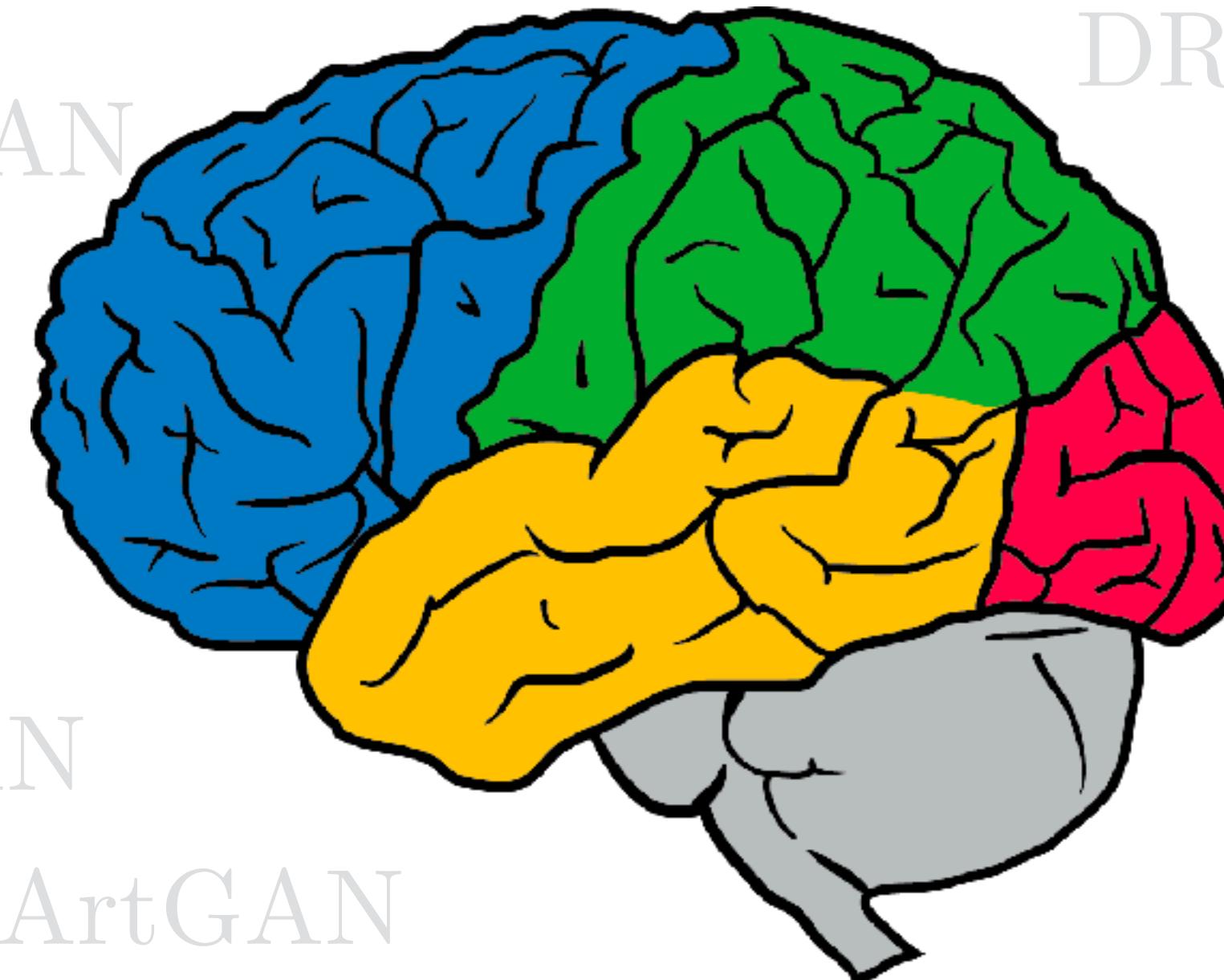


# Introduction to GANs

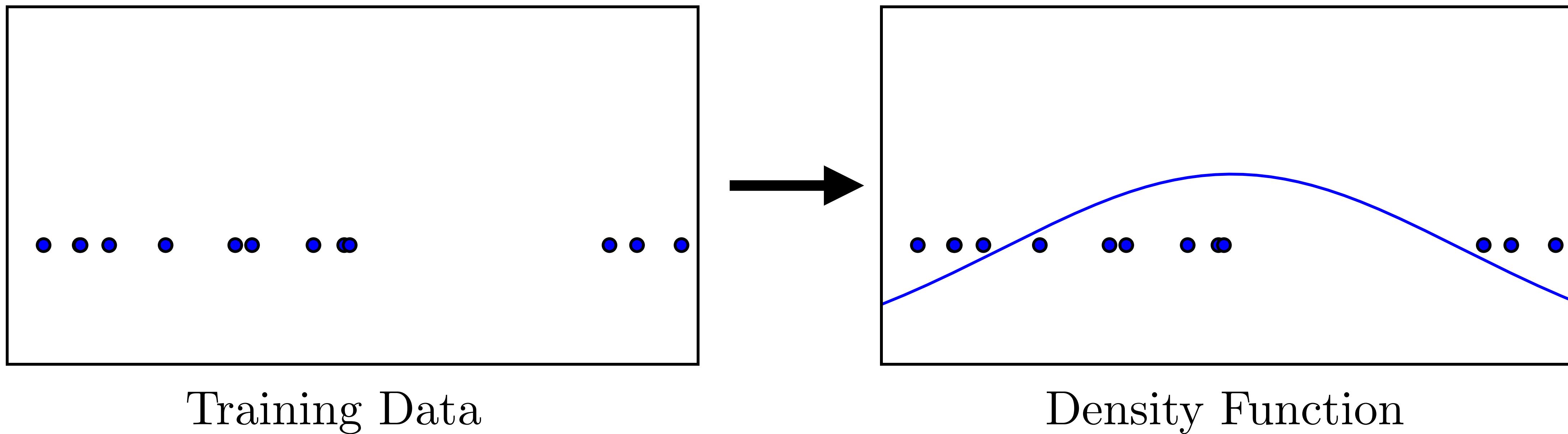
Ian Goodfellow, Staff Research Scientist, Google Brain

CVPR Tutorial on GANs

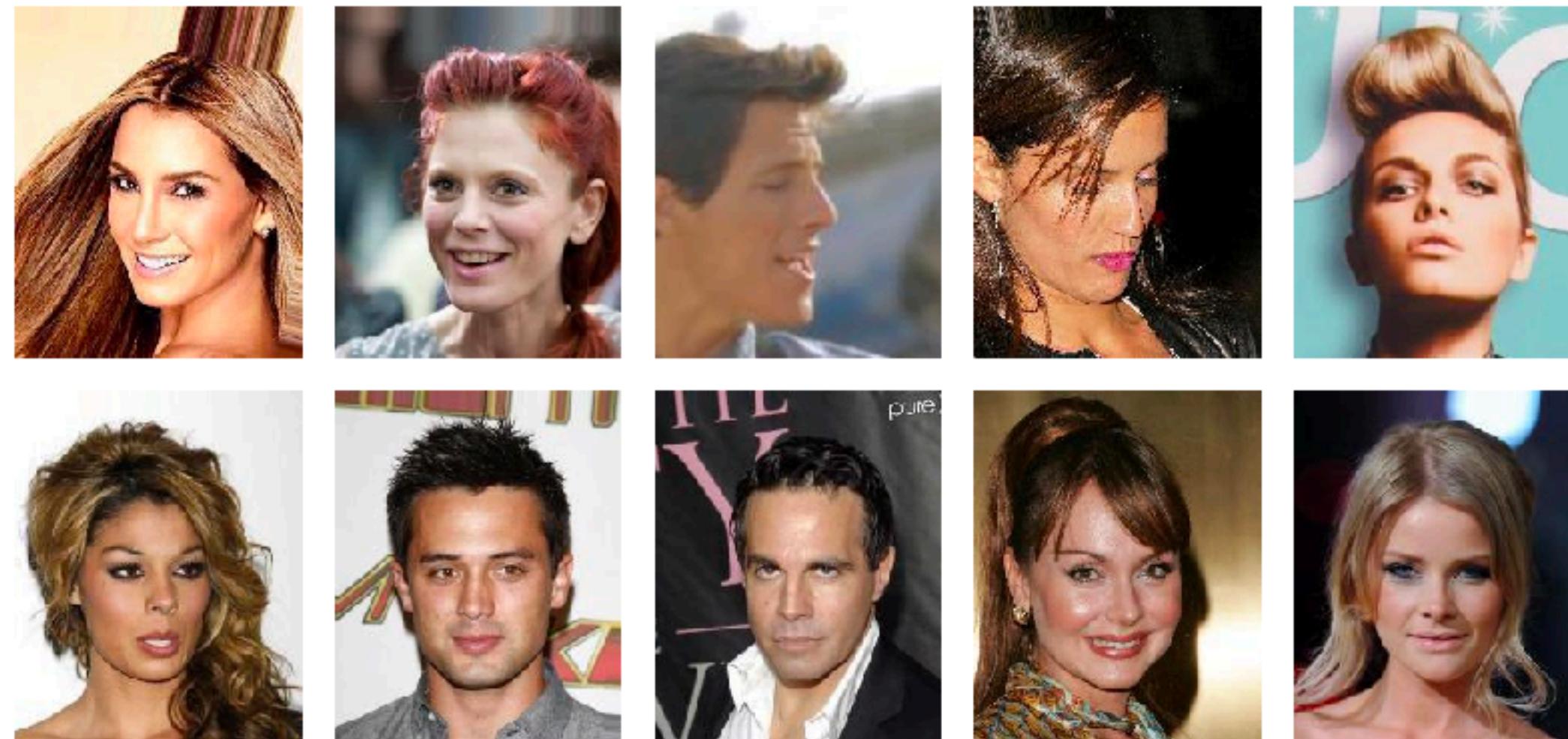
Salt Lake City, 2018-06-22



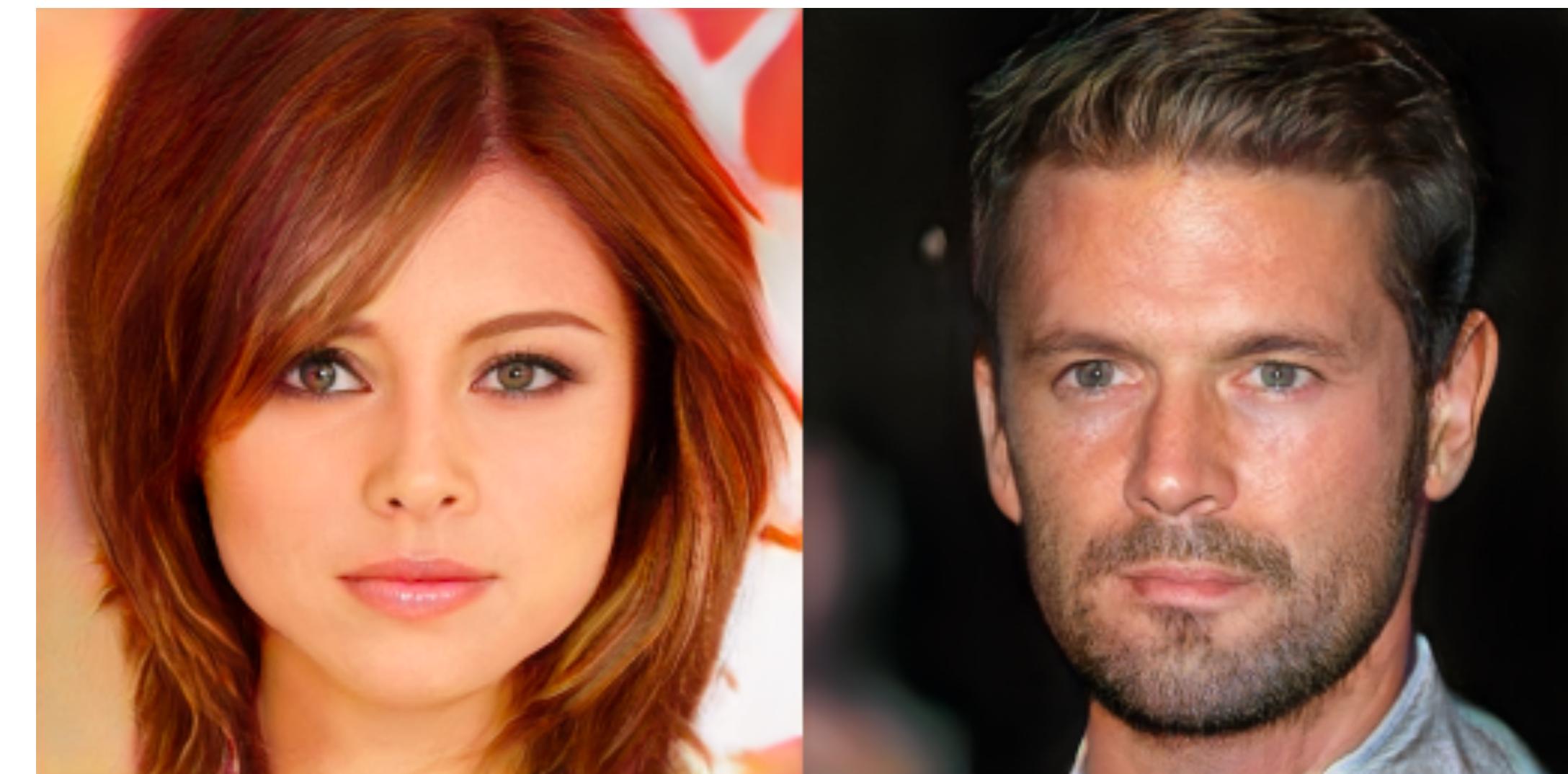
# Generative Modeling: Density Estimation



