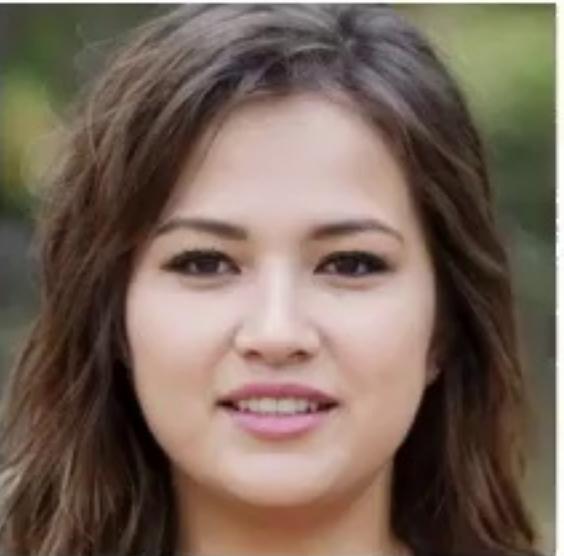


# A friendly introduction to Generative Adversarial Networks

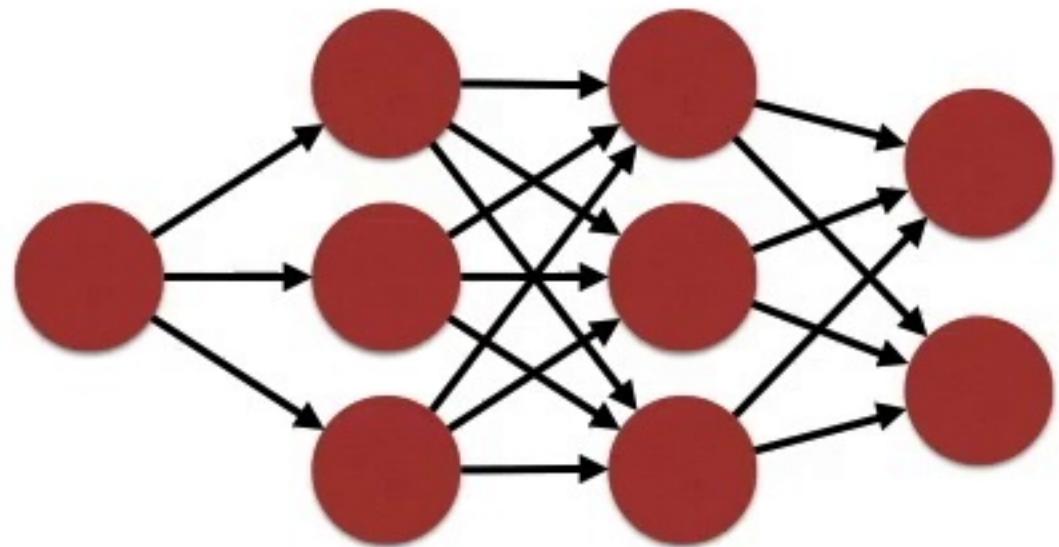
Luis Serrano

thispersondoesnotexist.com

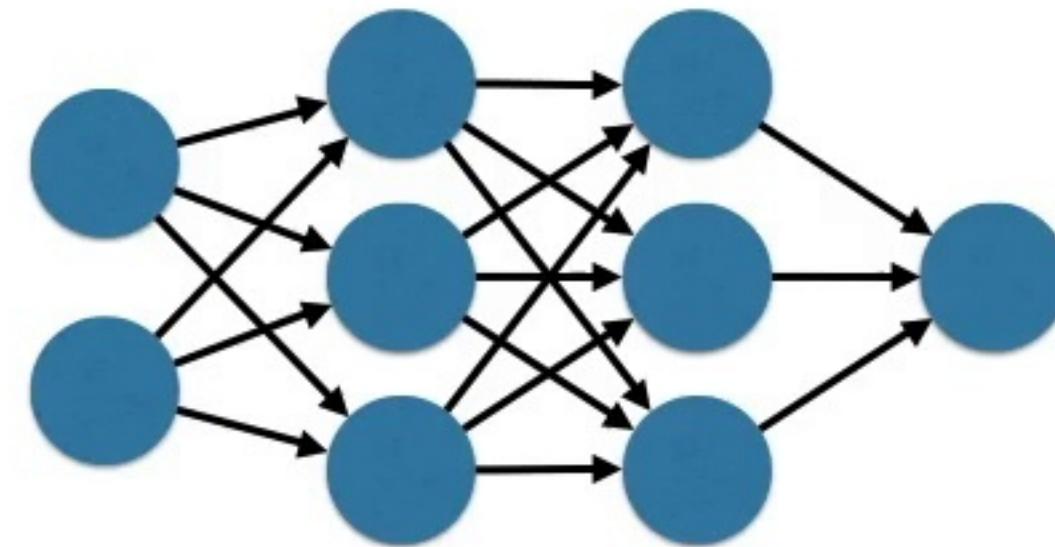


# General idea

# Generative Adversarial Networks



Generator



Discriminator

# Generative Adversarial Networks



Generator

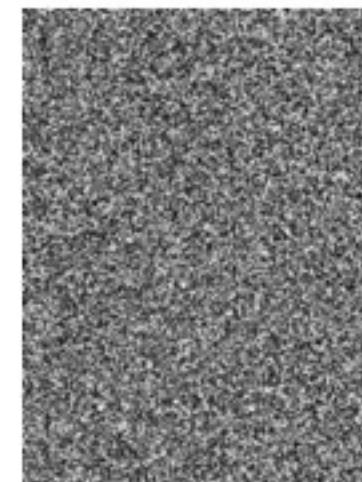


Discriminator

# Generative Adversarial Networks



Generator

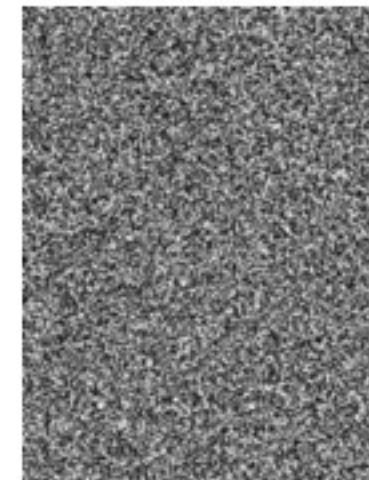


Discriminator

# Generative Adversarial Networks



Generator



Discriminator

Nope!

# Generative Adversarial Networks



Generator

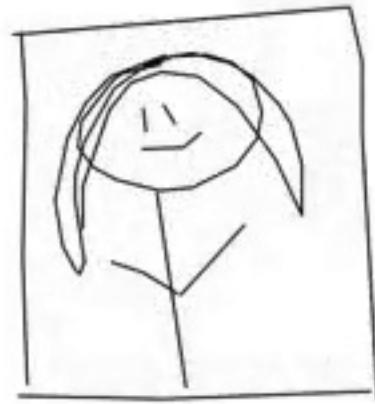


Discriminator

# Generative Adversarial Networks



Generator



Discriminator

Nope!

# Generative Adversarial Networks



Generator



Discriminator

Nope!

# Generative Adversarial Networks



Generator



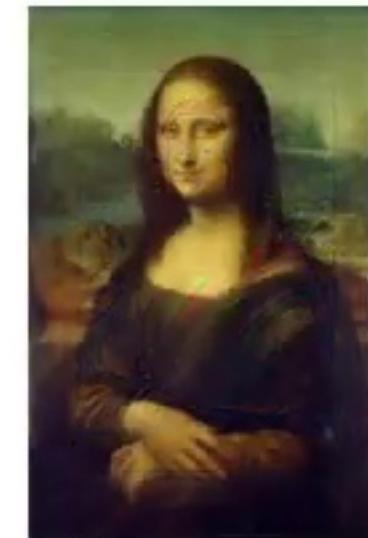
Discriminator

Nope!

# Generative Adversarial Networks



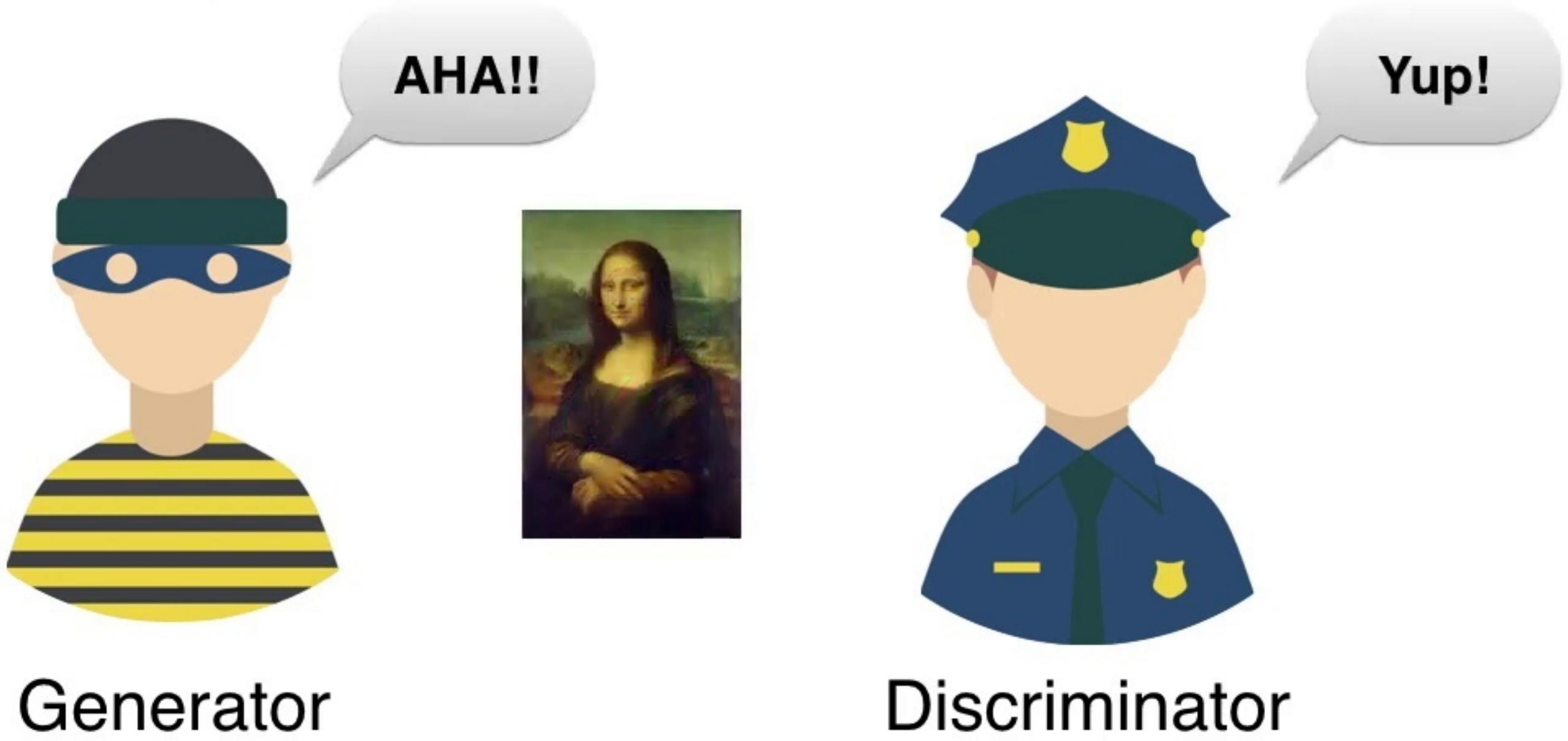
Generator



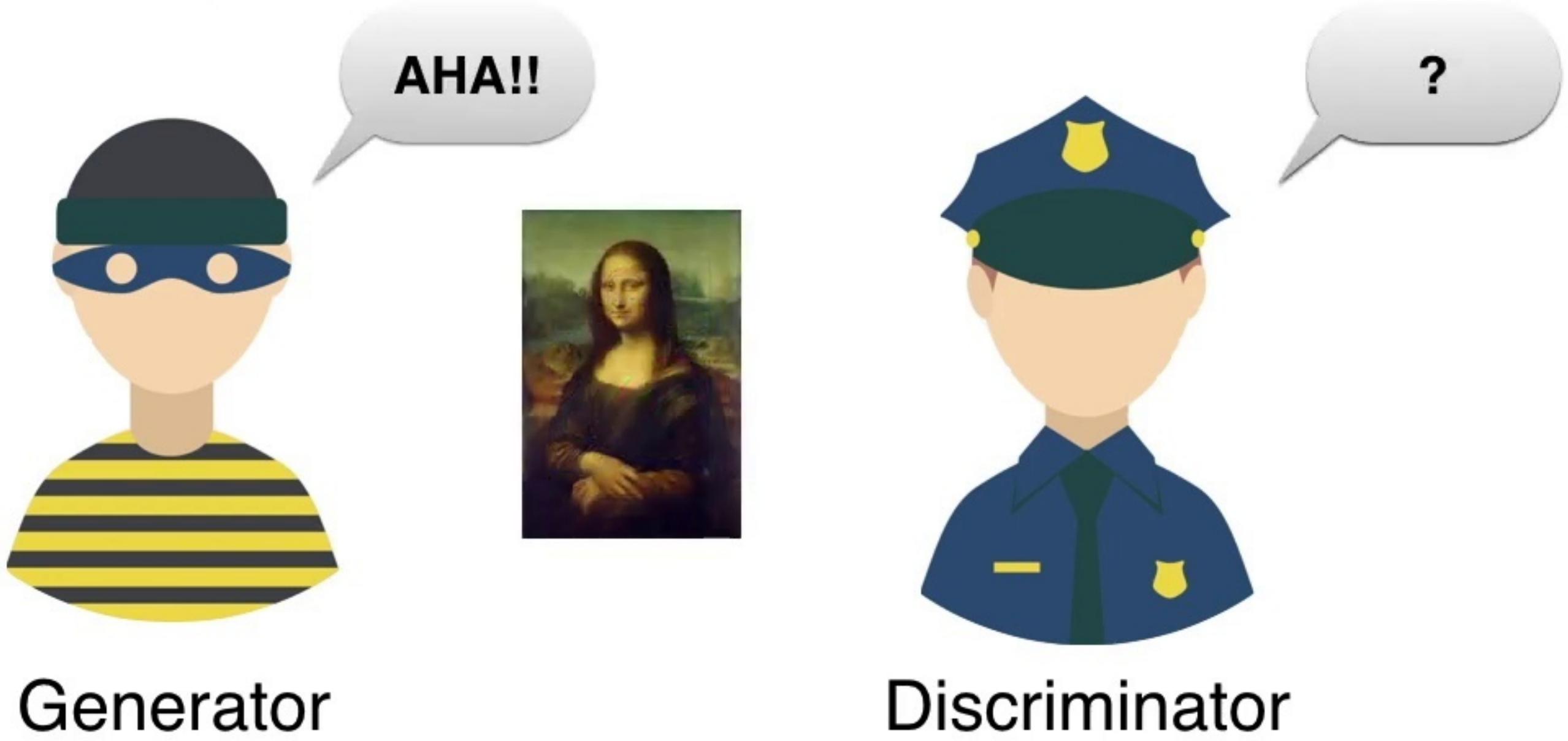
Discriminator

Yup!

