

Generative Adversarial Networks (GANs)

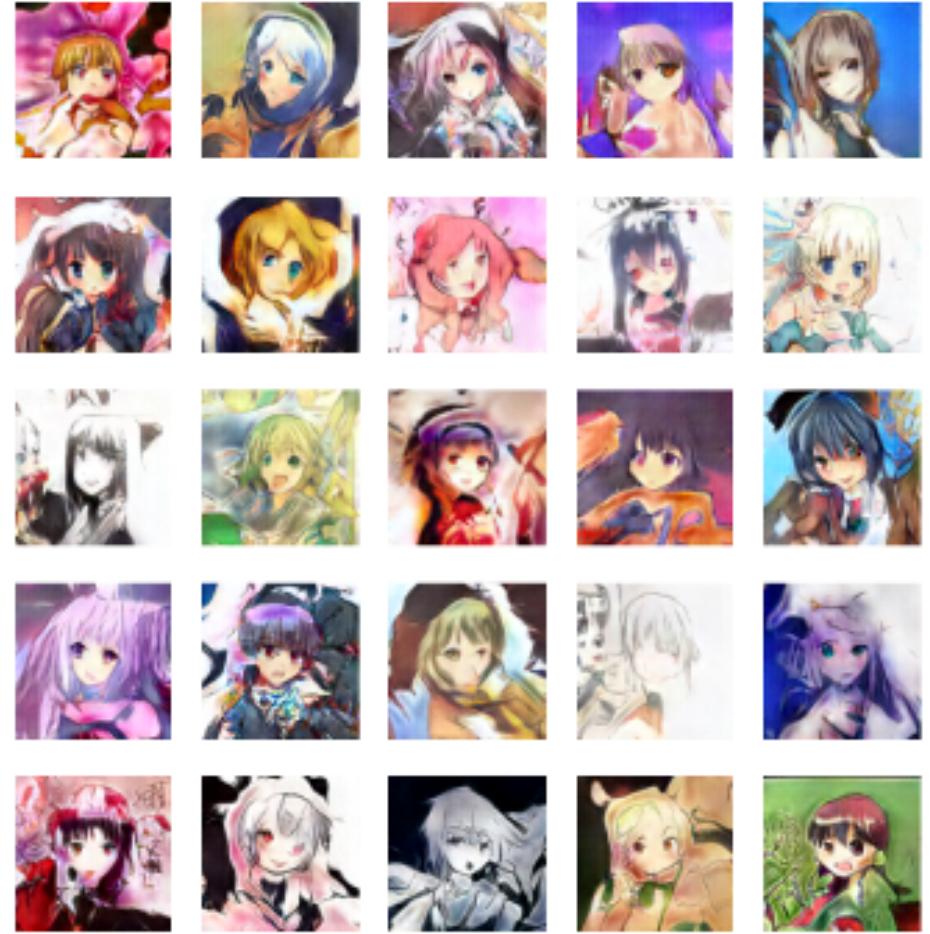
Shusen Wang

Image Generation

real images for training

0a4f1fff65b4cf5909 09afa44f15938b-0. jpg	0a5aa42fdc12fa232 abcff8eb1fb58b7-0. jpg	0a5aa42fdc12fa232 abcff8eb1fb58b7-1. jpg	0a5aa42fdc12fa232 abcff8eb1fb58b7-2. jpg
0a5e1011edf53411e ea93fefd22c8e29-0. jpg	0a5fe29f51a75ccb5 014a03527371c82-0. jpg	0a06b7df2c461a1e4 ae5dbb0afea0d3d- 0.jpg	0a06b7df2c461a1e4 ae5dbb0afea0d3d- 1.jpg
0a6c2a5e3802dd0a c14b76032644675e- 0.jpg	0a6c6ad87ac06491a a972d0aa1de0a59- 0.jpg	0a6c9d6dd70958e1 7a17abe17fd5876e- 0.jpg	0a6d7dc6f20e6c6c0 8a74f6ba32f6bd1-0. jpg
0a7a467454656735 0ec9ca45ee78f98c- 0.jpg	000a7ac0c73b86812 c0f94895ebe9e5a-0. jpg	0a7afbee5e81b228 459b325477e8f352- 0.jpg	0a7cee3393baf5c54 9452db5cf345d08- 0.jpg

generated images



Reference: <https://qiita.com/matty/items/e5bfe5e04b9d2f0bbd47>

GAN: Main Idea

- **Generator:** generates fake images to *fool* the **discriminator**.
- **Discriminator:** tries to *distinguish* between real and fake images.
- Train them against each other.
- Finally, the **discriminator** cannot distinguish between real and fake.
- → It means the fake images look like real.

GAN: Main Idea

- **Generator:** a **forger** who wants to create a fake Picasso painting.
- **Discriminator:** an **art dealer**.

