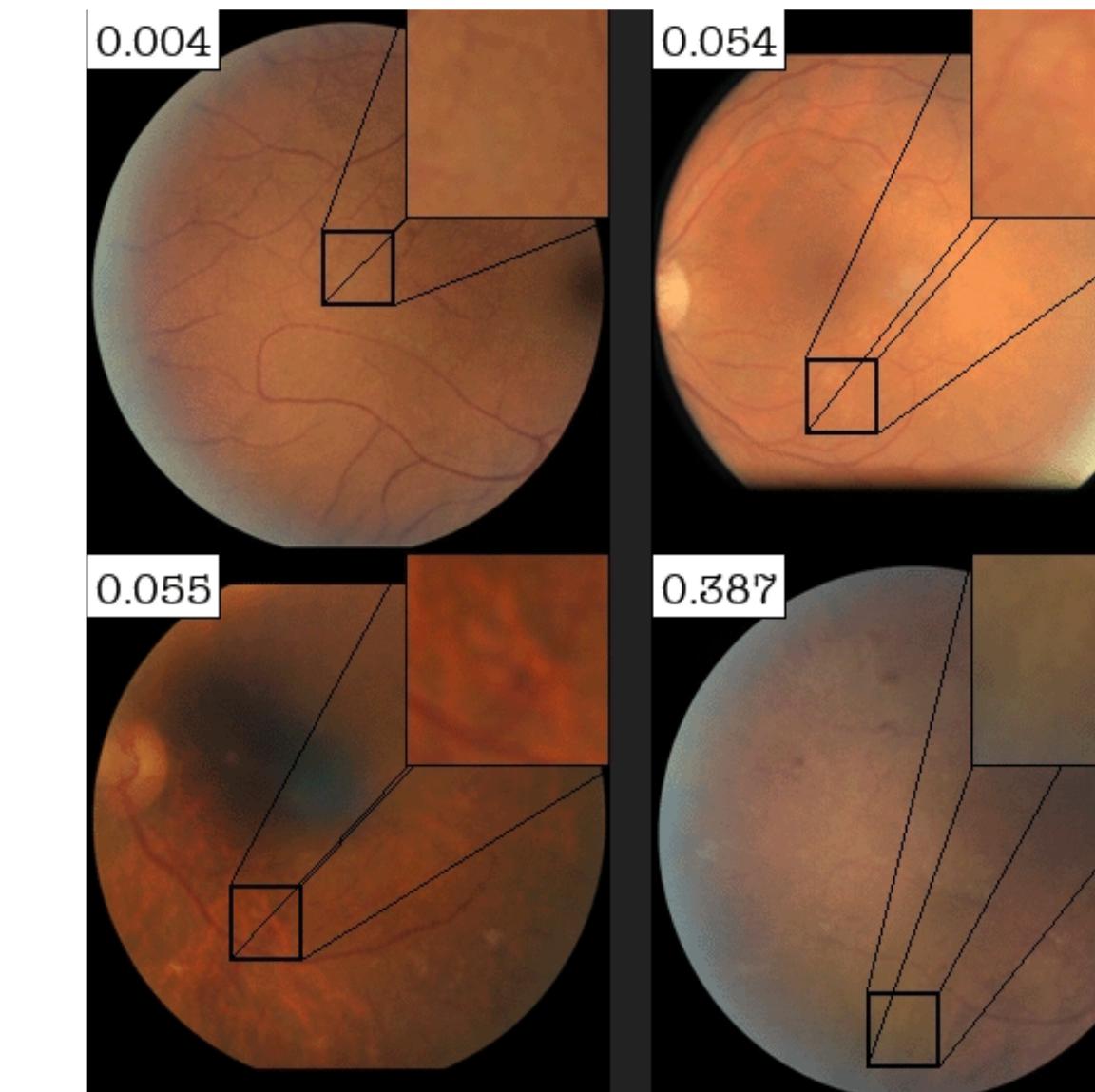
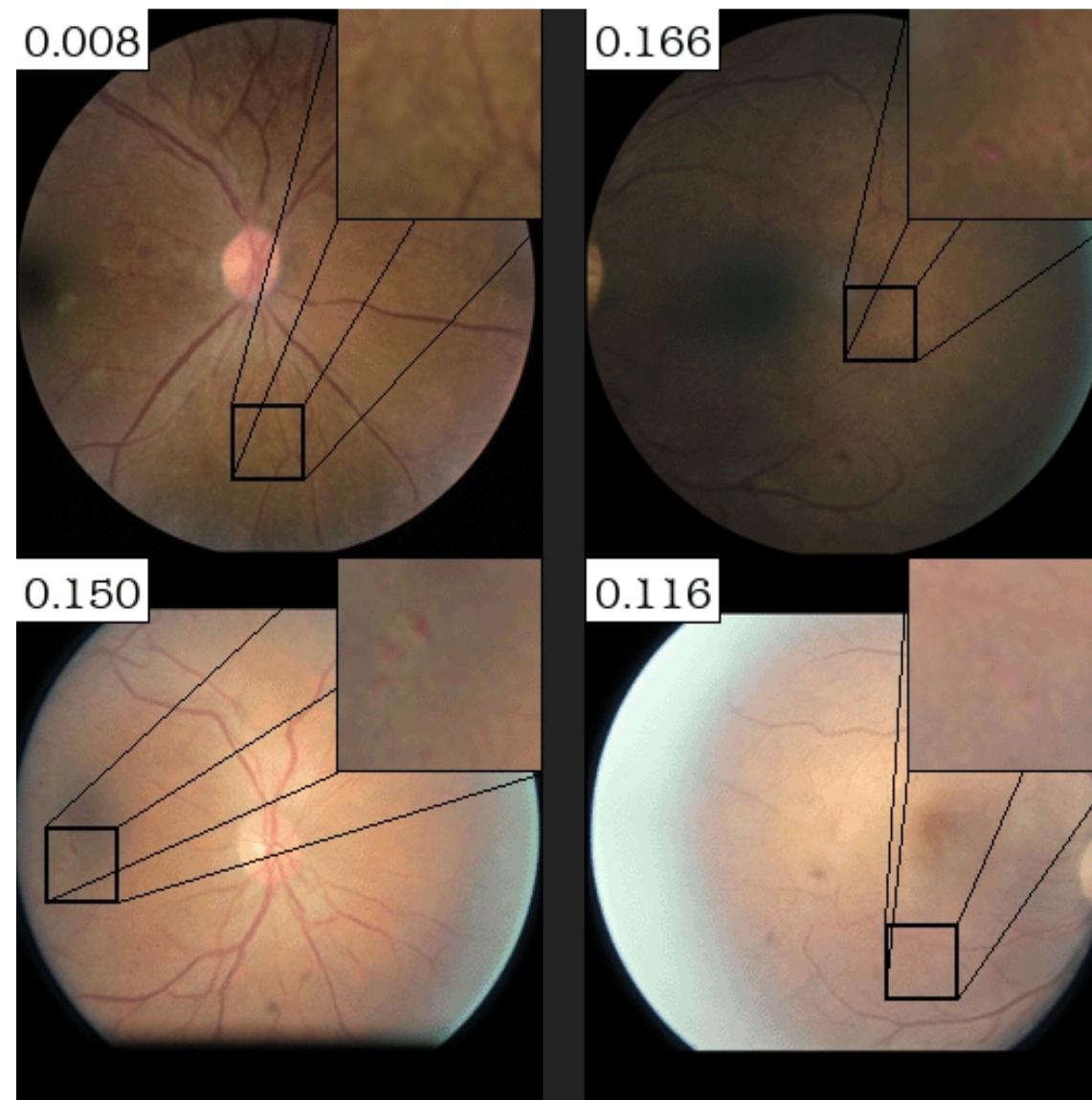
# Class-specific explanation

## Perceived Age Classifier:

Image of people removed due to copyright restrictions.