# Generative Modeling: Sample Generation

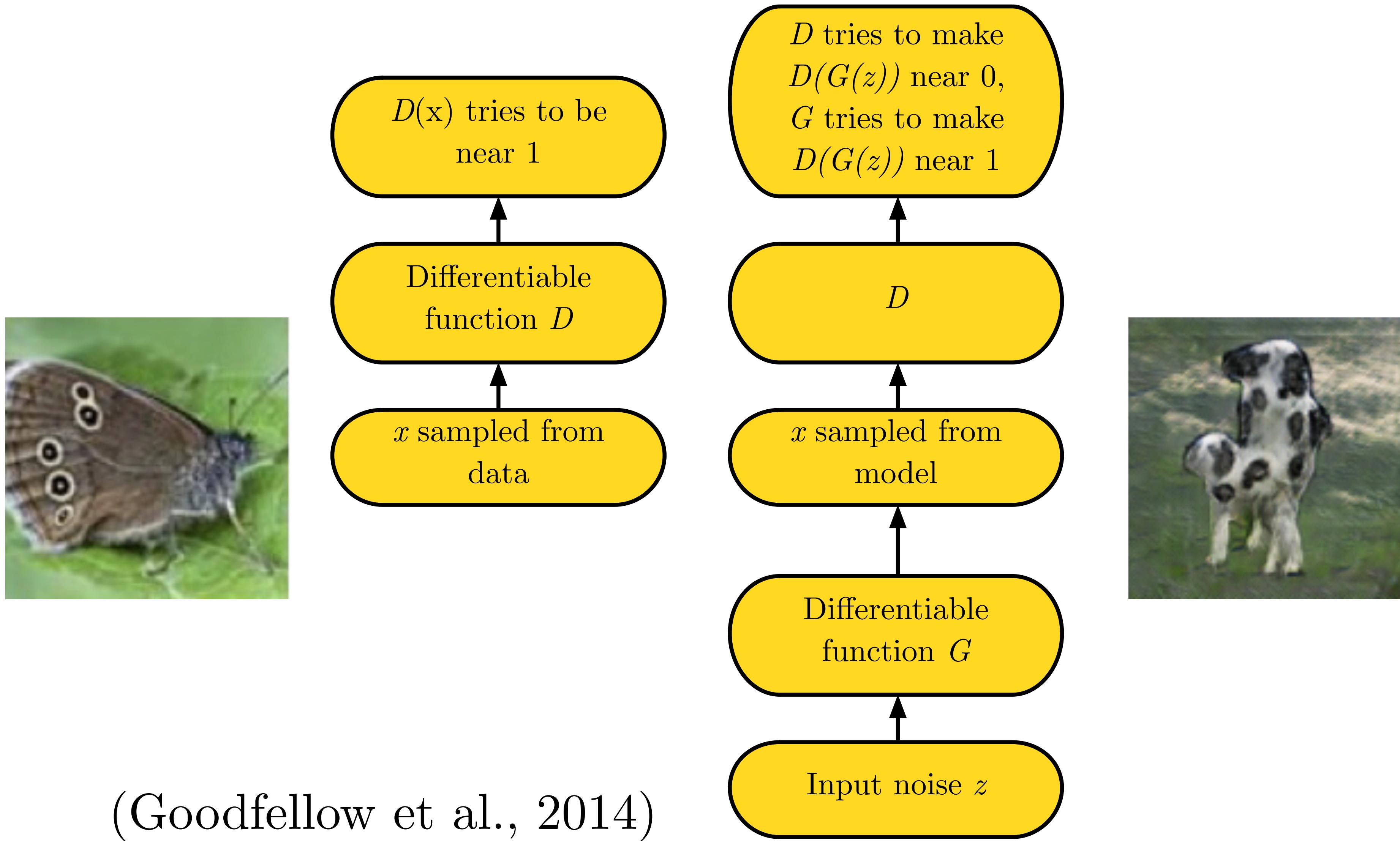


Training Data  
(CelebA)



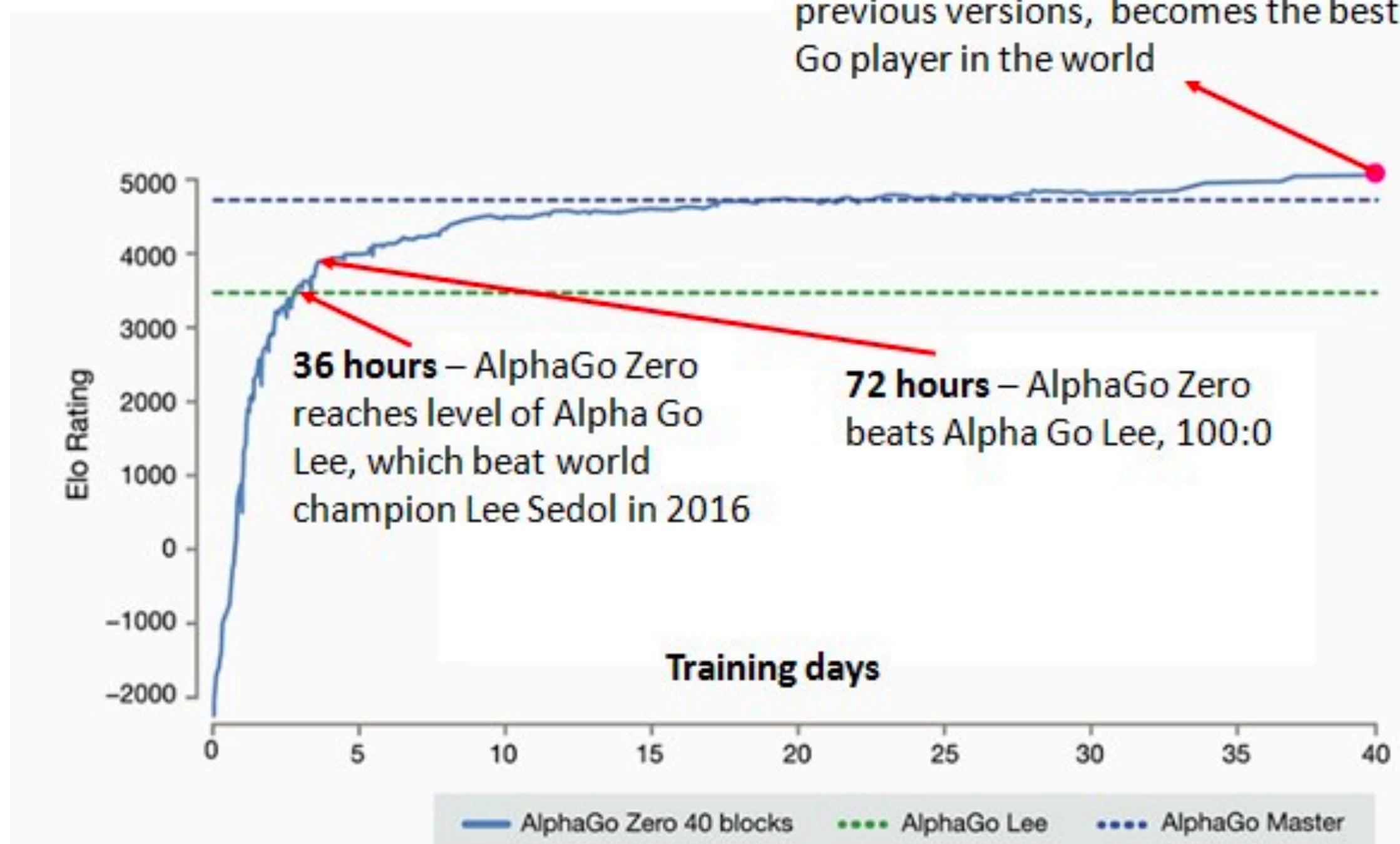
Sample Generator  
(Karras et al, 2017)

# Adversarial Nets Framework



# Self-Play

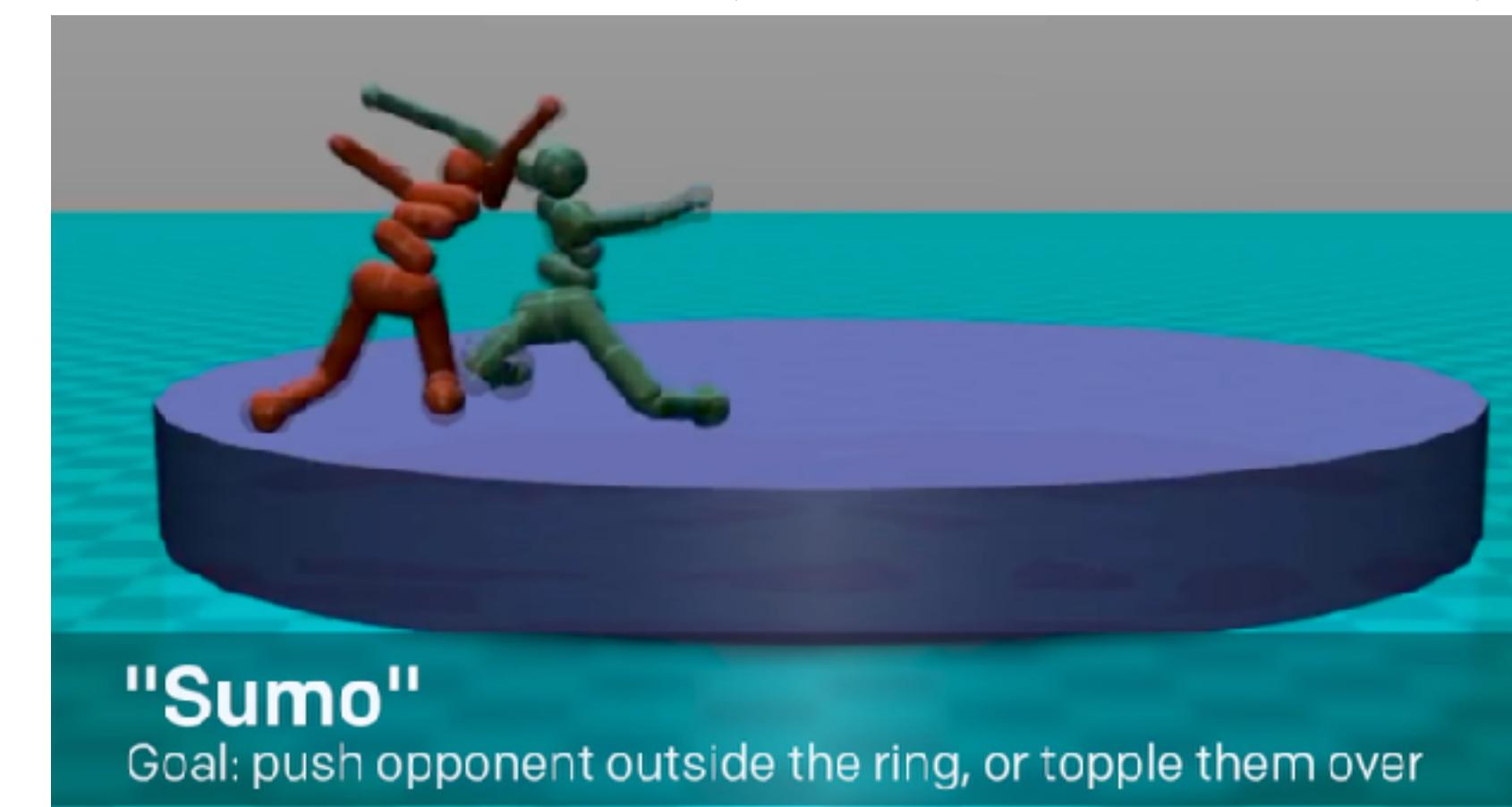
1959: Arthur Samuel's checkers agent



(Silver et al, 2017)



(OpenAI, 2017)

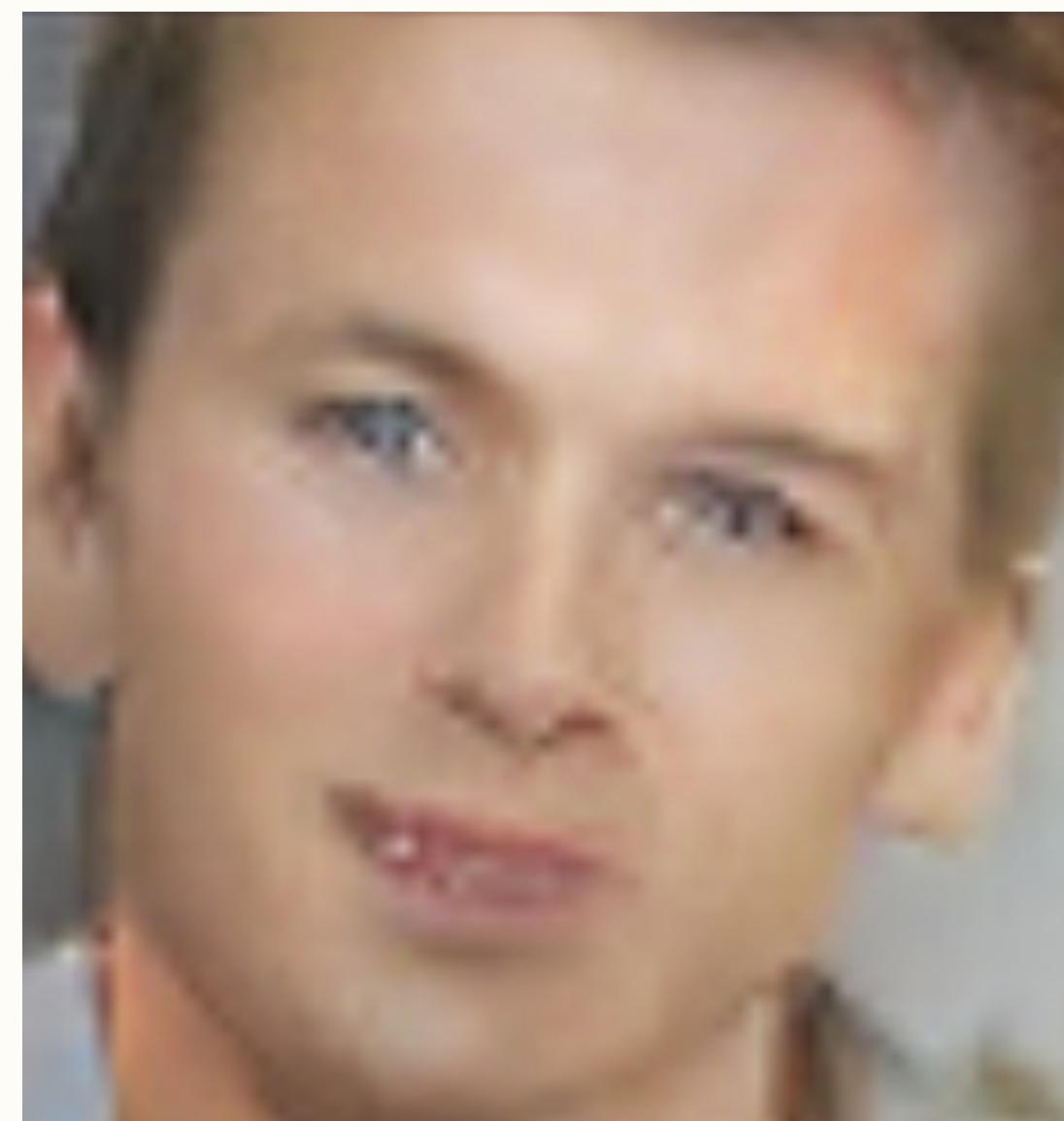


(Bansal et al, 2017)