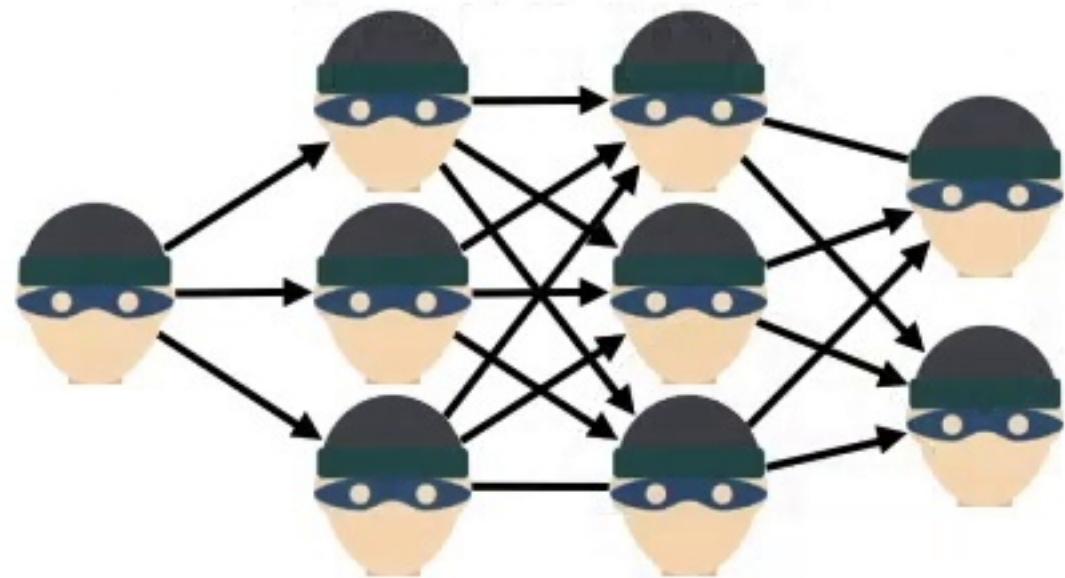
# Generative Adversarial Networks



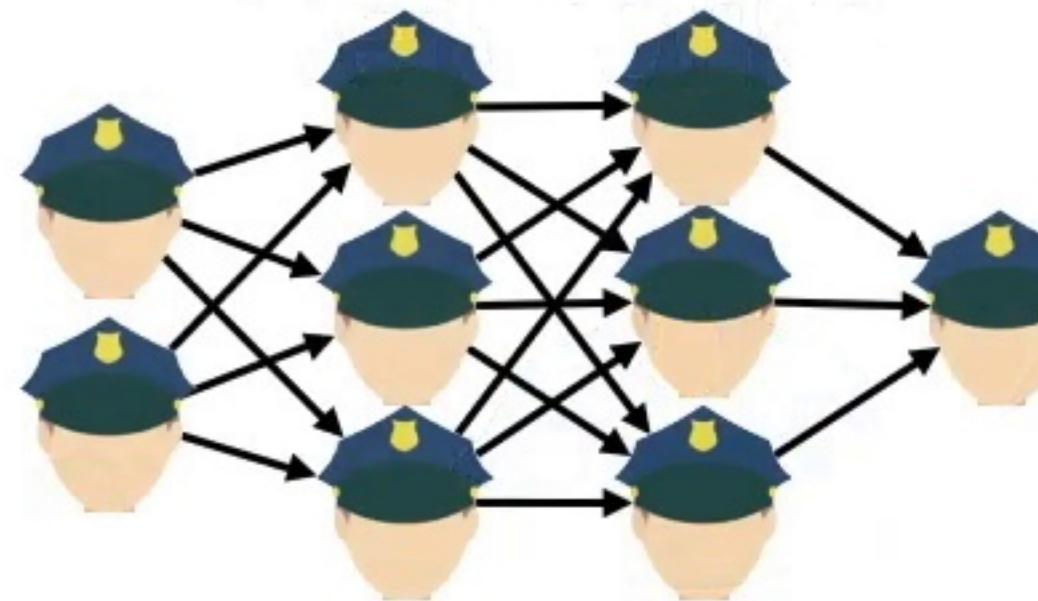
# Generative Adversarial Networks



# Generator



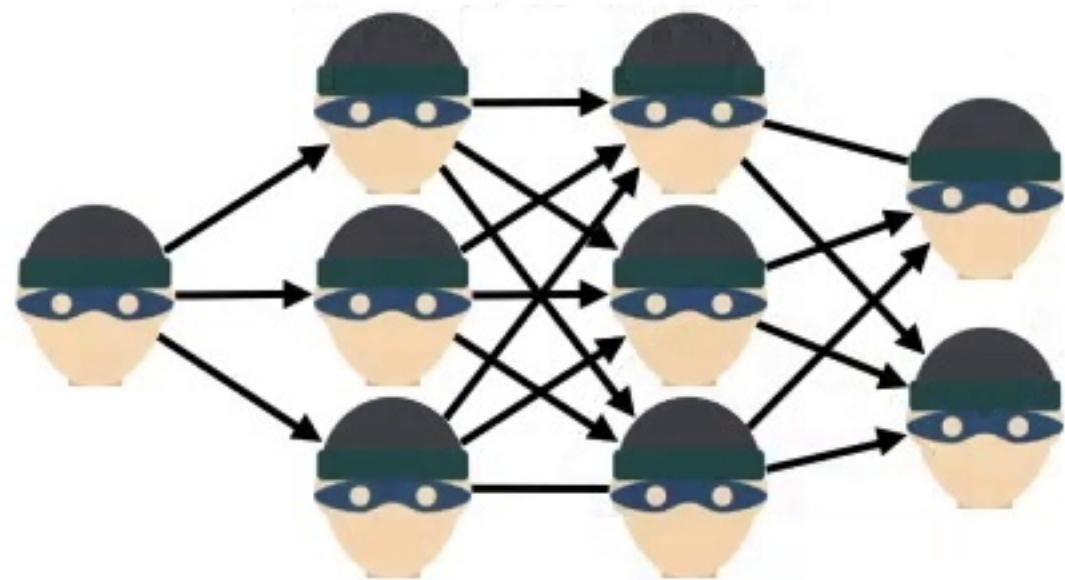
# Discriminator



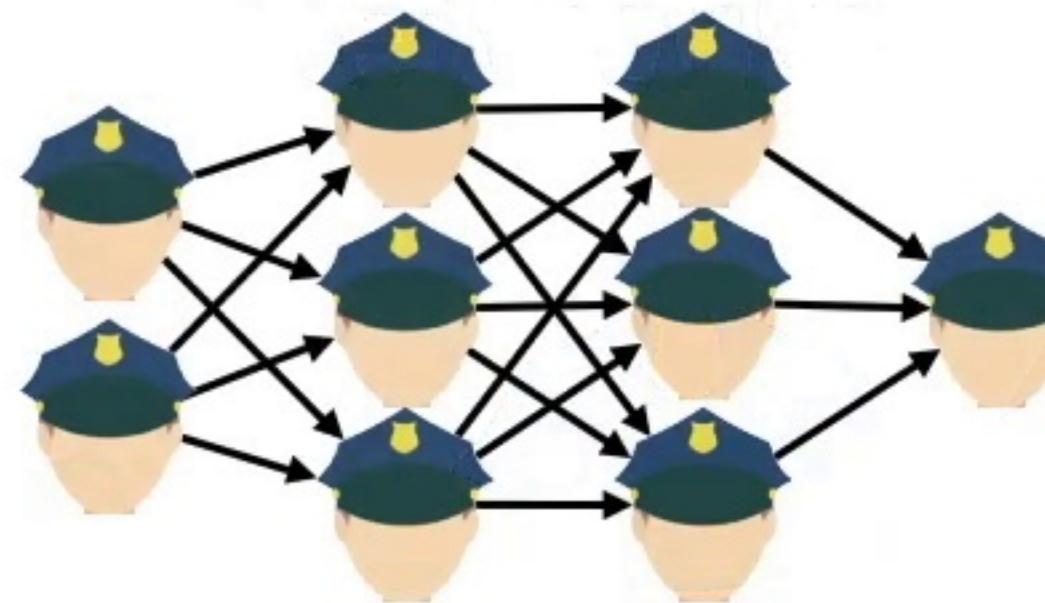
# Real images



# Generator



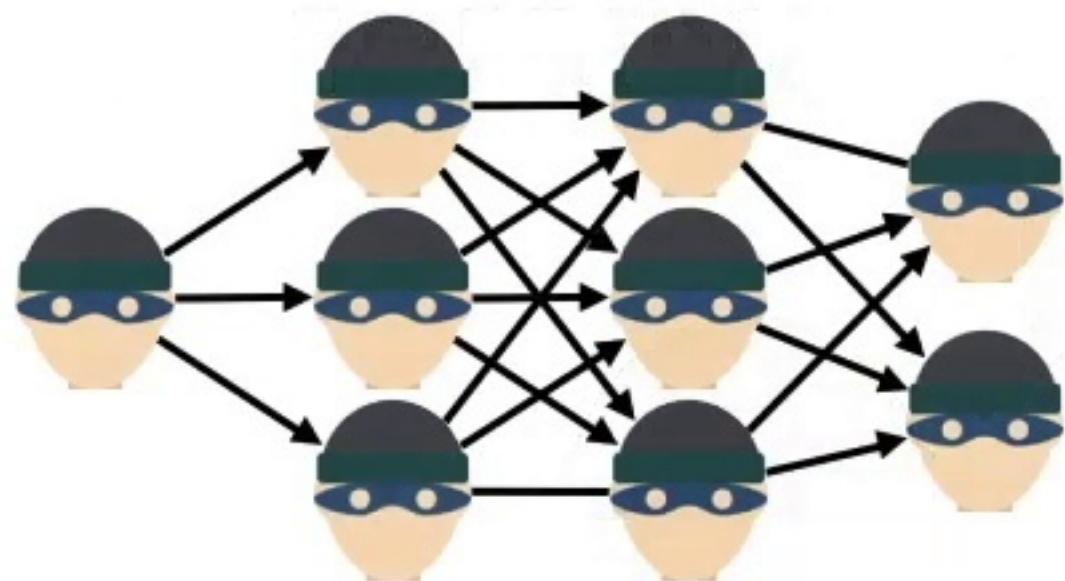
# Discriminator



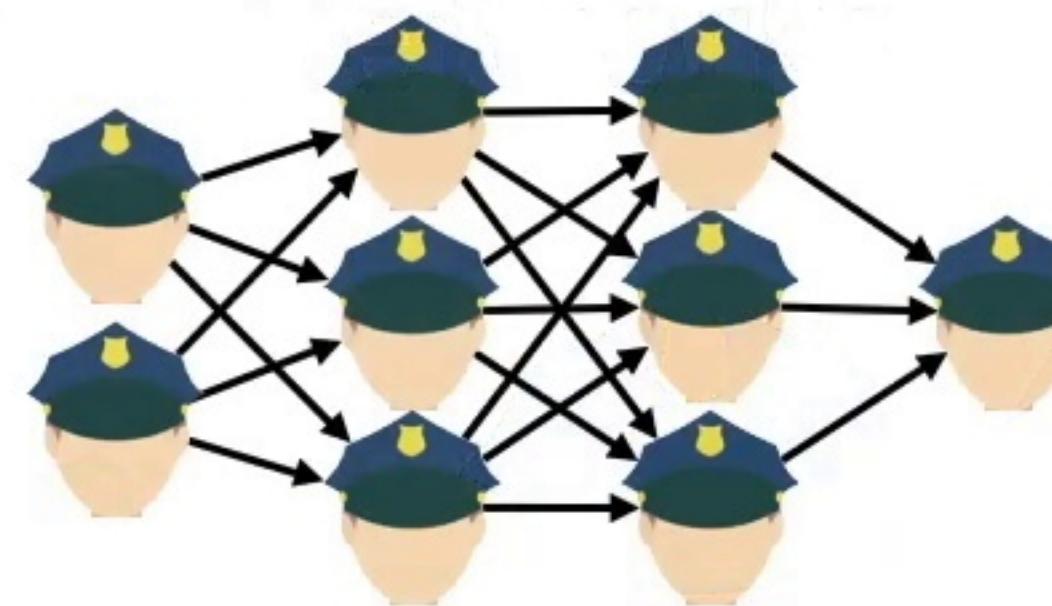
# Real images



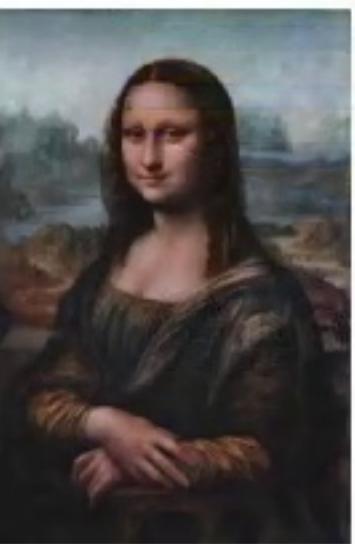
# Generator



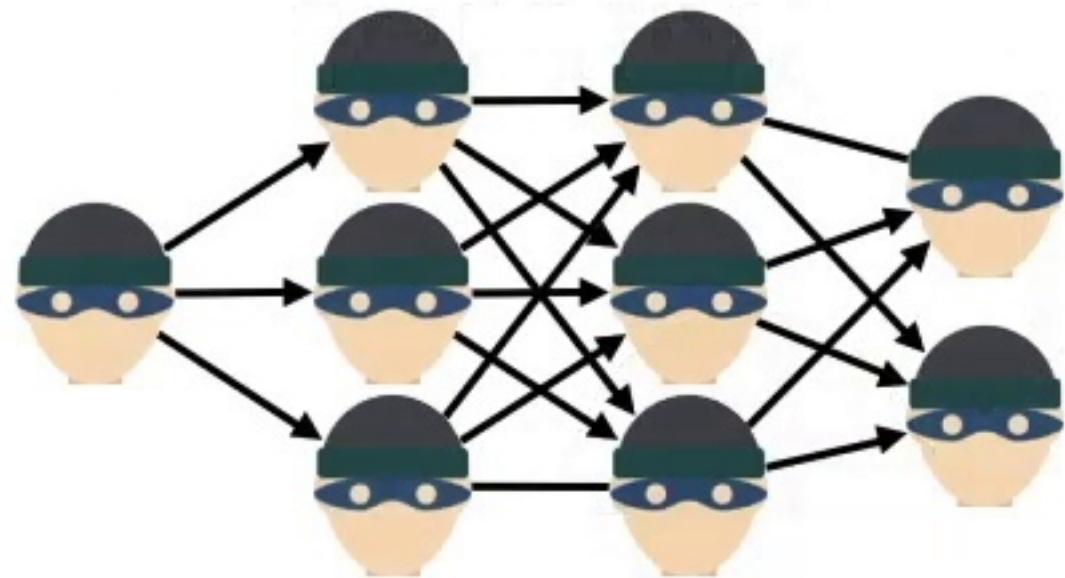