# Class-specific explanation

## Retinal Fundus Classifier:



**Attribute #1**  
“Exudates”

**Attribute #2**  
“Cotton Wool”

**Attribute #3**  
“Hemorrhages”

**Attribute #4**  
“Clustered Exudates”

## Original Plates

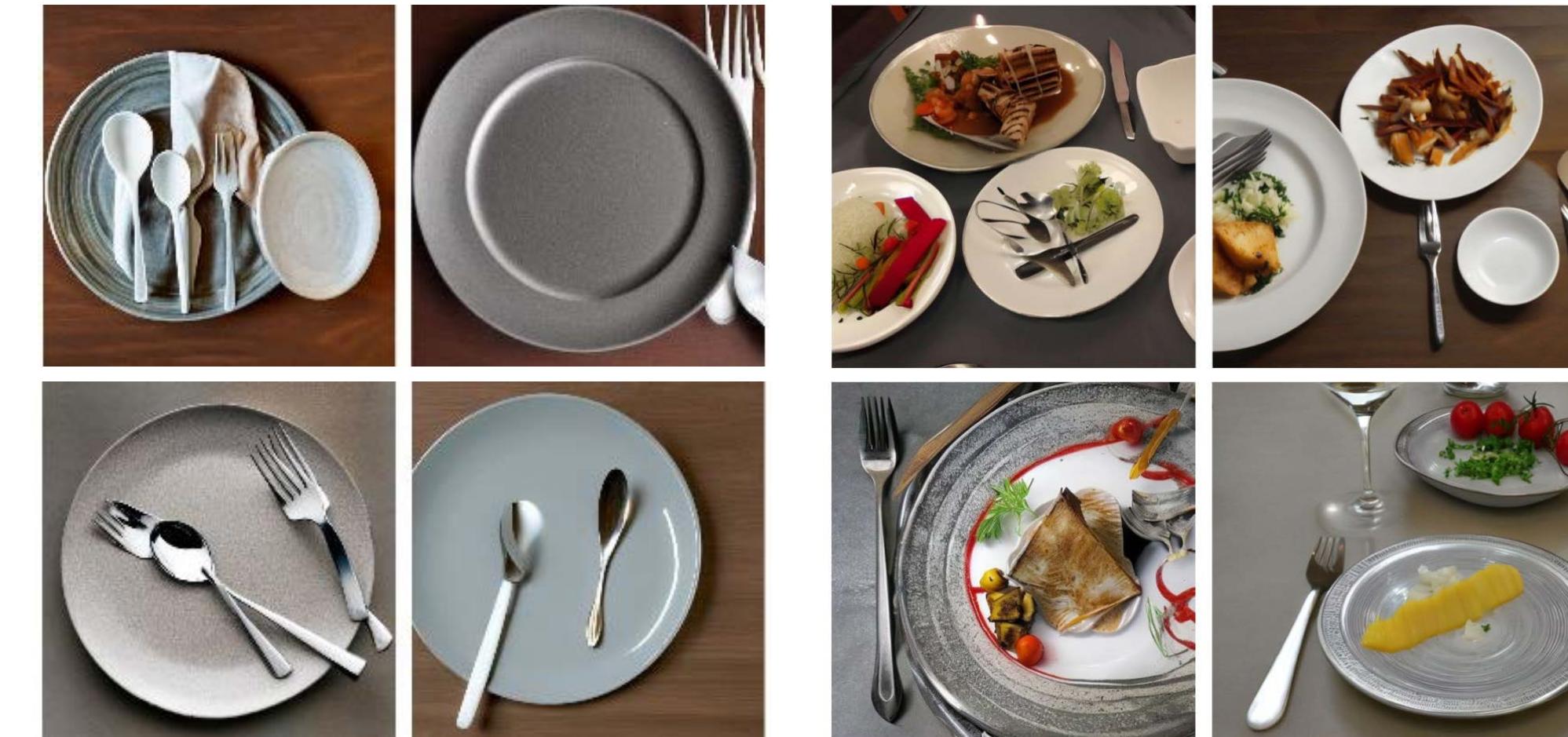


ImageNet

## Acquiring images of plates with utensils



Bing



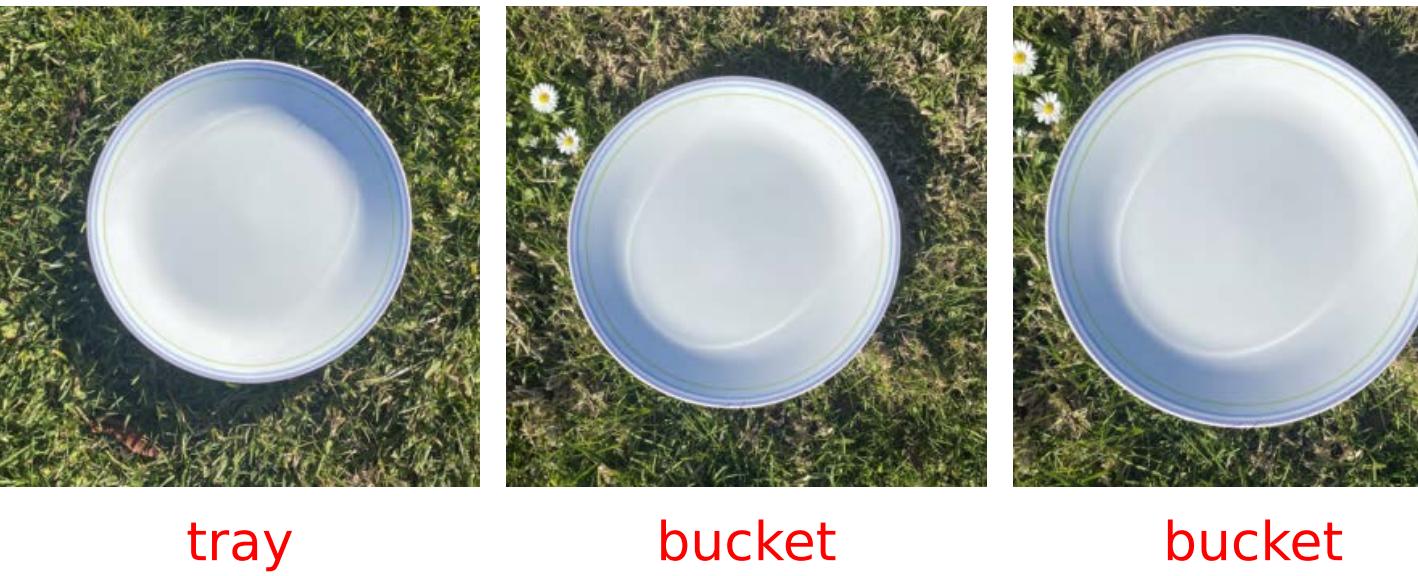
