



Generative Adversarial Networks (GANs)

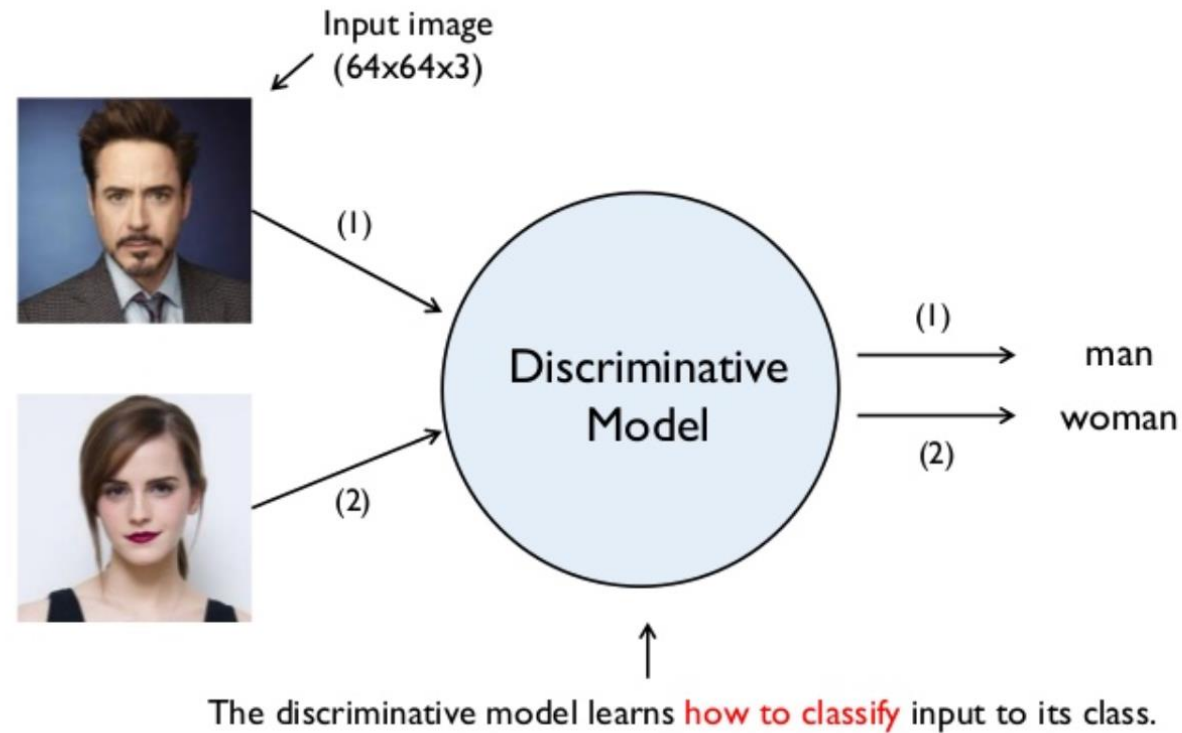
Industrial AI Lab.
Prof. Seungchul Lee

Source

- 1시간만에 GAN(Generative Adversarial Network) 완전 정복하기
 - by 최윤제 (고려대 석사생)
 - YouTube: https://www.youtube.com/watch?v=odpjk7_tGY0
 - Slides: <https://www.slideshare.net/NaverEngineering/1-gangenerative-adversarial-network>
- CSC321 Lecture 19: GAN
 - By Prof. Roger Grosse at Univ. of Toronto
 - http://www.cs.toronto.edu/~rgrosse/courses/csc321_2018/
- CS231n: CNN for Visual Recognition
 - Lecture 13: Generative Models
 - By Prof. Fei-Fei Li at Stanford University
 - <http://cs231n.stanford.edu/>

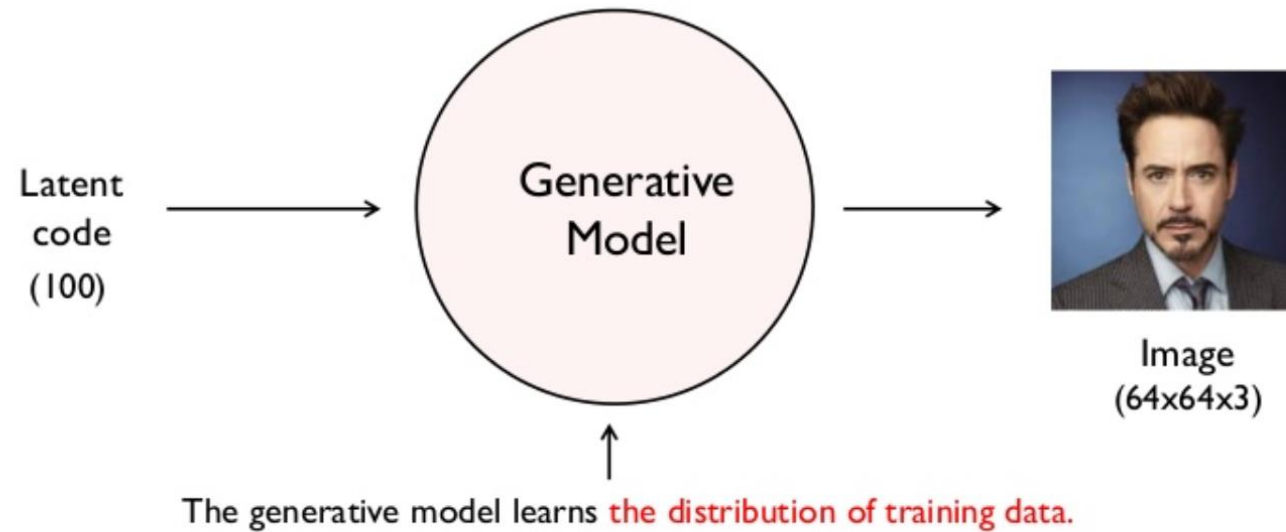
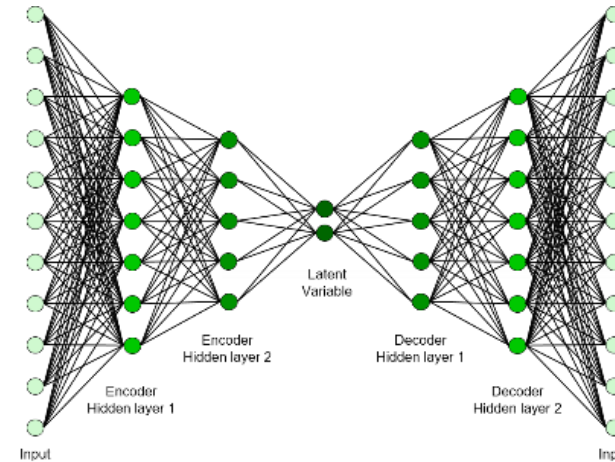
Supervised Learning

- Discriminative model



Unsupervised Learning

- Generative model



Model Distribution vs. Data Distribution

Probability Distribution

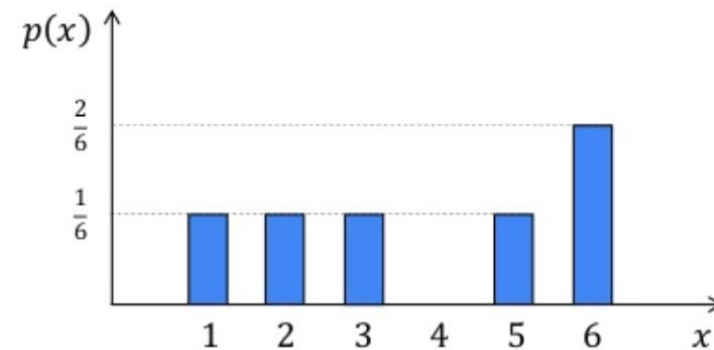
Probability Basics (Review)



Random variable

X	1	2	3	4	5	6
$P(X)$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{0}{6}$	$\frac{1}{6}$	$\frac{2}{6}$

Probability mass function



Probability Distribution

What if x is actual images in the training data?

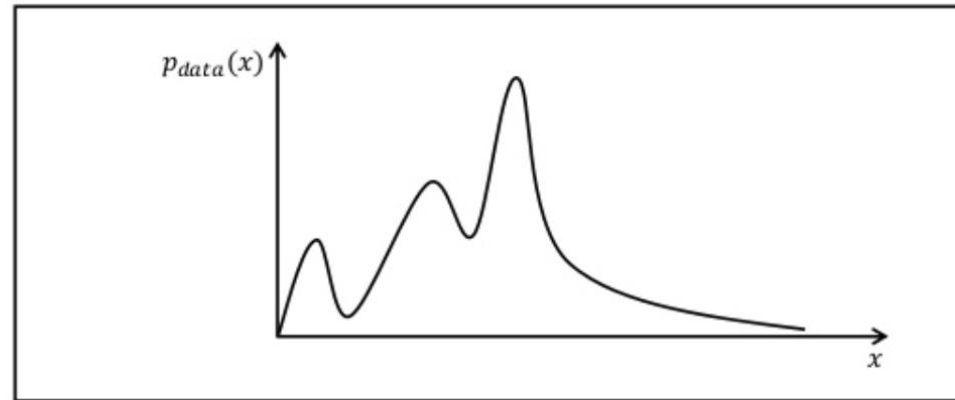
At this point, x can be represented as a (for example) 64x64x3 dimensional vector.



Probability Distribution

Probability density function

There is a $p_{data}(x)$ that represents the distribution of actual images.