# Discriminator



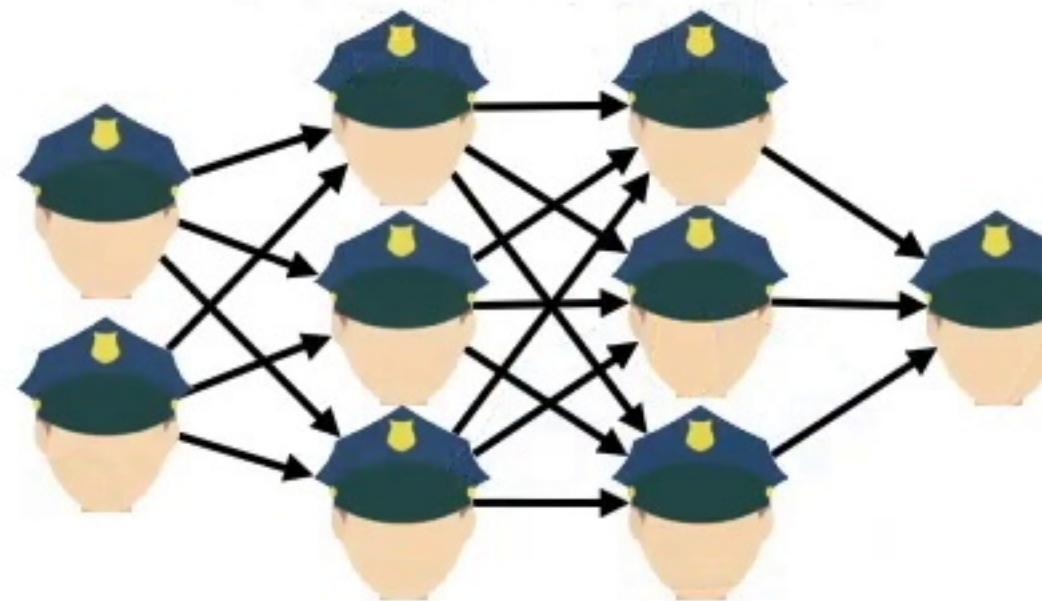
# Real images



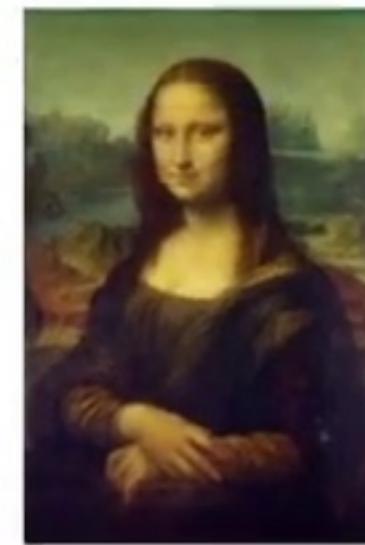
# Generator



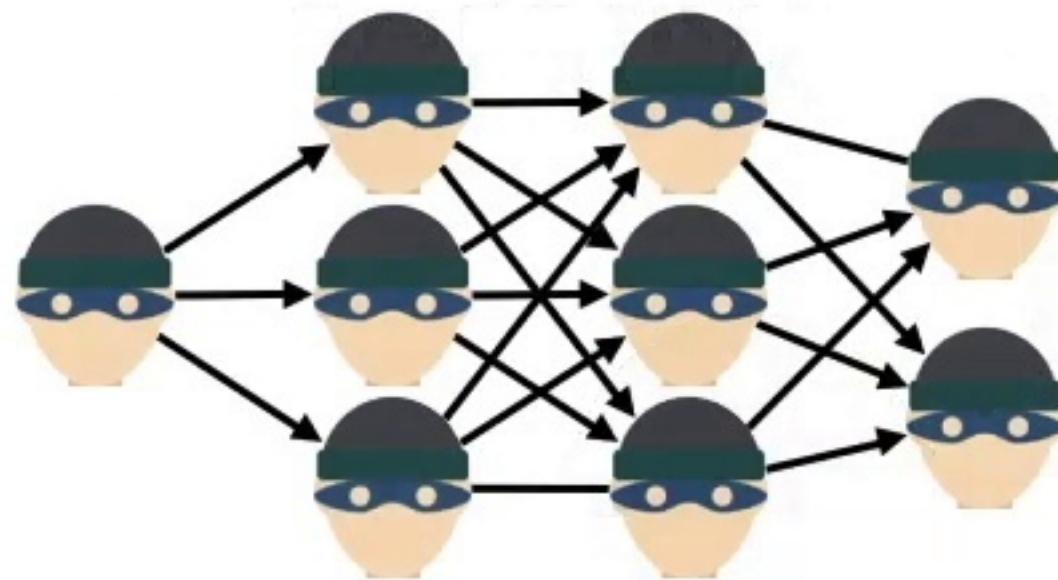
# Discriminator



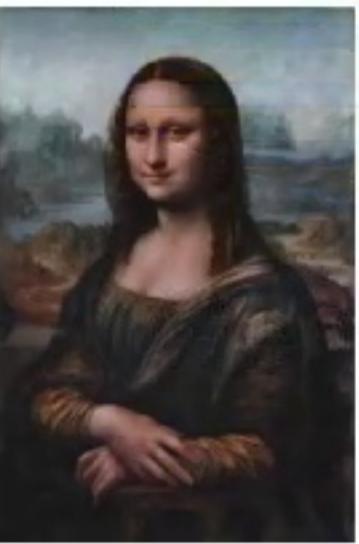
# Real images



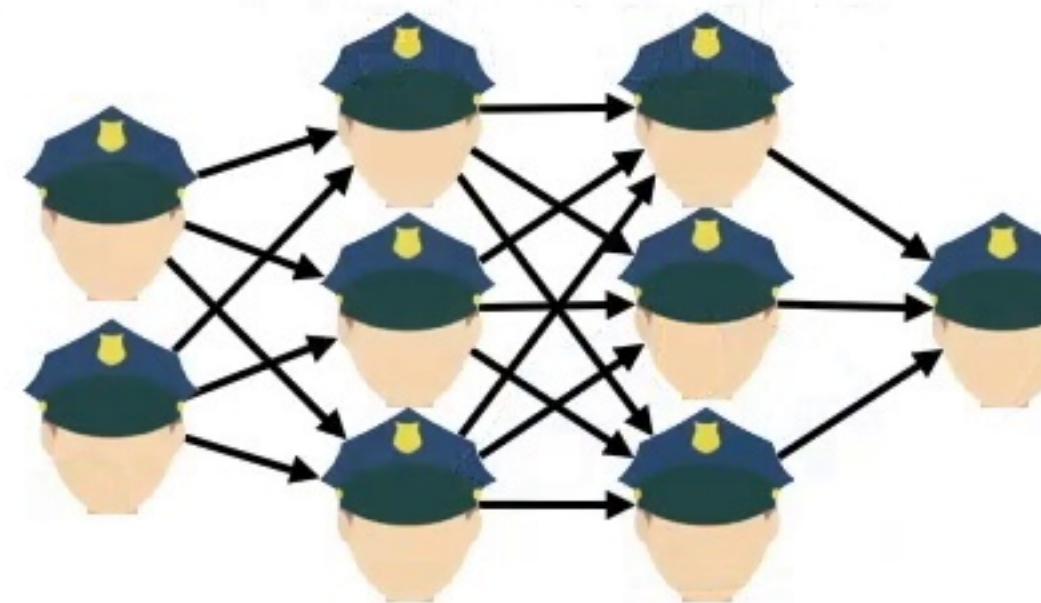
# Generator



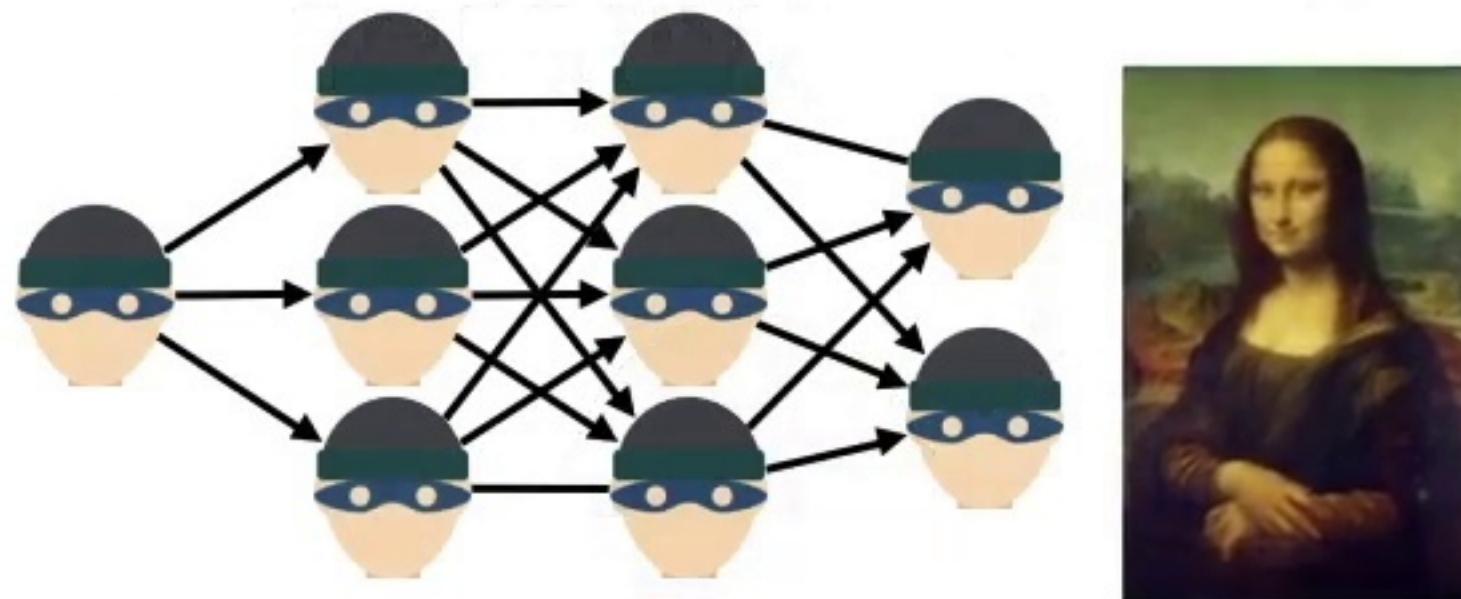
Real images



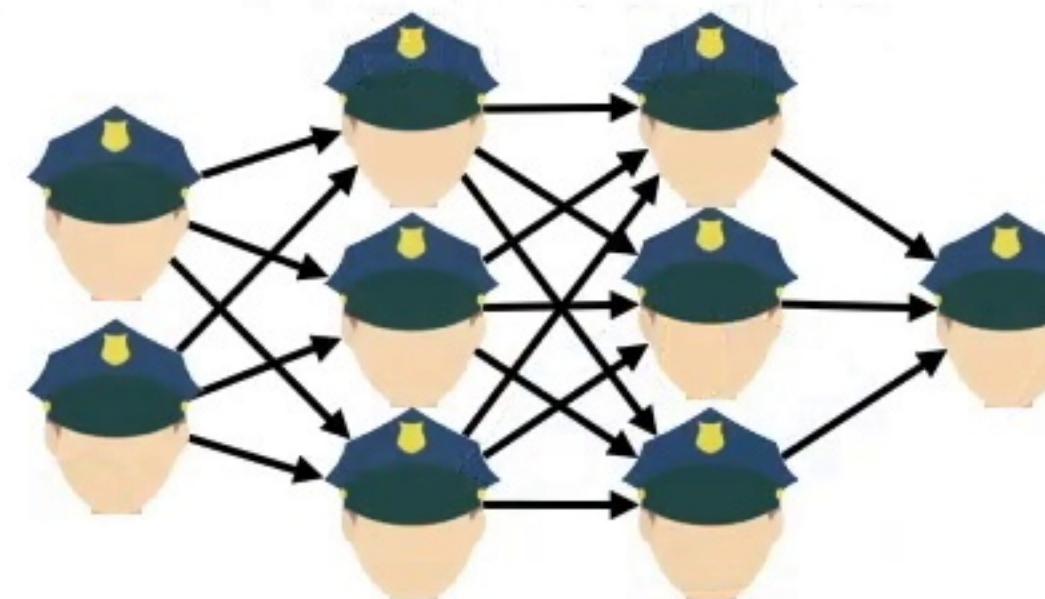
# Discriminator



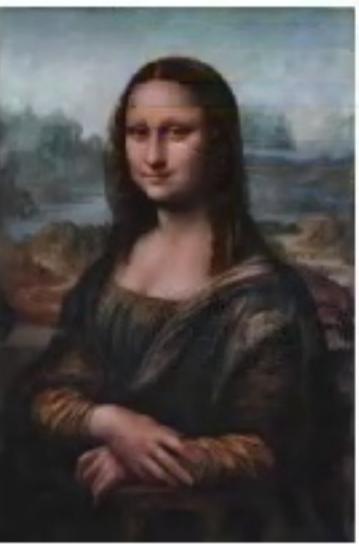
## Generator



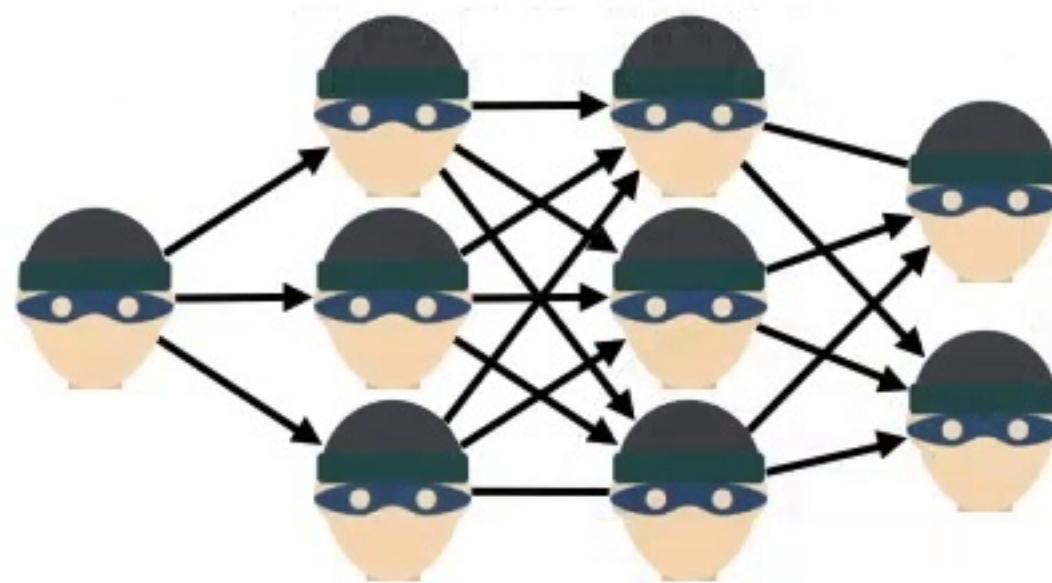