Stable Diffusion



ImageNet\*



tray



tray



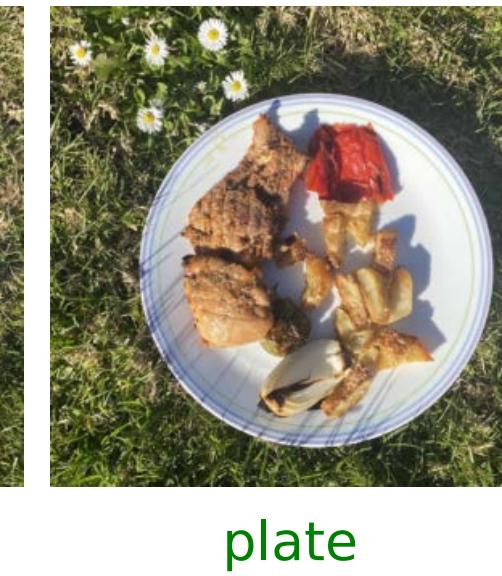
bucket



plate

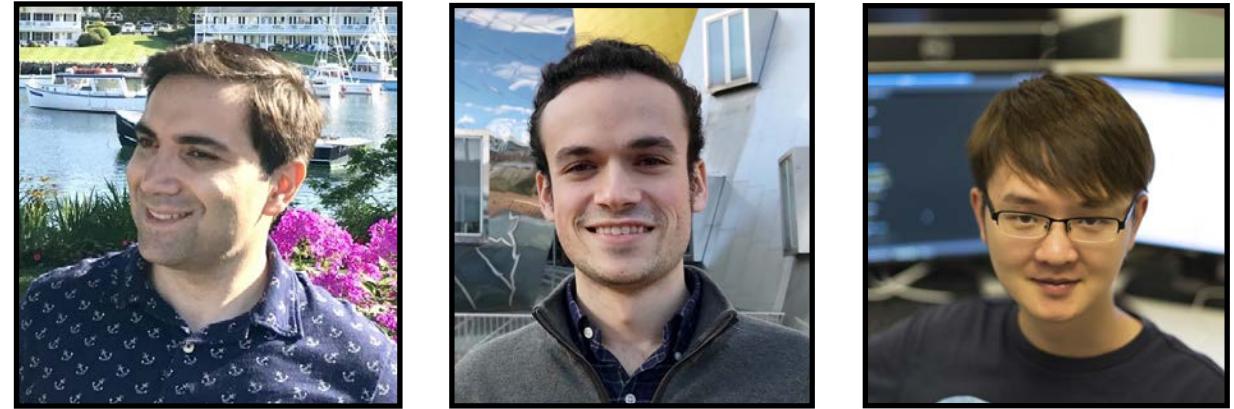


plate



plate

# Generative Models as a Data Source for Multiview Representation Learning



Jahanian, Puig, Tian, Isola  
ICLR 2022

Dataset



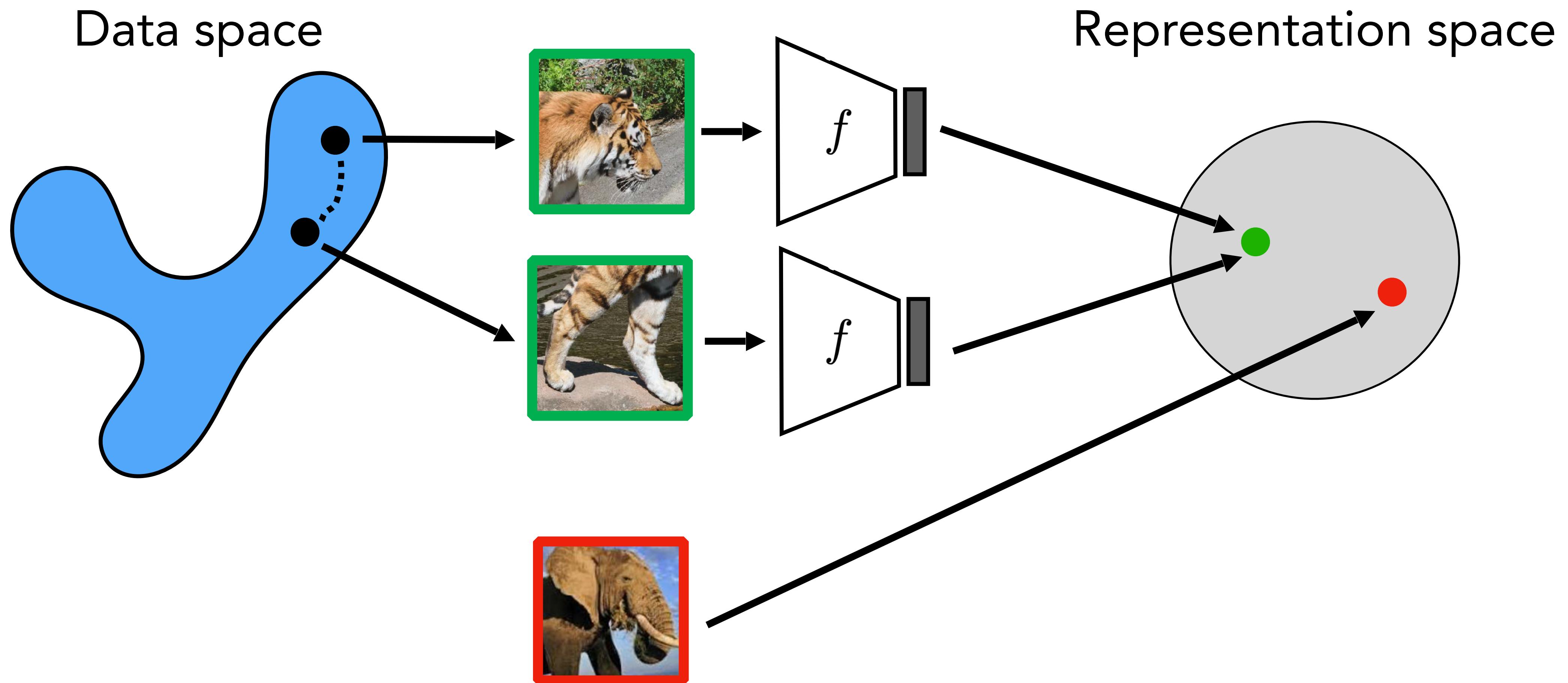
$$\mathbf{x} \sim \{\mathbf{x}_i\}_{i=1}^N$$