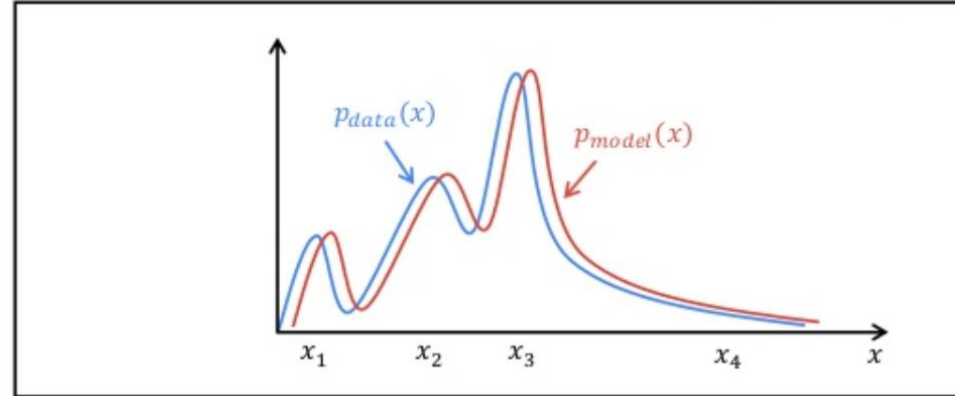


Probability Density Estimation Problem

- If $P_{model}(x)$ can be estimated as close to $P_{data}(x)$, then data can be generated by sampling from $P_{model}(x)$

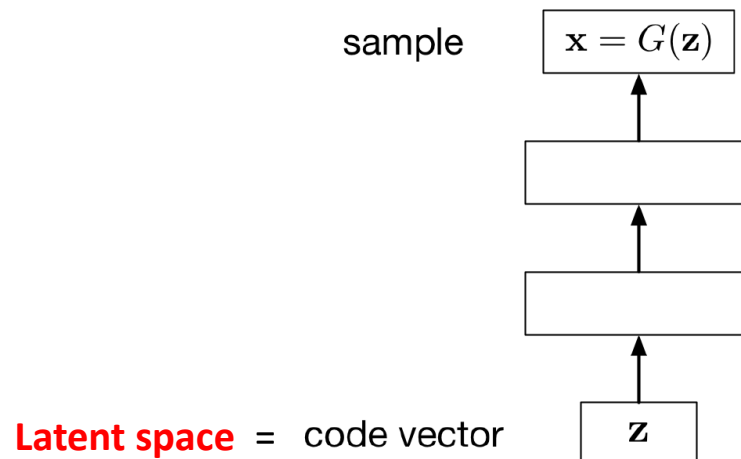
The goal of the generative model is to find a $p_{model}(x)$ that approximates $p_{data}(x)$ well.

↗ Distribution of images generated by the model
↘ Distribution of actual images



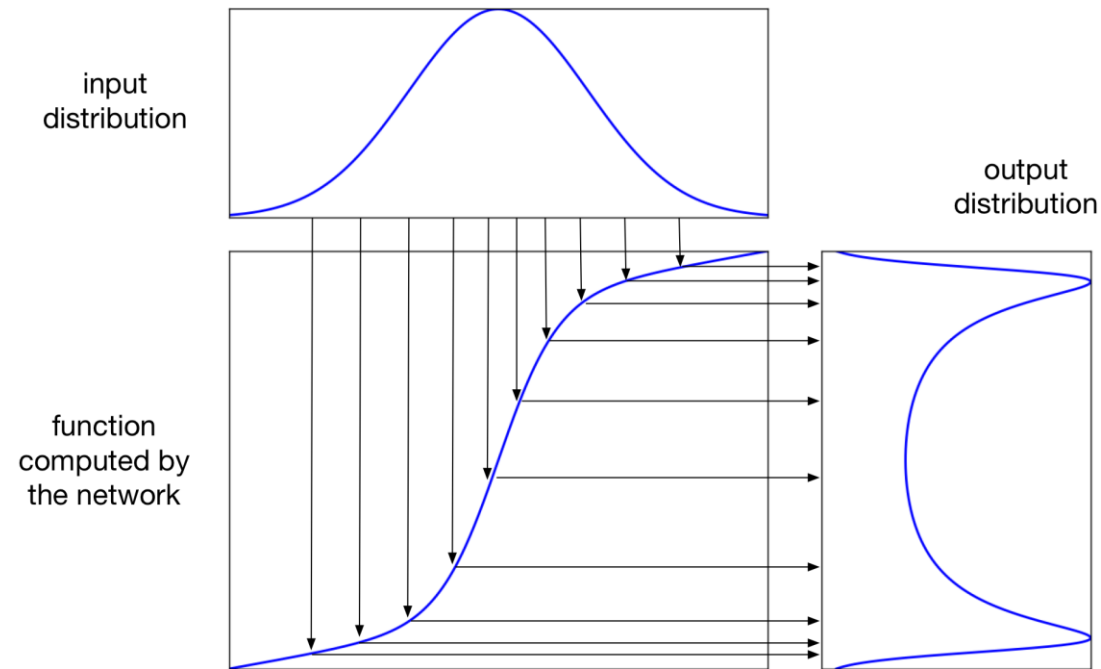
Generative Models from Lower Dimension

- Learn transformation via a neural network
- Start by sampling the code vector z from a fixed, simple distribution (e.g. uniform distribution or Gaussian distribution)
- Then this code vector is passed as input to a deterministic generator network G , which produces an output sample $x = G(z)$



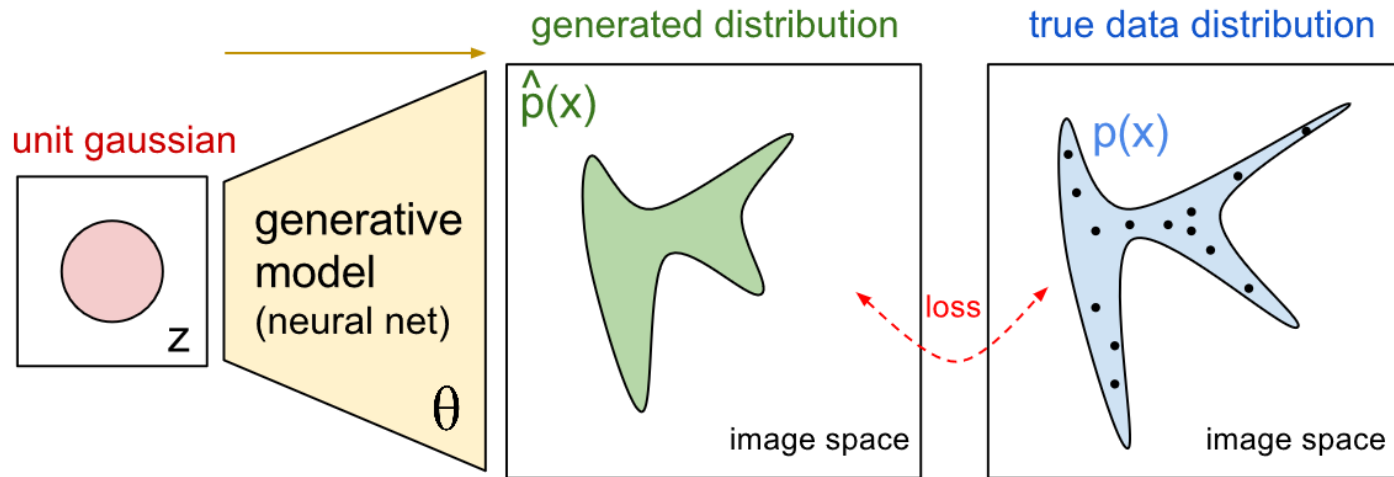
Deterministic Transformation (by Network)

- 1-dimensional example:



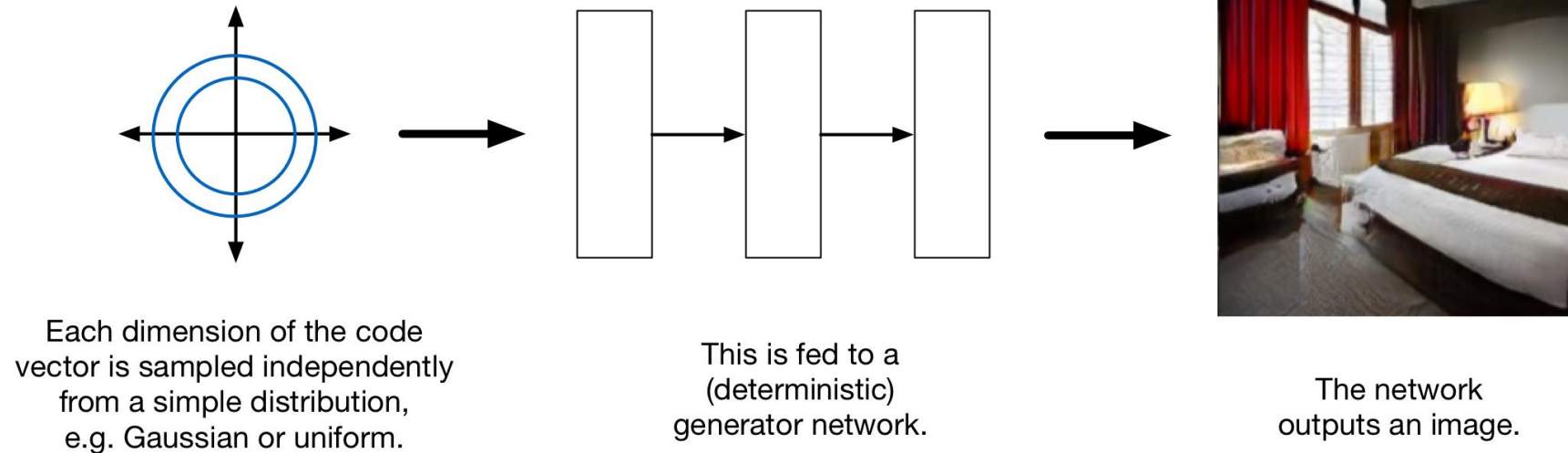
Deterministic Transformation (by Network)

- High dimensional example:



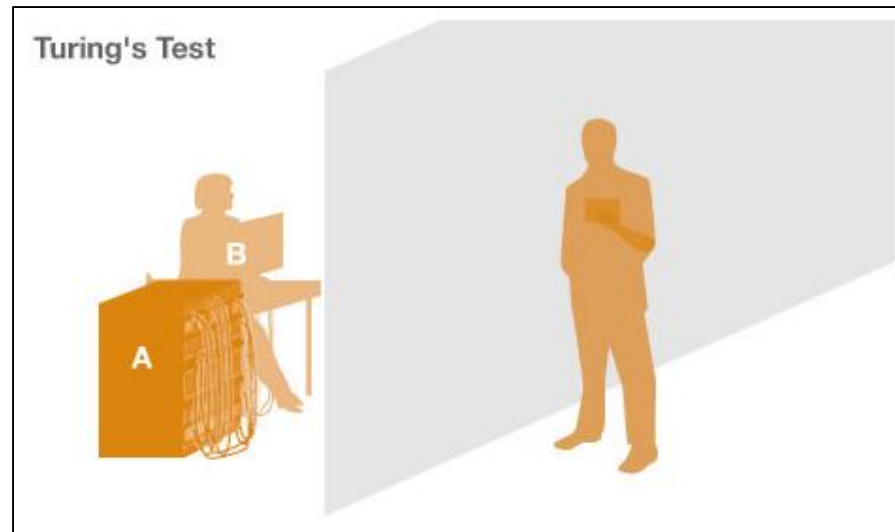
Prob. Density Function by Deep Learning

- Generative model of image



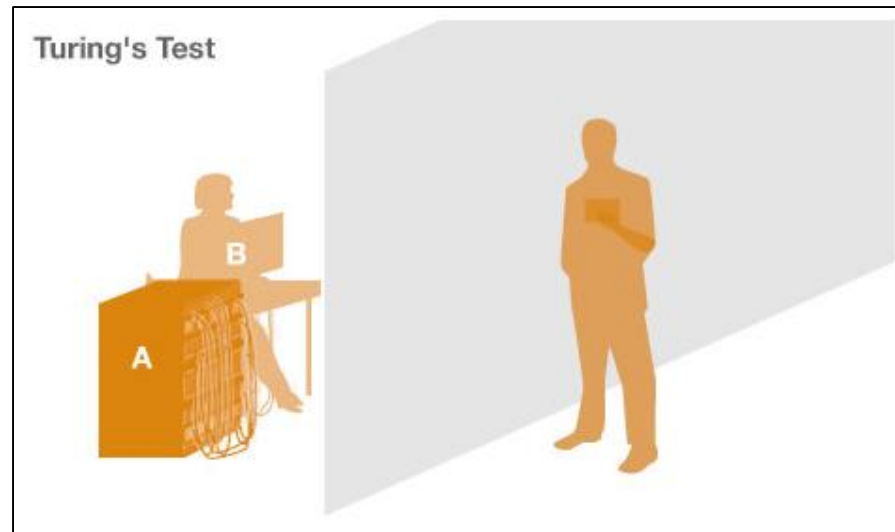
Generative Adversarial Networks (GANs)