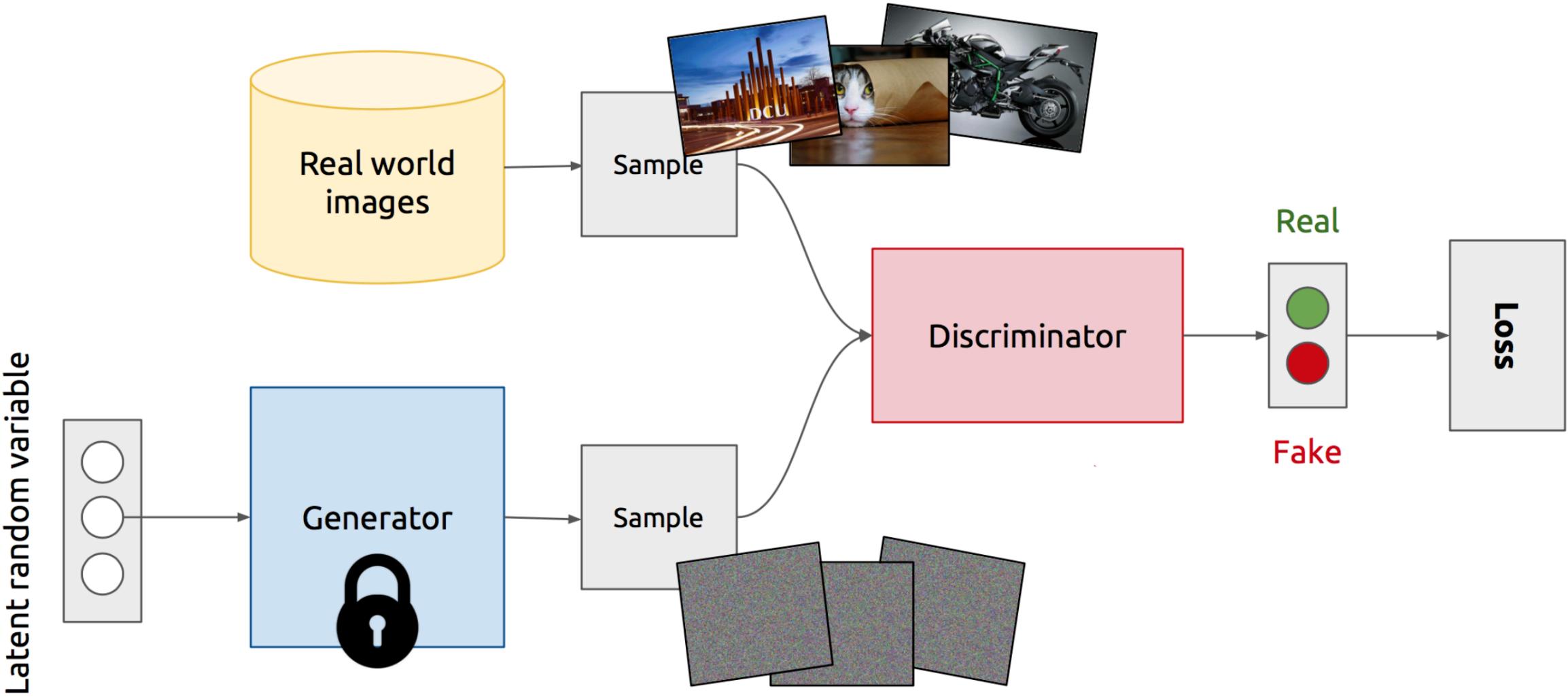


Which is real?

GAN: Main Idea

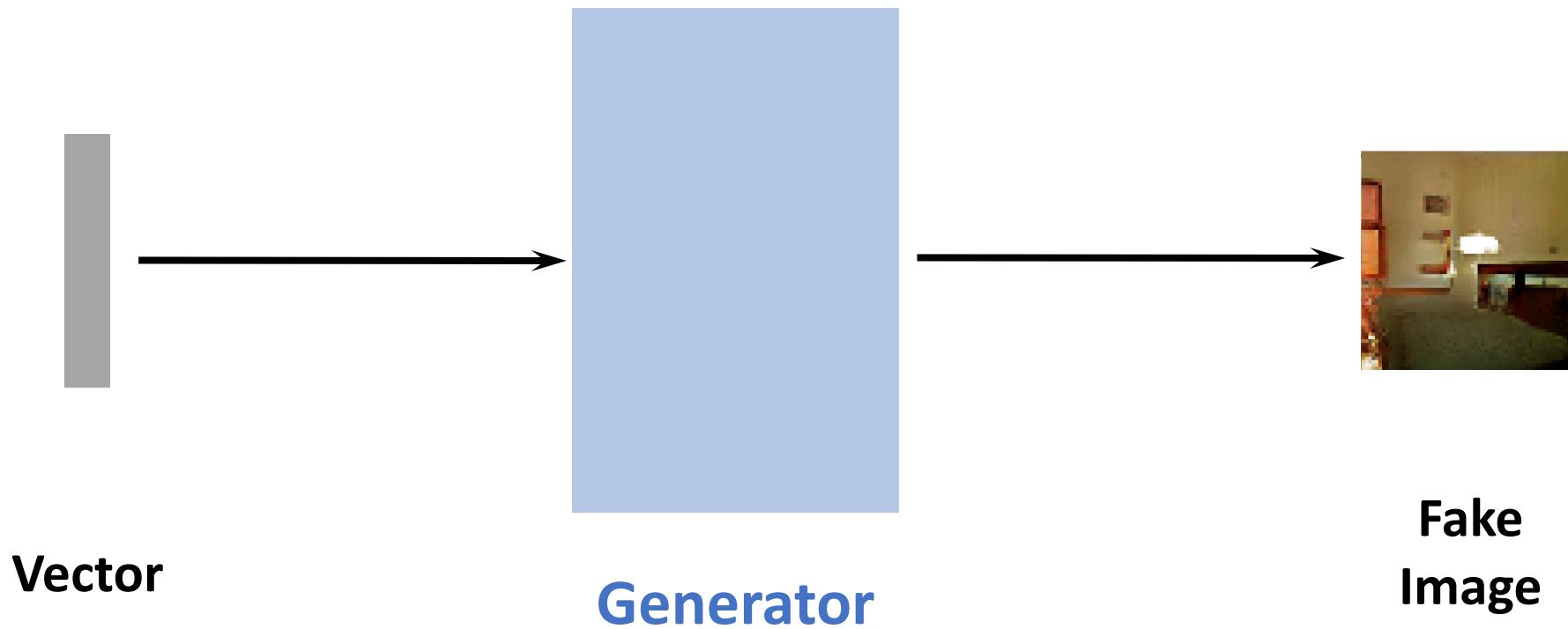
- **Generator:** a **forger** who wants to create a fake Picasso painting.
- **Discriminator:** an **art dealer**.
- Train them against each other.
 - **Forger** mixes his fake with authentic paintings and ask **art dealer** to assess them.
 - **Art dealer** gives feedback about what makes a Picasso look like a Picasso.
 - **Forger** improves his competence at imitating the style of Picasso.
 - **Art dealer** improves his competence at distinguishing real and fake Picasso.
- Finally, the **art dealer** cannot distinguish between real and fake.