Generative Model

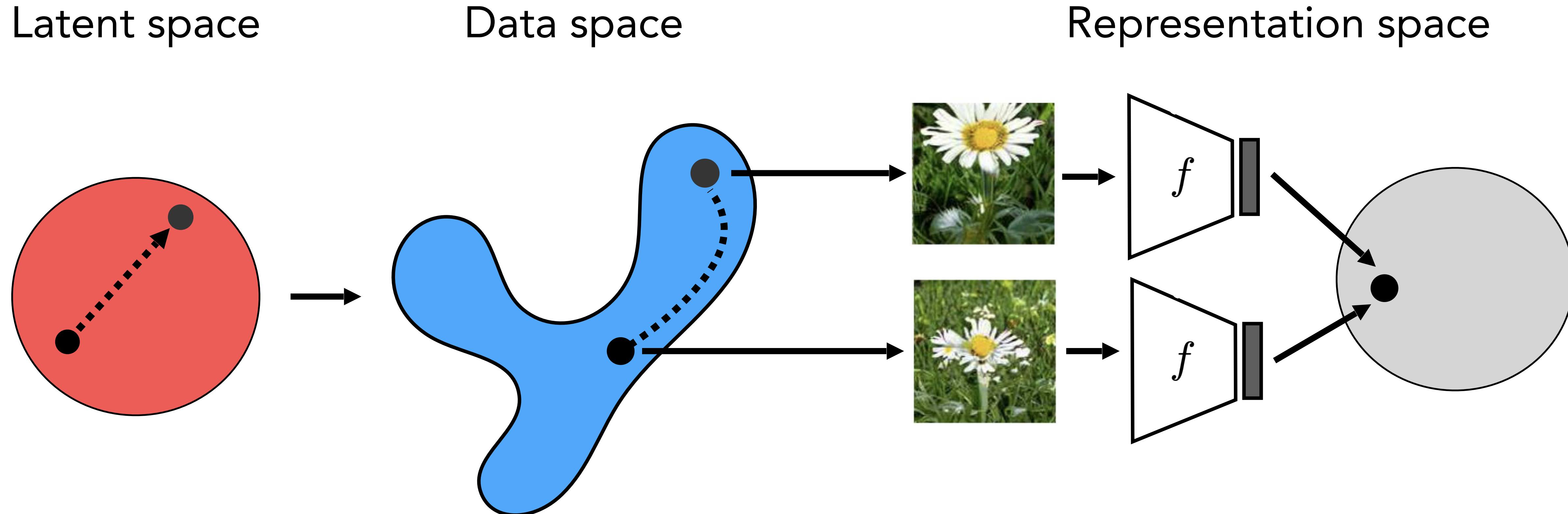


$$\mathbf{x} \sim G(T_{\mathbf{z}}(\mathbf{z}))$$

# Contrastive Learning



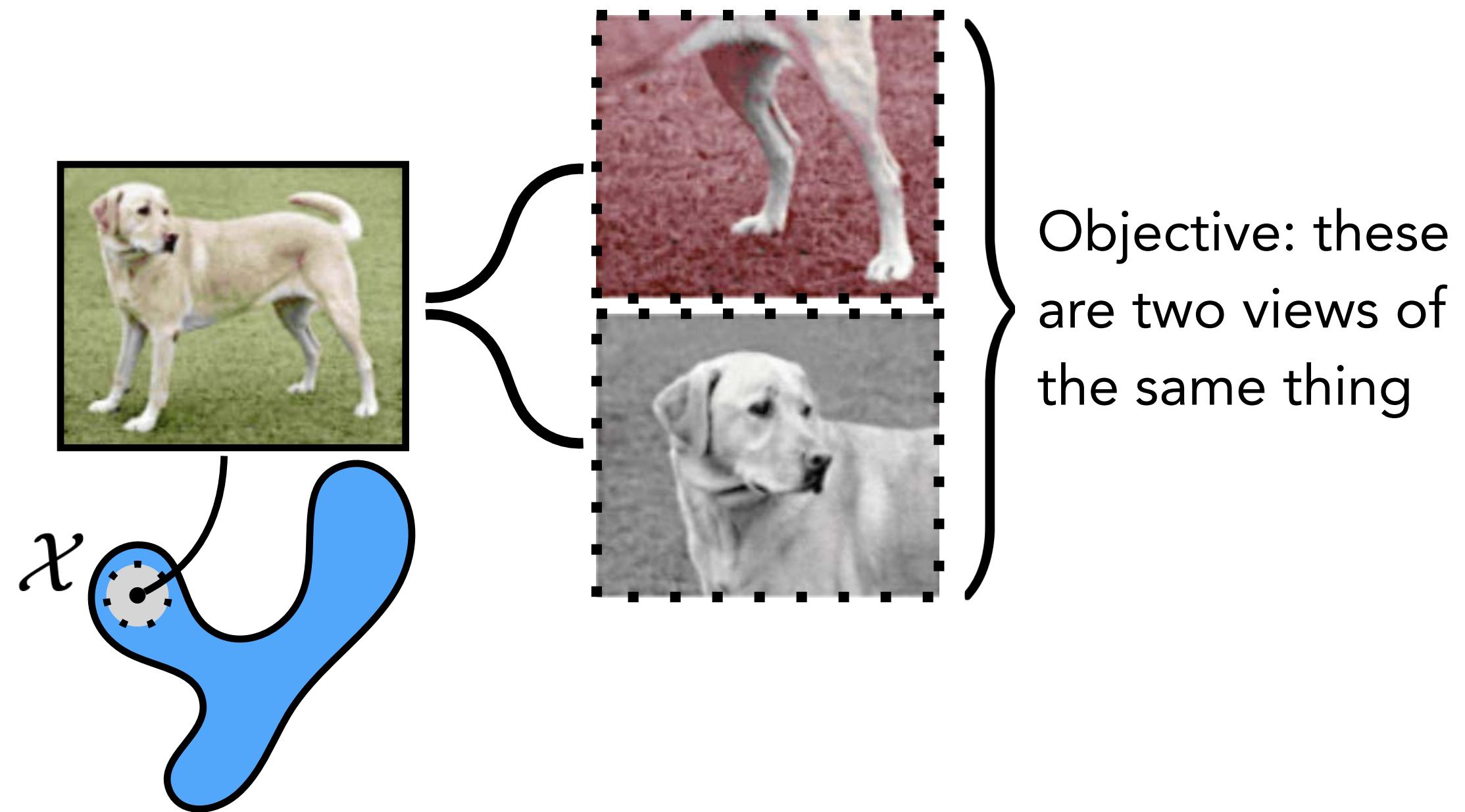
# **Contrastive learning + Generative modeling**