# 3.5 Years of Progress on Faces



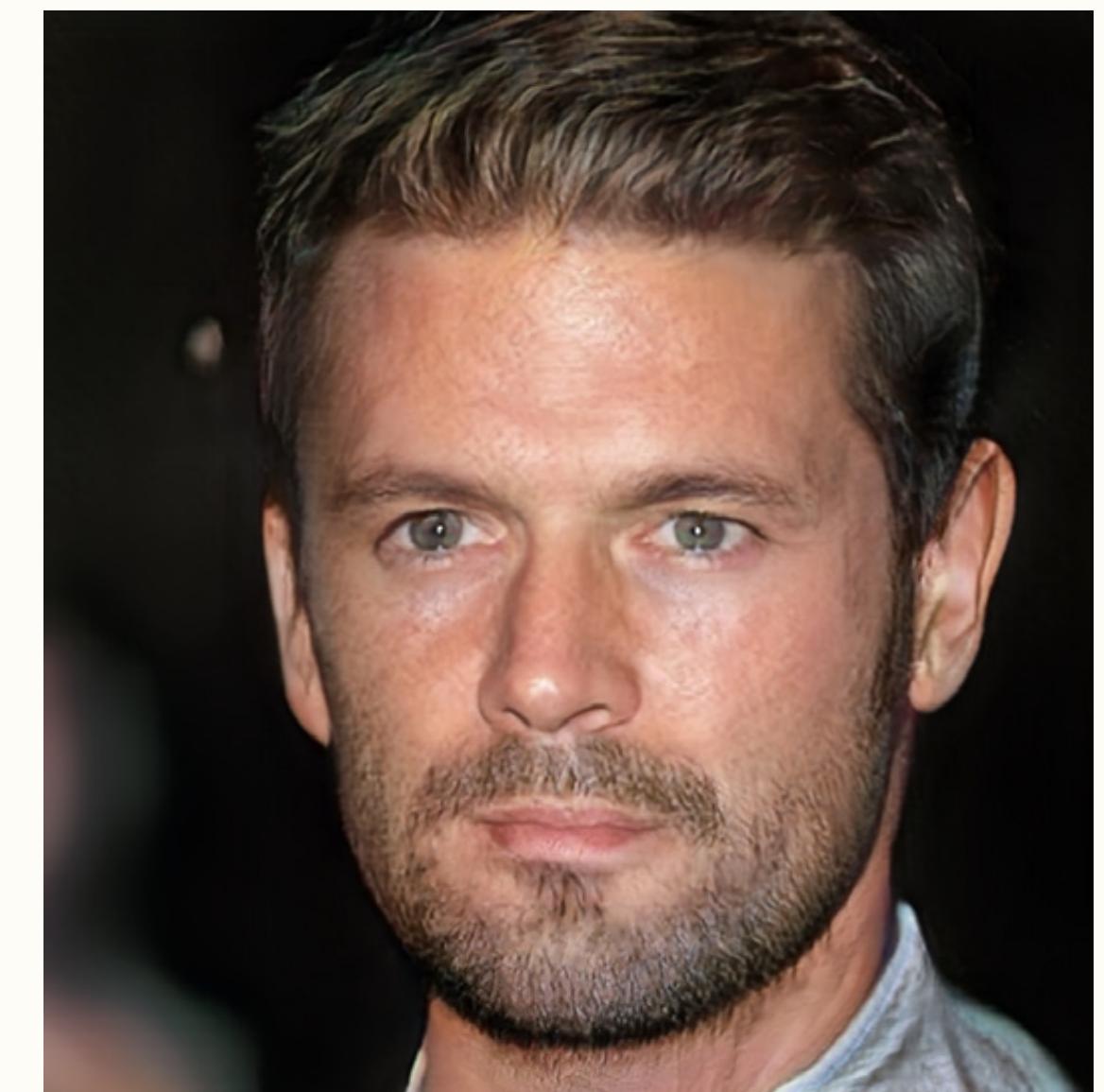
2014



2015



2016

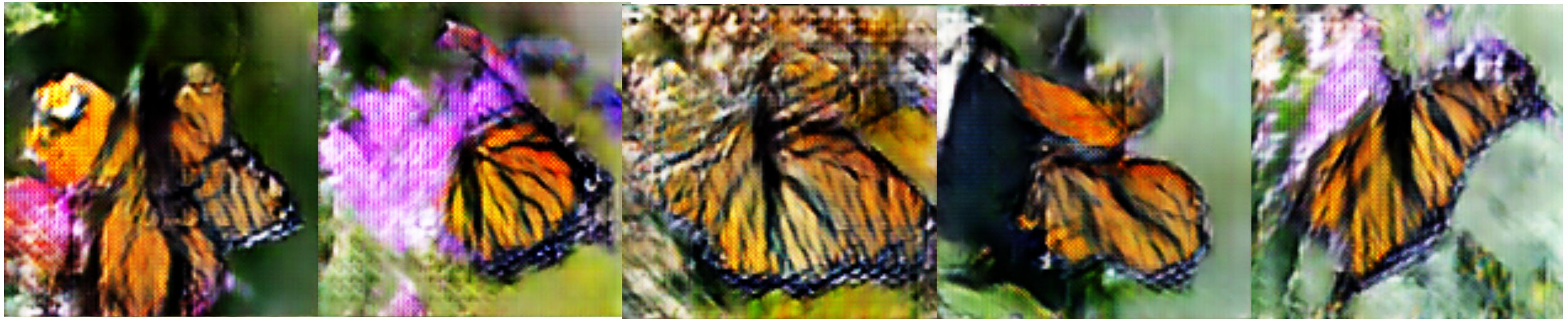


2017

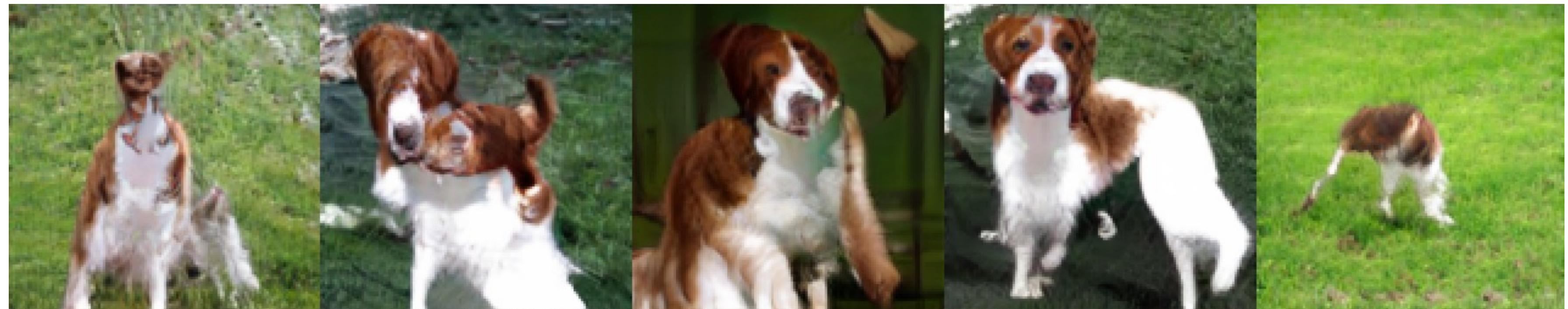
(Brundage et al, 2018)

# <2 Years of Progress on ImageNet

Odena et al  
2016



Miyato et al  
2017



Zhang et al  
2018

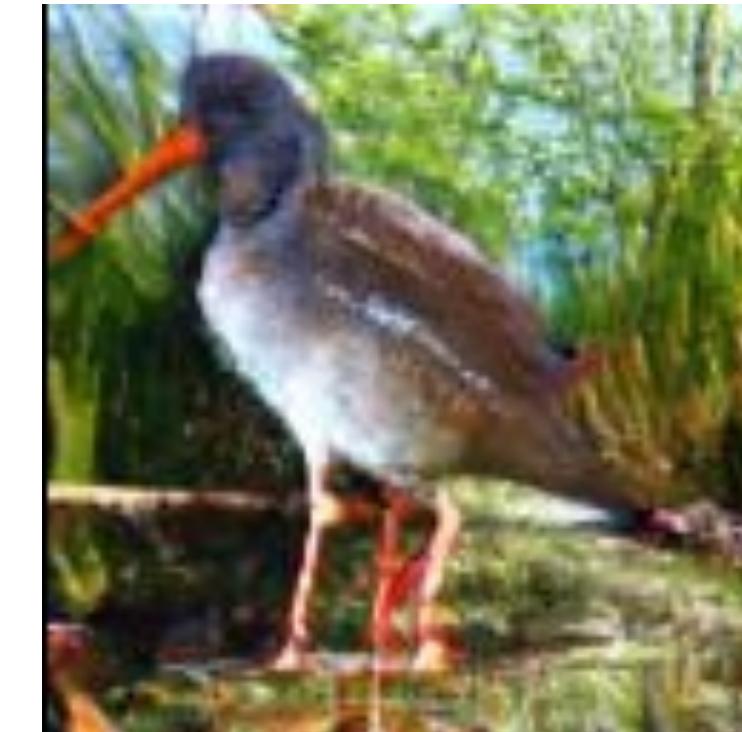


# Self-Attention GAN

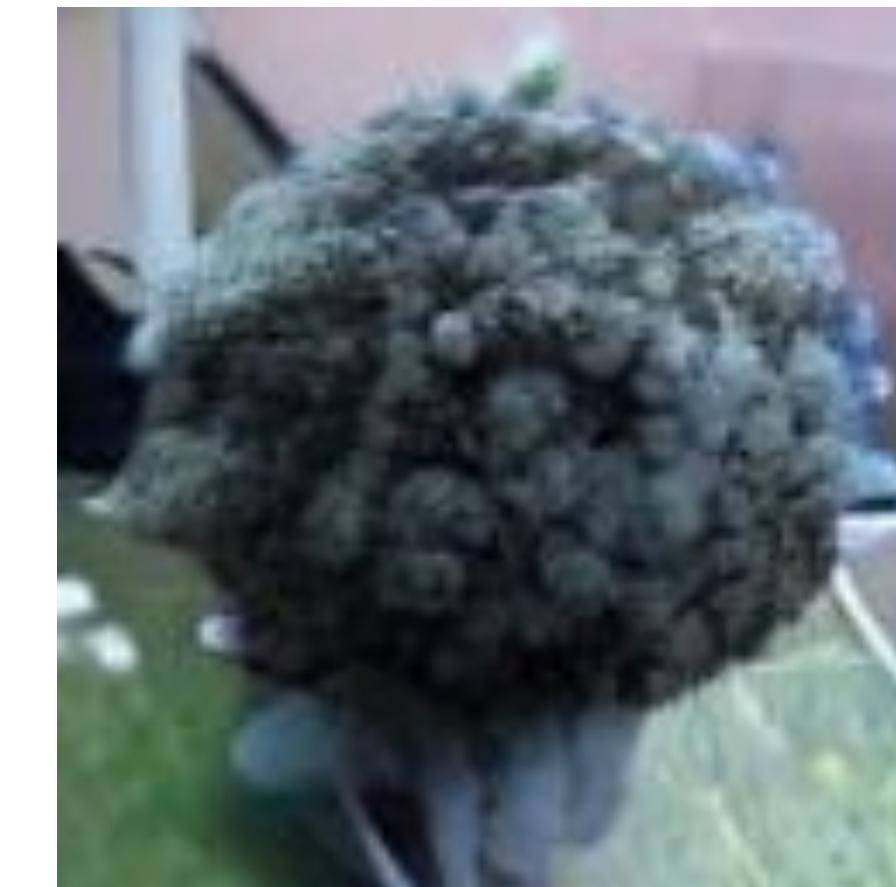
State of the art FID on ImageNet: 1000 categories, 128x128 pixels



Goldfish



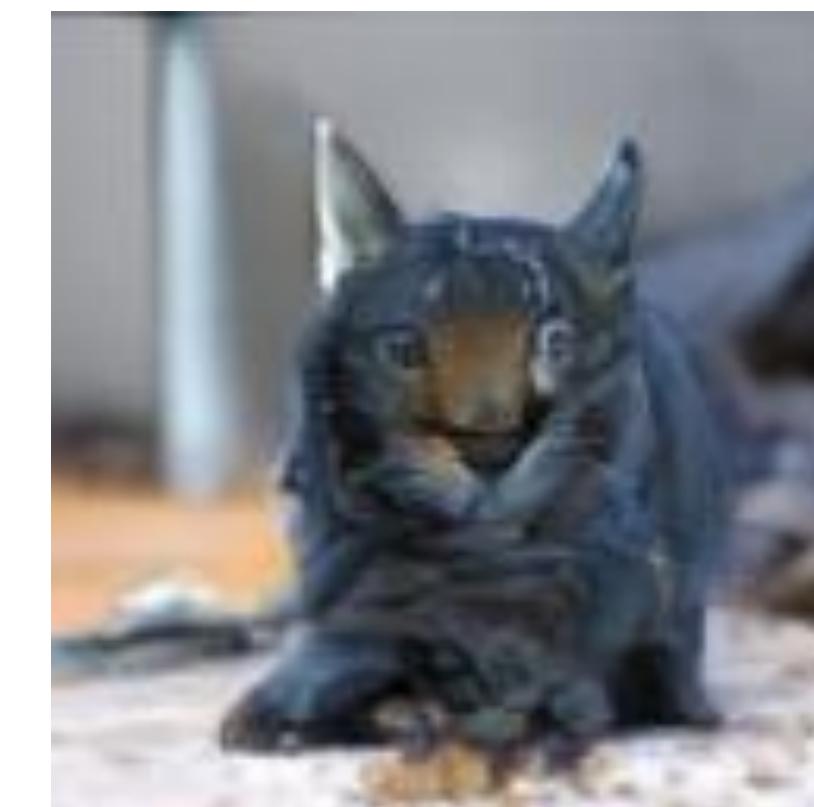
Redshank



Broccoli



Indigo Bunting



Tiger Cat

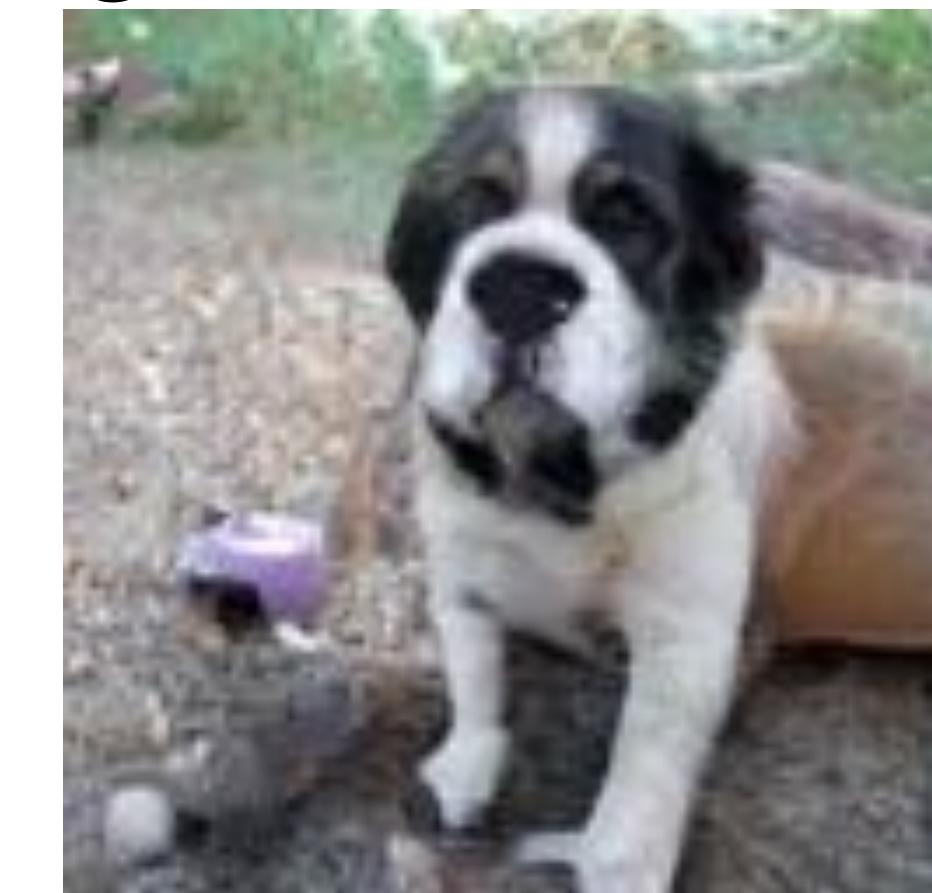


Geyser



Stone Wall

(Zhang et al., 2018)