## Discriminator



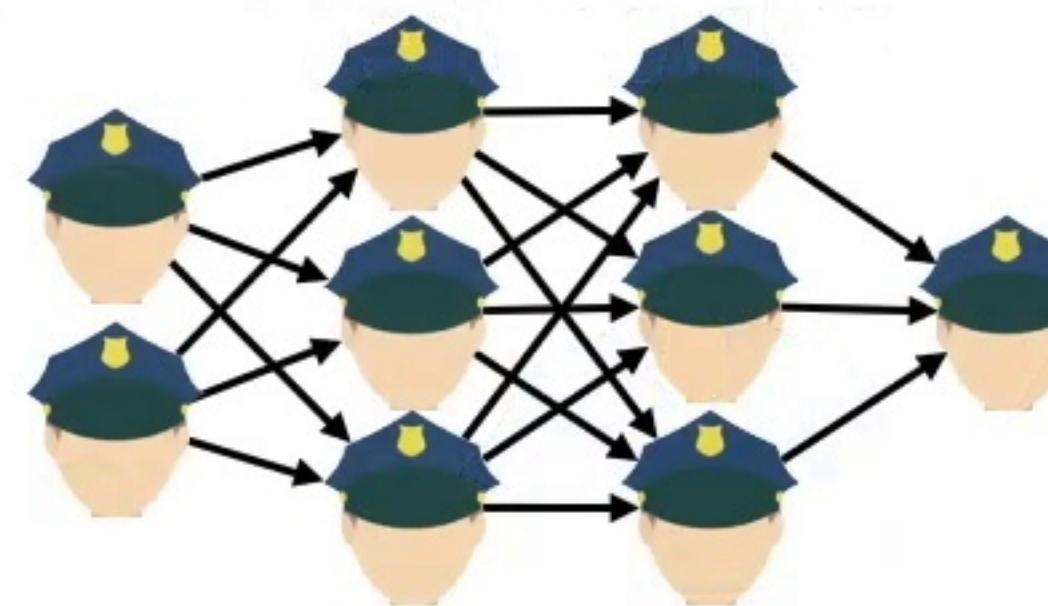
## Real images



## Generator



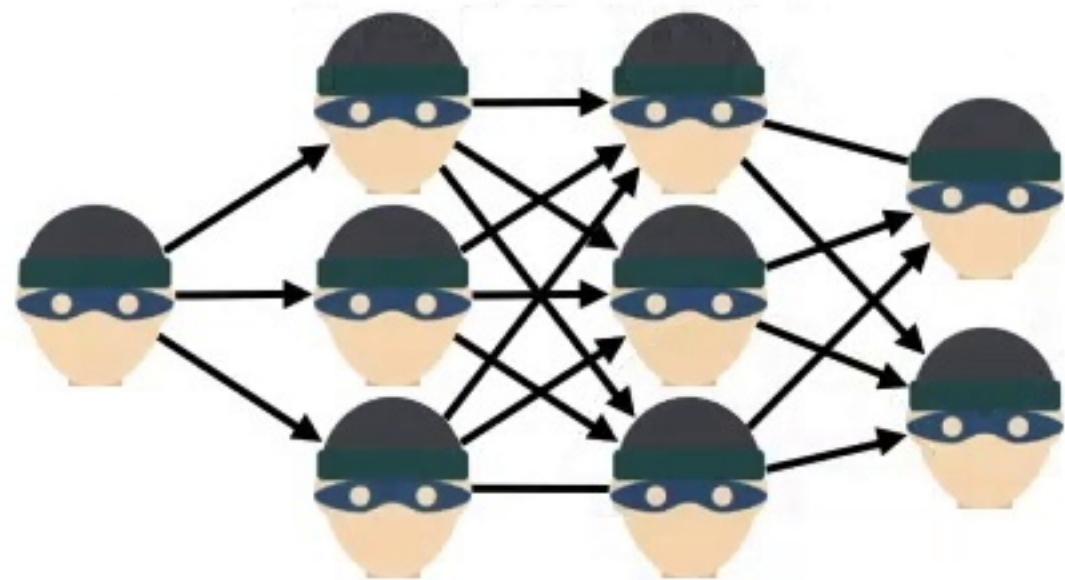
## Discriminator



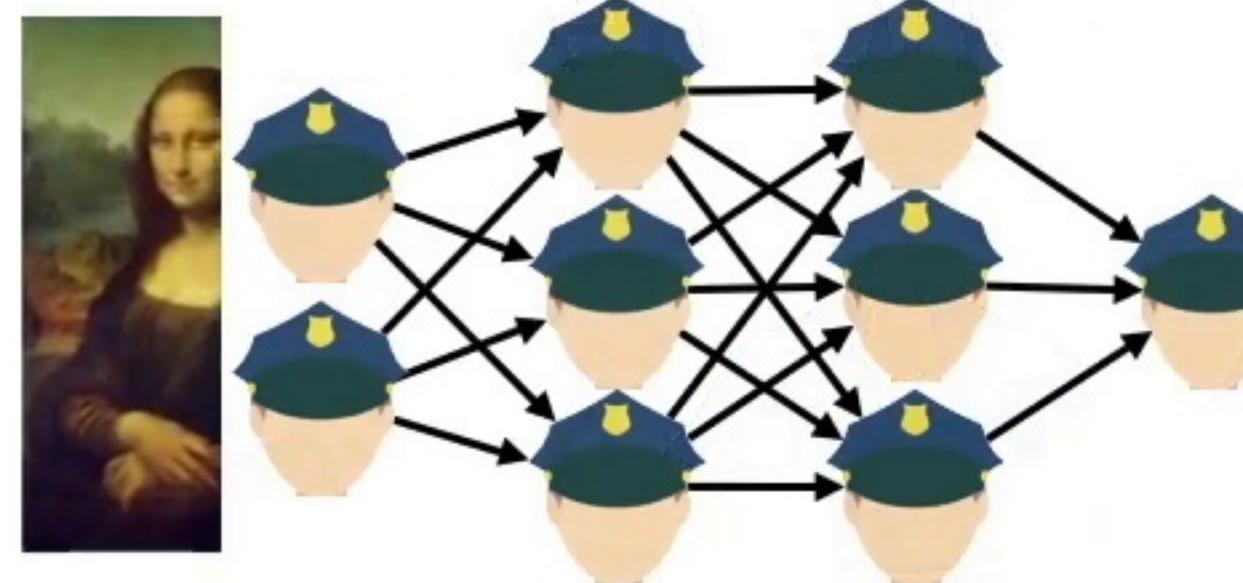
## Real images



# Generator



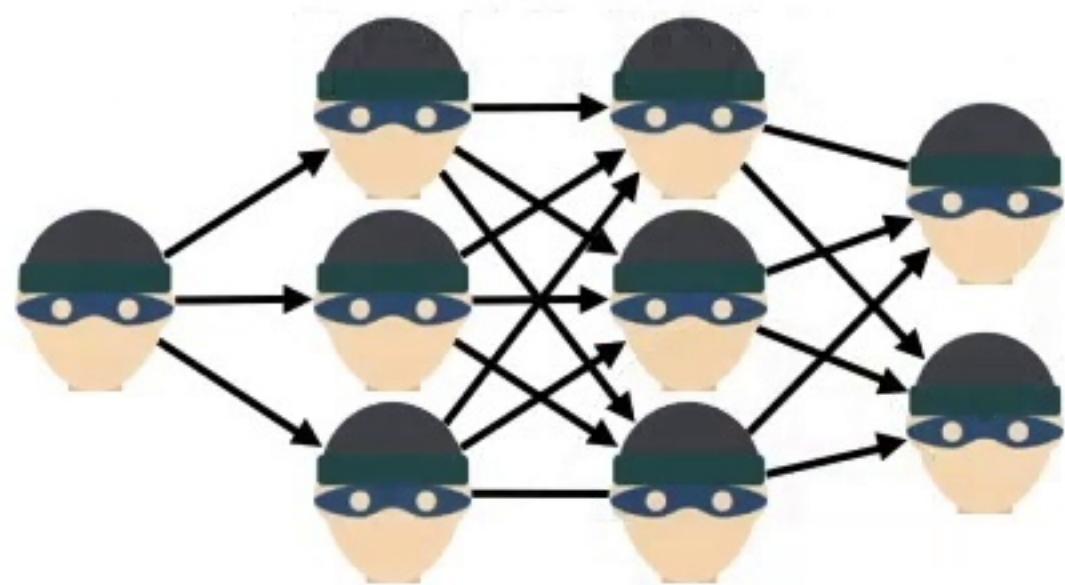
# Discriminator



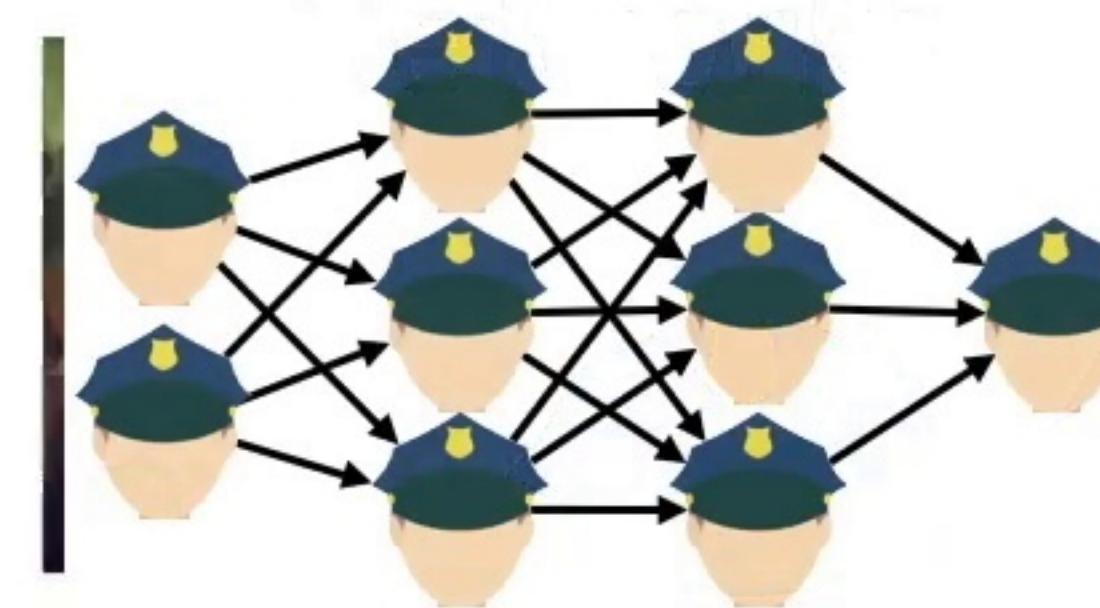
# Real images



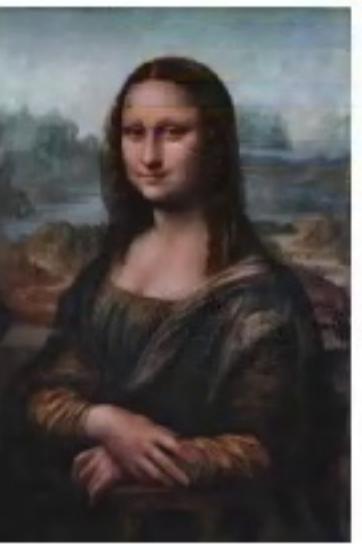
# Generator



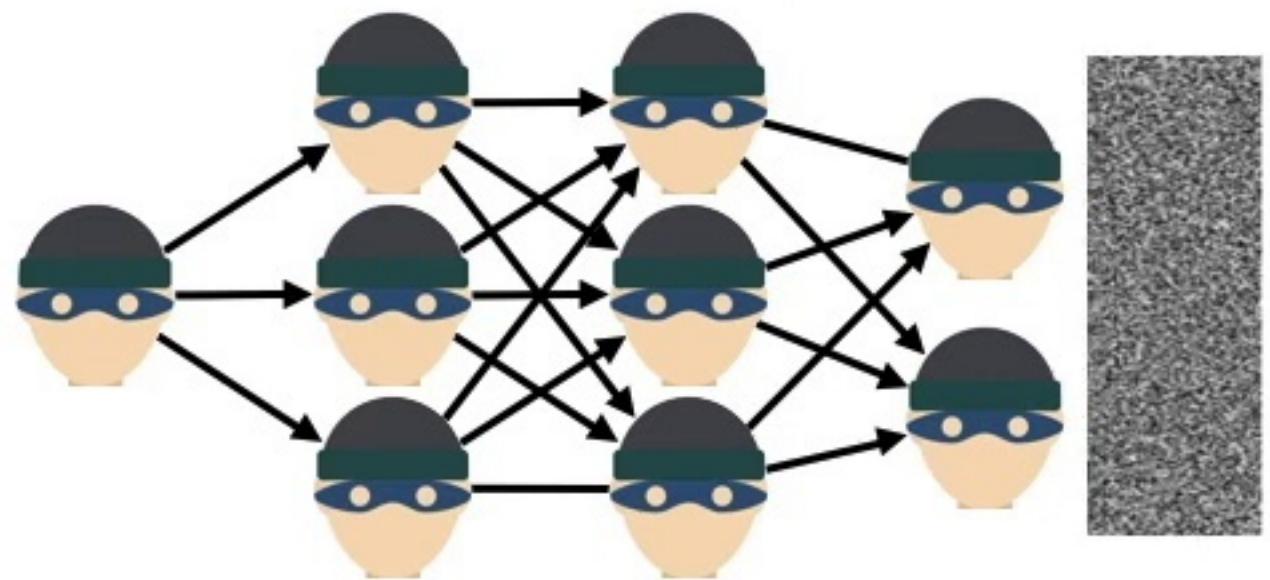
# Discriminator



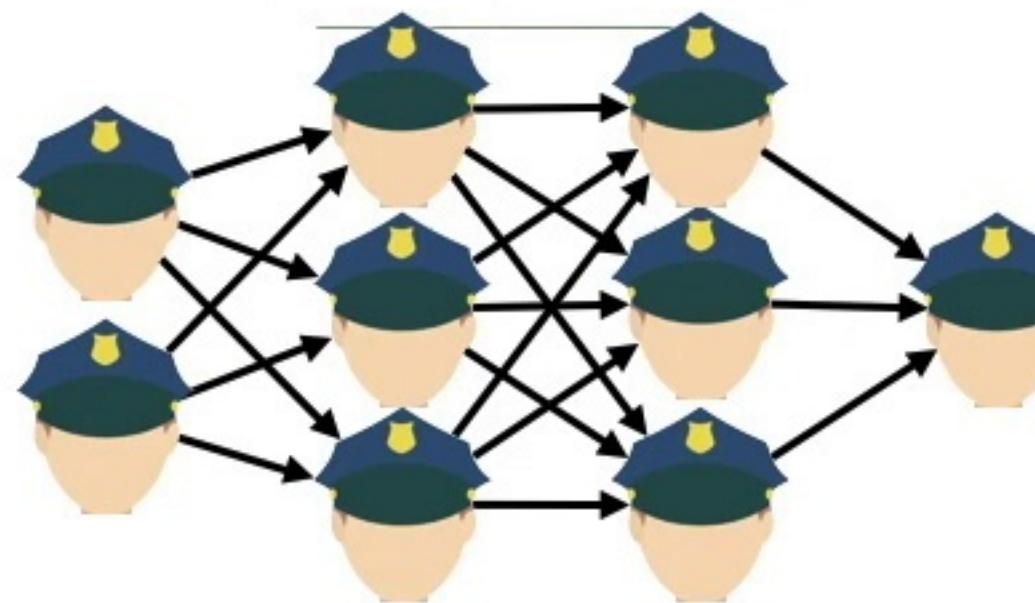