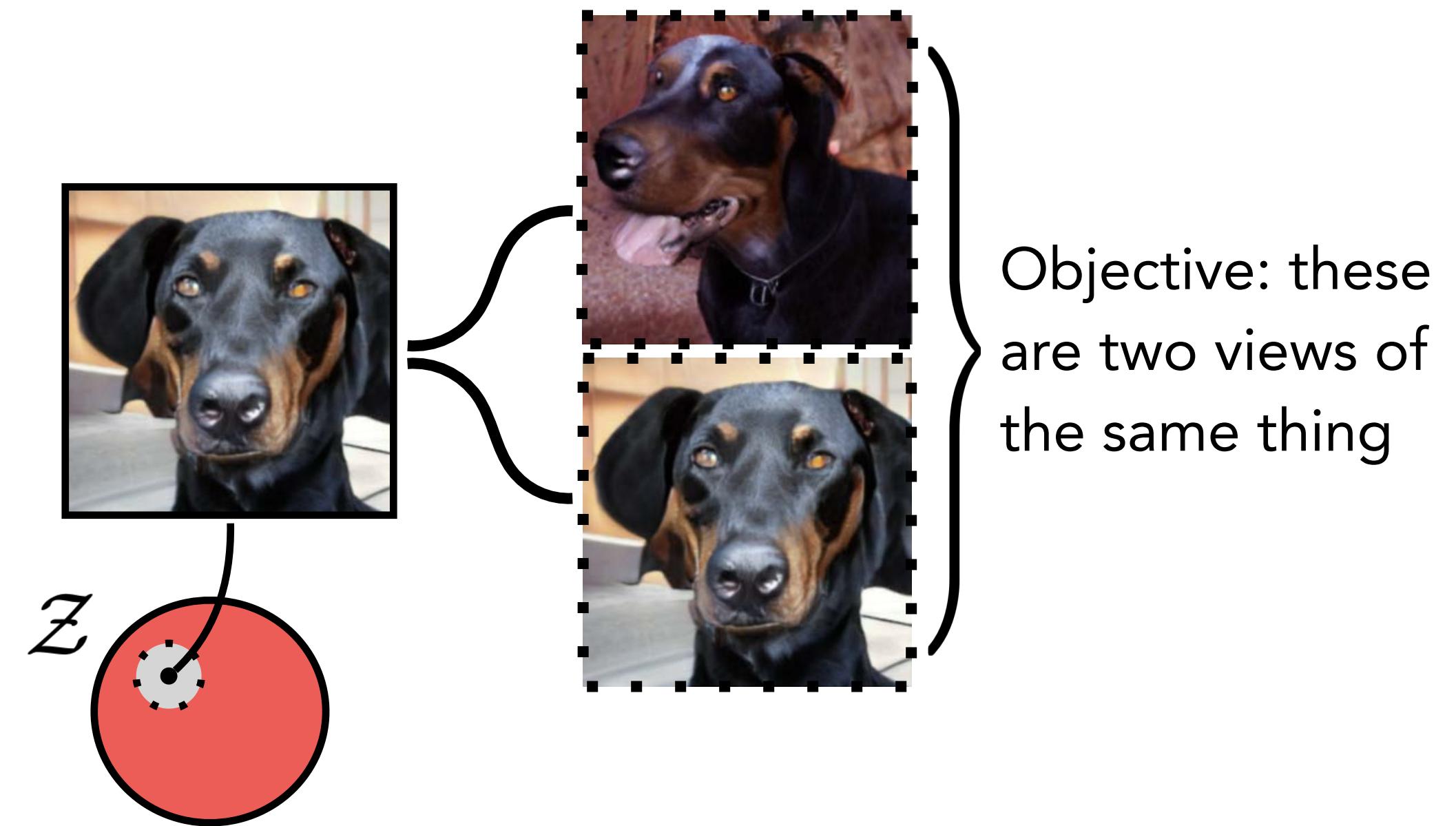
Create positive pairs by transformations in latent space, rather than in data space