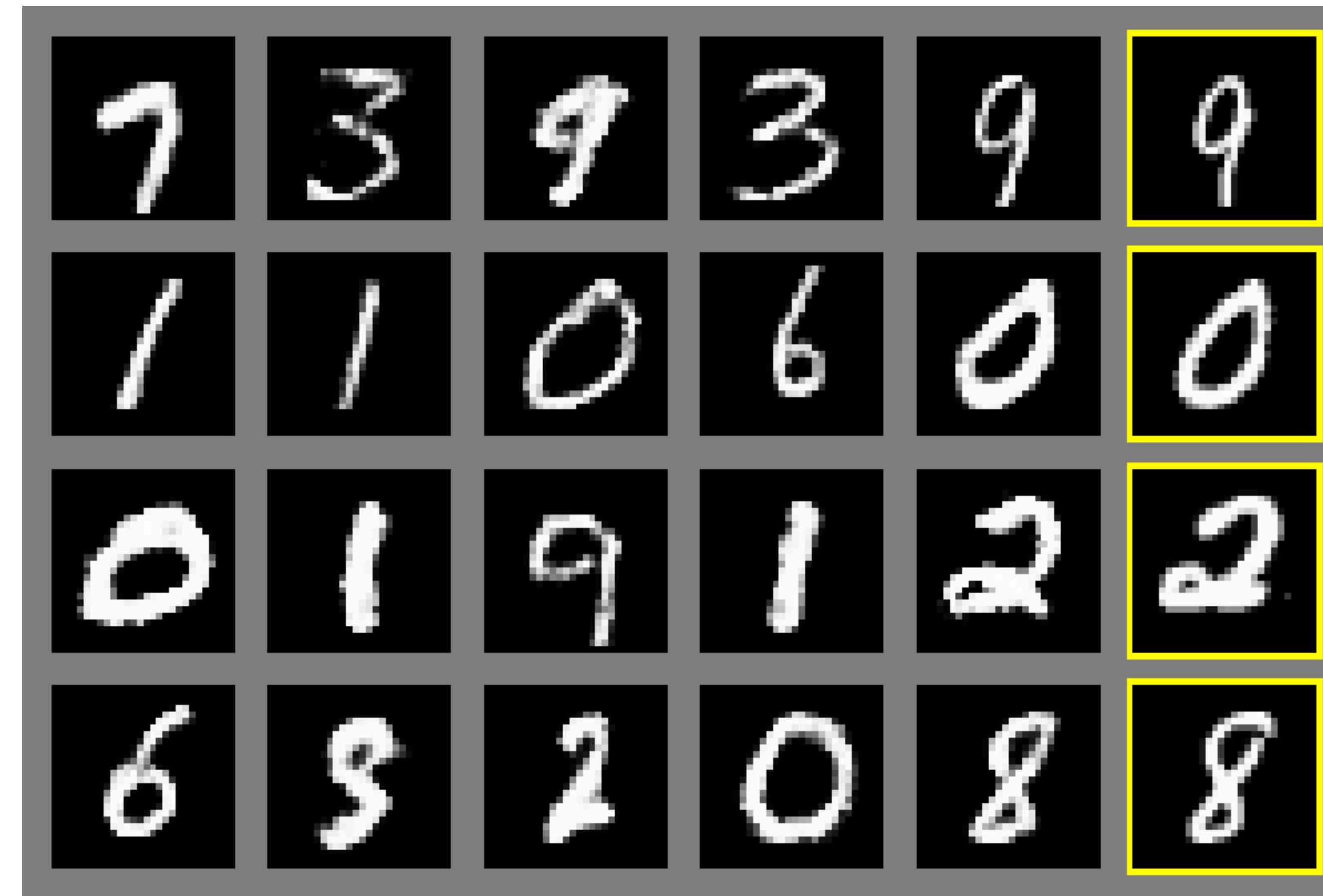
Saint Bernard

(Goodfellow 2018)

# From GAN to SAGAN

- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

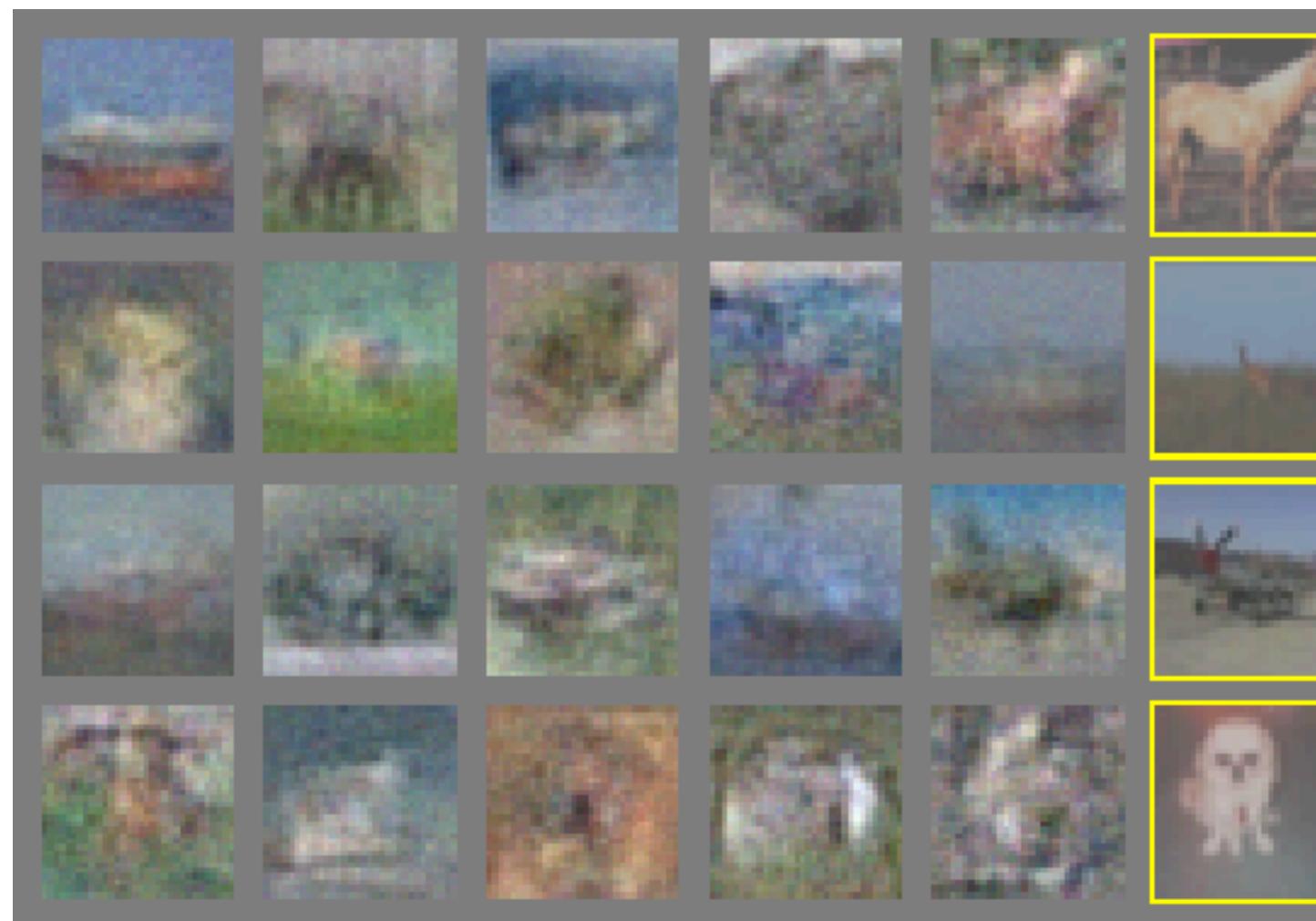
# No Convolution Needed to Solve Simple Tasks



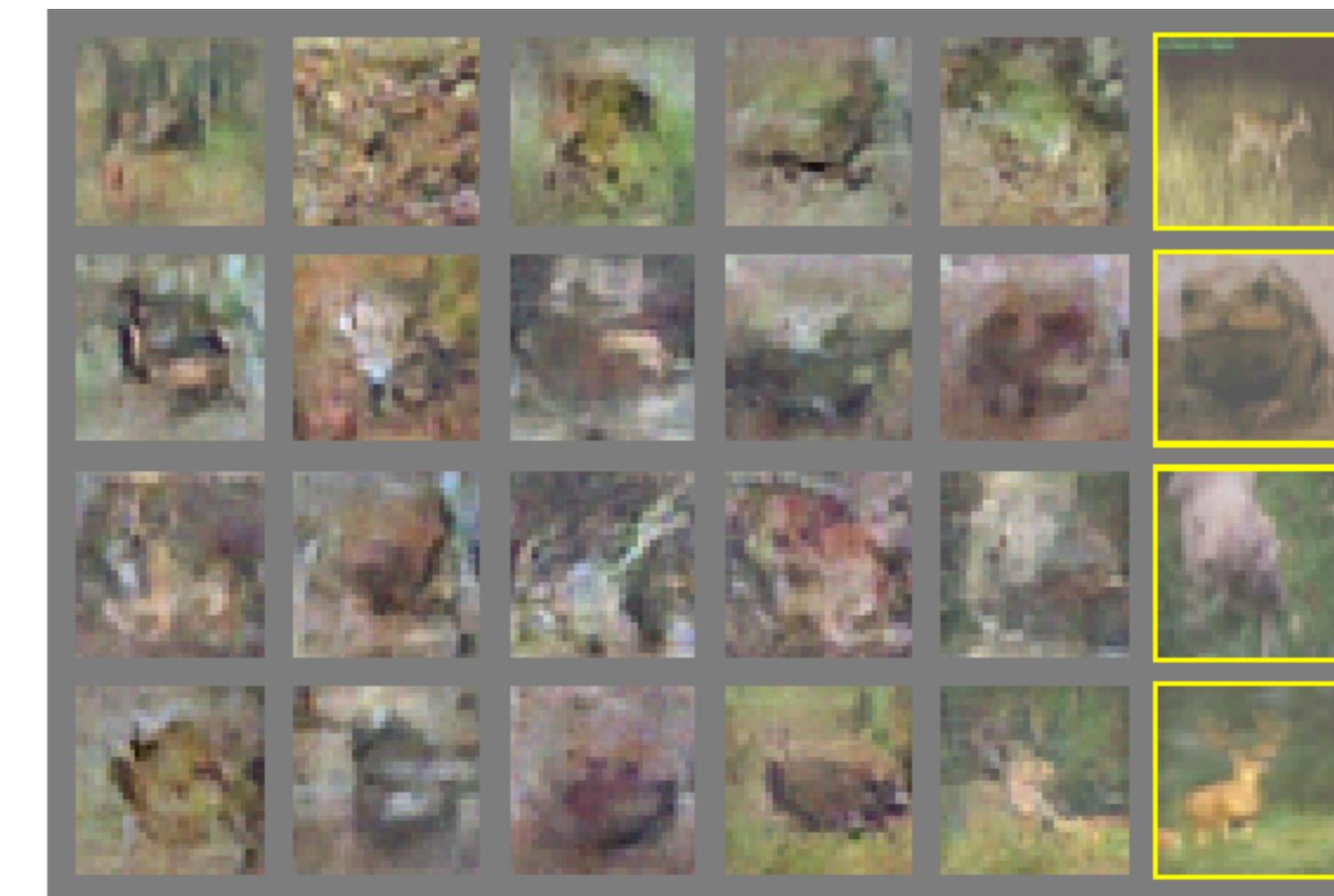
Original GAN, 2014

# Depth and Convolution for Harder Tasks

Original GAN (CIFAR-10)



No convolution



One convolutional layer

DCGAN (ImageNet)



Many convolutional layers  
(Radford et al, 2015)

# From GAN to SAGAN

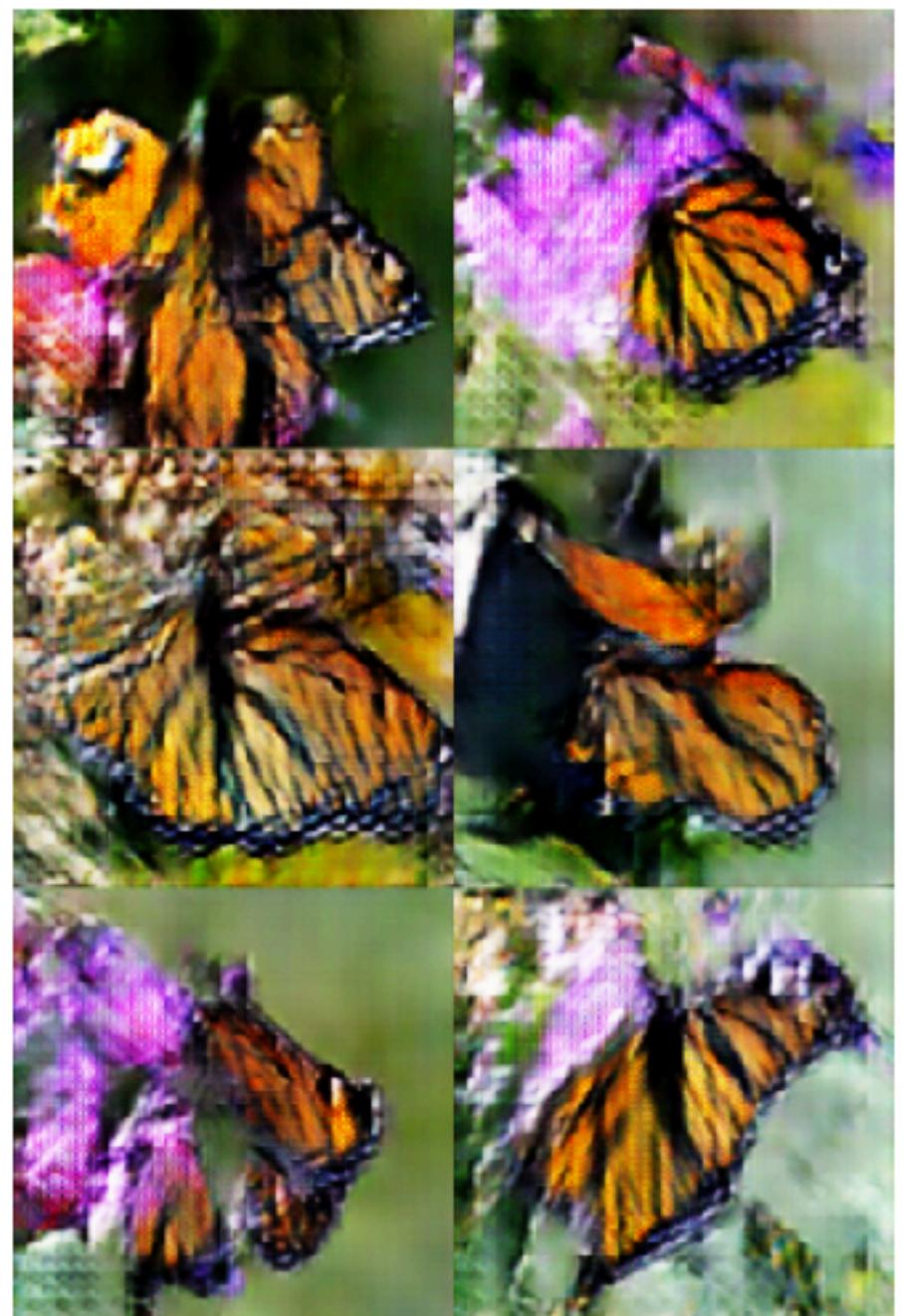
- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