GAN: Model Overview



Build Generator and Discriminator Networks

Generator: From Vector to Image



Generator: From Vector to Image

```
from keras.layers import Input, Activation, BatchNormalization, Dropout
from keras.layers import Dense, Reshape, UpSampling2D, Conv2DTranspose

depth = 256
dim = 7

input_vec = Input(shape=(100,), name='input_vec')

dense1 = Dense(dim*dim*depth, name='dense1')(input_vec)
bn1 = BatchNormalization(momentum=0.9, name='bn1')(dense1)
act1 = Activation('relu', name='act1')(bn1)
dropout1 = Dropout(rate=0.4, name='dropout1')(act1)
reshape1 = Reshape((dim, dim, depth), name='reshape1')(dropout1)

us2 = UpSampling2D(name='upsampling2')(reshape1)
convt2 = Conv2DTranspose(int(depth/2), 5, padding='same', name='convt2')(us2)
bn2 = BatchNormalization(momentum=0.9, name='bn2')(convt2)
act2 = Activation('relu', name='act2')(bn2)

us3 = UpSampling2D(name='upsampling3')(act2)
convt3 = Conv2DTranspose(int(depth/4), 5, padding='same', name='convt3')(us3)
bn3 = BatchNormalization(momentum=0.9, name='bn3')(convt3)
act3 = Activation('relu', name='act3')(bn3)

convt4 = Conv2DTranspose(int(depth/8), 5, padding='same', name='convt4')(act3)
bn4 = BatchNormalization(momentum=0.9, name='bn4')(convt4)
act4 = Activation('relu', name='act4')(bn4)

convt5 = Conv2DTranspose(1, 5, padding='same', activation='sigmoid', name='convt5')(act4)
```

Block 1:

from 100-dim to $7 \times 7 \times 256$

Block 2:

from $7 \times 7 \times 256$ to $14 \times 14 \times 128$

Block 3:

From $14 \times 14 \times 128$ to $28 \times 28 \times 64$

Block 4:

From $28 \times 28 \times 64$ to $28 \times 28 \times 32$

Generator: From Vector to Image

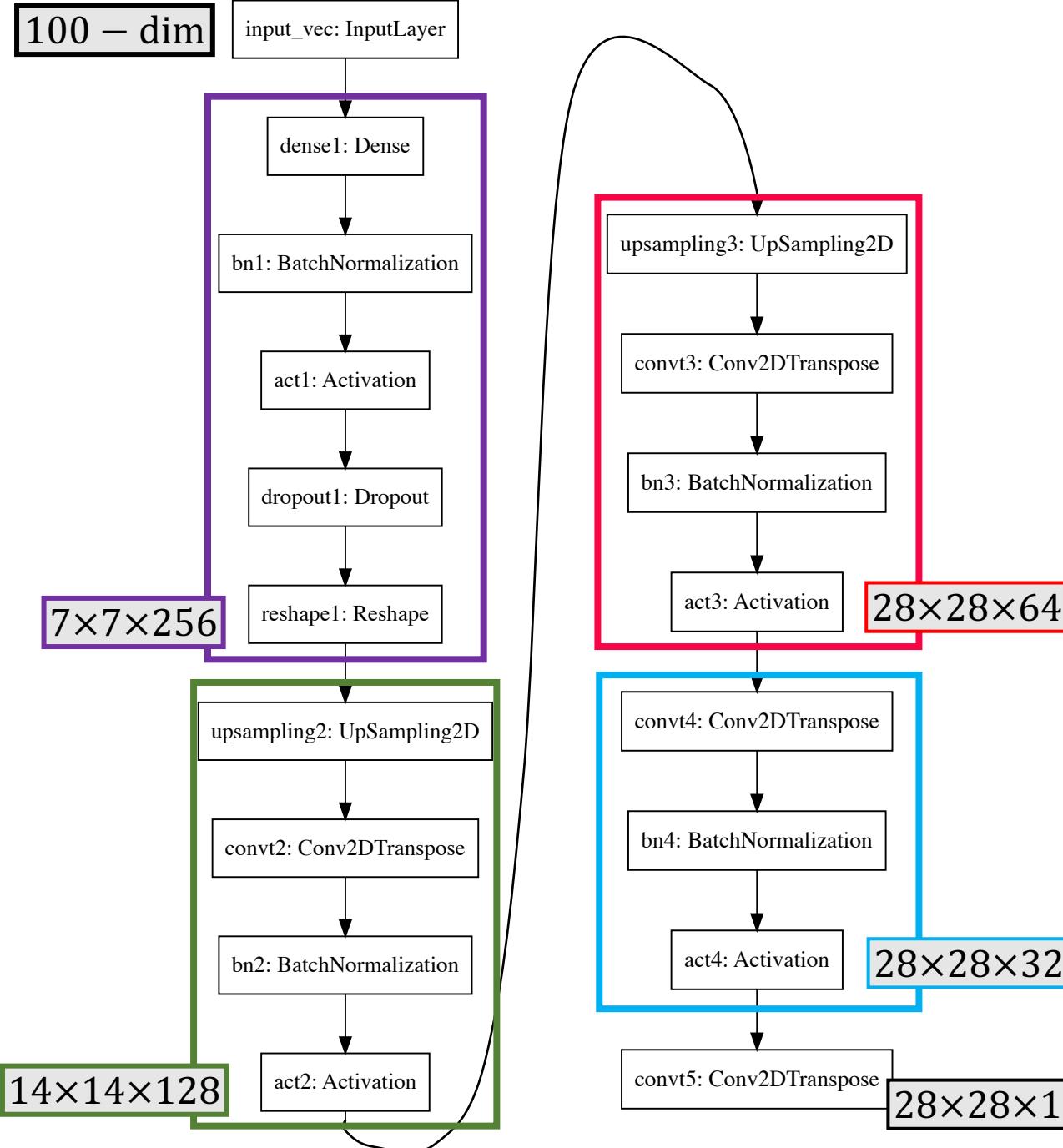
```
from keras.models import Model  
  
generator = Model(inputs=input_vec, outputs=conv5, name='generator')
```