# Real images



# Generator



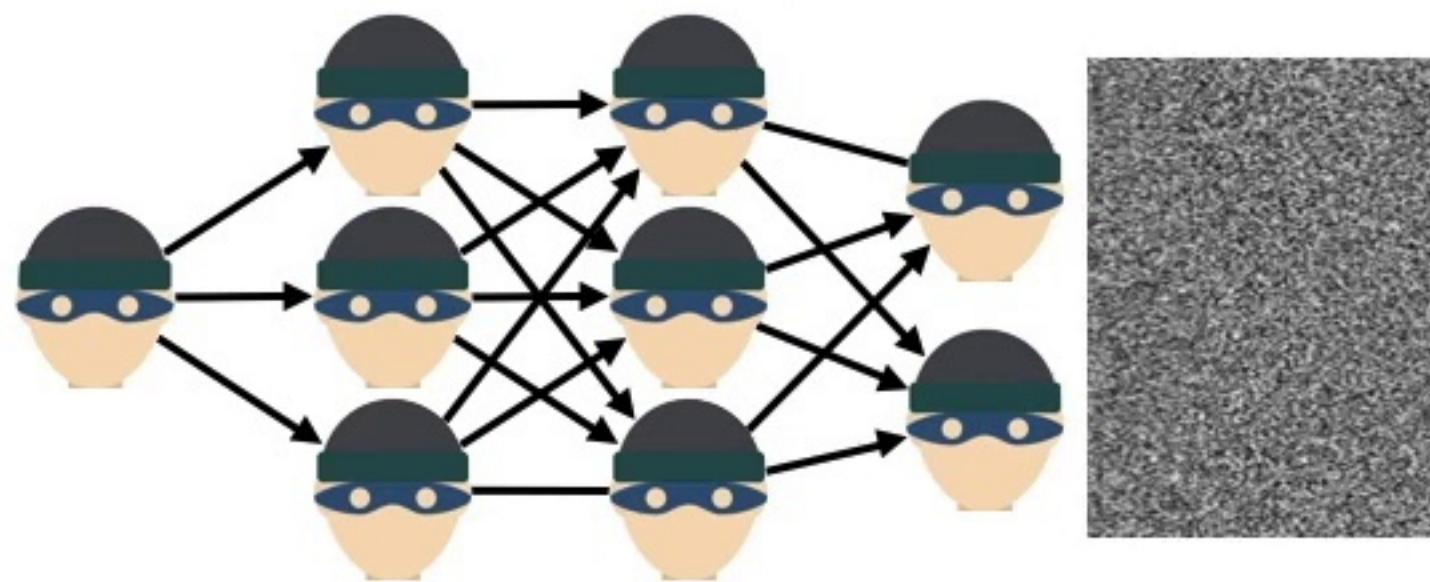
# Discriminator



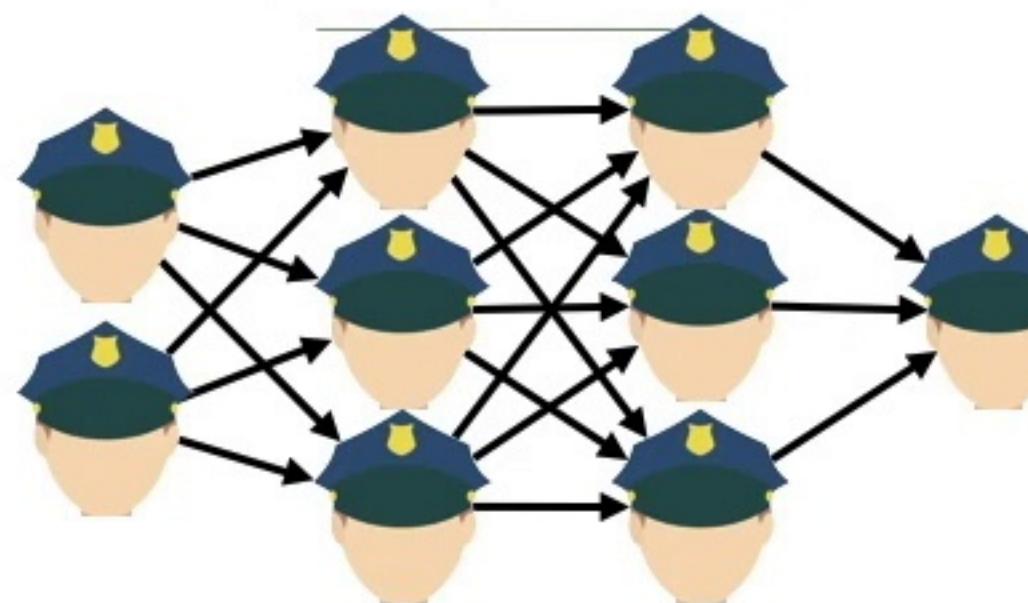
# Real images



## Generator



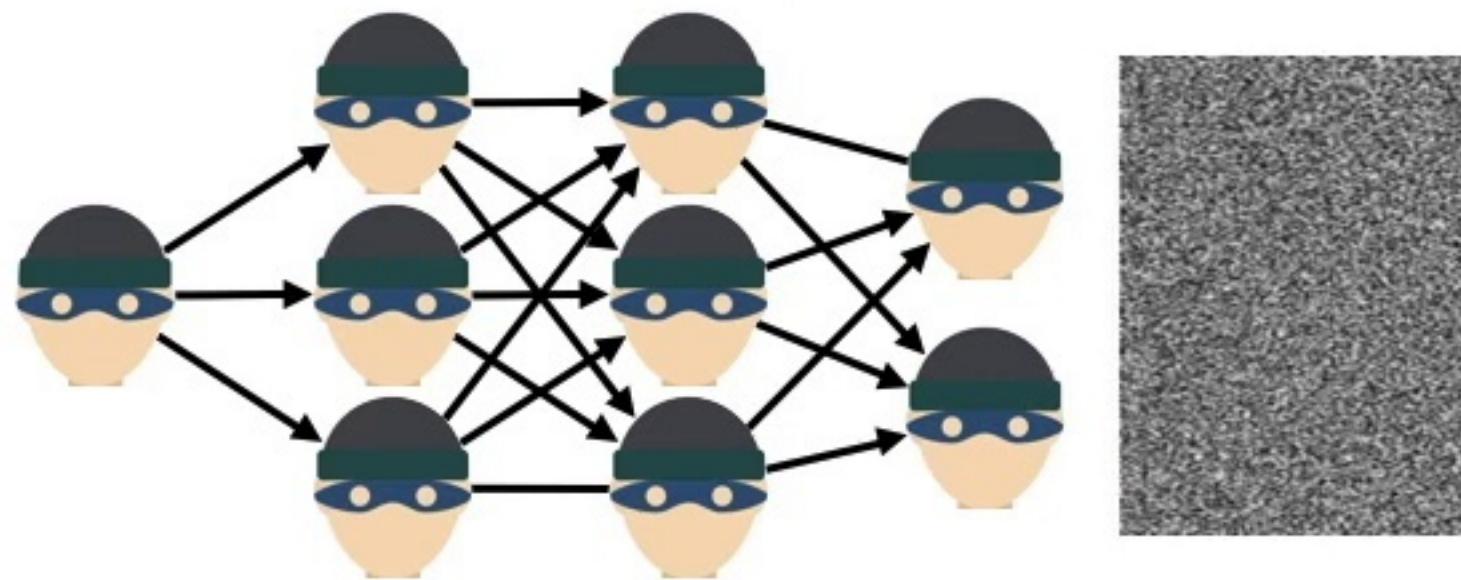
## Discriminator



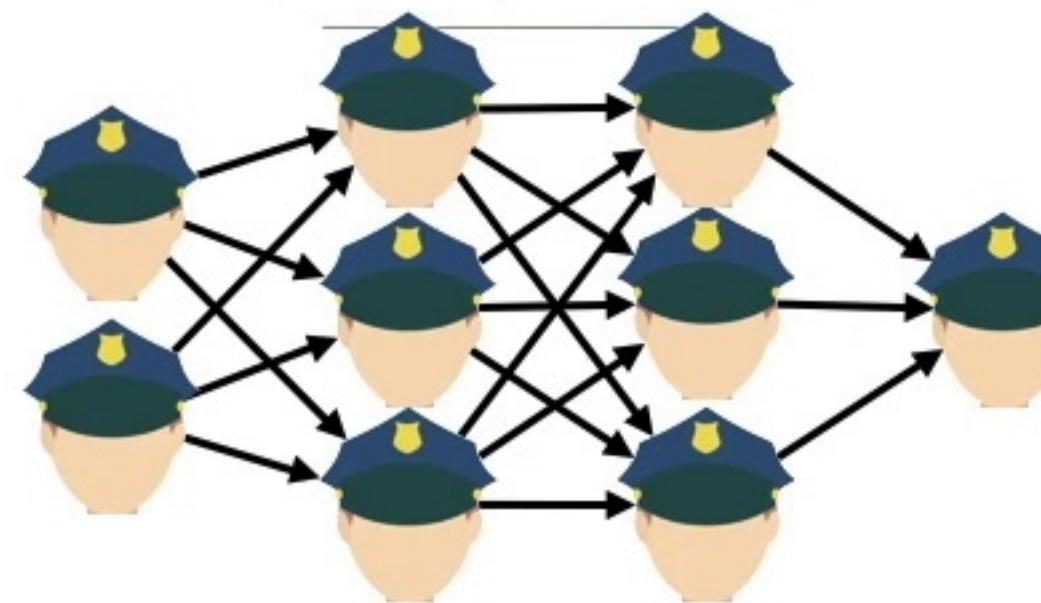
## Real images



## Generator



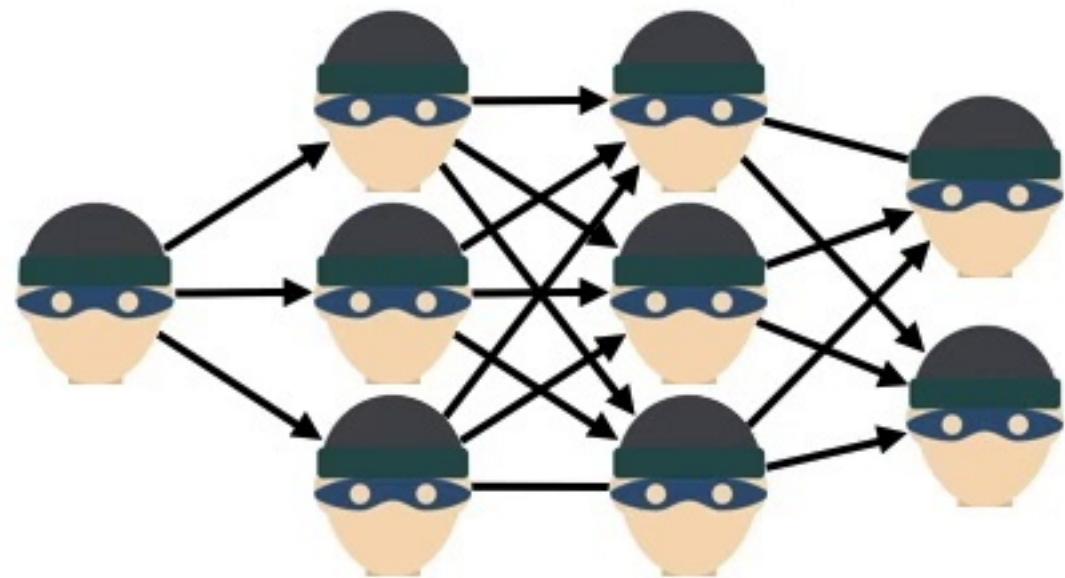
## Discriminator



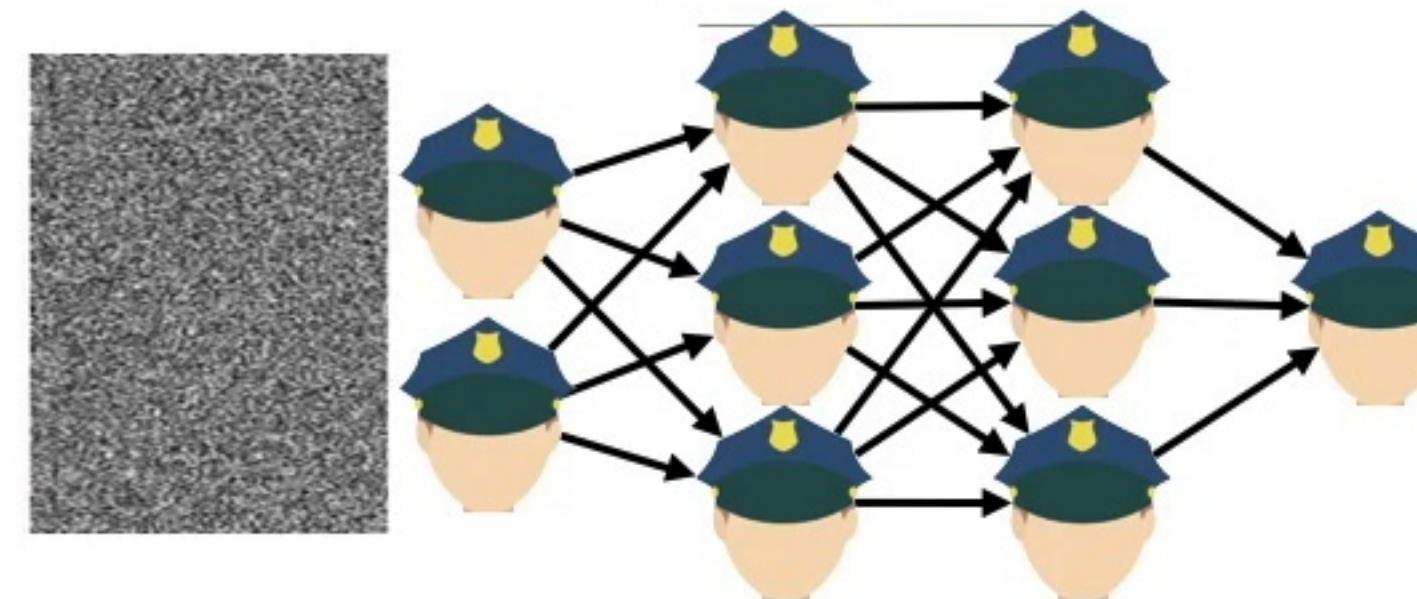
## Real images



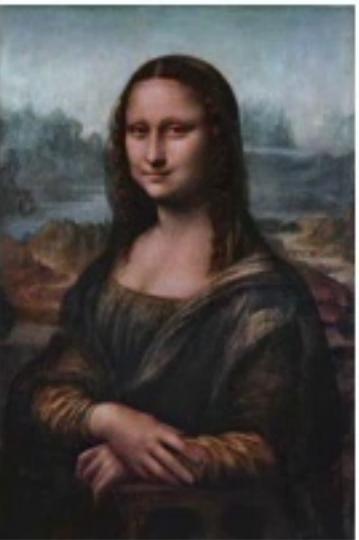
## Generator



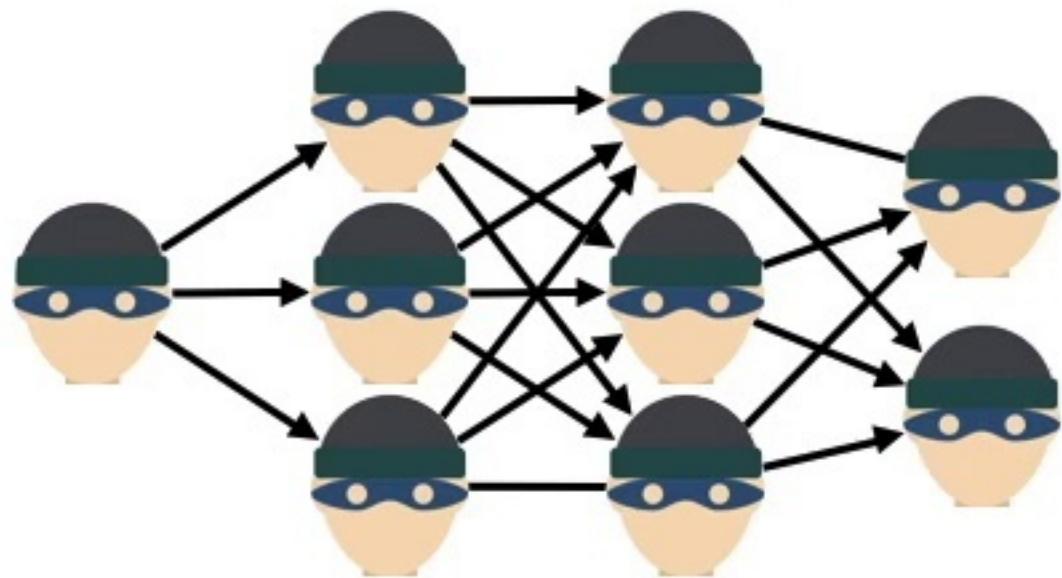