# Class-Conditional GANs



(Mirza and Osindero, 2014)

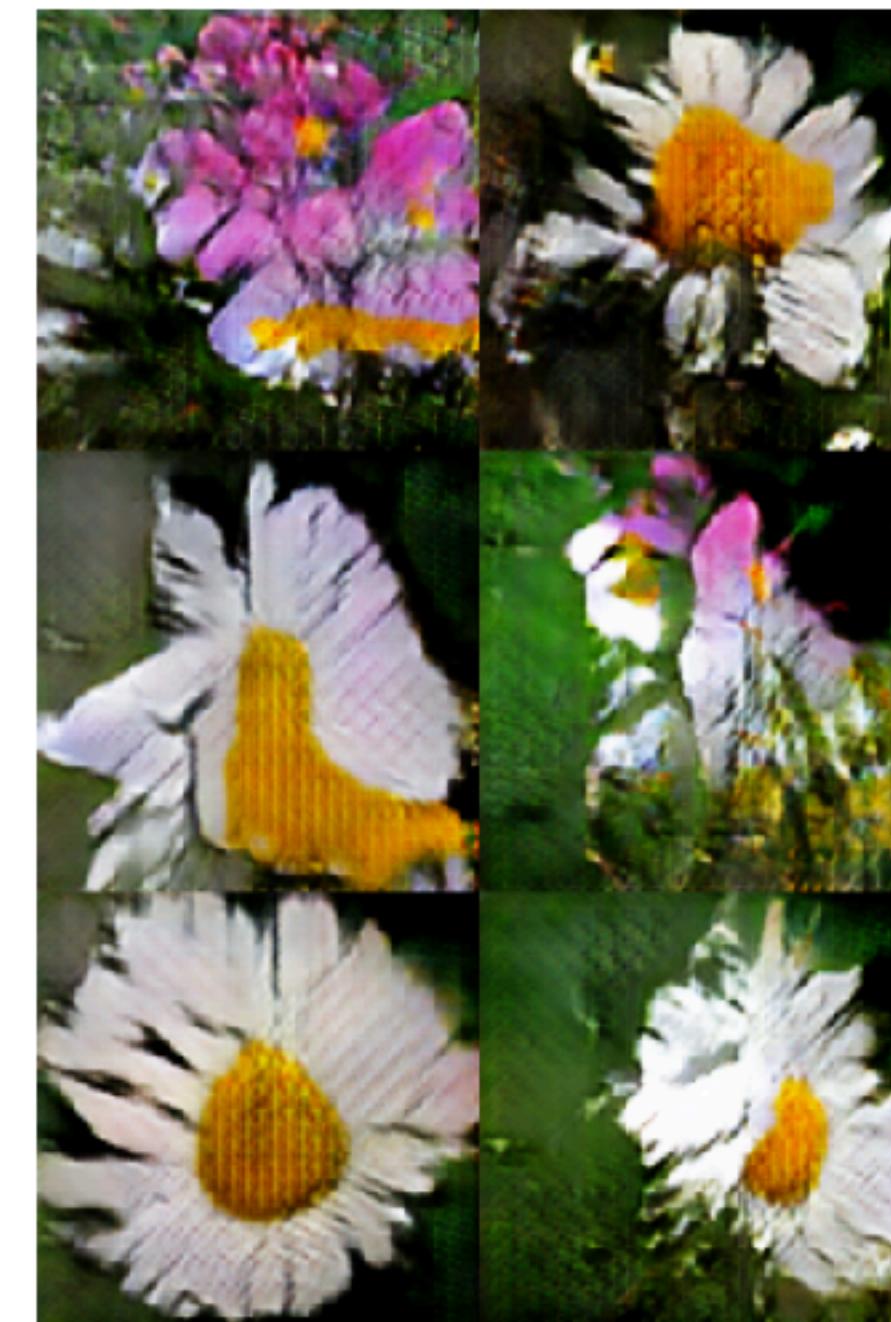
# AC-GAN: Specialist Generators



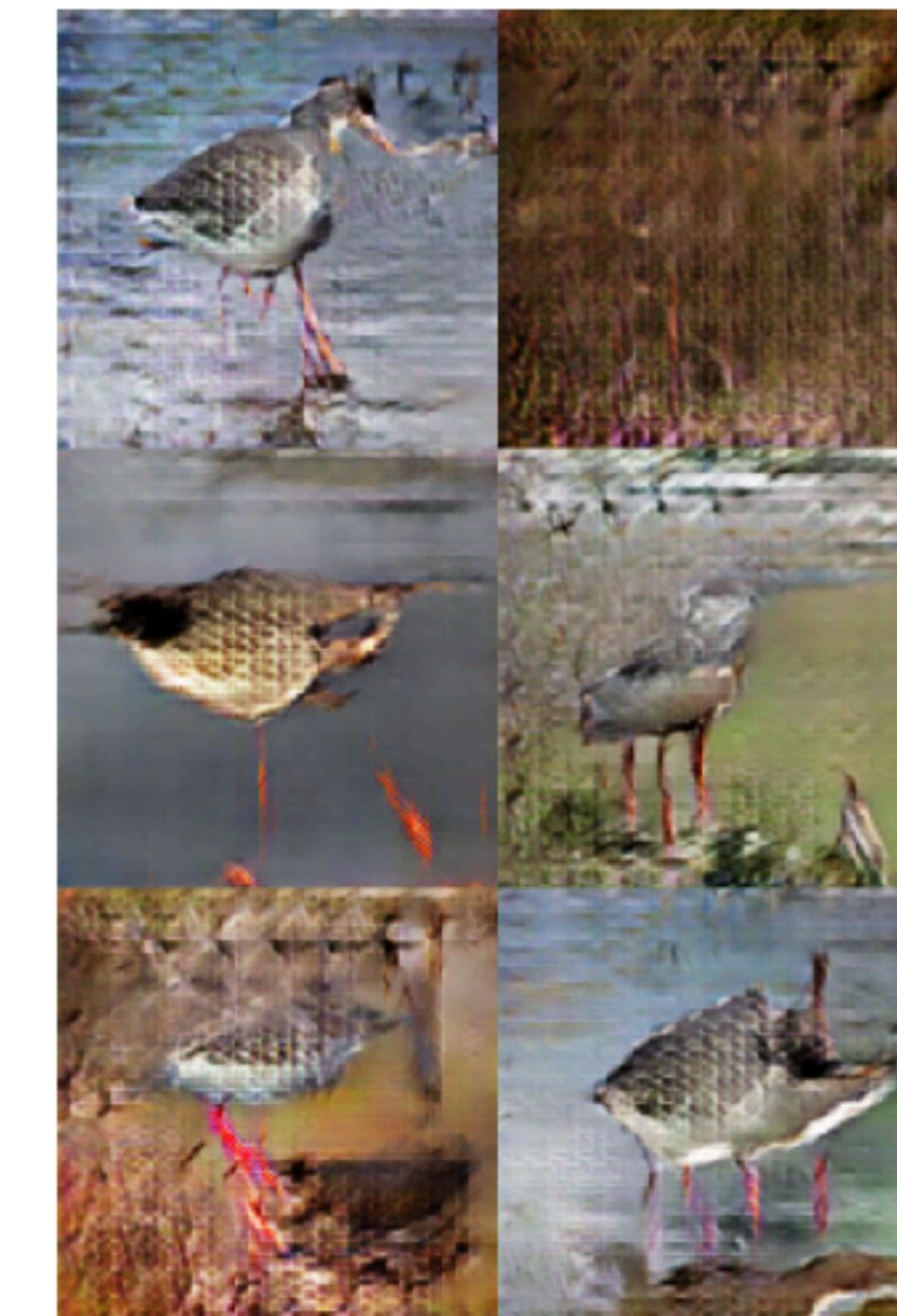
monarch butterfly



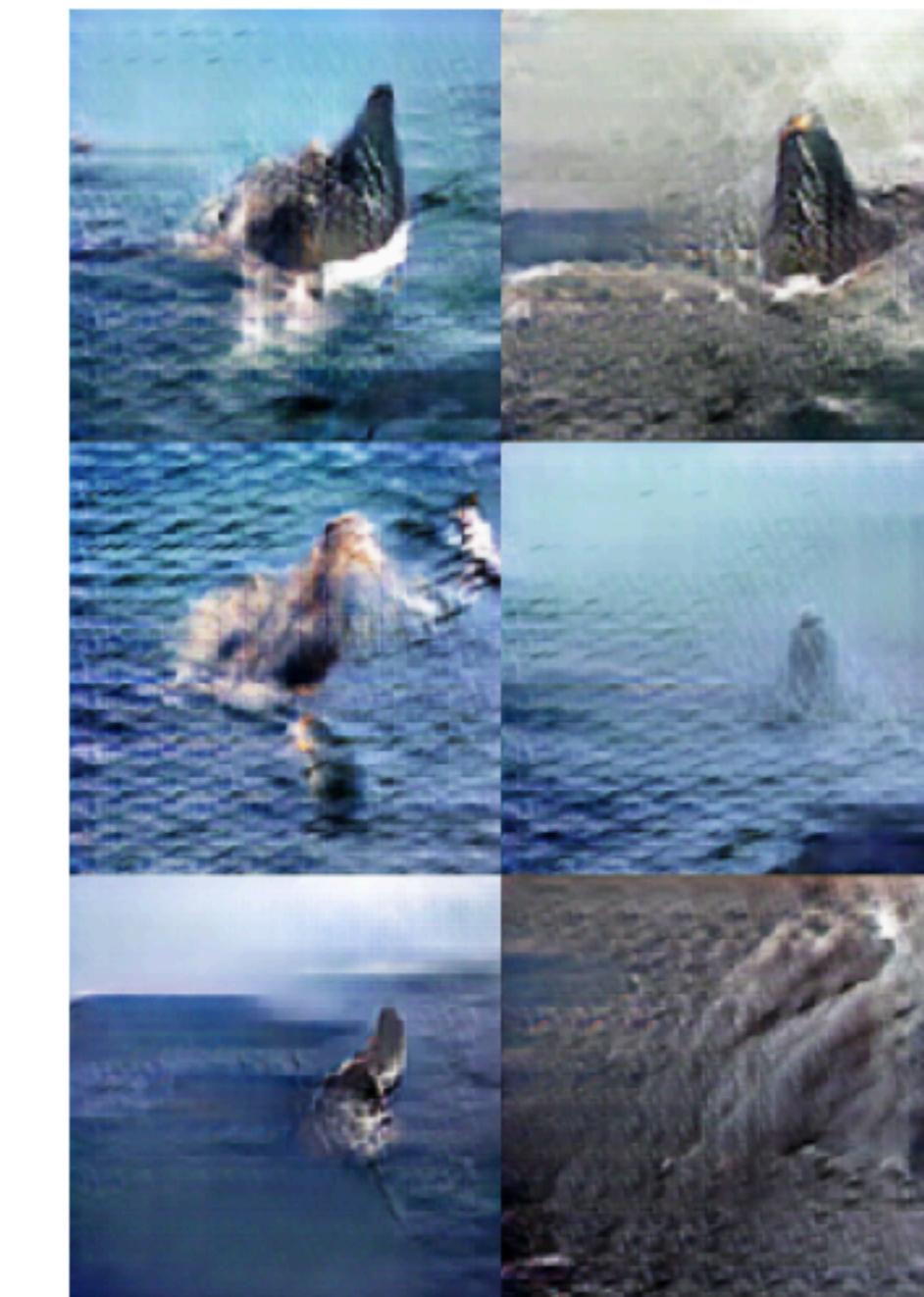
goldfinch



daisy



redshank

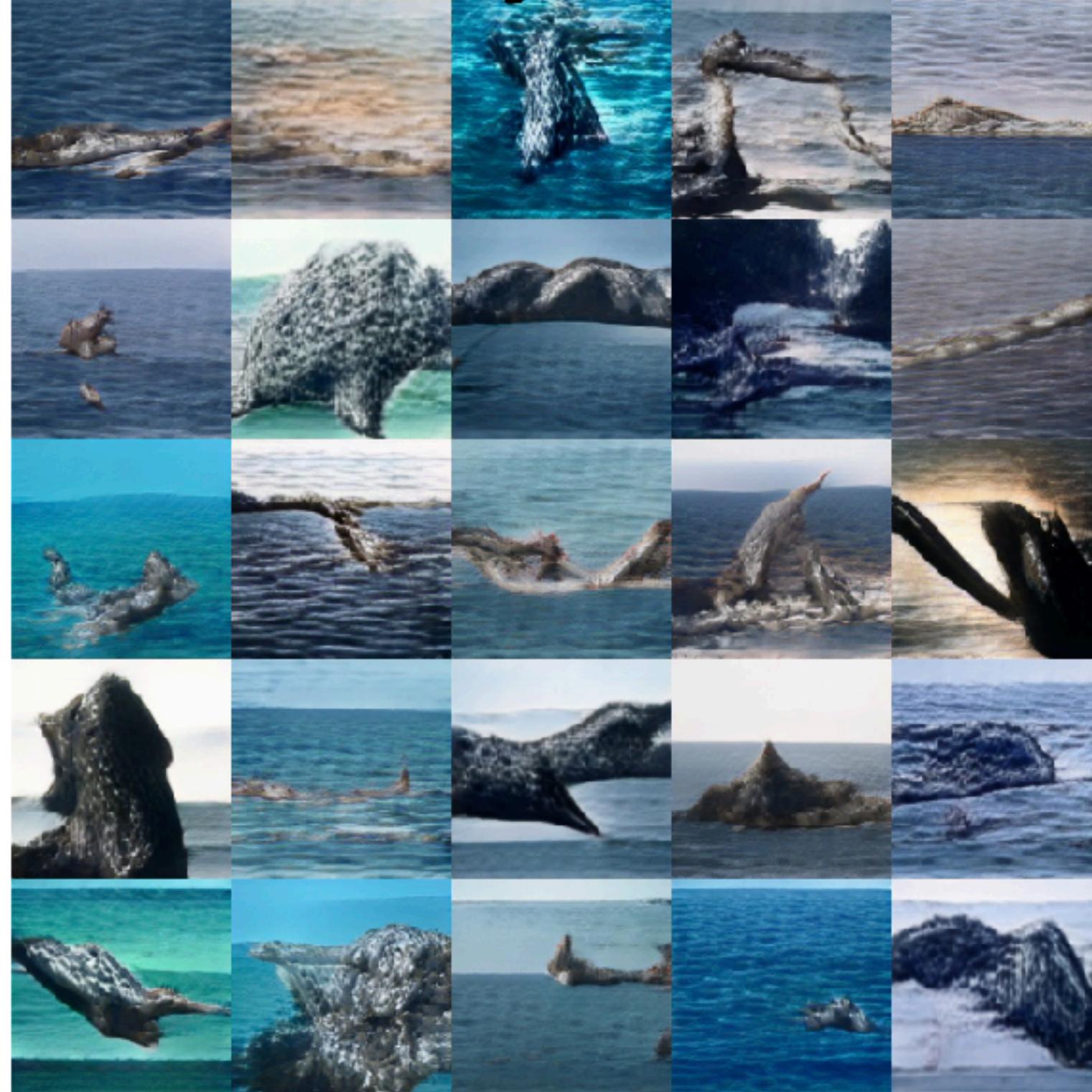


grey whale

(Odena et al, 2016)