# Contrastive learning + Generative modeling

## SimCLR views

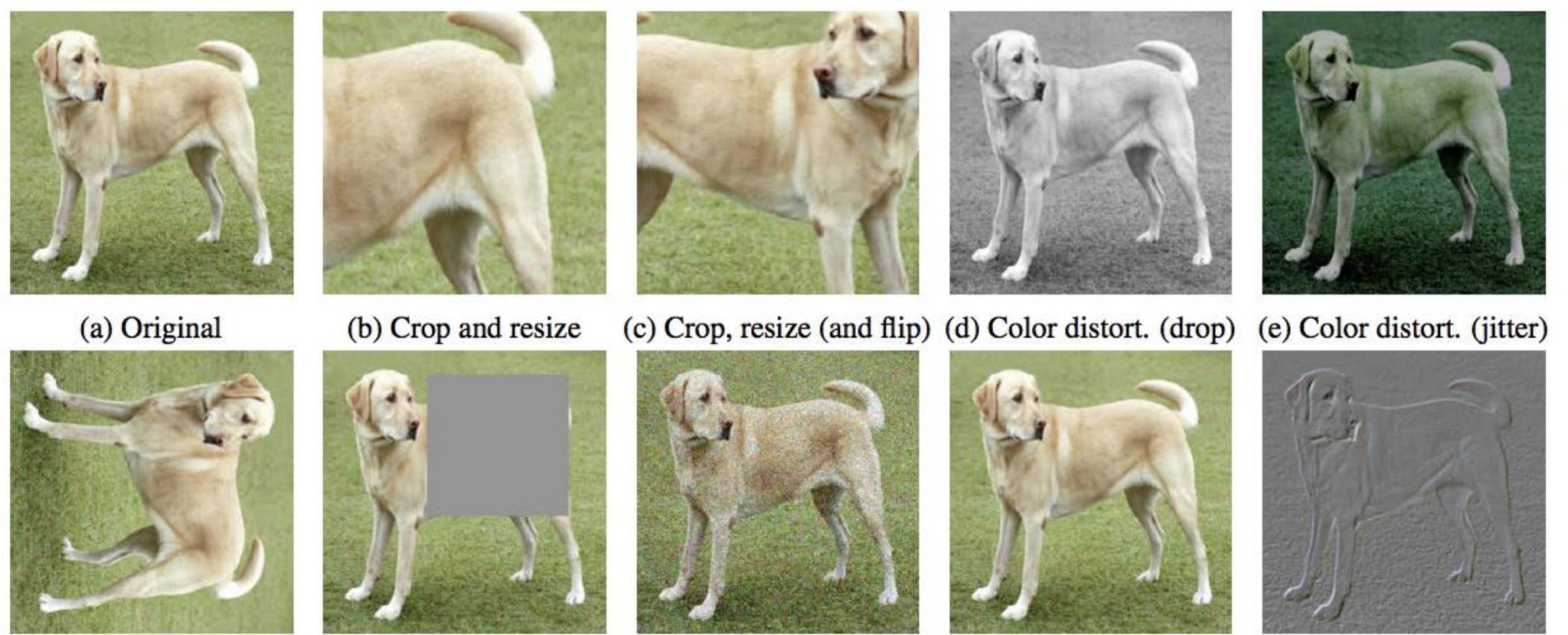


## Latent views



# Contrastive learning + Generative modeling

## SimCLR views



These are all different views of the same thing

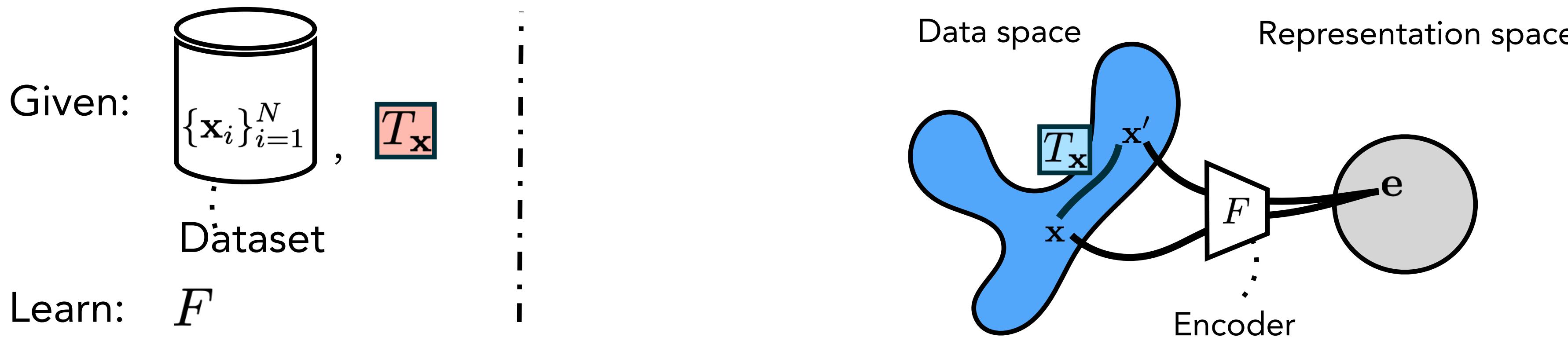
## Latent views



These are all different views of the same thing

# Contrastive learning + Generative modeling

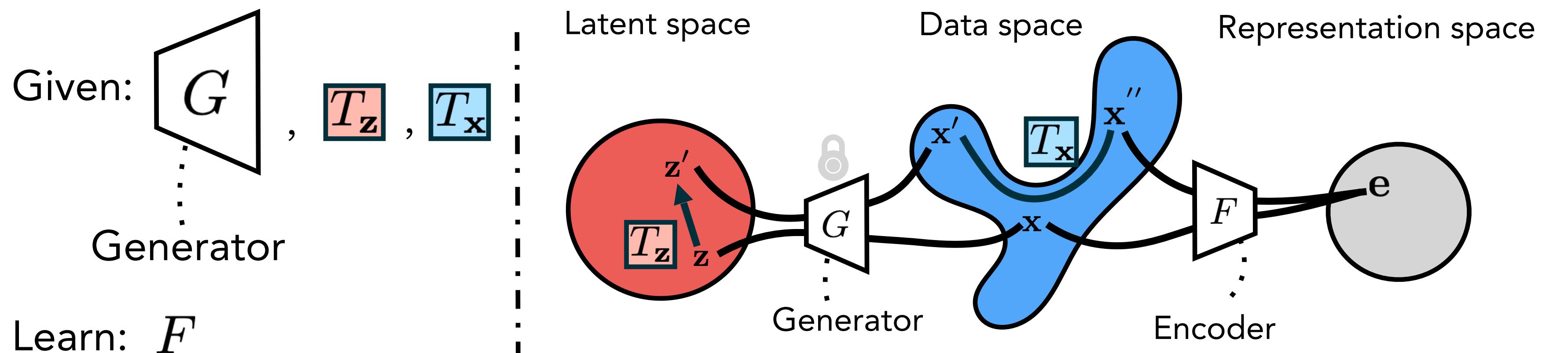
Contrastive learning from real data (SimCLR, etc)



Top-1 Accuracy on  
ImageNet1000 linear  
transfer

43.9%

Contrastive learning from generated data



Only  $T_x \rightarrow 35.7\%$

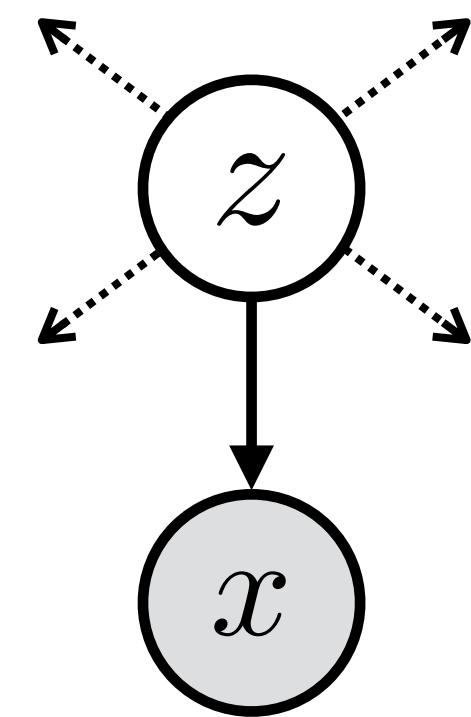
$T_z + T_x \rightarrow 42.6\%$

# Contrastive learning + Generative modeling

Deep generative views improve contrastive learning beyond only using standard data augmentation.

When the generative model is high quality, can even outperform learning from real data.

# Data++



Datapoint++



Samples from implicit generative models act like decorated data, *data++*, with extra functionality.

With special operators, you can *interpolate*, *extrapolate*, *manipulate*, *compose*, *optimize*, and *label* these datapoints.

Everything you can do with regular data, you can also try with *data++*. It might work better!

# Meta-learning: learning to learn fast

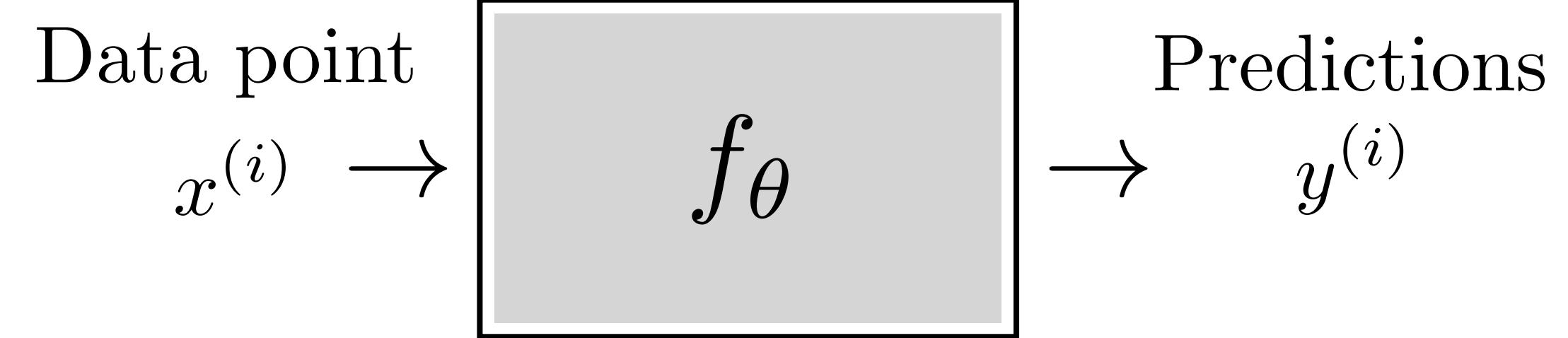
Meta-learning



Learning



Inference



# MAML: Model-Agnostic Meta-Learning

[Finn, Abbeel, Levine 2017]

- So far we saw transfer learning as: given some prior model/representation, how can we quickly adapt it?
- Could we *learn* to do transfer learning?
- Consider finetuning: given an init, update it with SGD
- MAML: *learn* an init such just a few steps of SGD will update it very effectively

# MAML: Model-Agnostic Meta-Learning

[Finn, Abbeel, Levine 2017]

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## Algorithm 1 Model-Agnostic Meta-Learning