Layer (type)	Output Shape	Param #
input_vec (InputLayer)	(None, 100)	0
dense1 (Dense)	(None, 12544)	1266944
bn1 (BatchNormalization)	(None, 12544)	50176
act1 (Activation)	(None, 12544)	0
dropout1 (Dropout)	(None, 12544)	0
reshape1 (Reshape)	(None, 7, 7, 256)	0
upsampling2 (UpSampling2D)	(None, 14, 14, 256)	0
convt2 (Conv2DTranspose)	(None, 14, 14, 128)	819328
bn2 (BatchNormalization)	(None, 14, 14, 128)	512
act2 (Activation)	(None, 14, 14, 128)	0
upsampling3 (UpSampling2D)	(None, 28, 28, 128)	0
convt3 (Conv2DTranspose)	(None, 28, 28, 64)	204864
bn3 (BatchNormalization)	(None, 28, 28, 64)	256
act3 (Activation)	(None, 28, 28, 64)	0
convt4 (Conv2DTranspose)	(None, 28, 28, 32)	51232
bn4 (BatchNormalization)	(None, 28, 28, 32)	128
act4 (Activation)	(None, 28, 28, 32)	0
convt5 (Conv2DTranspose)	(None, 28, 28, 1)	801

Total params: 2,394,241

Trainable params: 2,368,705

Non-trainable params: 25,536



Discriminator: From Image to Binary

```
from keras.layers import Input, LeakyReLU, Dropout
from keras.layers import Dense, Flatten, Conv2D

depth = 64

input_img = Input(shape=(28, 28, 1), name='input_img')

conv1 = Conv2D(depth, 5, strides=2, padding='same', name='conv1')(input_img)
act1 = LeakyReLU(alpha=0.2, name='act1')(conv1)
dropout1 = Dropout(0.4, name='dropout1')(act1)

conv2 = Conv2D(depth*2, 5, strides=2, padding='same', name='conv2')(dropout1)
act2 = LeakyReLU(alpha=0.2, name='act2')(conv2)
dropout2 = Dropout(0.4, name='dropout2')(act2)

conv3 = Conv2D(depth*4, 5, strides=2, padding='same', name='conv3')(dropout2)
act3 = LeakyReLU(alpha=0.2, name='act3')(conv3)
dropout3 = Dropout(0.4, name='dropout3')(act3)

conv4 = Conv2D(depth*8, 5, strides=1, padding='same', name='conv4')(dropout3)
act4 = LeakyReLU(alpha=0.2, name='act4')(conv4)
dropout4 = Dropout(0.4, name='dropout4')(act4)

flat5 = Flatten(name='flat5')(dropout4)
dense5 = Dense(1, activation='sigmoid', name='dense5')(flat5)
```

Block 1:
from $28 \times 28 \times 1$ to $14 \times 14 \times 64$

Block 2:
from $14 \times 14 \times 64$ to $7 \times 7 \times 128$

Block 3:
From $7 \times 7 \times 128$ to $4 \times 4 \times 256$

Block 4:
From $4 \times 4 \times 256$ to $4 \times 4 \times 512$

Discriminator: From Image to Binary

```
from keras.models import Model  
  
discriminator = Model(inputs=input_img, outputs=dense5, name='discriminator')
```

Training

Training of GAN

Alternating minimization

Repeat the 2 steps:

1. Update the **discriminator network**;
2. Update the **generator network**.

Update the **Discriminator**

Train a classifier

1. Generate a batch of **fake images** by the **generator**;
2. Randomly sample a batch of **real images**;
3. Inputs: $\mathbf{X} = [\text{real_images}, \text{ fake_images}]$;
4. Targets: $\mathbf{y} = [\text{True}, \dots, \text{True}, \text{False}, \dots, \text{False}]$;
5. Update the **discriminator network** using \mathbf{X} and \mathbf{y} .

Update the **Discriminator**

```
from keras.optimizers import RMSprop

optimizer = RMSprop(lr=0.0002, decay=6e-8)
discriminator.compile(loss='binary_crossentropy',
                      optimizer=optimizer,
                      metrics=[ 'accuracy' ] )
```

Update the Discriminator

```
# train the discriminator Uniformly sample a batch of real images
discriminator.trainable = True
rand_idx = np.random.randint(0, n, size=batch_size)
images_real = x_train[rand_idx]
latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
images_fake = generator.predict(latent_vecs)
x = np.concatenate((images_real, images_fake), axis=0)
y = np.concatenate([np.ones((batch_size, 1)),
                    np.zeros((batch_size, 1))])
d_loss = discriminator.train_on_batch(x, y)
```

Update the **Discriminator**

```
# train the discriminator
discriminator.trainable = True                                Generate fake images
rand_idx = np.random.randint(0, n, size=batch_size)
images_real = x_train[rand_idx]
latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
images_fake = generator.predict(latent_vecs)
x = np.concatenate((images_real, images_fake), axis=0)
y = np.concatenate([np.ones((batch_size, 1)),
                    np.zeros((batch_size, 1))])
d_loss = discriminator.train_on_batch(x, y)
```

Update the **Discriminator**

```
# train the discriminator
discriminator.trainable = True
rand_idx = np.random.randint(0, n, size=batch_size)
images_real = x_train[rand_idx]
latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
images_fake = generator.predict(latent_vecs)
x = np.concatenate((images_real, images_fake), axis=0)
y = np.concatenate([np.ones((batch_size, 1)),
                    np.zeros((batch_size, 1))])
a_loss = aiscriminator.train_on_batch(x, y)
```