- In generative modeling, we'd like to train a network that models a distribution, such as a distribution over images.
- GANs do not work with any **explicit** density function !
 - Instead, take game-theoretic approach



Turing Test

- One way to judge the quality of the model is to sample from it.
- GANs are based on a very different idea:
 - Model to produce samples which are indistinguishable from the real data, as judged by a discriminator network whose job is to tell real from fake

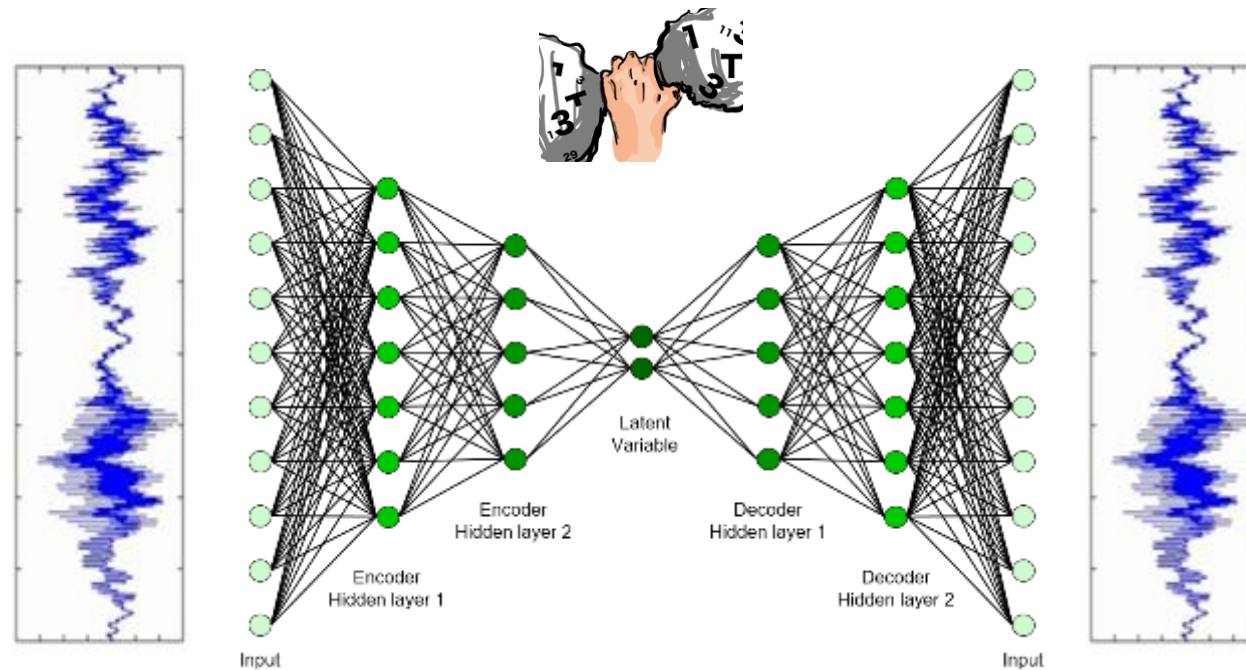


Generative Adversarial Networks (GAN)

- The idea behind Generative Adversarial Networks (GANs): train two different networks
 - Generator network: try to produce realistic-looking samples
 - Discriminator network: try to distinguish between real and fake data
- The generator network tries to fool the discriminator network

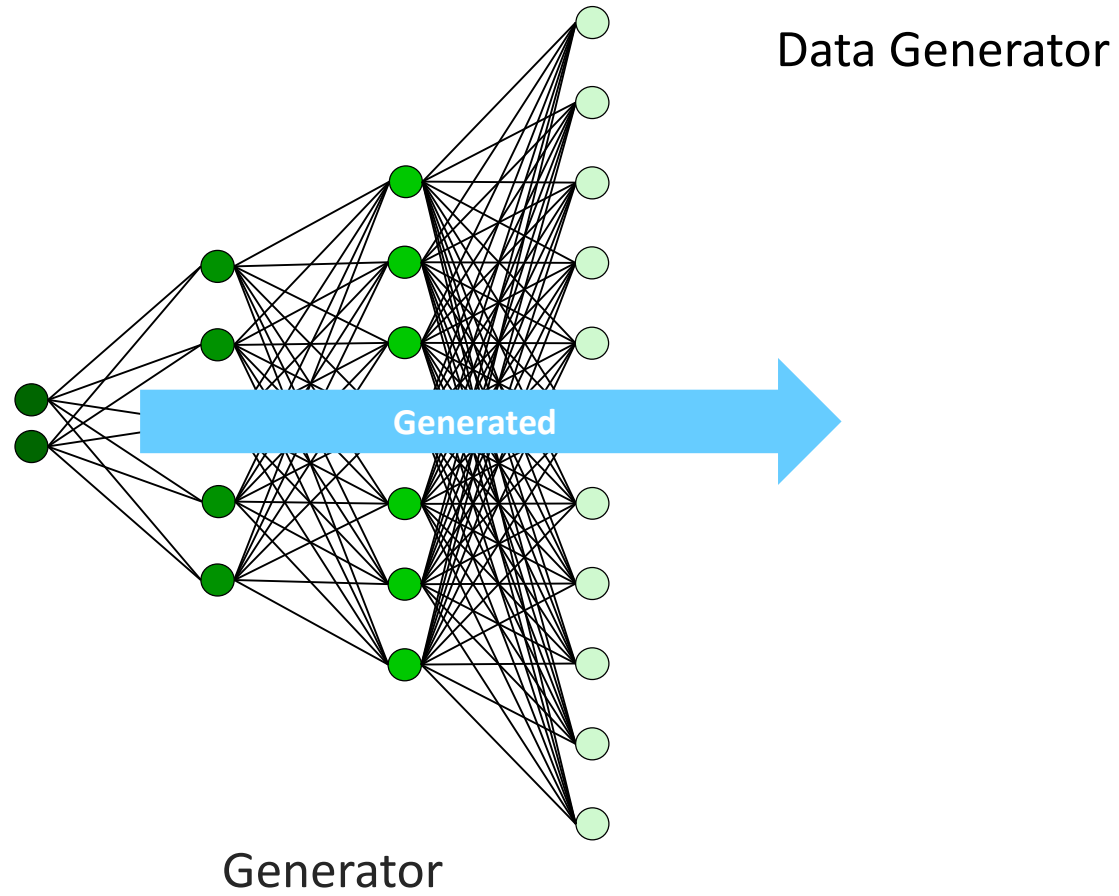
Autoencoder

- Dimension reduction
- Recover the input data
 - Learns an encoding of the inputs so as to recover the original input from the encodings as well as possible



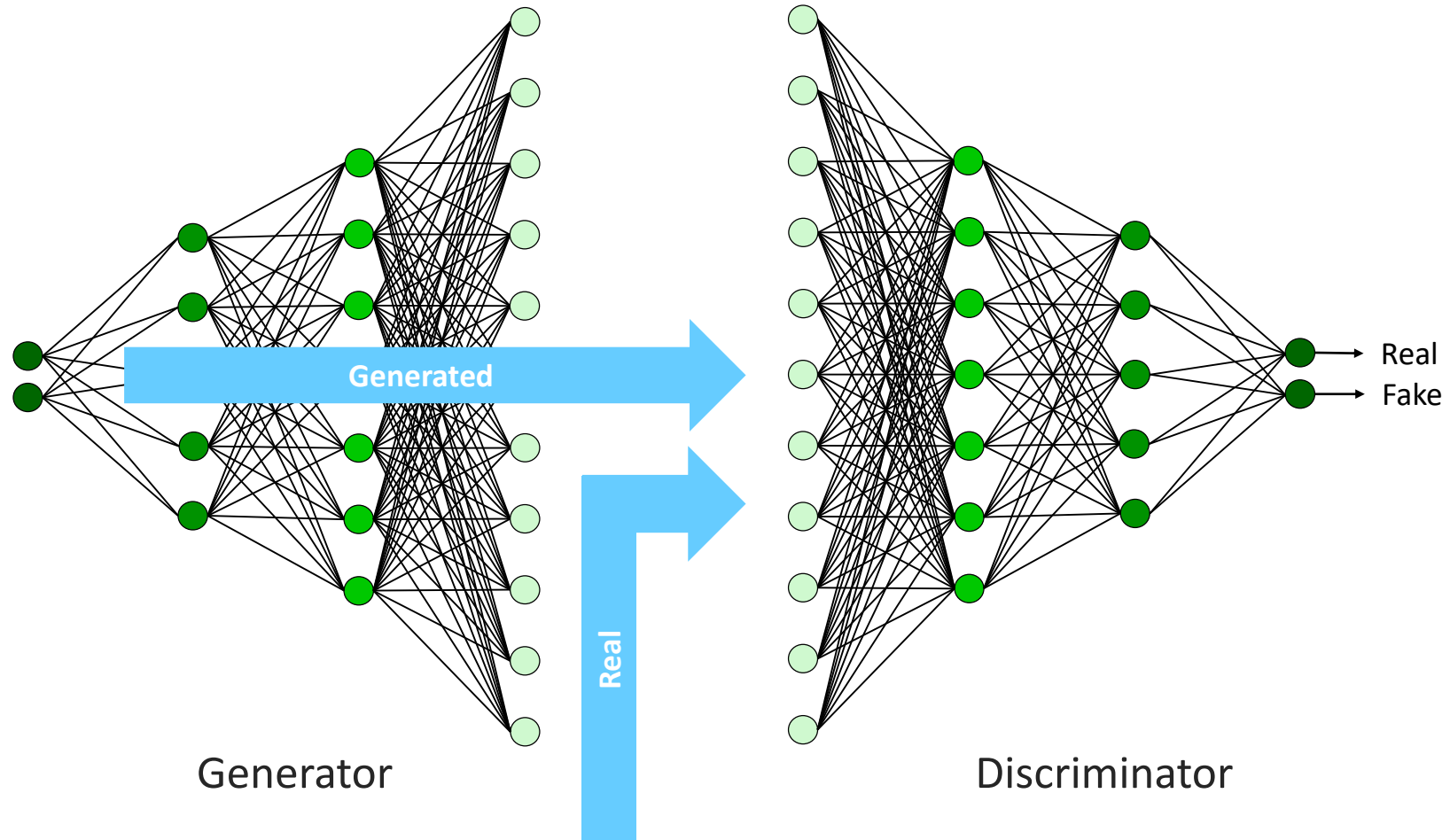
Generative Adversarial Networks (GAN)