## Discriminator



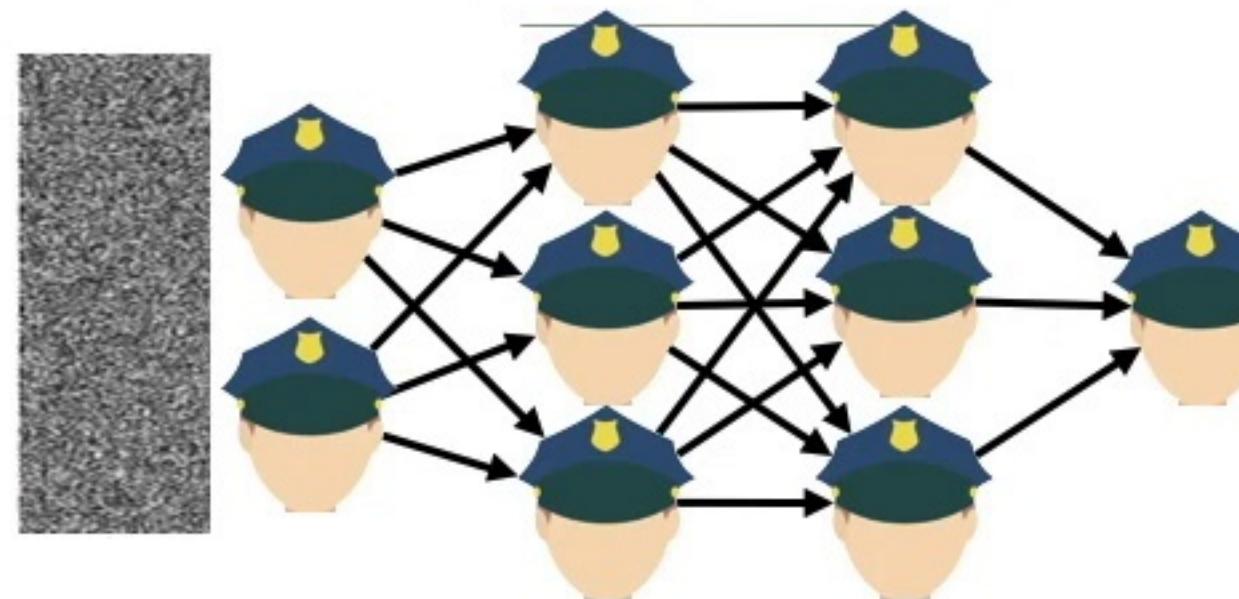
Real images



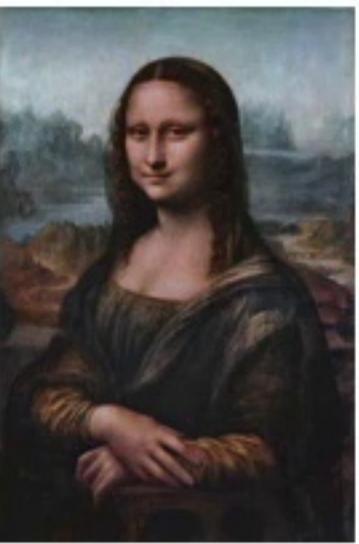
# Generator



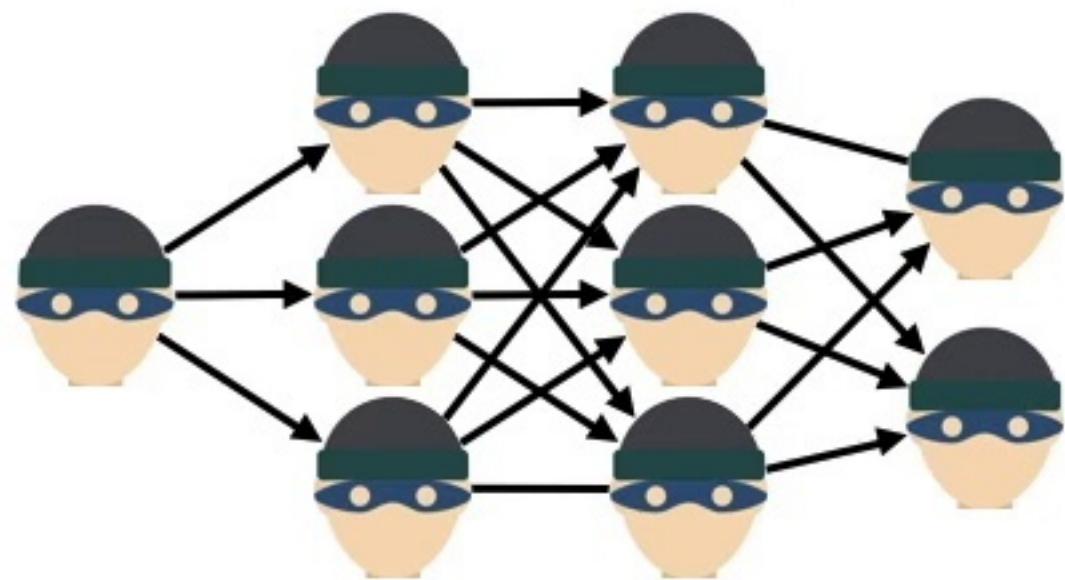
# Discriminator



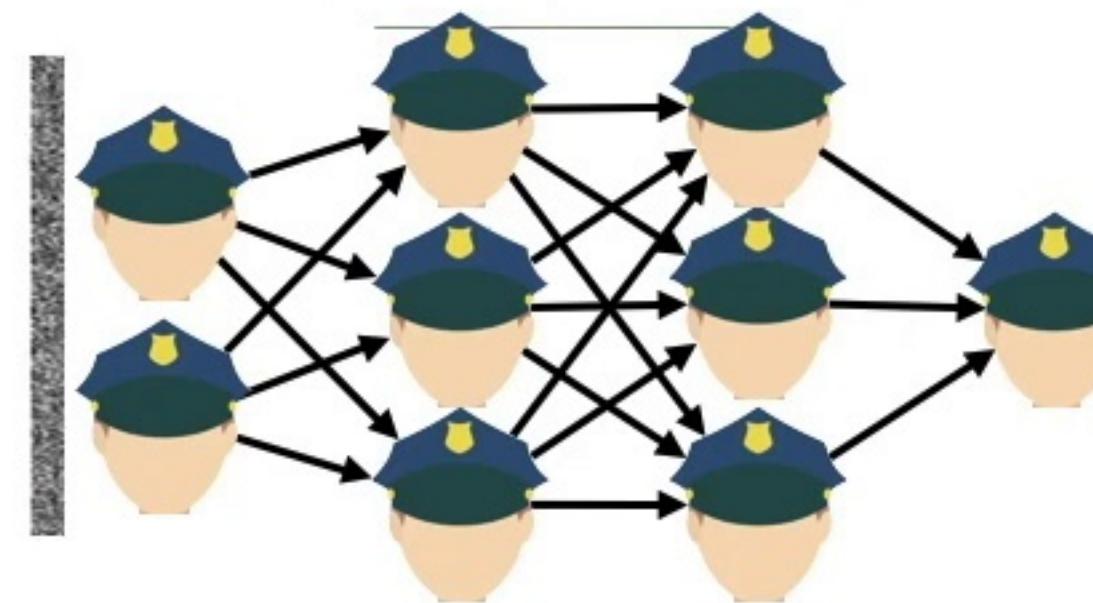
Real images



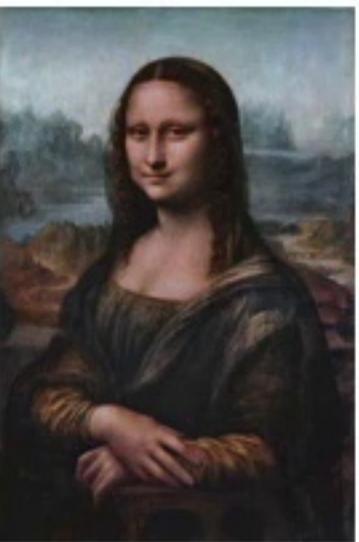
# Generator



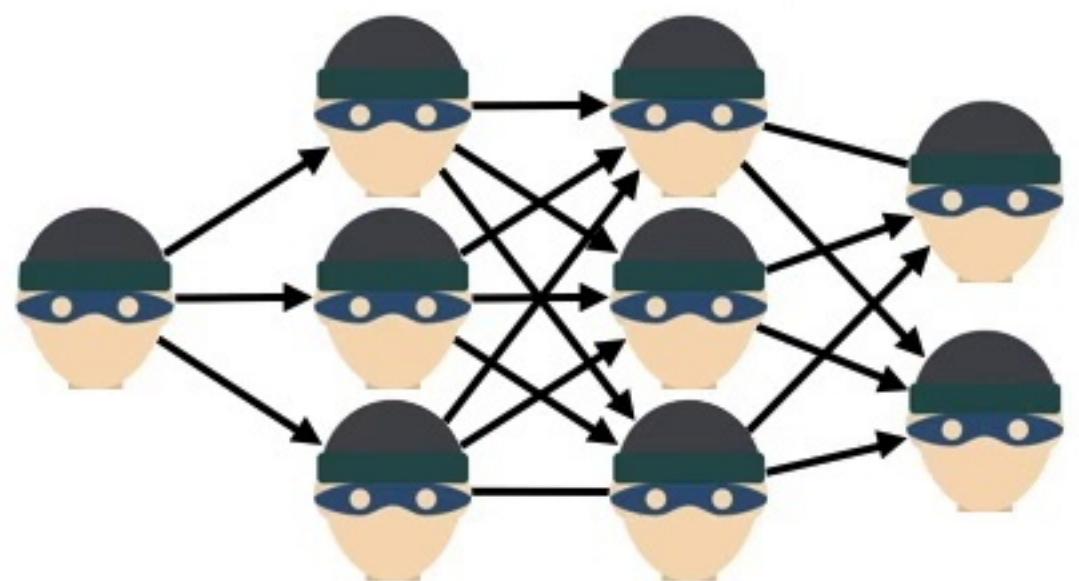
# Discriminator



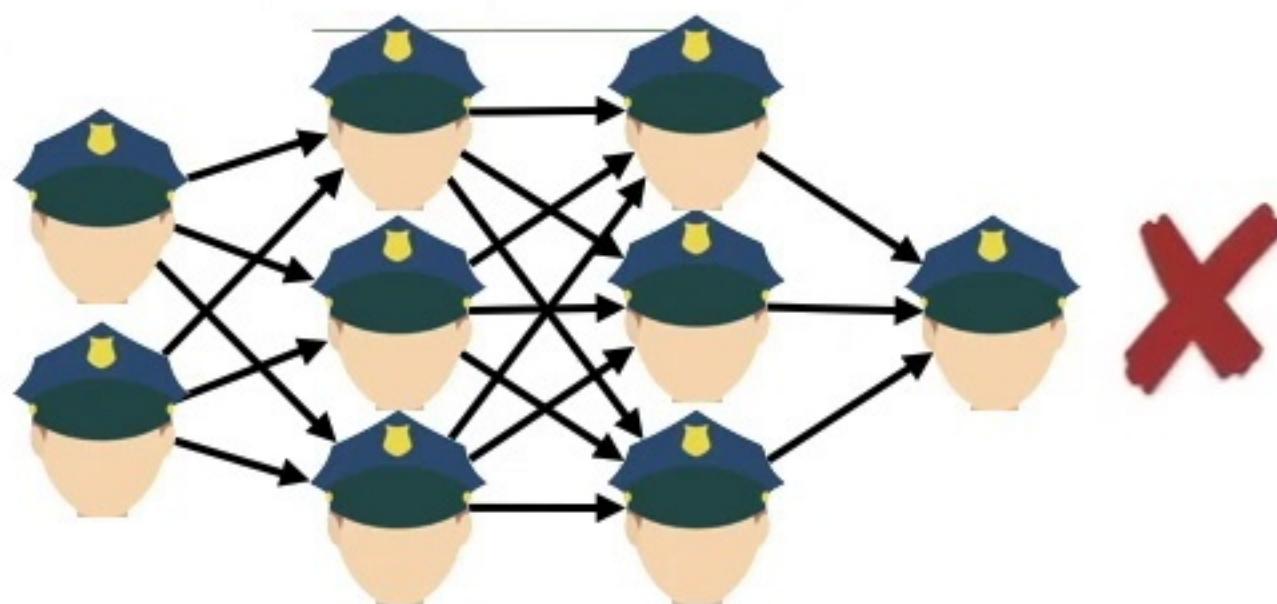
Real images



## Generator



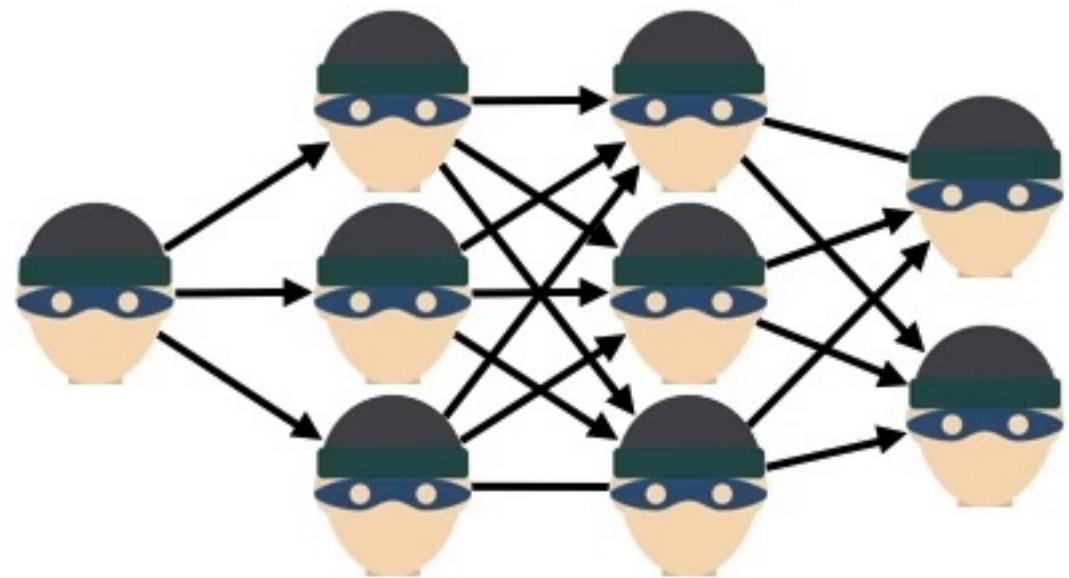