Set input and targets

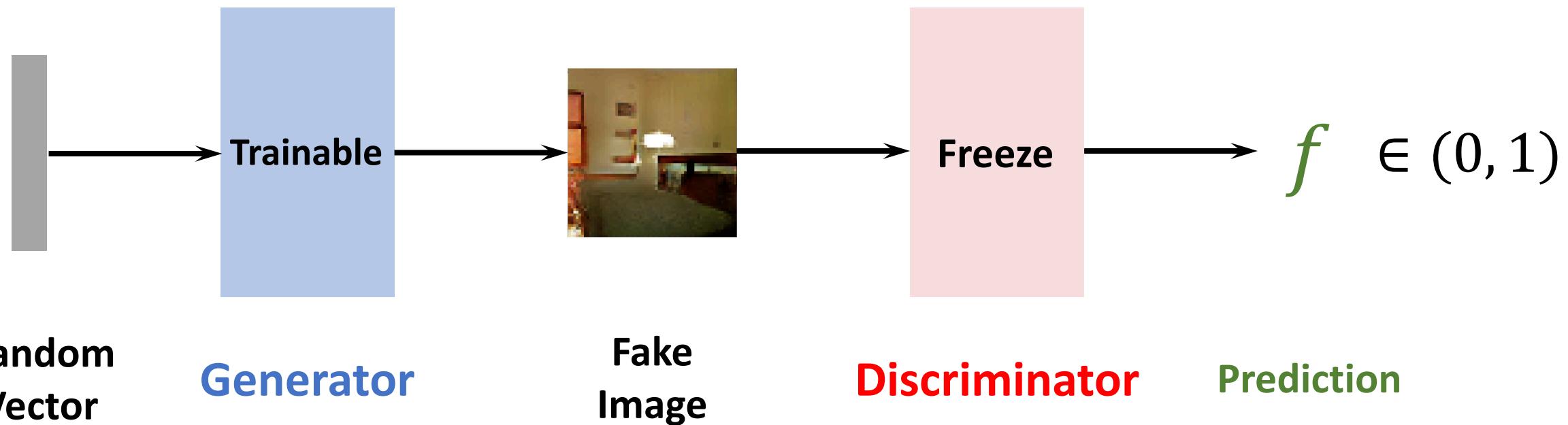
Update the Discriminator

```
# train the discriminator
discriminator.trainable = True
rand_idx = np.random.randint(0, n, size=batch_size)
images_real = x_train[rand_idx]
latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
images_fake = generator.predict(latent_vecs)
x = np.concatenate((images_real, images_fake), axis=0)
y = np.concatenate([np.ones((batch_size, 1)),
                    np.zeros((batch_size, 1))])
d_loss = discriminator.train_on_batch(x, y)
```

One update of the discriminator's parameters

Update the Generator

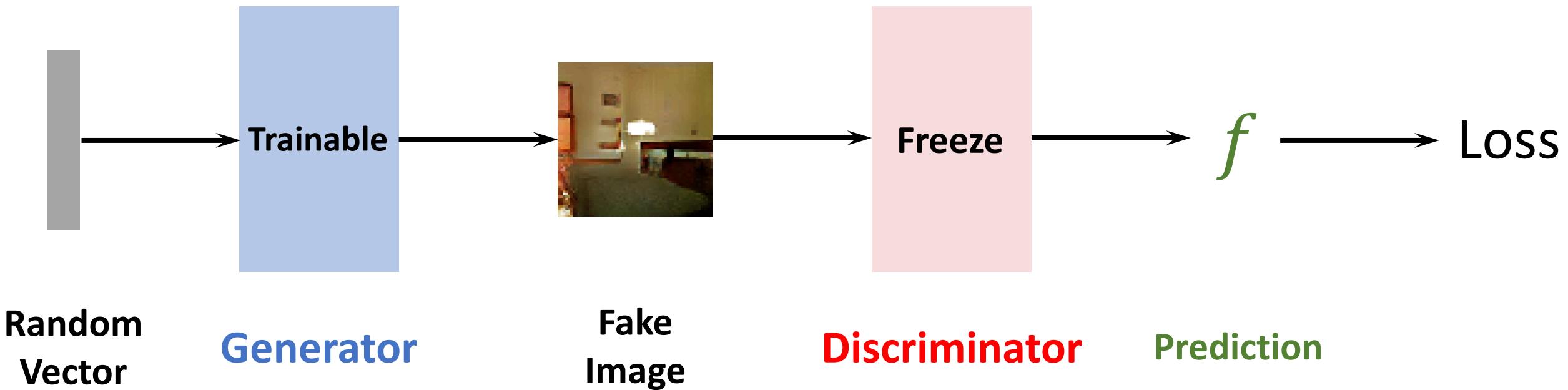
Connect the **generator** and **discriminator** (freeze **discriminator's** parameters).



Update the Generator

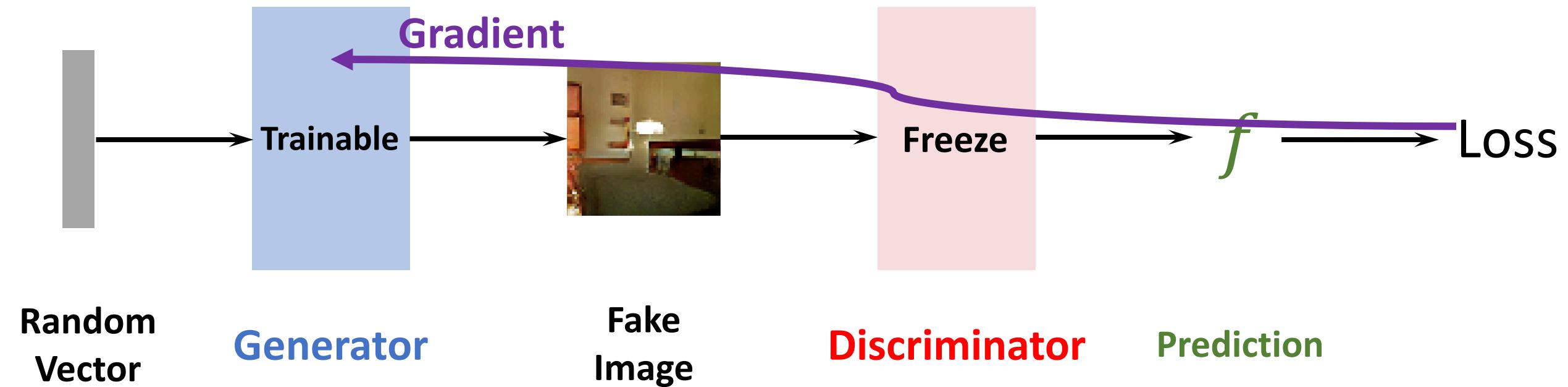
Connect the **generator** and **discriminator** (freeze **discriminator's** parameters).