- Analogous to Turing Test

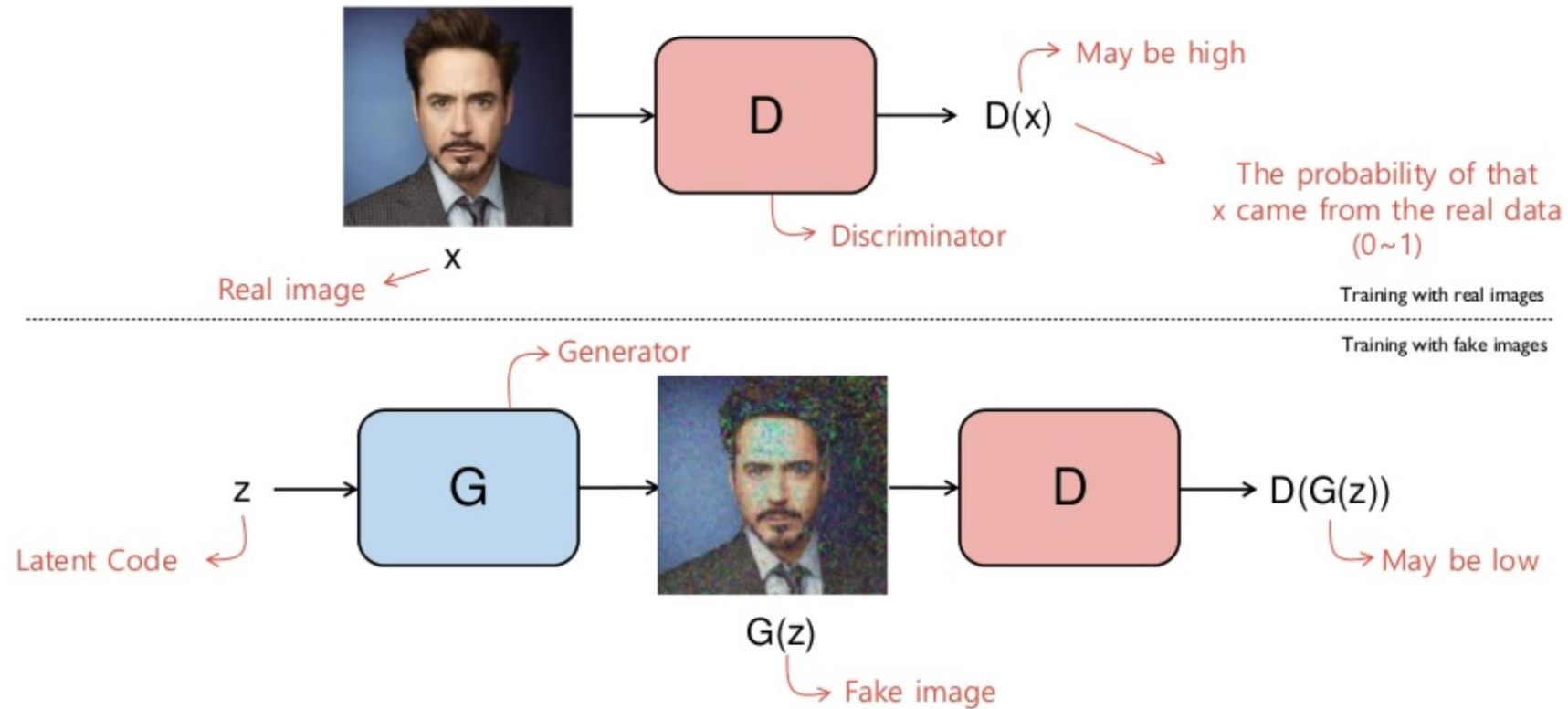


Generative Adversarial Networks (GAN)