# SN-GAN: Shared Generator

Gray whale



Welsh springer spaniel



Persian cat



(Miyato et al, 2017)

# From GAN to SAGAN

- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

# Spectral Normalization

$$\sigma(A) := \max_{\mathbf{h}: \mathbf{h} \neq 0} \frac{\|A\mathbf{h}\|_2}{\|\mathbf{h}\|_2} = \max_{\|\mathbf{h}\|_2 \leq 1} \|A\mathbf{h}\|_2$$

$$\|f\|_{\text{Lip}} \leq \prod_{l=1}^{L+1} \sigma(W^l)$$

$$\bar{W}_{\text{SN}}(W) := W/\sigma(W)$$

(Miyato et al, 2017)

# From GAN to SAGAN

- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

# Hinge LOSS

$$V_D(\hat{G}, D) = \mathbb{E}_{\mathbf{x} \sim q_{\text{data}}(\mathbf{x})} [\min(0, -1 + D(\mathbf{x}))] + \mathbb{E}_{\mathbf{z} \sim p(\mathbf{z})} [\min(0, -1 - D(\hat{G}(\mathbf{z})))] \quad (16)$$

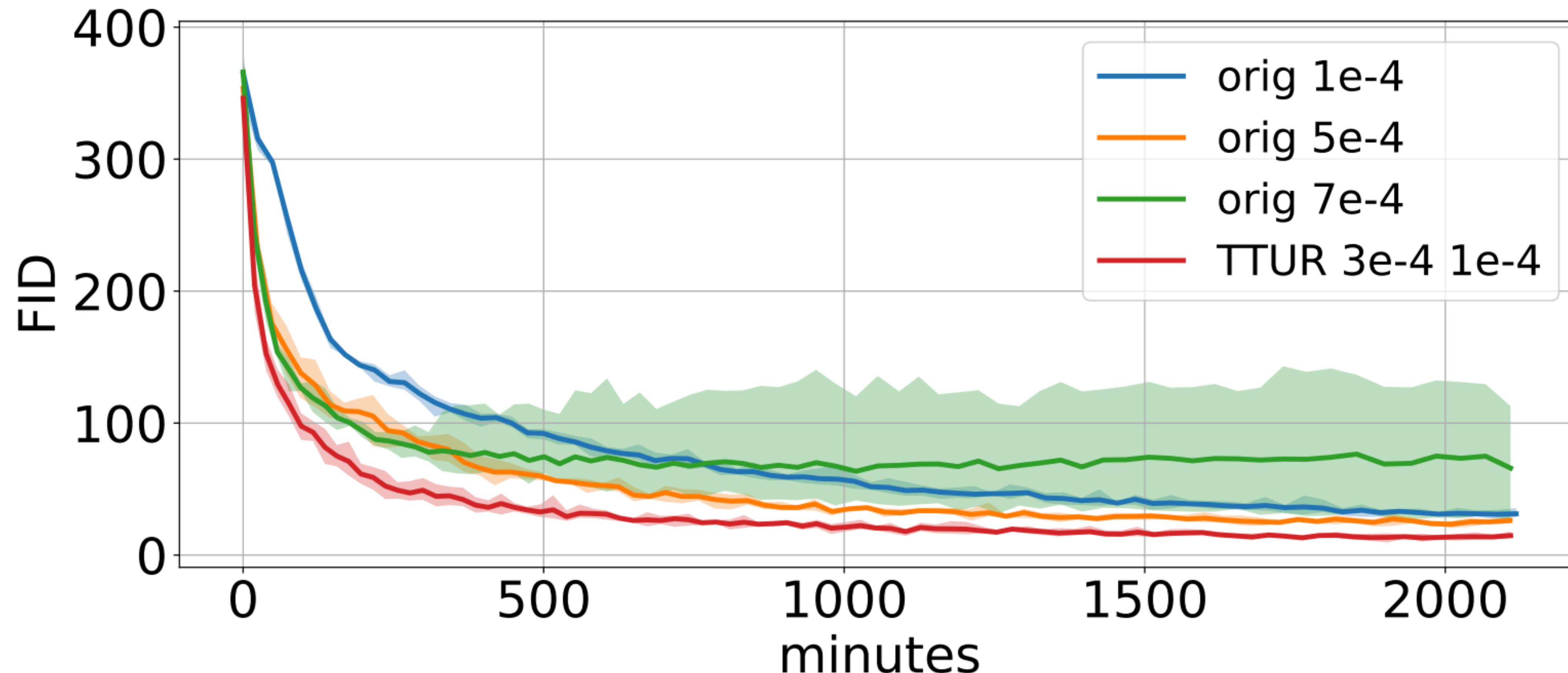
$$V_G(G, \hat{D}) = -\mathbb{E}_{\mathbf{z} \sim p(\mathbf{z})} [\hat{D}(G(\mathbf{z}))], \quad (17)$$

(Miyato et al 2017, Lim and Ye 2017, Tran et al 2017)

# From GAN to SAGAN

- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

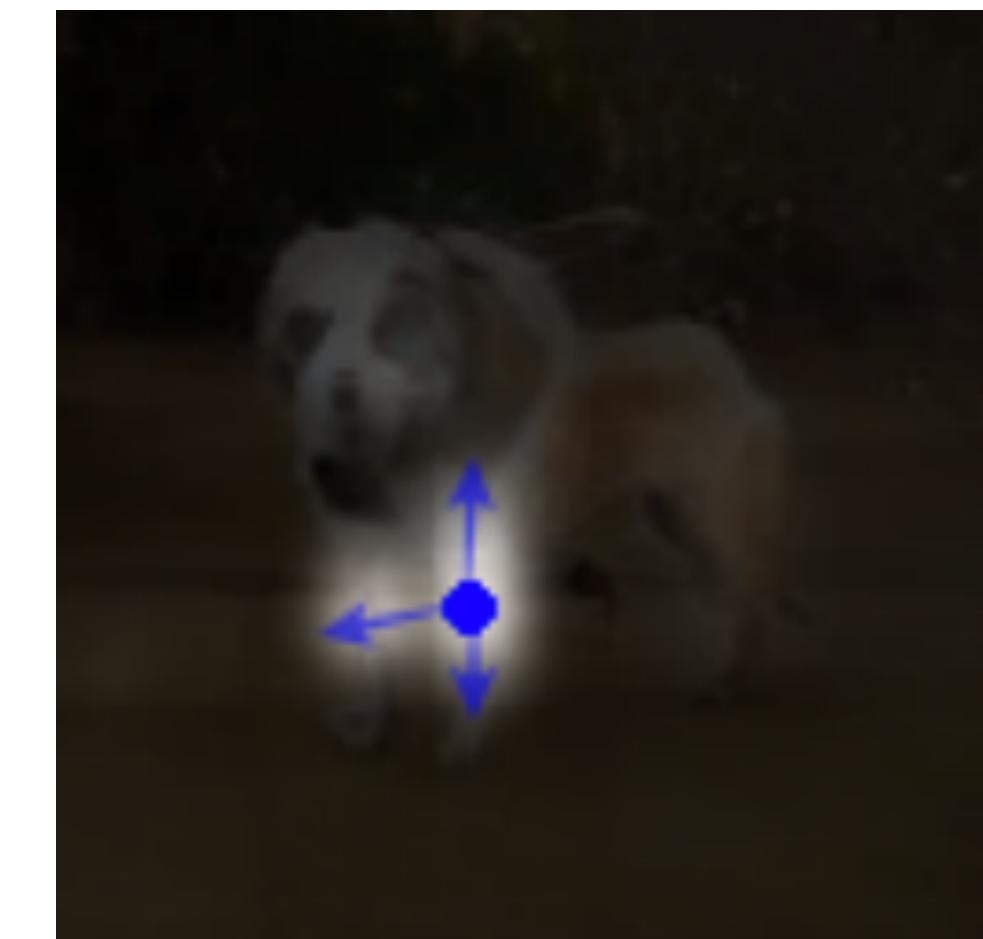
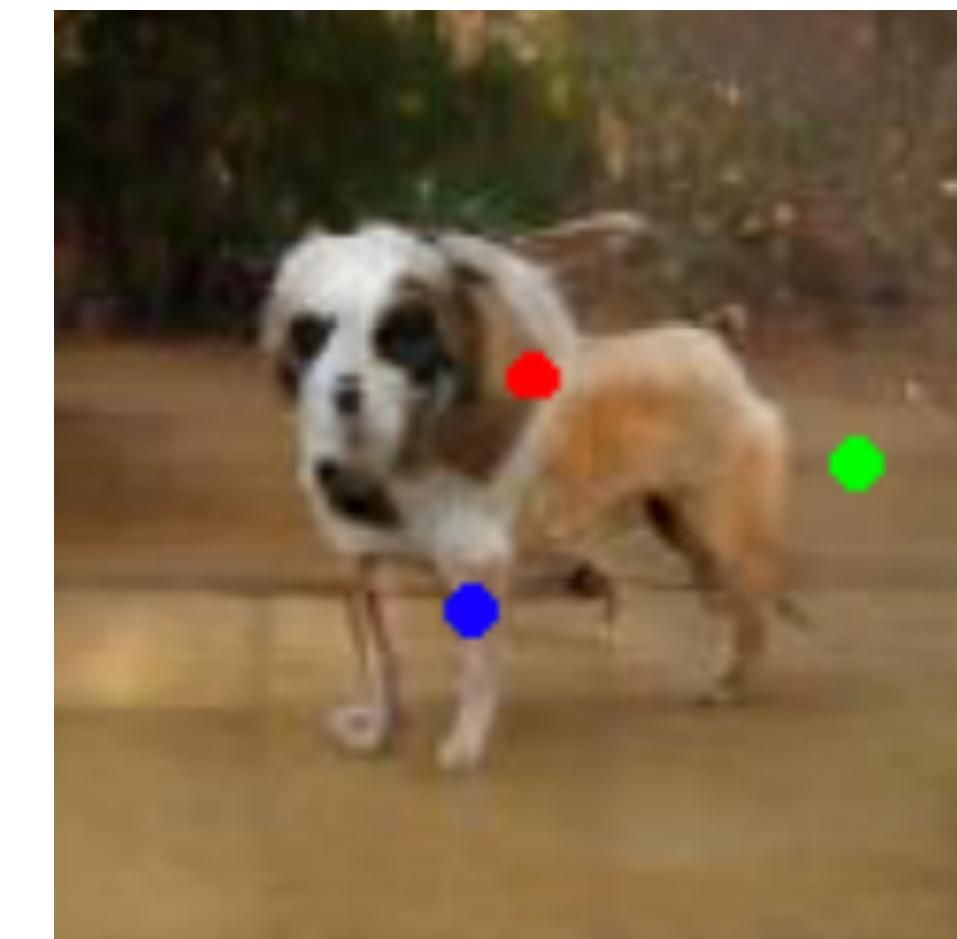
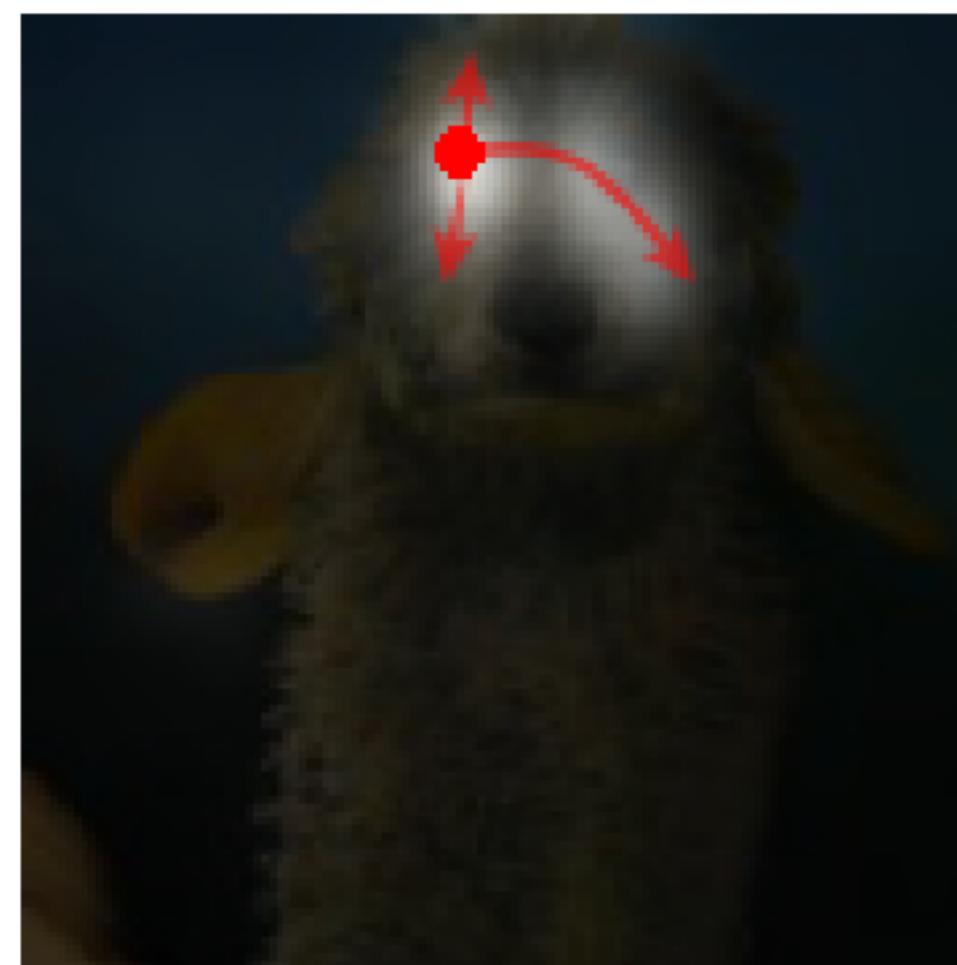
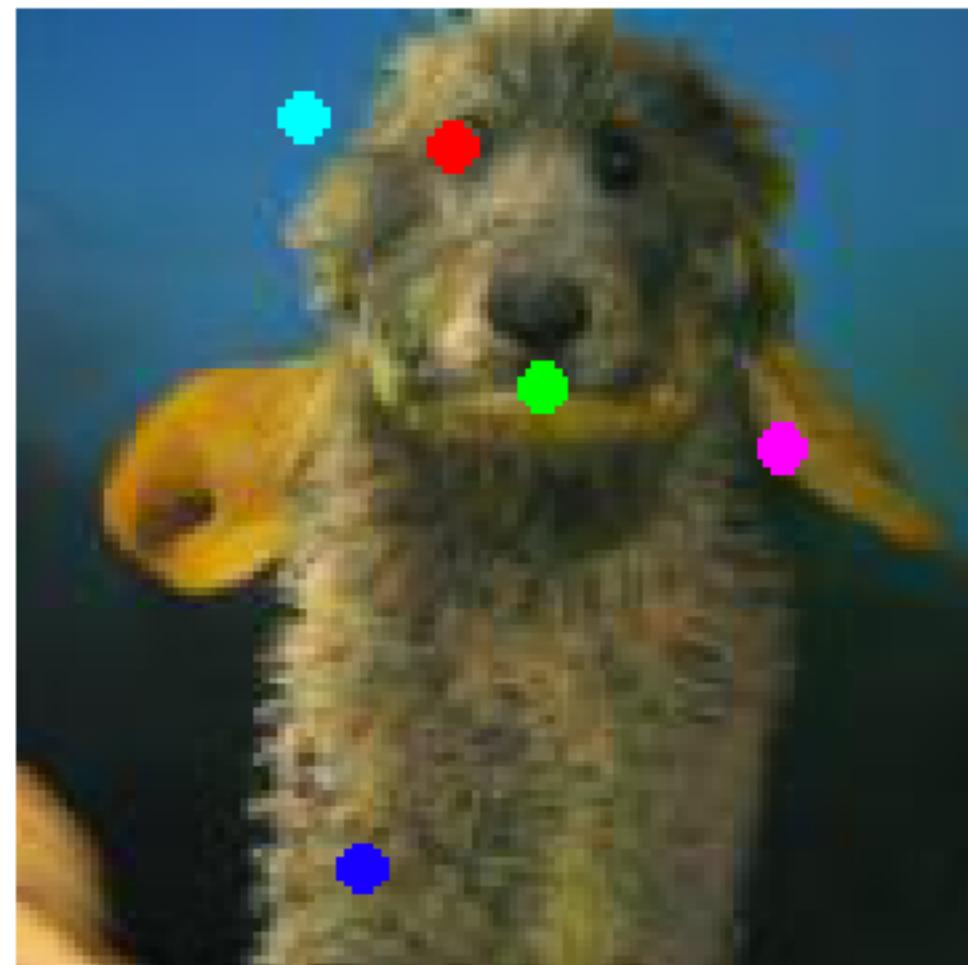
# Two-Timescale Update Rule