Minimize Loss = $\text{Dist}(\text{True}, f)$ w.r.t. **generator**. (Encourage f be **True**.)



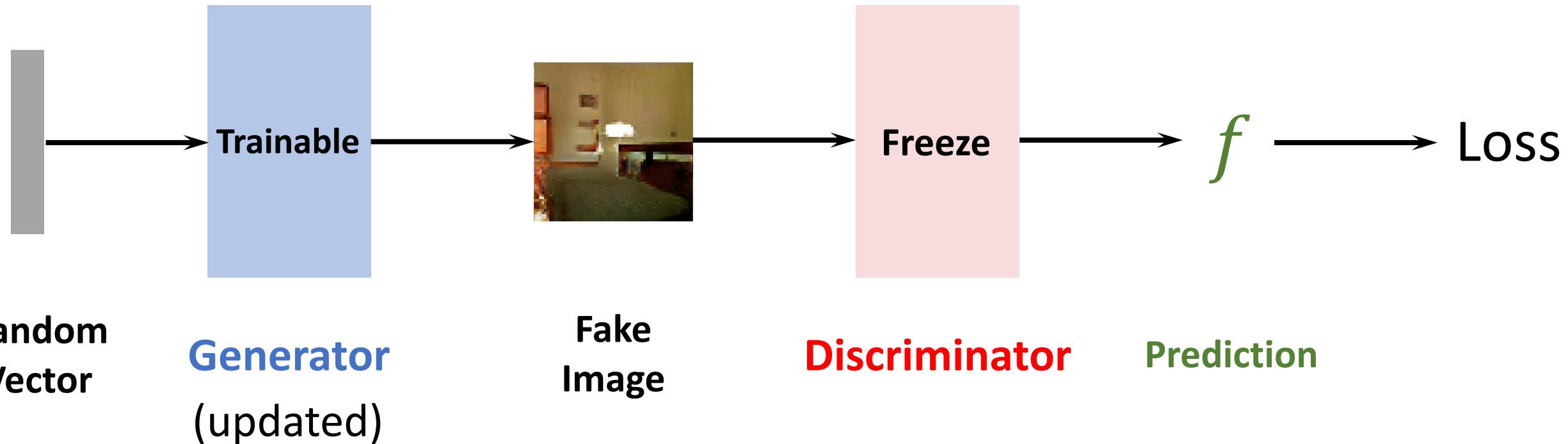
Update the Generator

- \mathbf{W}_G : parameters in the generator.
- Gradient: $\text{Grad} = \frac{\partial \text{Loss}}{\partial \mathbf{W}_G}$.



Update the Generator

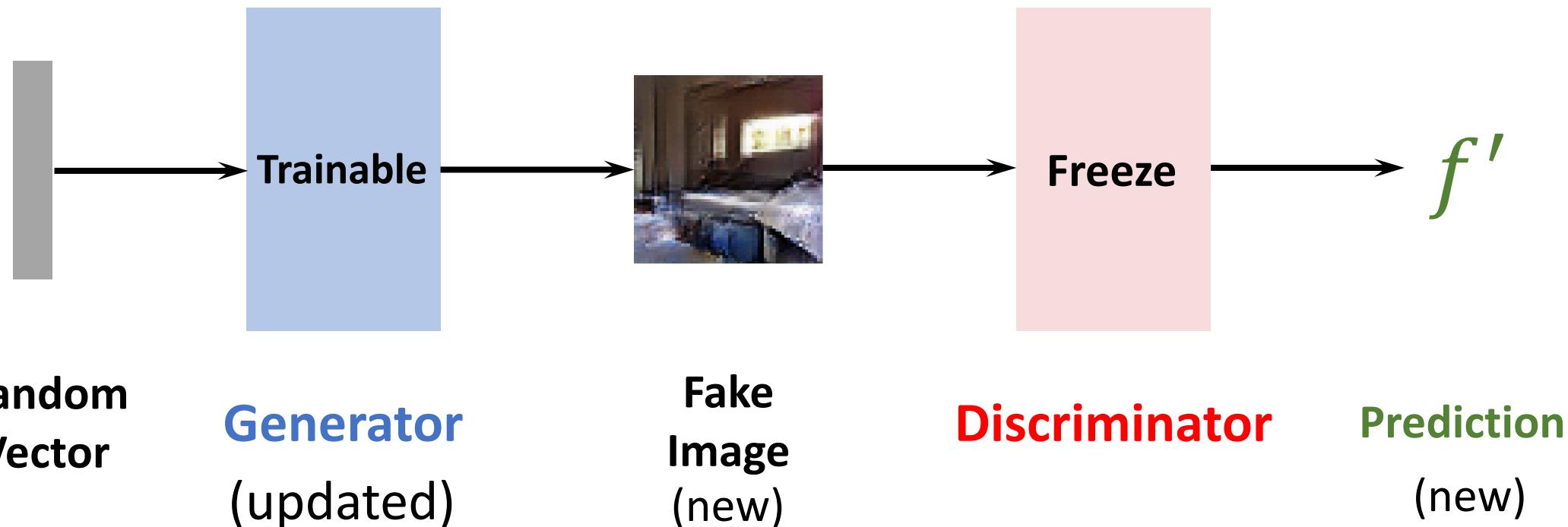
- \mathbf{W}_G : parameters in the generator.
- Gradient: $\text{Grad} = \frac{\partial \text{Loss}}{\partial \mathbf{W}_G}$.
- Gradient descent: $\mathbf{W}_G \leftarrow \mathbf{W}_G - \alpha \cdot \text{Grad}$.