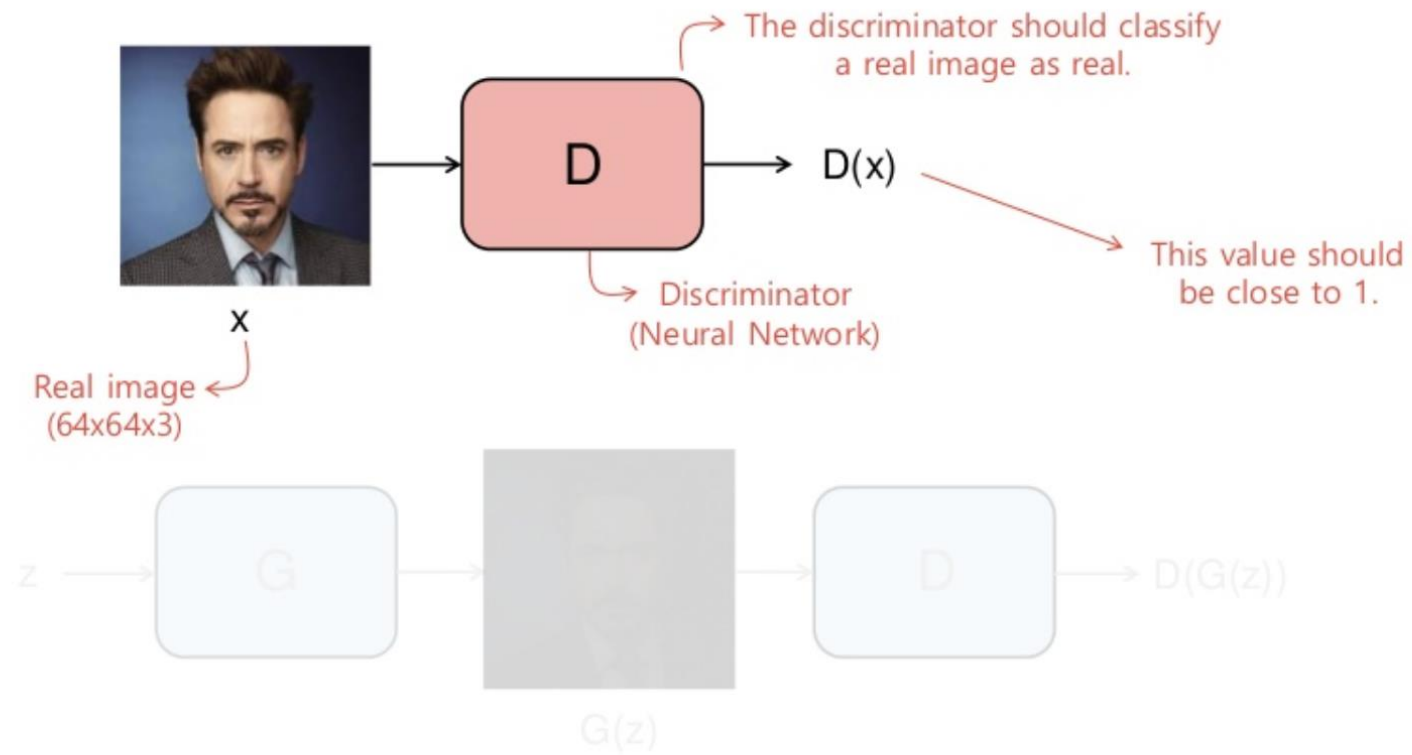
- Analogous to Turing Test



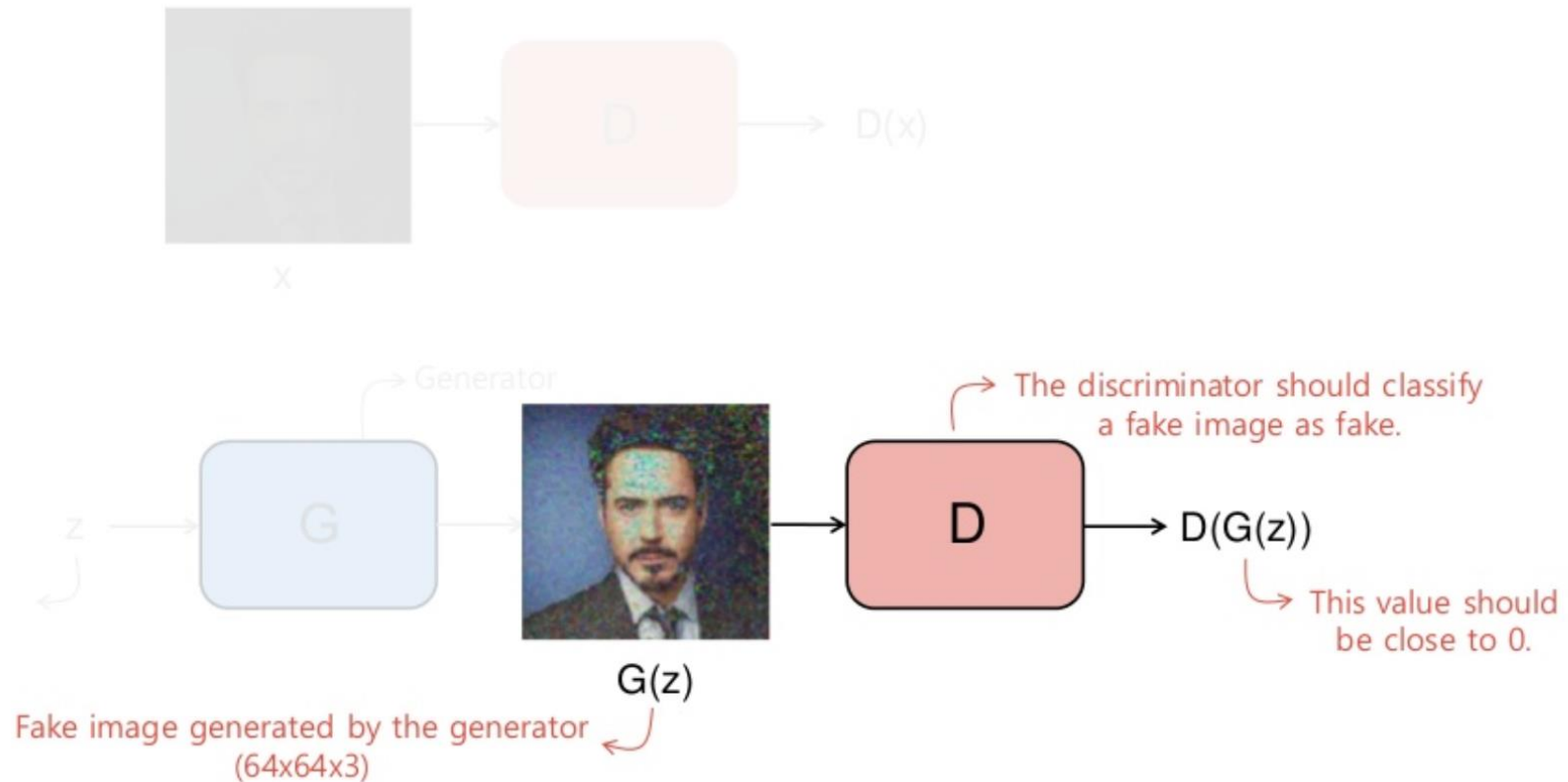
Intuition for GAN



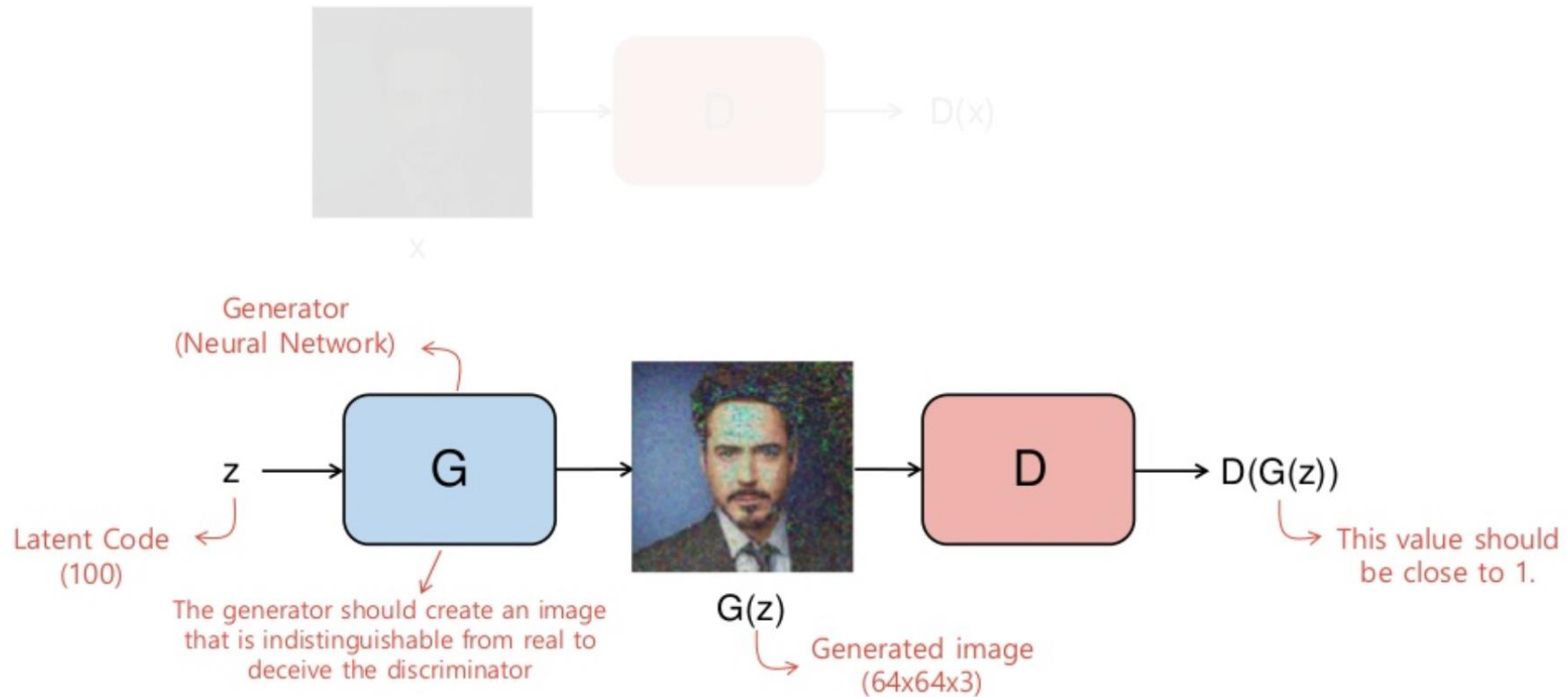
Discriminator Perspective



Discriminator Perspective



Generator Perspective



Objective Function of GAN

$$\text{loss} = -y \log h(x) - (1 - y) \log(1 - h(x))$$

Sample x from real data distribution

Sample latent code z from Gaussian distribution

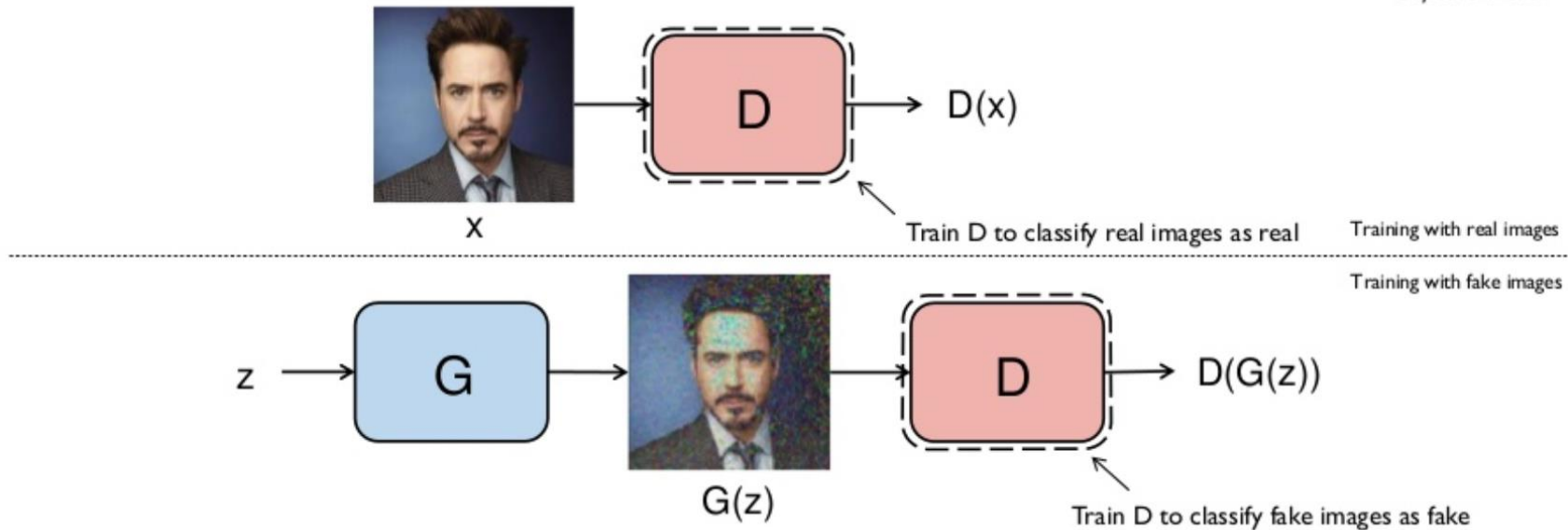
$$\min_G \max_D V(D, G) = E_{x \sim p_{\text{data}}(x)} [\log D(x)] + E_{z \sim p_z(z)} [\log(1 - D(G(z)))]$$

D should maximize $V(D, G)$

Maximum when $D(x) = 1$

Maximum when $D(G(z)) = 0$

Objective function



Objective Function of GAN

$$\min_G \max_D V(D, G) = \cancel{E_{x \sim p_{data}(x)} [\log D(x)]} + E_{z \sim p_z(z)} [\log(1 - D(G(z)))]$$

G is independent of this part

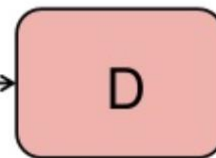
G should minimize $V(D, G)$

Minimum when $D(G(z)) = 1$

Objective function

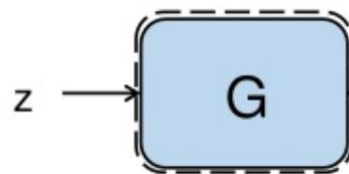


x



$D(x)$

Training with real images

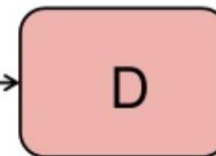


z

Train G to deceive D



$G(z)$



$D(G(z))$

Training with fake images

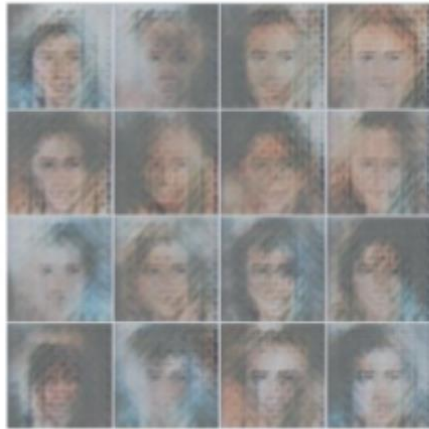
Non-Saturating Game

$$\min_G E_{z \sim p_z(z)} [\log(1 - D(G(z)))]$$

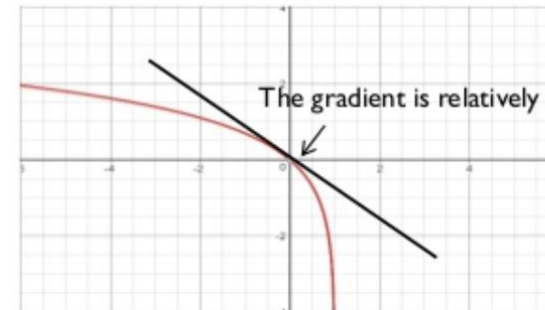
Objective function of G

At the beginning of training, the discriminator can clearly classify the generated image as fake because the quality of the image is very low.