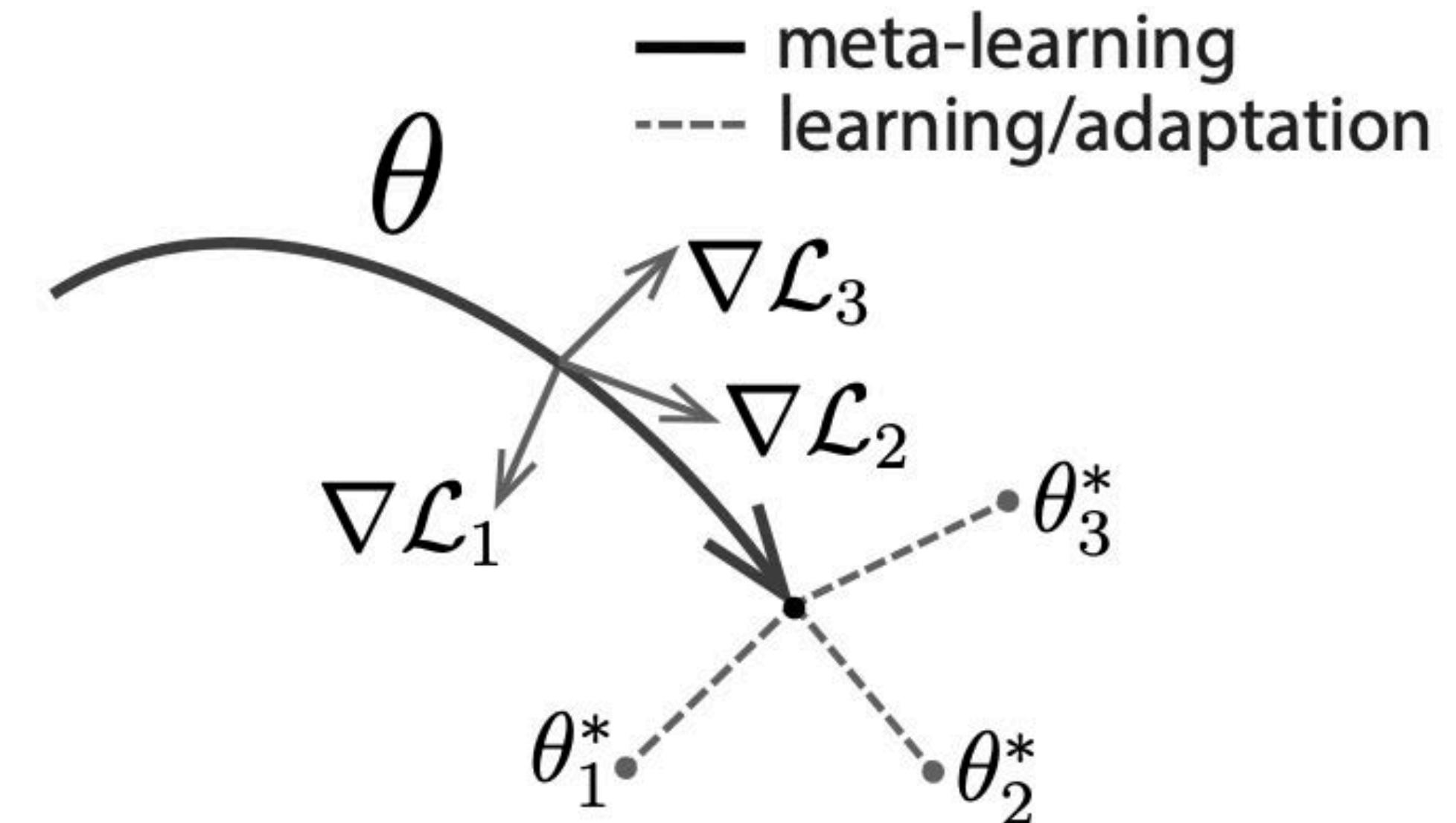
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**Require:**  $p(\mathcal{T})$ : distribution over tasks

**Require:**  $\alpha, \beta$ : step size hyperparameters

```
1: randomly initialize  $\theta$ 
2: while not done do
3:   Sample batch of tasks  $\mathcal{T}_i \sim p(\mathcal{T})$ 
4:   for all  $\mathcal{T}_i$  do
5:     1. Starting with init, run a few steps of SGD on task i
6:     2. Compute loss after these steps
7:   end for
8:   init  $\leftarrow$  backprop through
9: end while
```

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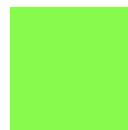
# MAML: Model-Agnostic Meta-Learning

[Finn, Abbeel, Levine 2017]

init  $\leftarrow$  backprop through 

How to backprop through  ?

1 step SGD:

 = `forward(x, backward(forward(x, θ)) + θ)`

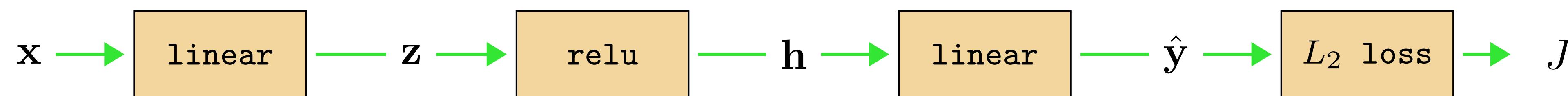
2 steps SGD:

 = `forward(x, backward(forward(x, backward(forward(x, θ)) + θ), θ) + θ)`

# You can backprop through backward!

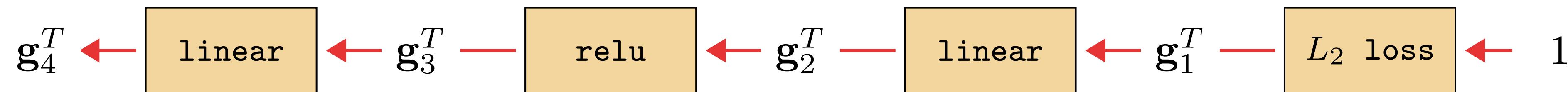
```
forward(x, backward(forward(x, backward(forward(x, θ)) + θ), θ) + θ)
```

Example forward and backward through a simple net:



$$z = \mathbf{W}_1 x$$
$$\begin{matrix} z \\ \vdots \end{matrix} = \begin{matrix} \mathbf{W}_1 \\ \vdots \end{matrix} \begin{matrix} x \\ \vdots \end{matrix}$$

$$\hat{y} = \mathbf{W}_2 h$$
$$\begin{matrix} \hat{y} \\ \vdots \end{matrix} = \begin{matrix} \mathbf{W}_2 \\ \vdots \end{matrix} \begin{matrix} h \\ \vdots \end{matrix}$$



$$g_4^T = \mathbf{W}_1^T g_3^T$$
$$\begin{matrix} g_4^T \\ \vdots \end{matrix} = \begin{matrix} \mathbf{W}_1^T \\ \vdots \end{matrix} \begin{matrix} g_3^T \\ \vdots \end{matrix}$$

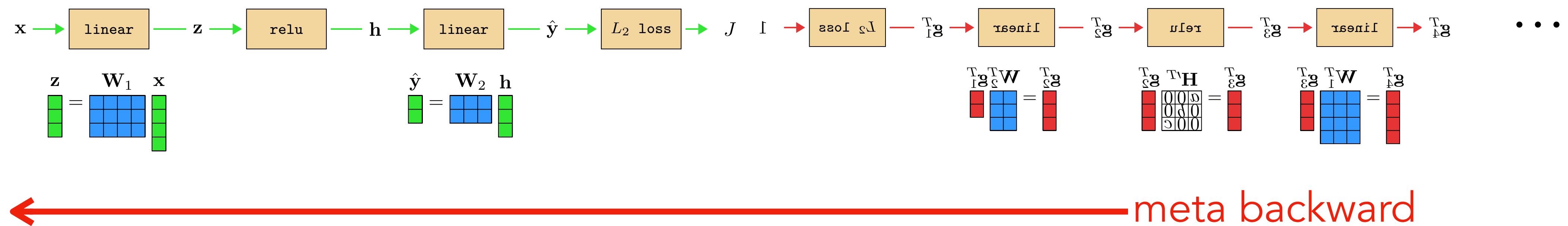
$$g_3^T = \mathbf{H}'^T g_2^T$$
$$\begin{matrix} g_3^T \\ \vdots \end{matrix} = \begin{matrix} \mathbf{H}'^T \\ \vdots \end{matrix} \begin{matrix} g_2^T \\ \vdots \end{matrix}$$
$$\begin{matrix} a & 0 & 0 \\ 0 & b & 0 \\ 0 & 0 & c \end{matrix}$$

$$g_2^T = \mathbf{W}_2^T g_1^T$$
$$\begin{matrix} g_2^T \\ \vdots \end{matrix} = \begin{matrix} \mathbf{W}_2^T \\ \vdots \end{matrix} \begin{matrix} g_1^T \\ \vdots \end{matrix}$$