Update the Generator

Question: What will happen if we do the followings? (We don't actually do.)

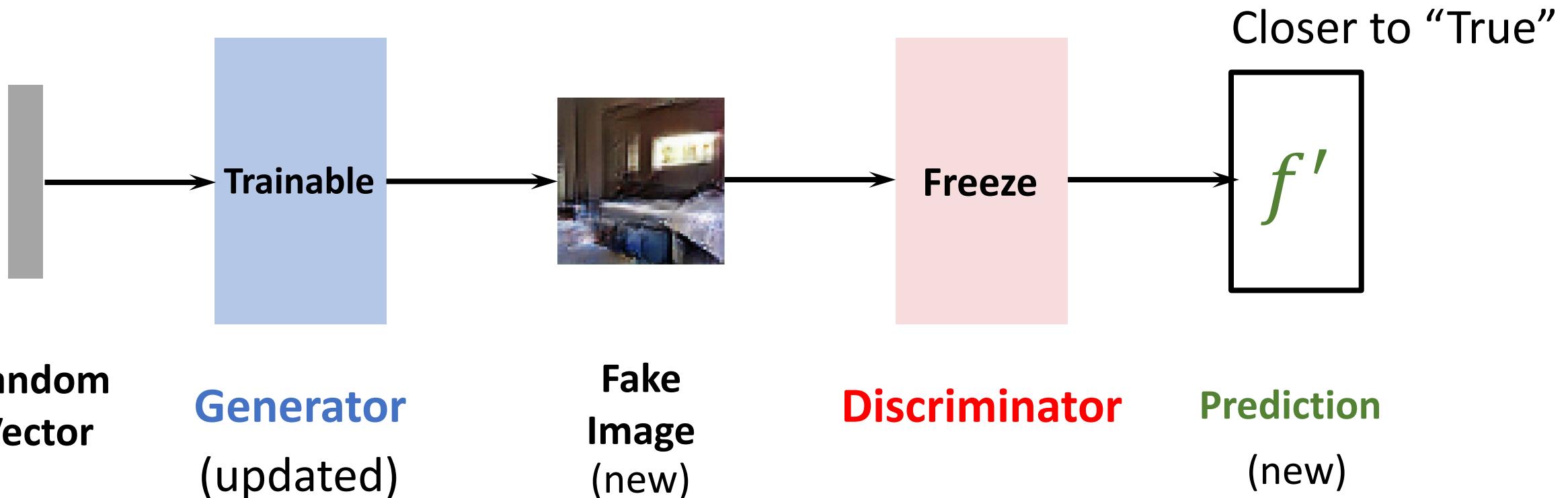
- Use the same **vector**.
- Generate a fake image using the updated **generator**.



Update the Generator

Question: What will happen if we do the followings? (We don't actually do.)

- Use the same **vector**.
- Generate a fake image using the updated **generator**.
- The **discriminator** thinks the new fake image more “real” than before.



Update the Generator

Connect the generator and discriminator (freeze discriminator's parameters).

```
from keras.layers import Input
from keras.models import Model

discriminator.trainable = False
gan_input = Input(shape=(100,), name='gan_input')
fake_img = generator(gan_input)
f = discriminator(fake_img)
gan = Model(inputs=gan_input, outputs=f, name='gan')
```

Update the Generator

Connect the generator and discriminator (freeze discriminator's parameters).

Minimize Loss = $\text{Dist}(\text{True}, f)$ w.r.t. generator. (Encourage f be True.)

```
from keras.optimizers import RMSprop

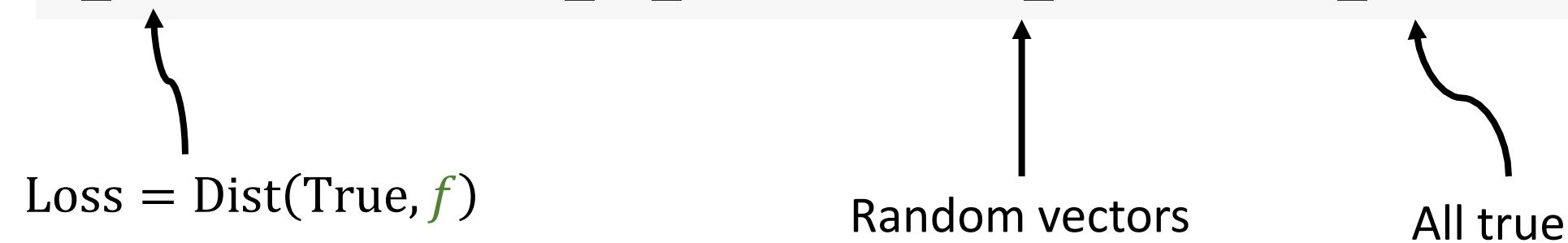
gan_optimizer = RMSprop(lr=0.0001, decay=3e-8)
gan.compile(optimizer=gan_optimizer,
            loss='binary_crossentropy',
            metrics=[ 'accuracy' ] )
```

Update the Generator

Connect the **generator** and **discriminator** (freeze **discriminator's** parameters).