This means that $D(G(z))$ is almost zero at early stages of training.



Images created by the generator at the beginning of training



$$y = \log(1 - x)$$

Non-Saturating Game

$$\min_G E_{z \sim p_z(z)} [\log(1 - D(G(z)))]$$

↓ Modification (heuristically motivated)

$$\max_G E_{z \sim p_z(z)} [\log D(G(z))]$$

- Practical Usage

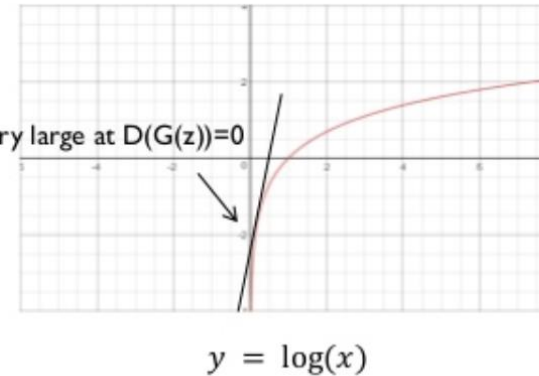
Use **binary cross entropy loss function** with fake label (1)

$$\min_G E_{z \sim p_z(z)} [-y \log D(G(z)) - (1 - y) \log(1 - D(G(z)))]$$

↓ $y = 1$

$$\min_G E_{z \sim p_z(z)} [-\log D(G(z))]$$

The gradient is very large at $D(G(z))=0$



Solving a MinMax Problem

Step 1: Fix G and perform a gradient step to

$$\max_D E_{x \sim p_{\text{data}}(x)} [\log D(x)] + E_{x \sim p_z(z)} [\log(1 - D(G(z)))]$$

Step 2: Fix D and perform a gradient step to

$$\max_G E_{x \sim p_z(z)} [\log D(G(z))]$$

OR

Step 1: Fix G and perform a gradient step to

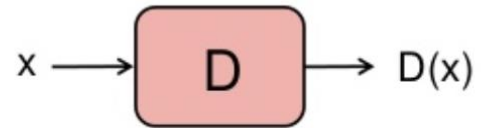
$$\min_D E_{x \sim p_{\text{data}}(x)} [-\log D(x)] + E_{x \sim p_z(z)} [-\log(1 - D(G(z)))]$$

Step 2: Fix D and perform a gradient step to

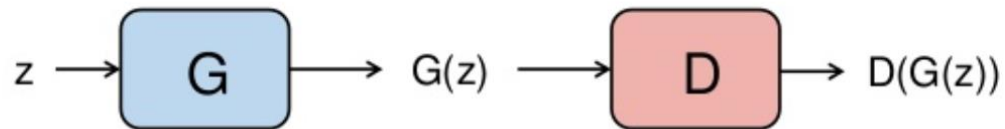
$$\min_G E_{x \sim p_z(z)} [-\log D(G(z))]$$

GAN Implementation in TensorFlow

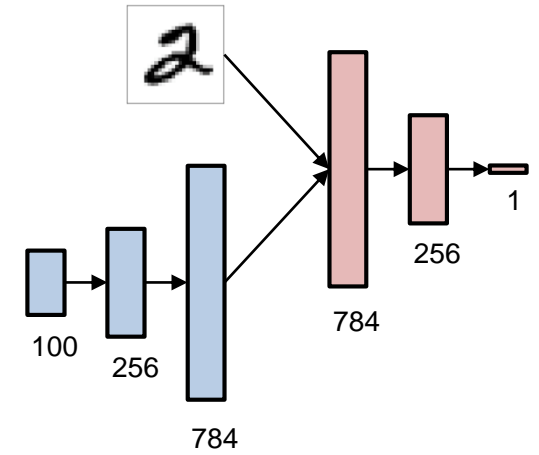
TensorFlow Implementation



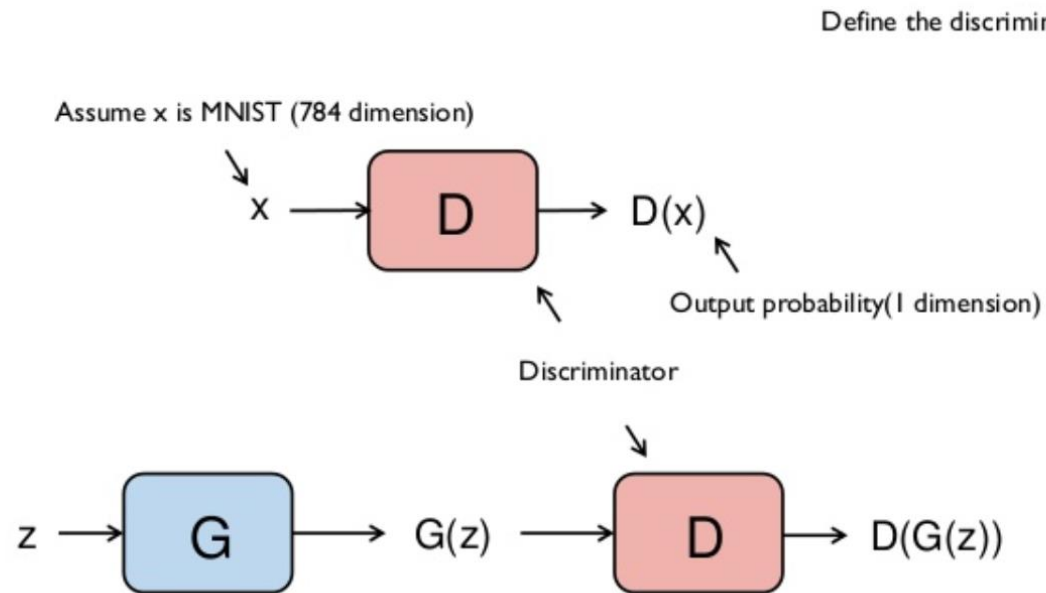
Training with real images



Training with fake images

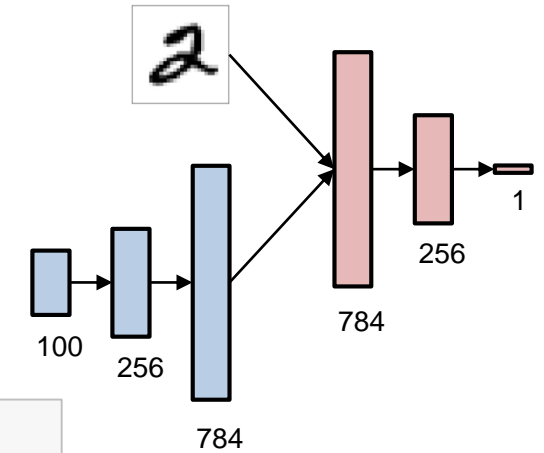


TensorFlow Implementation

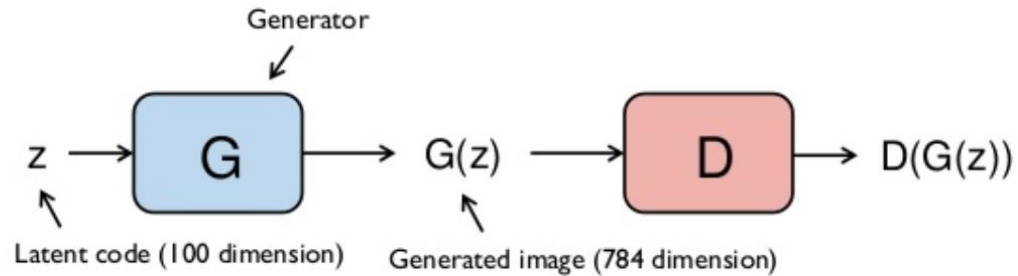


Define the discriminator

```
n_D_input = 28*28  
n_D_hidden = 256  
n_D_output = 1  
  
n_G_input = 100  
n_G_hidden = 256  
n_G_output = 28*28
```

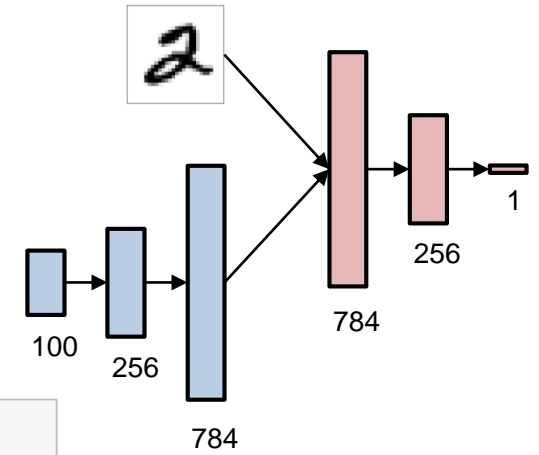


TensorFlow Implementation



Define the generator

```
n_D_input = 28*28  
n_D_hidden = 256  
n_D_output = 1  
  
n_G_input = 100  
n_G_hidden = 256  
n_G_output = 28*28
```



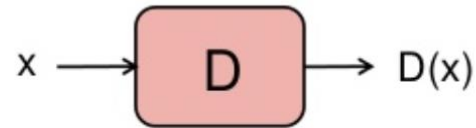
TensorFlow Implementation

Step 1: Fix G and perform a gradient step to

$$\min_D E_{x \sim p_{\text{data}}(x)} [-\log D(x)] + E_{x \sim p_z(z)} [-\log(1 - D(G(z)))]$$