# You can backprop through backward!

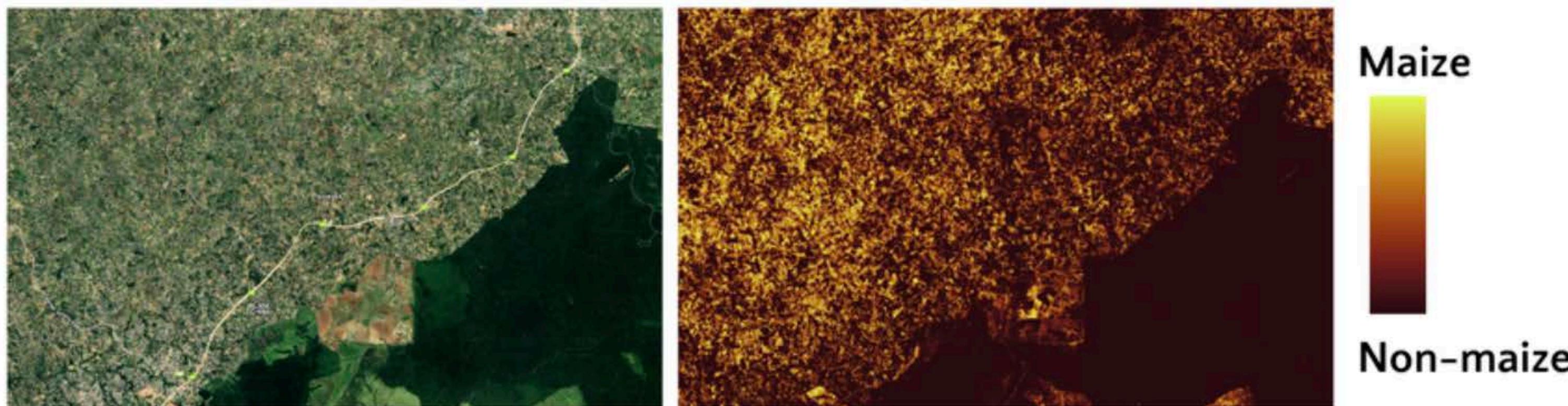
```
forward(x, backward(forward(x, backward(forward(x, θ)) + θ), θ) + θ)
```

## Example forward and backward through a simple net:

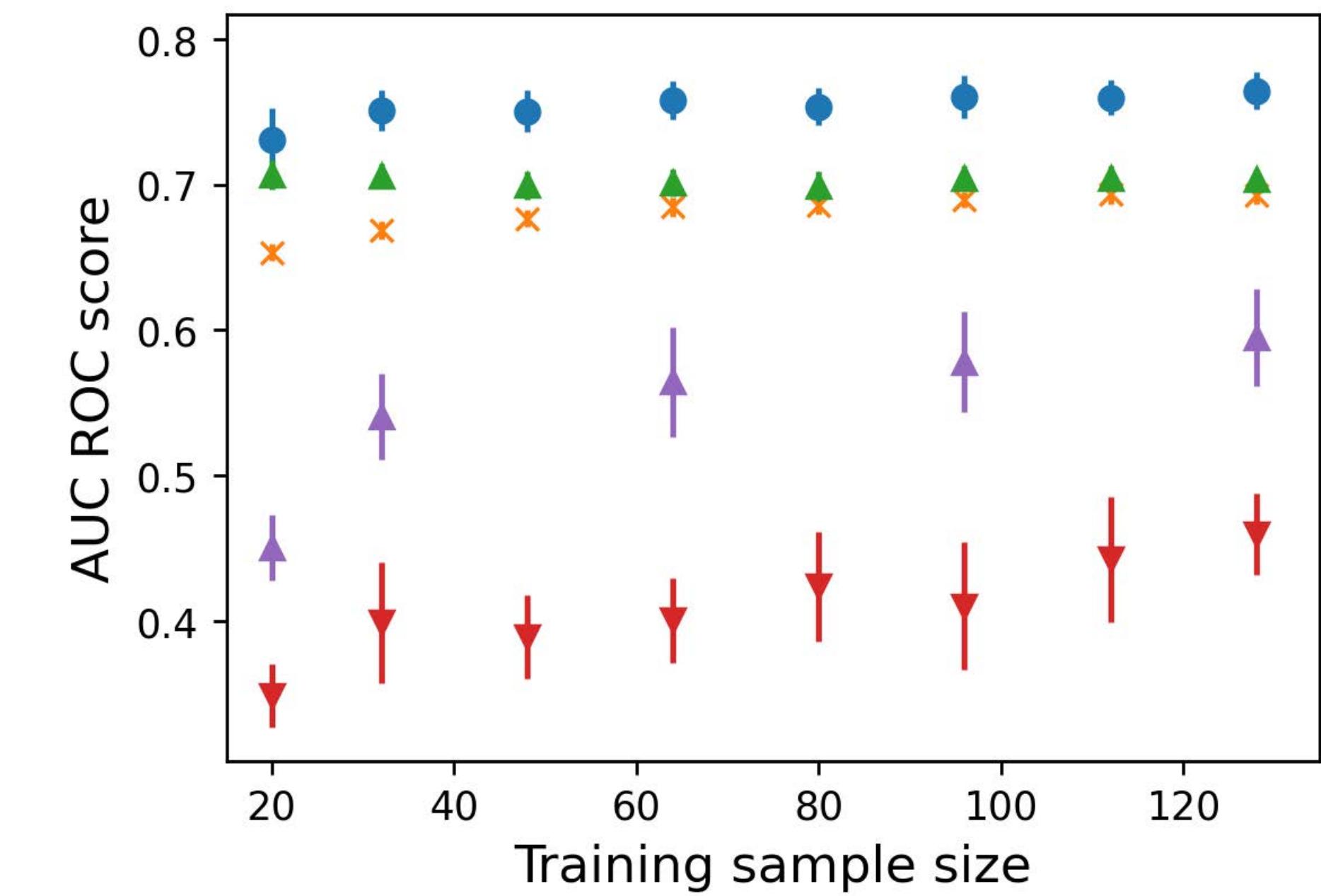


# Task-Informed MAML for Agriculture

- In practice, the gains of this method are not often worth the additional computational cost at training time (worse than just pretraining?)
- Tseng et al. introduce a geospatial embedding that encodes task-specific context into meta-learning, and helps performance



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(a) Kenya: Maize vs. Rest



# Meta-learning by sequence modeling

- Definition of learning:
  - input: a sequence  $x_0, y_0, x_1, y_1, x_2, y_2, \dots$
  - output: a function  $f: x \rightarrow y$
- $x_0, y_0, x_1, y_1, x_2, y_2, x_3, ?$
- RNN state + params is  $f$ , apply that  $f$  to  $x_3$

# Transfer Learning II

- Transferring knowledge about the inputs
  - Generative models as data++
- Meta-learning

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