Minimize Loss = $\text{Dist}(\text{True}, f)$ w.r.t. **generator**. (Encourage f be **True**.)

```
# train the generator
discriminator.trainable = False
fake_targets = np.ones([batch_size, 1]) # pretend the images are real
latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
a_loss = gan.train_on_batch(latent_vecs, fake_targets)
```



Summary of Training

```
for t in range(train_steps):
    # train the discriminator
    discriminator.trainable = True
    rand_idx = np.random.randint(0, n, size=batch_size)
    images_real = x_train[rand_idx]
    latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
    images_fake = generator.predict(latent_vecs)
    x = np.concatenate((images_real, images_fake), axis=0)
    y = np.concatenate([np.ones((batch_size, 1)),
                        np.zeros((batch_size, 1))])
    d_loss = discriminator.train_on_batch(x, y)

    # train the generator
    discriminator.trainable = False
    fake_targets = np.ones([batch_size, 1]) # pretend the images are real
    latent_vecs = np.random.uniform(-1.0, 1.0, size=[batch_size, 100])
    a_loss = gan.train_on_batch(latent_vecs, fake_targets)
```

Difficulties in Training GAN

Discriminator Shouldn't Be Too Good

- **Generator**: a **forger** who wants to create a fake Picasso painting.
- **Discriminator**: an **art dealer** providing feedbacks.

What if the **art dealer** is 100% correct at judging Picasso painting?

Discriminator Shouldn't Be Too Good

- **Generator**: a **forger** who wants to create a fake Picasso painting.
- **Discriminator**: an **art dealer** providing feedbacks.

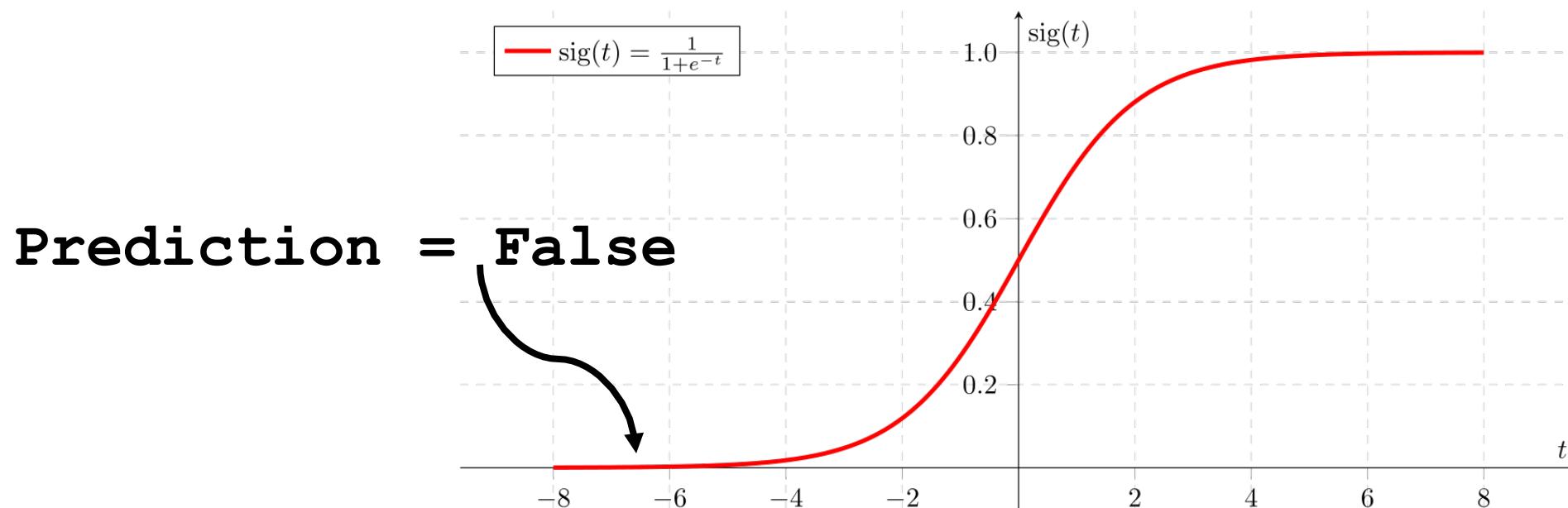
What if the **art dealer** is 100% correct at judging Picasso painting?

- Whatever forged painting sent to the **art dealer** is recognized as fake.
- The **forger** cannot learn anything from the *feedback*.
 - No positive case to follow.
- The **forger** need some success.
 - So he will know what kind of fake painting can fool the **dealer**.

Discriminator Shouldn't Be Too Good

Explanation: vanishing gradient

- Suppose the **discriminator** is perfect.
- Whatever the **generators** forged is recognized fake by the **discriminator**.
- → The gradient (averaged over a batch of samples) is near zero.



Discriminator Shouldn't Be Too Bad

- **Generator**: a **forger** who wants to create a fake Picasso painting.
- **Discriminator**: an **art dealer** providing feedbacks.

What if the **art dealer** cannot distinguish between real and fake paintings?

- The **art dealer's** judgement is almost *random guess*.
- The **forger** cannot learn anything from the *feedback*.
- → When the **forger's** skill is good, getting **amateurish art dealer's** feedback is not helpful.

Useful Tricks

1. Carefully tune the learning rates.

- If the **discriminator** improves too fast,
 - classification accuracy can be near 100%,
 - vanishing gradient,
 - the **generator** is dead.
- If the **discriminator** improves too slow,
 - the **discriminator** cannot provide useful feedback,
 - the **generator** has to wait for the **discriminator**,
 - slow convergence.

Useful Tricks

2. Add noise to the real and fake images; decay the noise over time.

- When training the **discriminator**, perturb the inputs (both real and fake images).

Useful Tricks

2. Add noise to the real and fake images; decay the noise over time.

- When training the **discriminator**, perturb the inputs (both real and fake images).

3. Add noise to the labels.

- When training the **discriminator**, perturb the labels (both real and fake images).
- Real = 1 \rightarrow Real \sim Uniform(0.7, 1.2) .
- Fake = 0 \rightarrow Fake \sim Uniform(0.0, 0.3) .

Useful Tricks

Many other tricks...

- Further reading:
- <https://github.com/soumith/ganhacks>