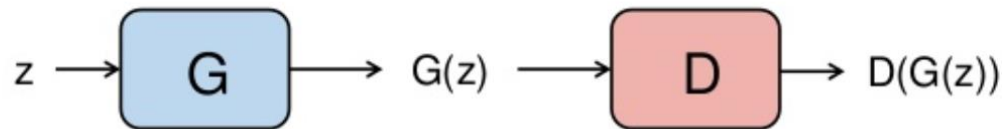
Step 2: Fix D and perform a gradient step to

$$\min_G E_{x \sim p_z(z)} [-\log D(G(z))]$$



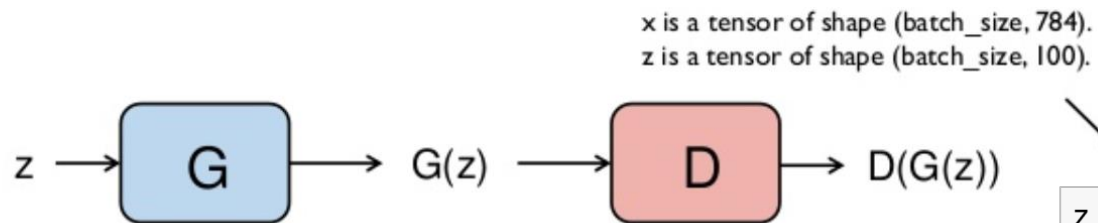
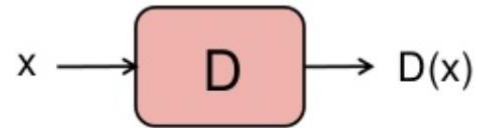
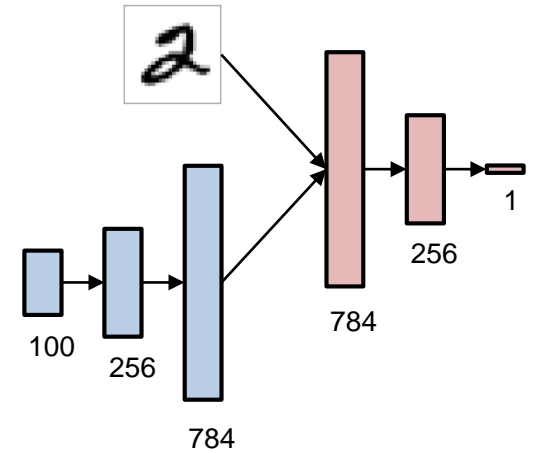
```
D_loss = tf.reduce_mean(- tf.log(D_real) - tf.log(1 - D_fake))  
G_loss = tf.reduce_mean(- tf.log(D_fake))
```

```
D_var_list = [weights['D1'], biases['D1'], weights['D2'], biases['D2']]  
G_var_list = [weights['G1'], biases['G1'], weights['G2'], biases['G2']]
```



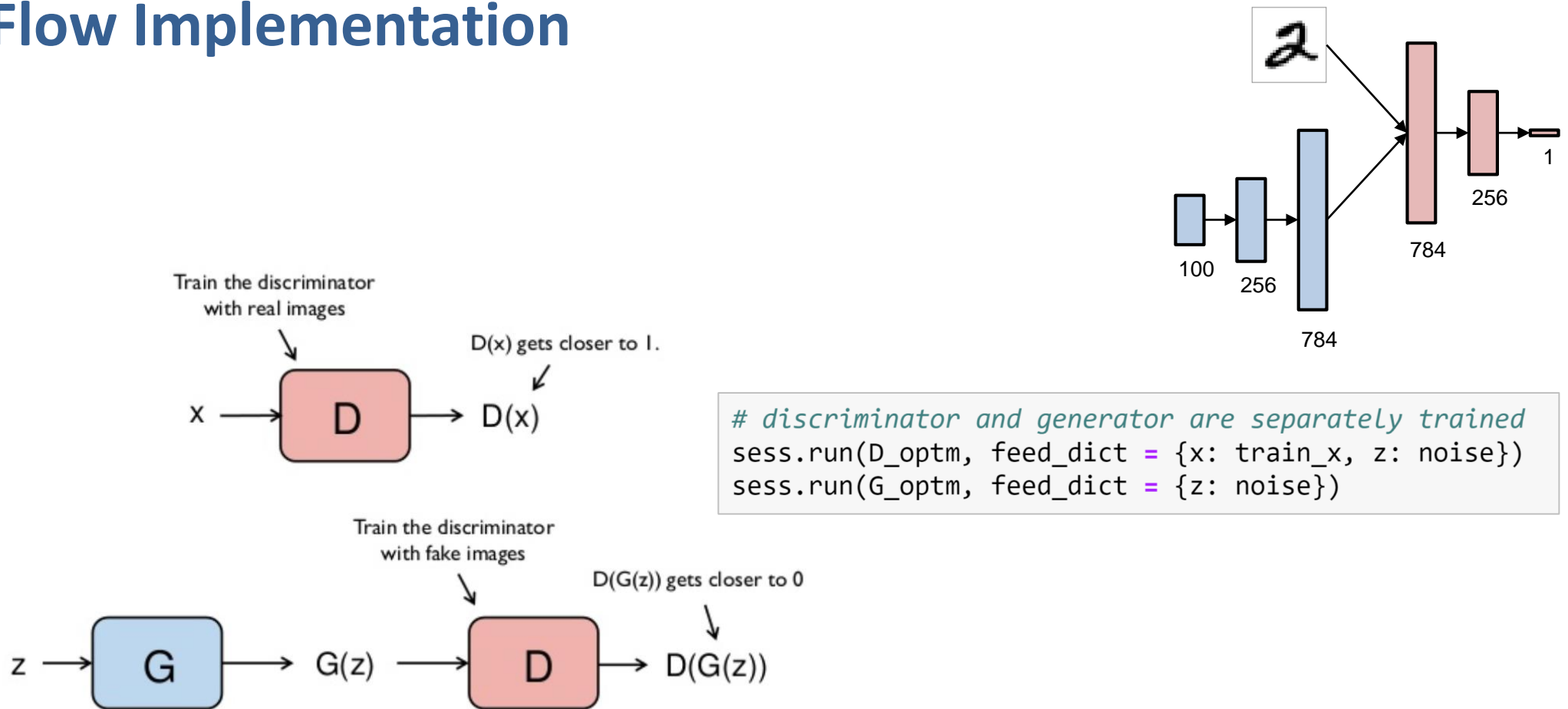
```
LR = 0.0002  
D_optm = tf.train.AdamOptimizer(LR).minimize(D_loss, var_list = D_var_list)  
G_optm = tf.train.AdamOptimizer(LR).minimize(G_loss, var_list = G_var_list)
```

TensorFlow Implementation

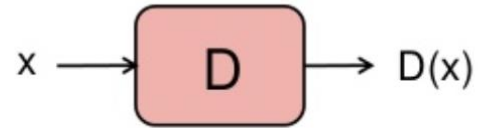
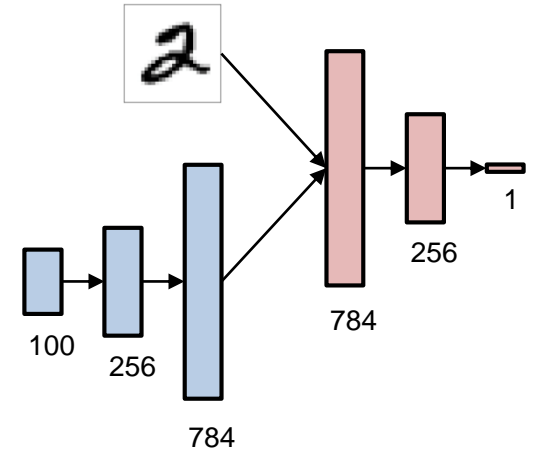


```
z = tf.placeholder(tf.float32, [None, n_G_input])  
x = tf.placeholder(tf.float32, [None, n_D_input])
```

TensorFlow Implementation

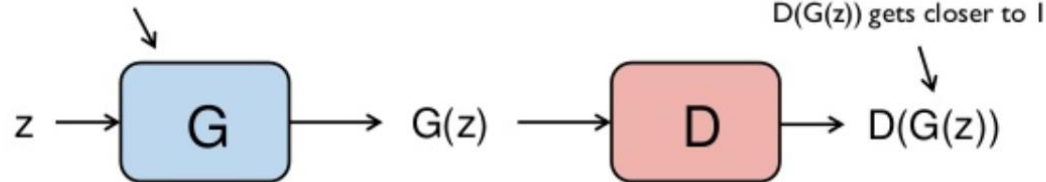


TensorFlow Implementation



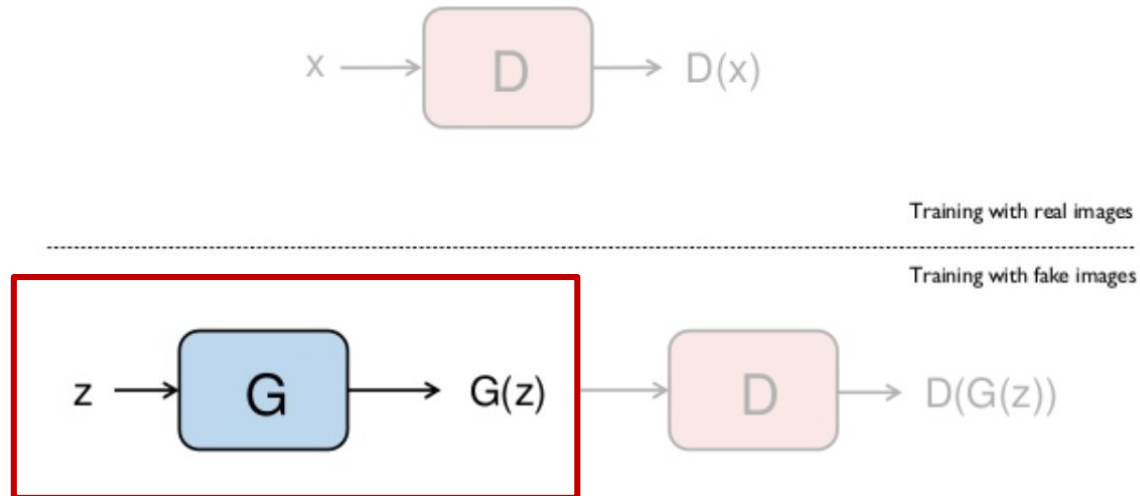
```
# discriminator and generator are separately trained  
sess.run(D_optm, feed_dict = {x: train_x, z: noise})  
sess.run(G_optm, feed_dict = {z: noise})
```

Train the generator
to deceive the discriminator

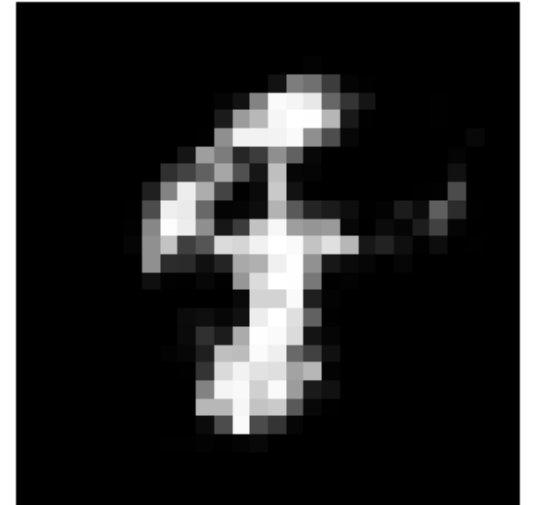


After Training

- After training, use generator network to generate new data



```
noise = make_noise(n_batch, n_G_input)
G_img = sess.run(G_output, feed_dict = {z: noise})
```