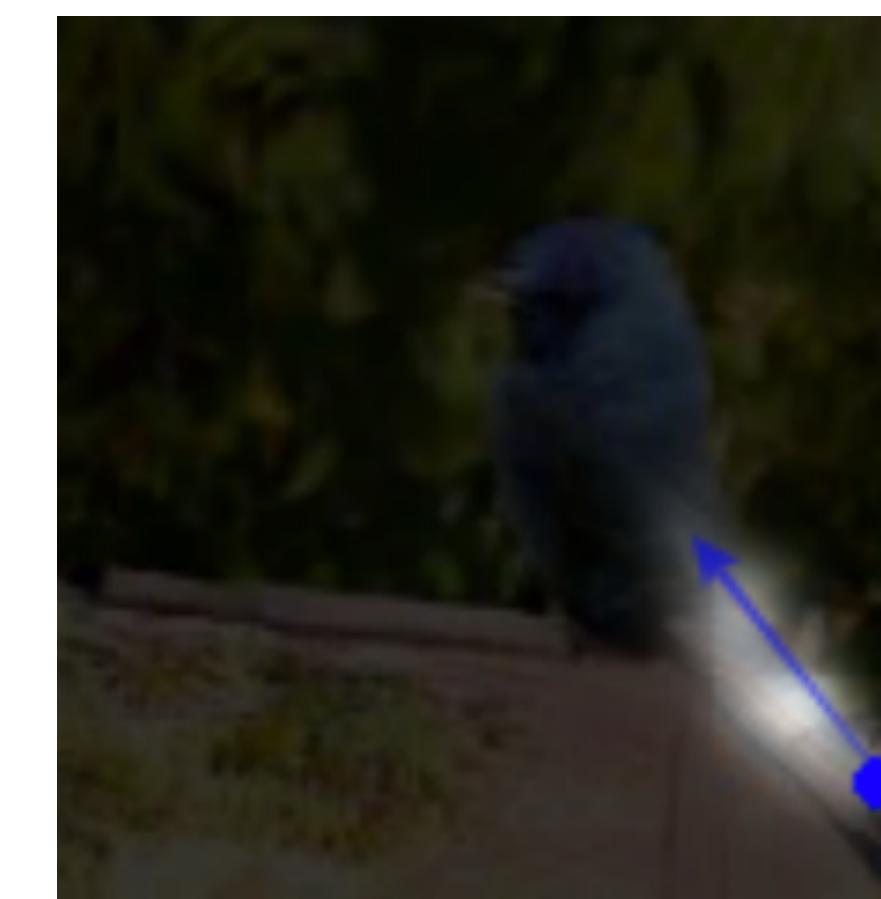
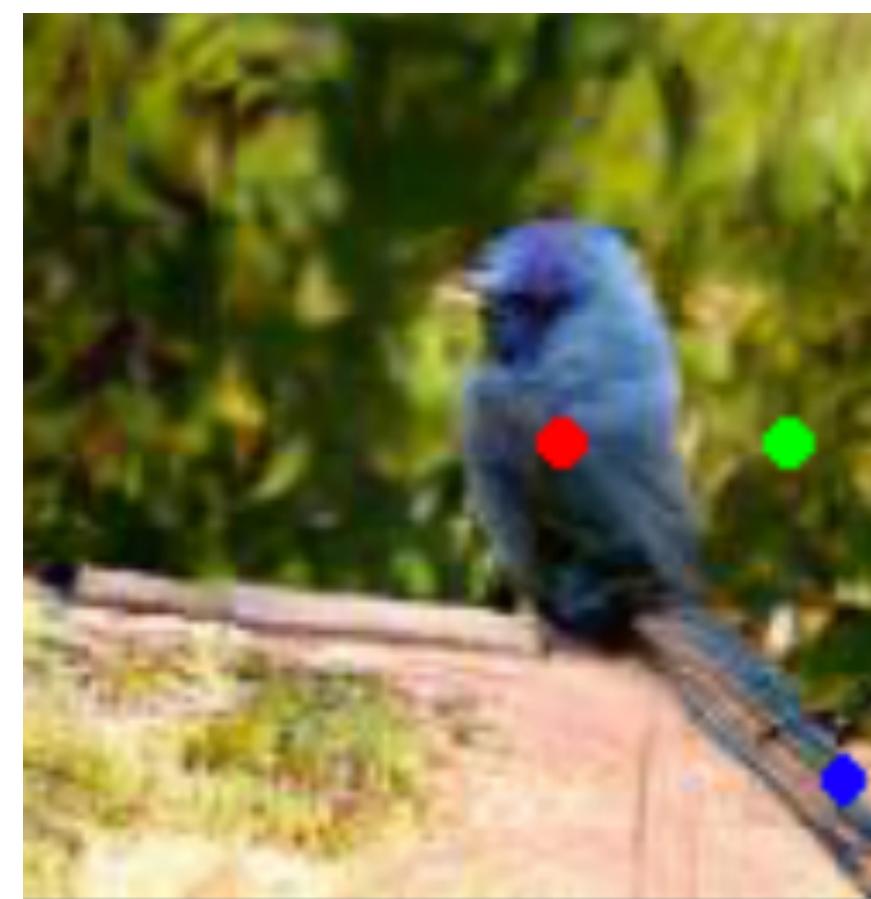
# From GAN to SAGAN

- Depth and Convolution
- Class-conditional generation
- Spectral Normalization
- Hinge loss
- Two-timescale update rule
- Self-attention

# Self-Attention



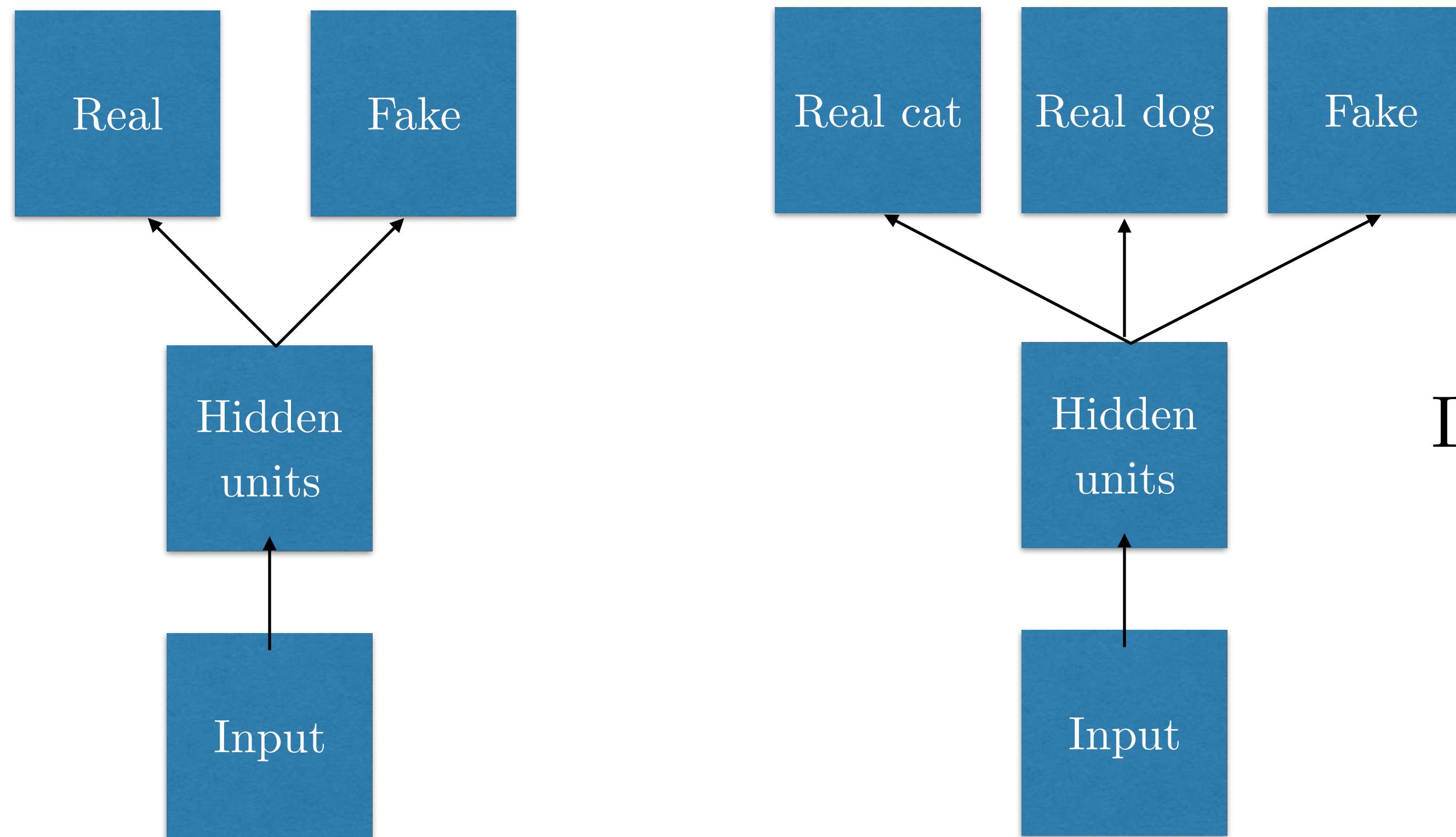
Use layers from  
Wang et al 2018



# Applying GANs

- Semi-supervised Learning
- Model-based optimization
- Extreme personalization
- Program synthesis

# Supervised Discriminator for Semi-Supervised Learning



(Odena 2016, Salimans et al 2016)

(Goodfellow 2018)