## Discriminator



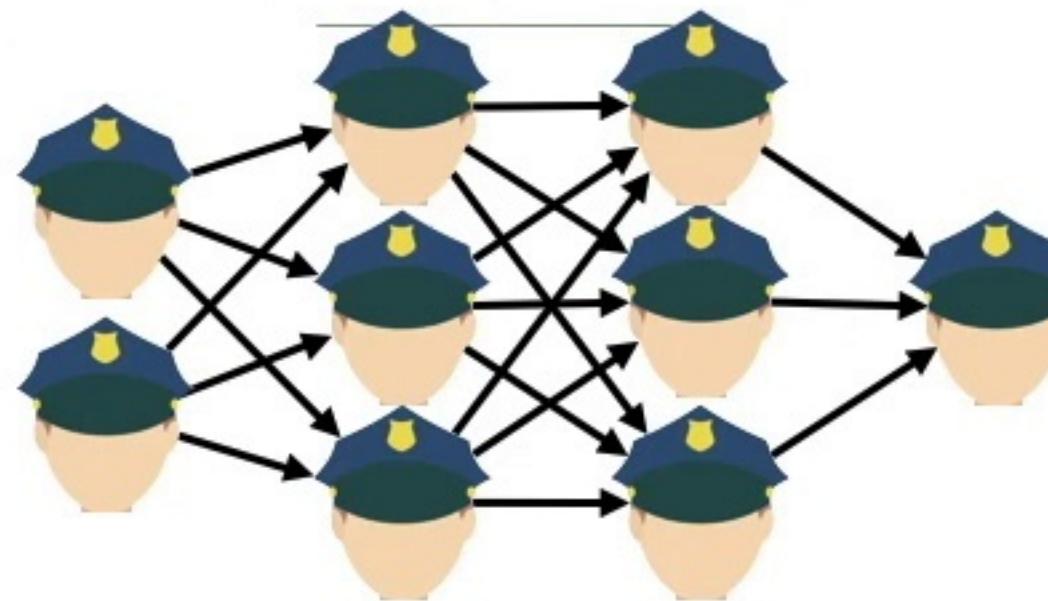
Real images



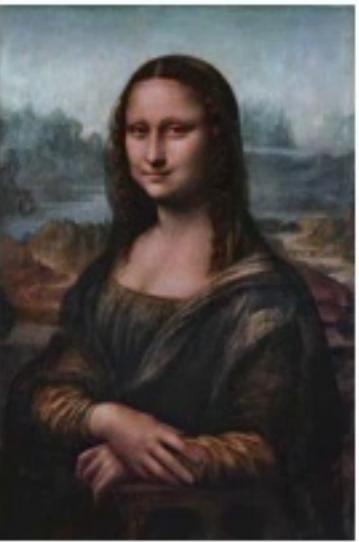
# Generator



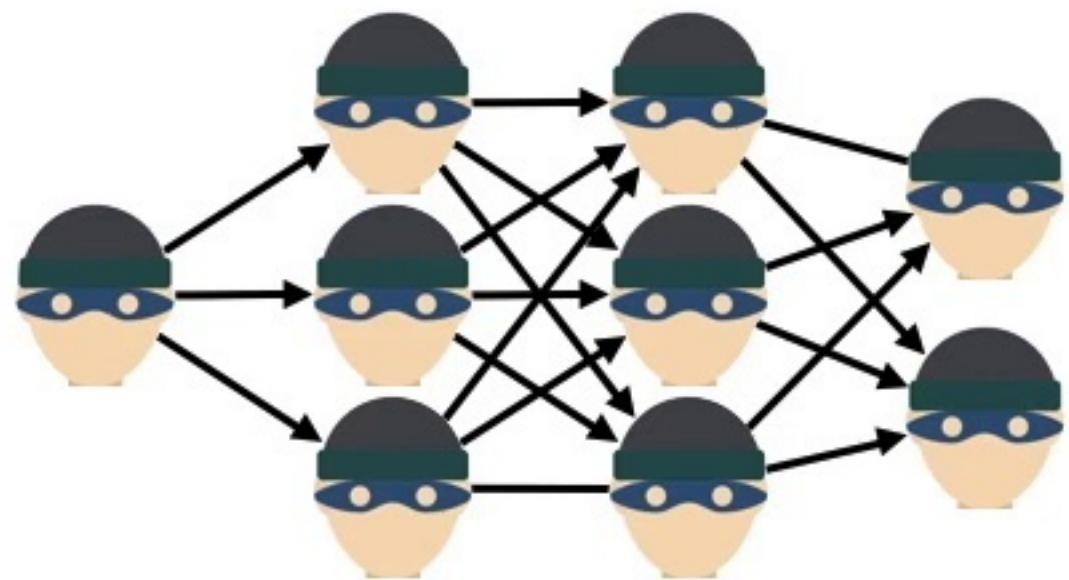
# Discriminator



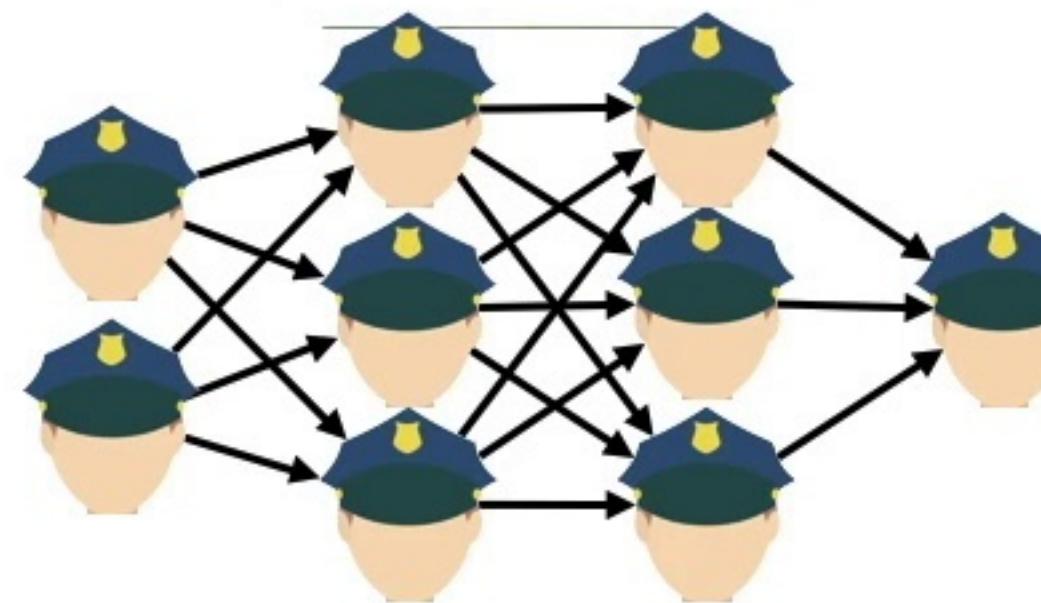
Real images



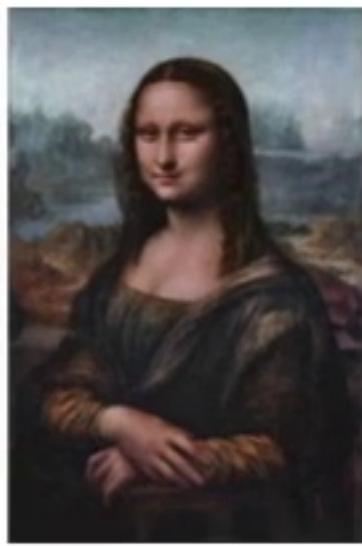
# Generator



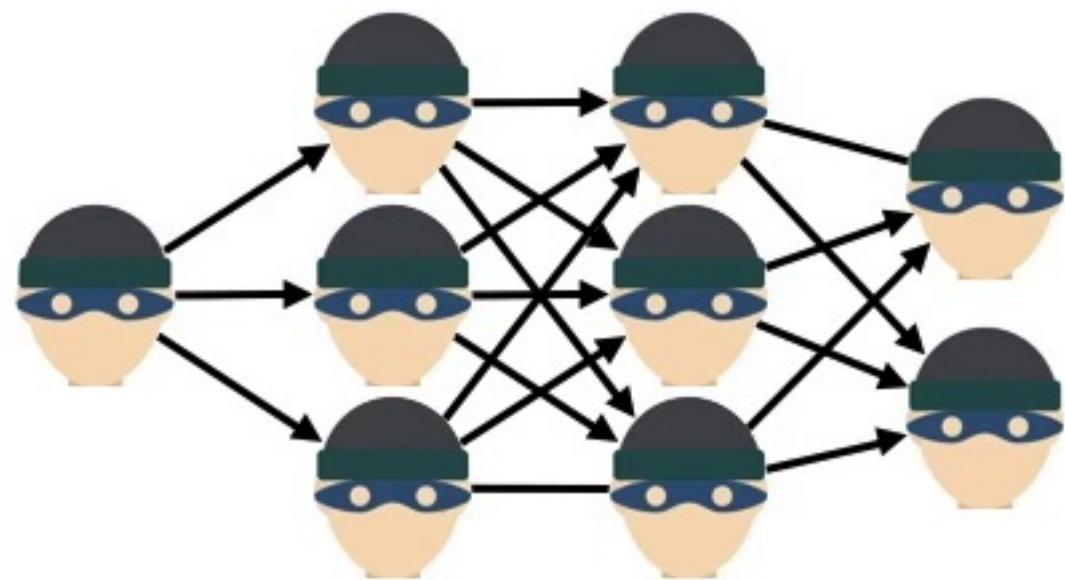
# Discriminator



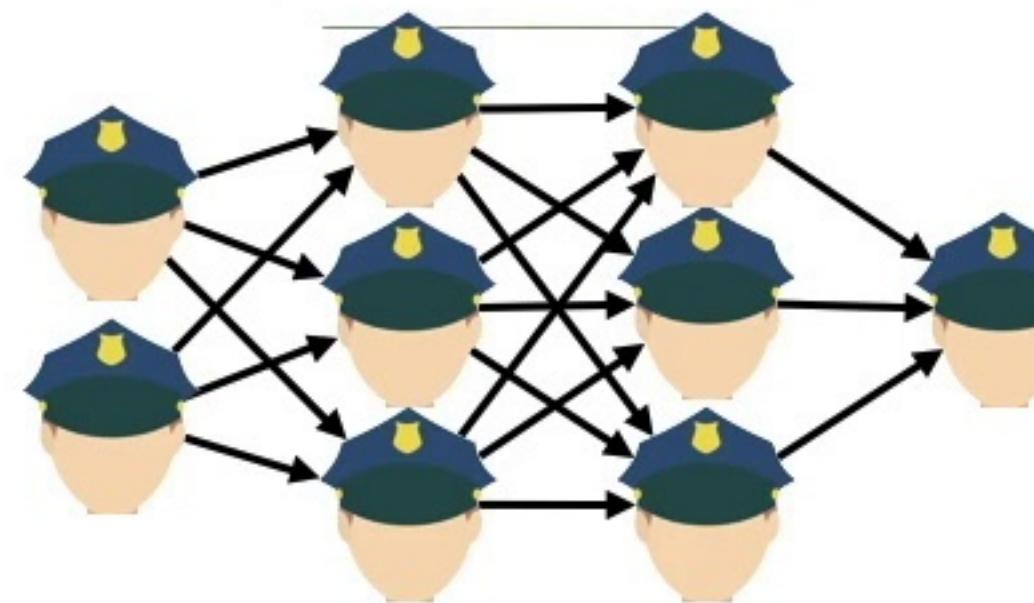
Real images



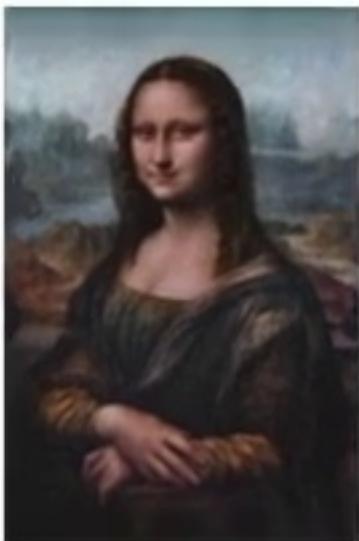
# Generator



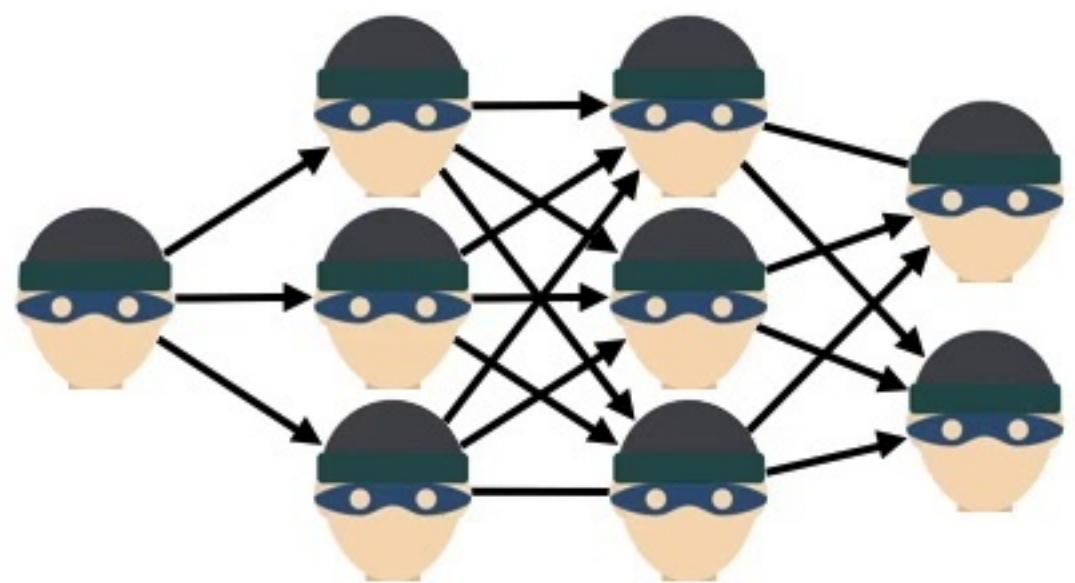