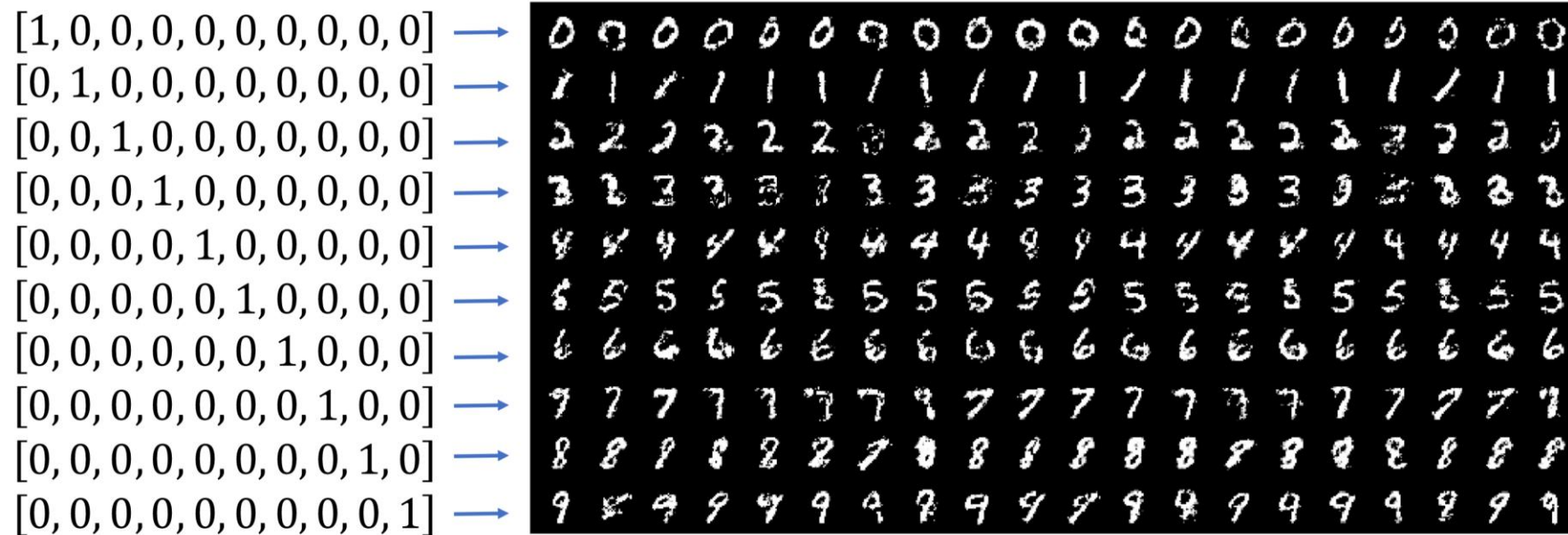
Conditional GAN

Conditional GAN

- In an unconditioned generative model, there is no control on modes of the data being generated.
- In the Conditional GAN (CGAN), the generator learns to generate a fake sample with a specific condition or characteristics (such as a label associated with an image or more detailed tag) rather than a generic sample from unknown noise distribution.

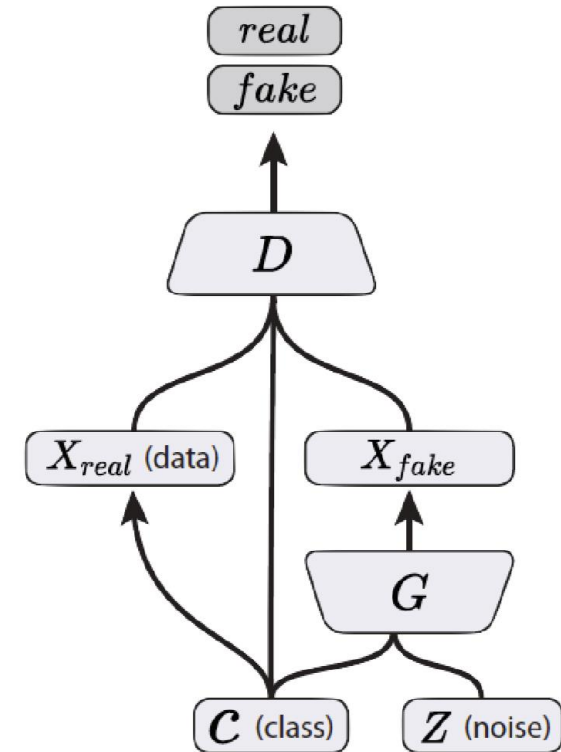
Conditional GAN

- MNIST digits generated conditioned on their class label



Conditional GAN

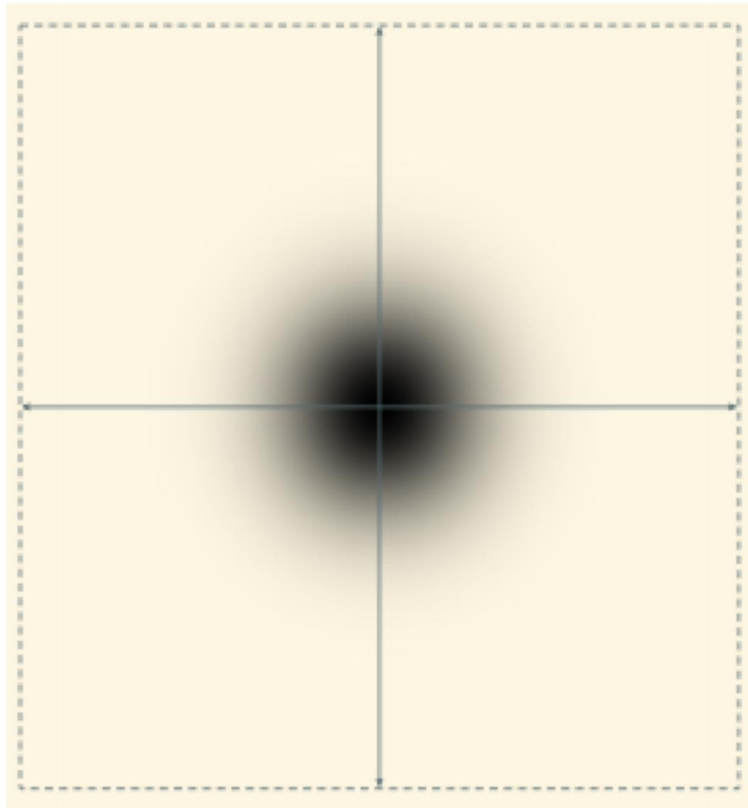
- Simple modification to the original GAN framework that conditions the model on additional information for better multi-modal learning
- Many practical applications of GANs when we have explicit supervision available



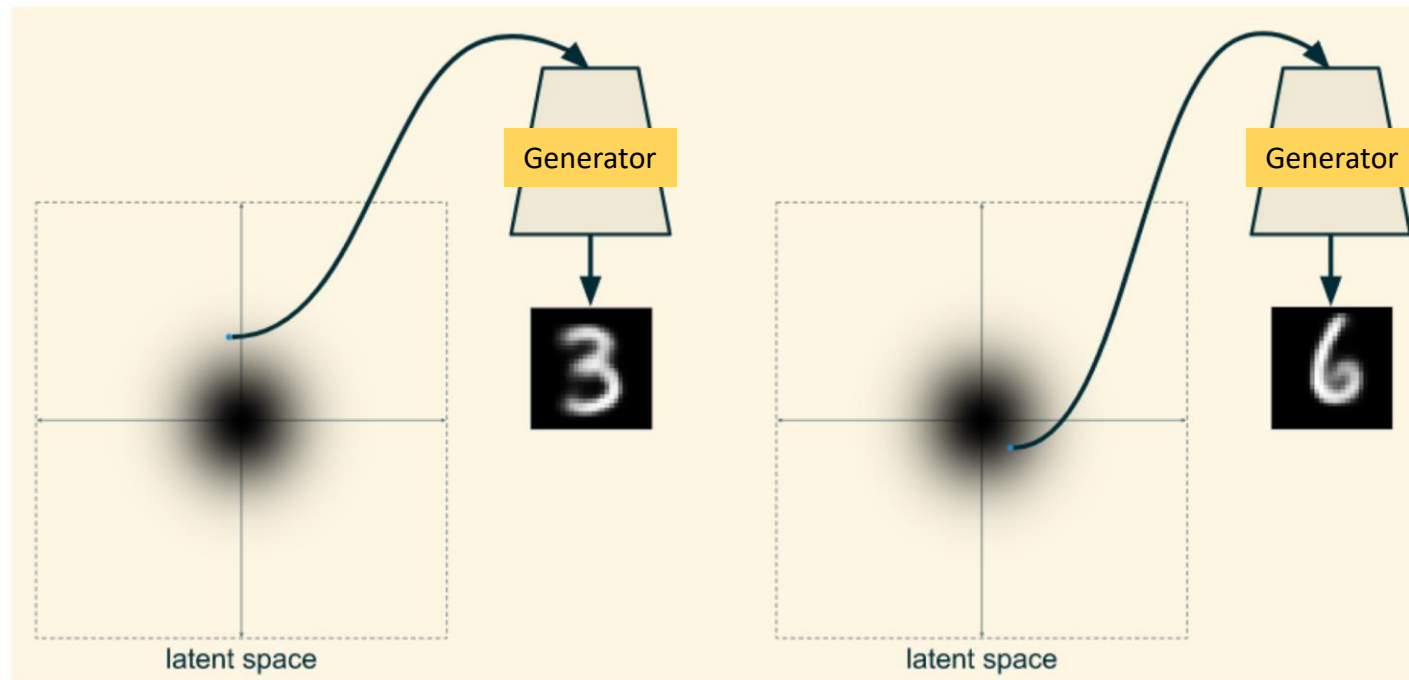
Conditional GAN
(Mirza & Osindero, 2014)

Normal Distribution of MNIST

- A standard normal distribution
- This is how we would like points corresponding to MNIST digit images to be distributed in the latent space



Generator at GAN



Generator at Conditional GAN

- Feed a random point in latent space and desired number.
- Even if the same latent point is used for two different numbers, the process will work correctly since the latent space only encodes features such as stroke width or angle