# Semi-Supervised Classification

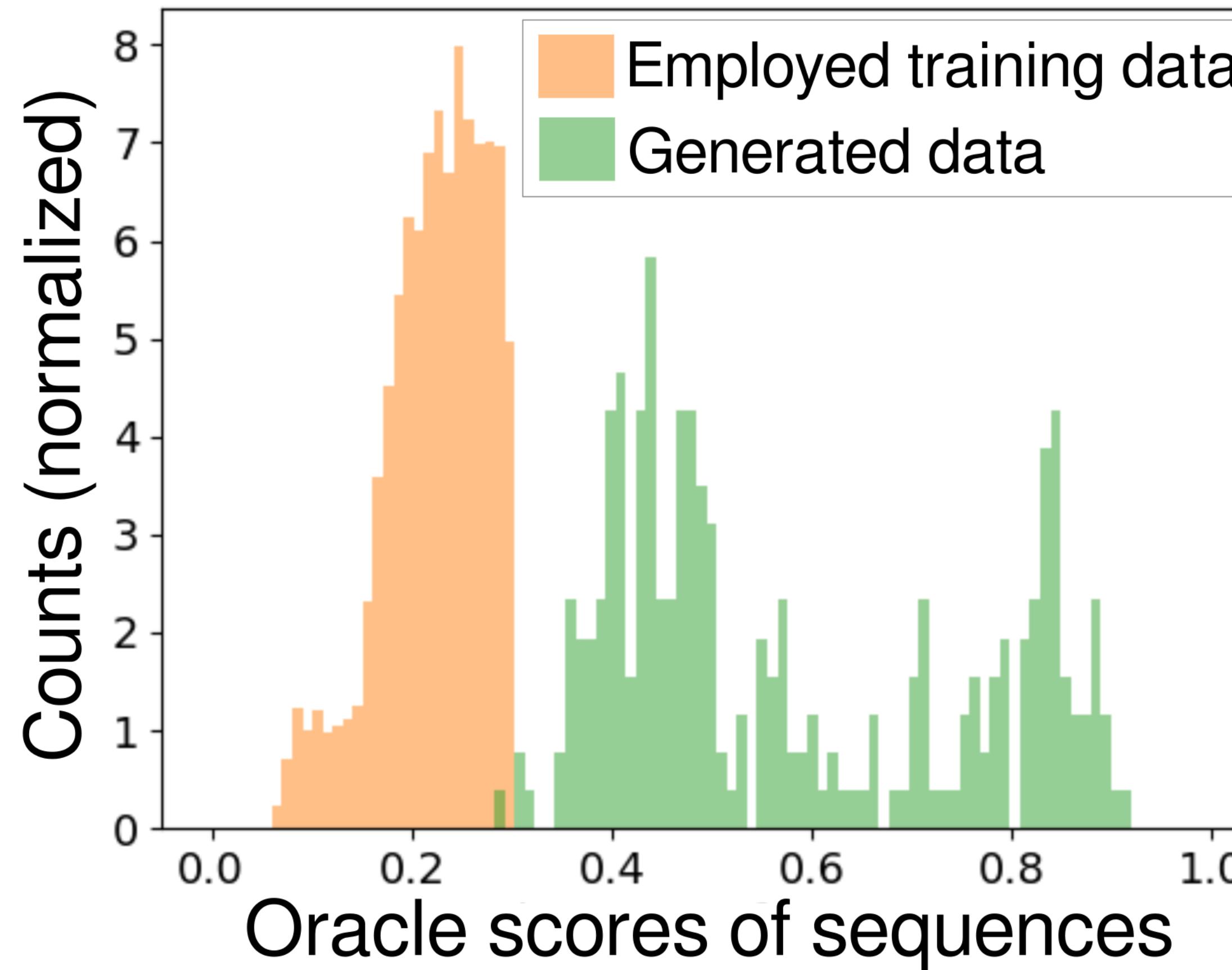
MNIST: 100 training labels -> 80 test mistakes

SVHN: 1,000 training labels -> 4.3% test error

CIFAR-10: 4,000 labels -> 14.4% test error

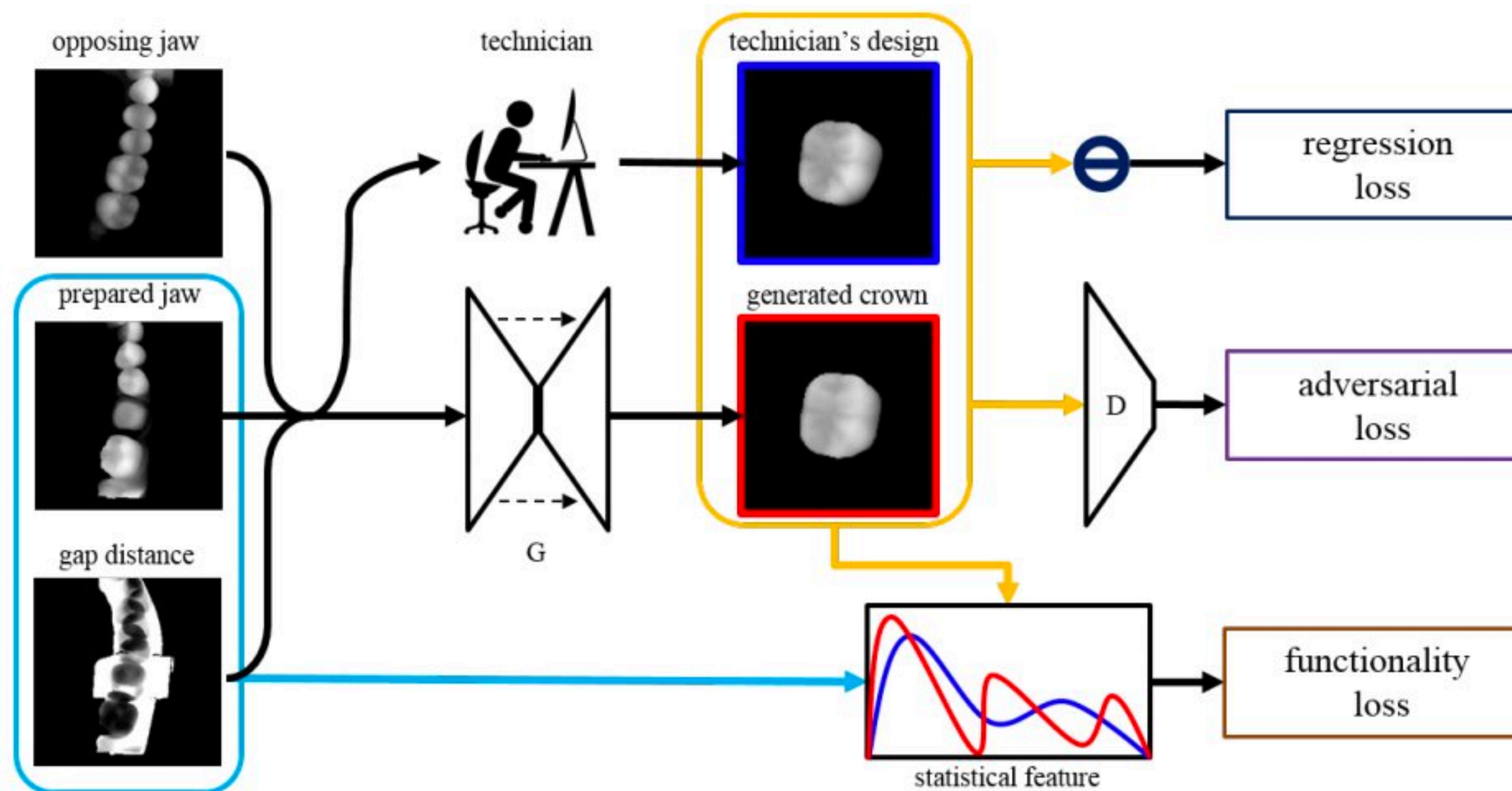
(Dai et al 2017)

# Designing DNA to optimize protein binding



(Killoran et al, 2017)

# Personalized GANufacturing

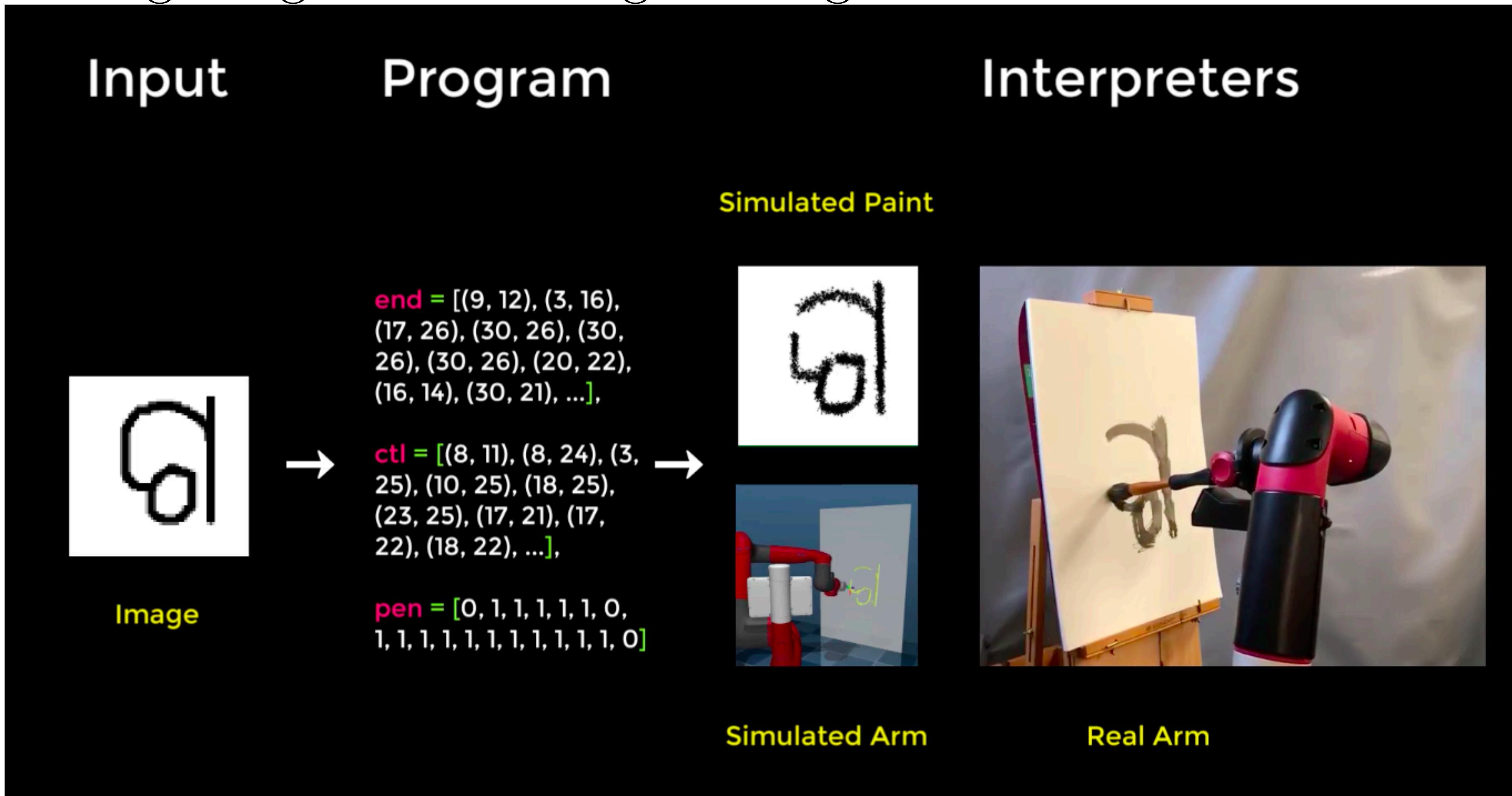


(Hwang et al 2018)

(Goodfellow 2018)

# SPIRAL

Synthesizing Programs for Images Using Reinforced Adversarial Learning



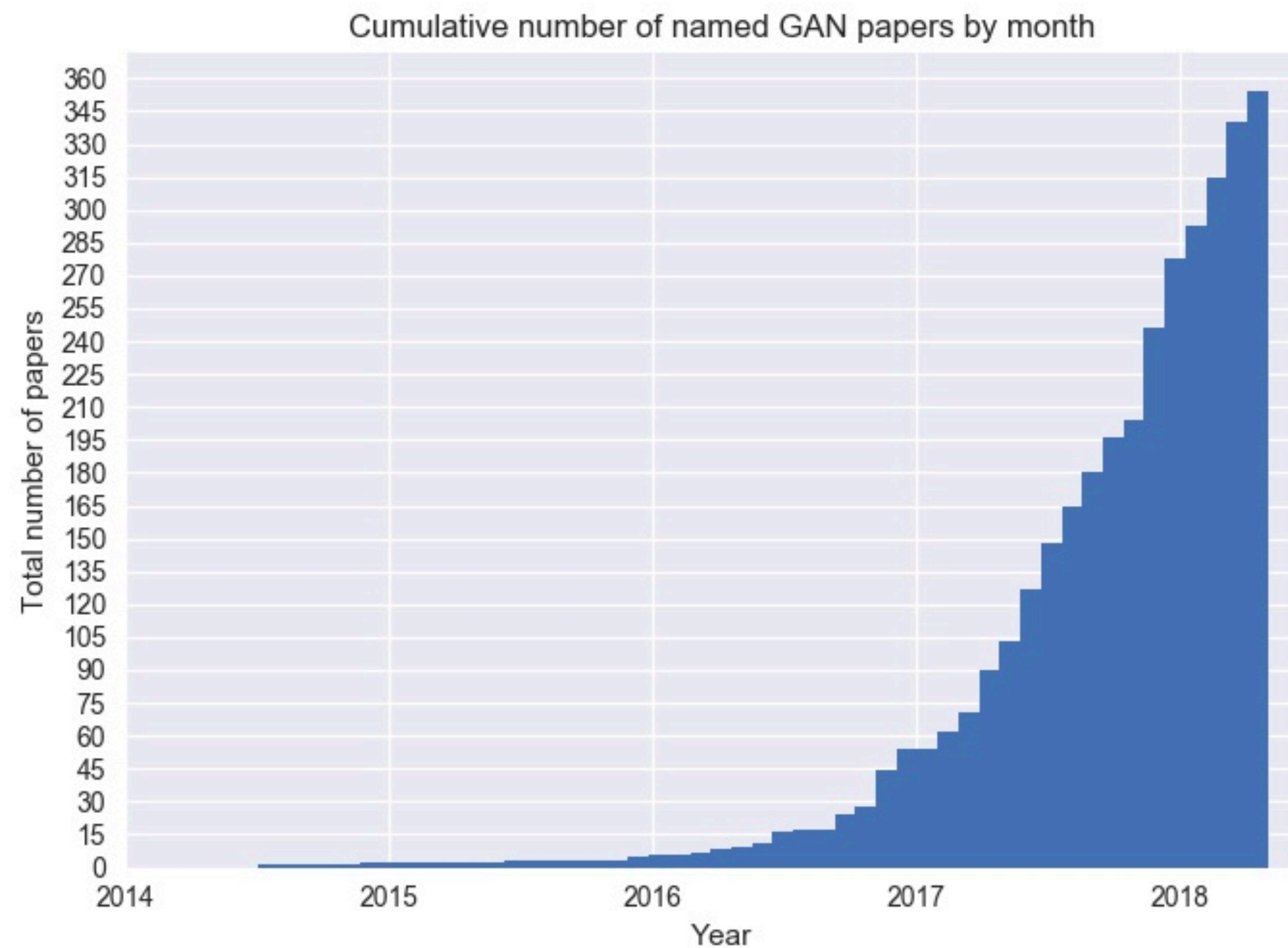
(Ganin et al, 2018)

(Goodfellow 2018)

# Other applications

- Planning
- World Models for RL agents
- Fairness and Privacy
- Missing data
- Topics covered at workshop:
  - Training data for other agents (Philip Isola, Taesung Park, Jun-Yan Zhu)
  - Inference in other probabilistic models (Mihaela Rosca)
  - Domain adaptation (Judy Hoffman)
  - Imitation Learning (Stefano Ermon)

# Track updates at the GAN Zoo



<https://github.com/hindupuravinash/the-gan-zoo>

# Questions