# Discriminator



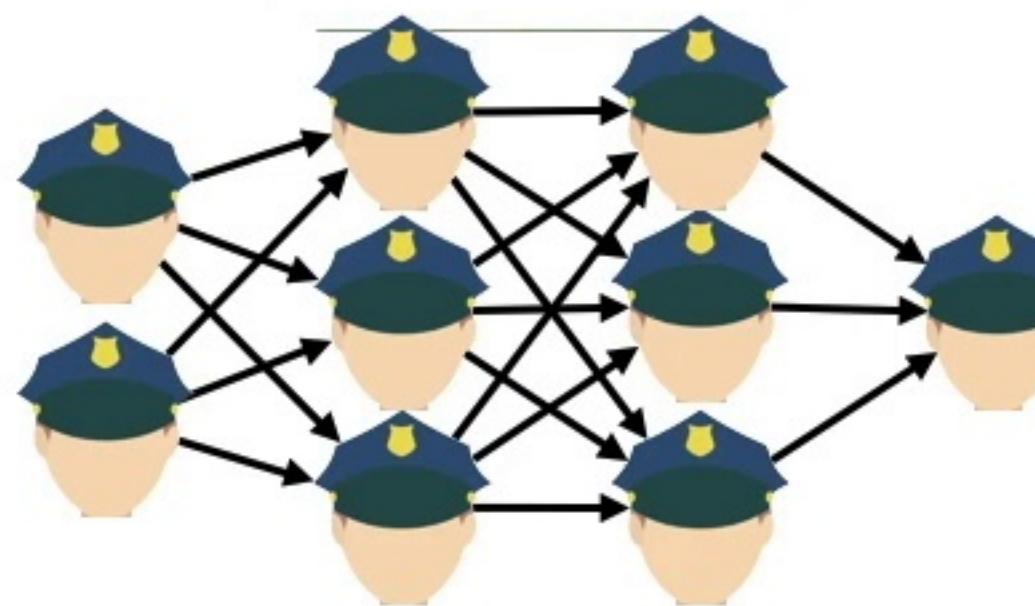
Real images



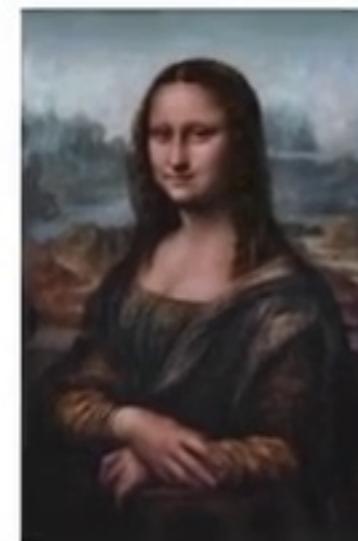
## Generator



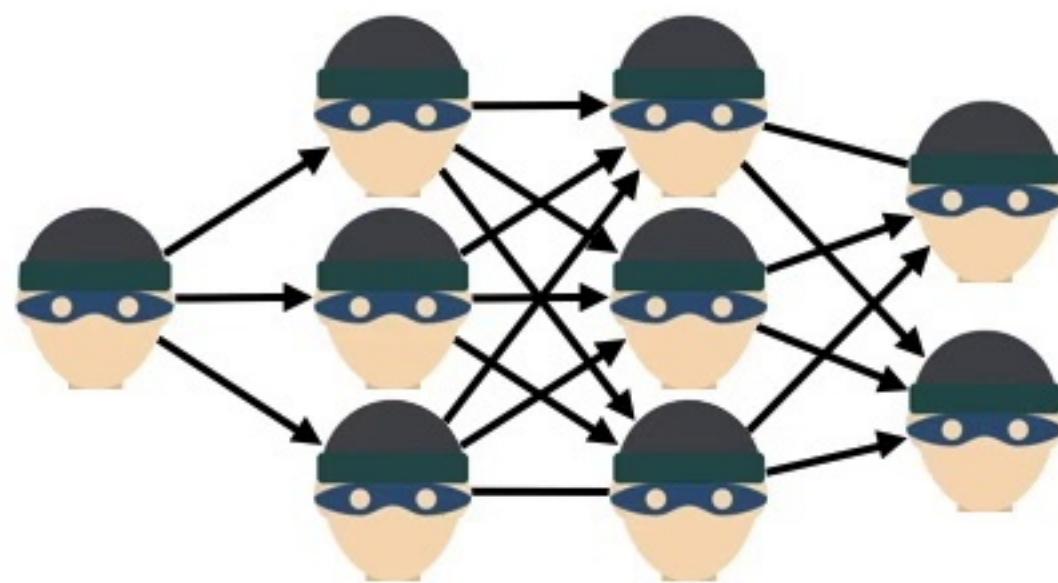
## Discriminator



Real images

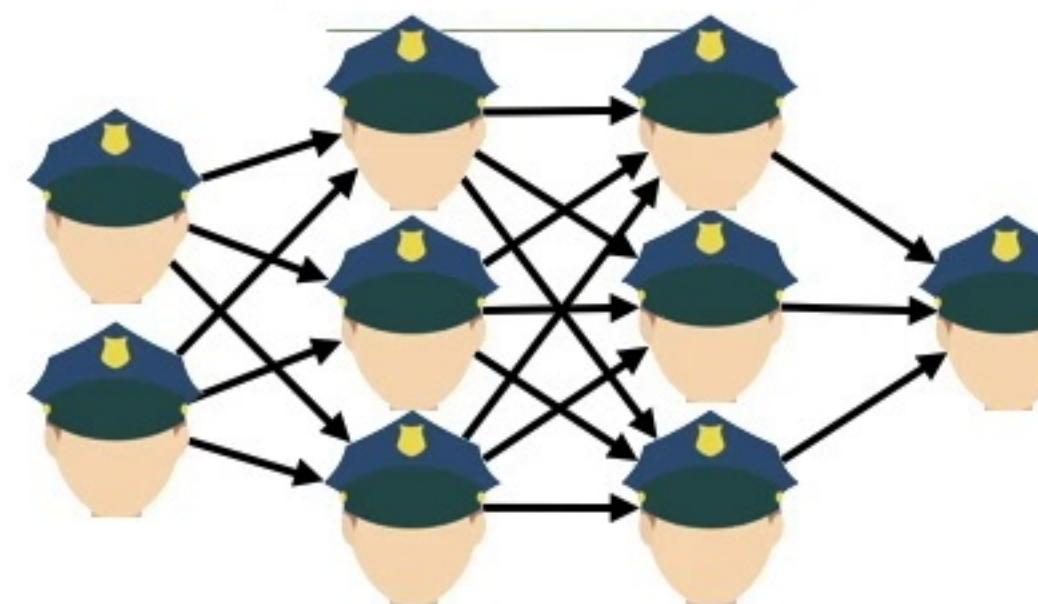


# Generator

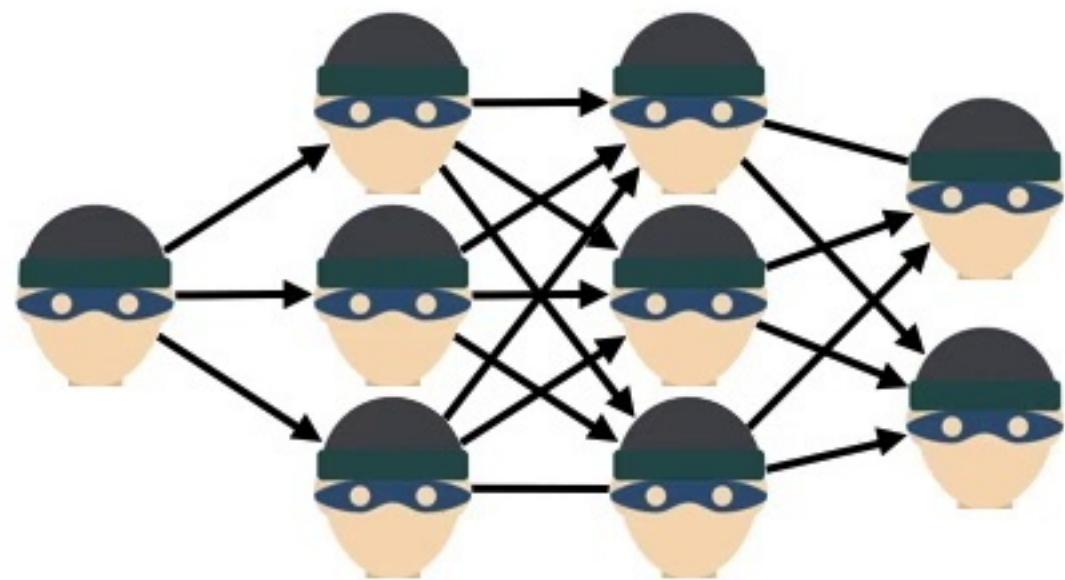


Real images

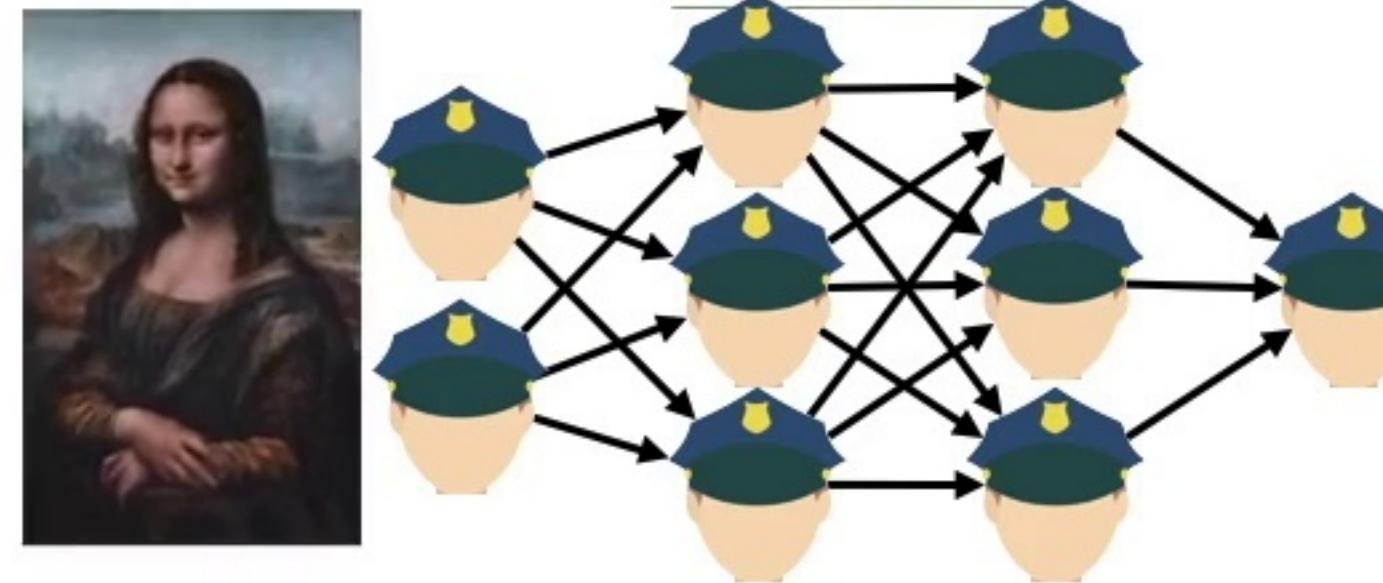
# Discriminator



# Generator

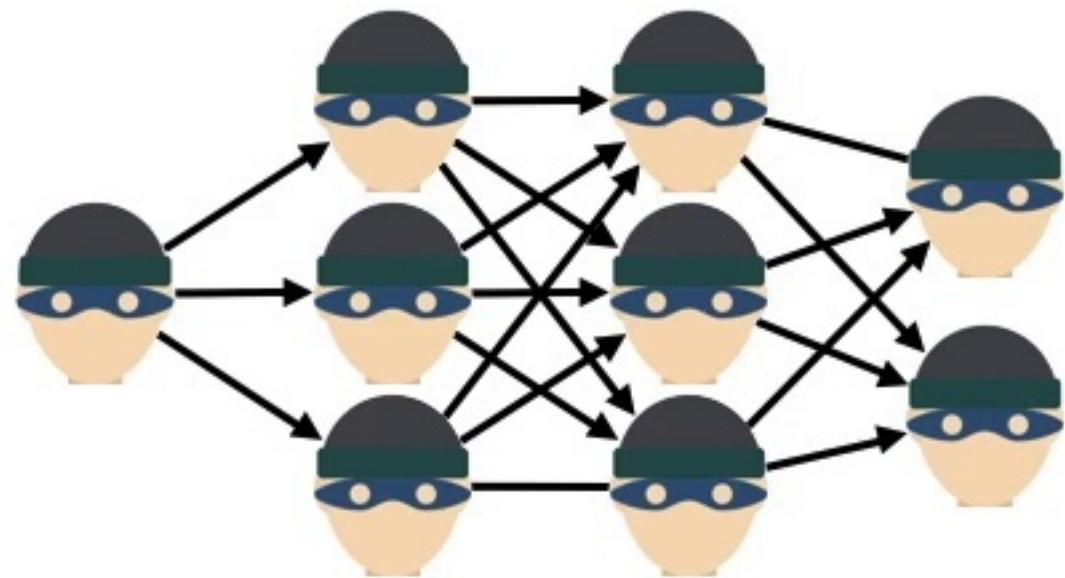


# Discriminator

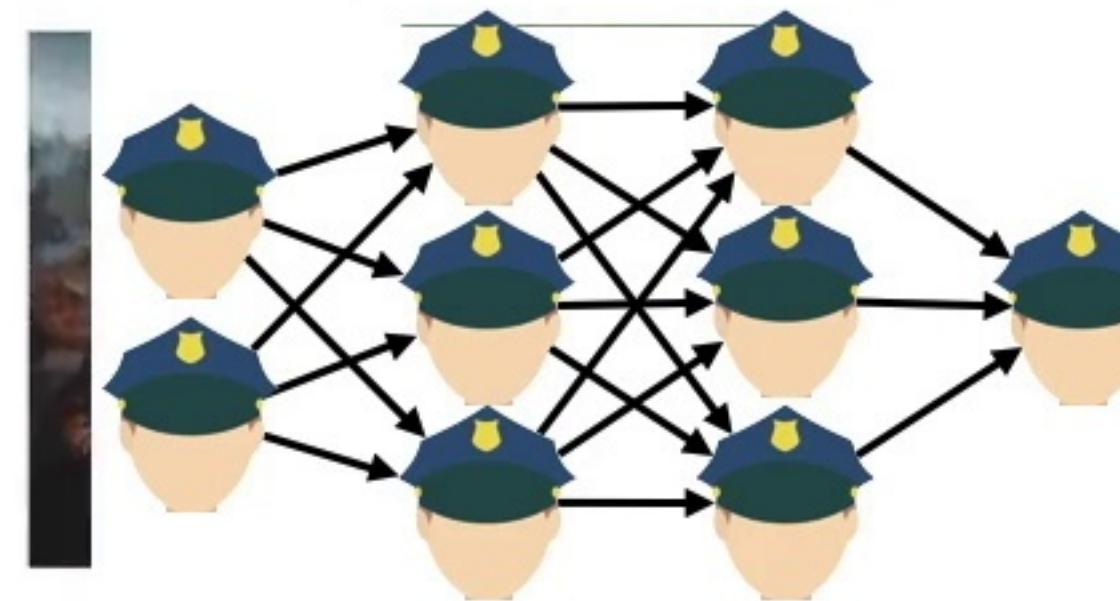


Real images

# Generator

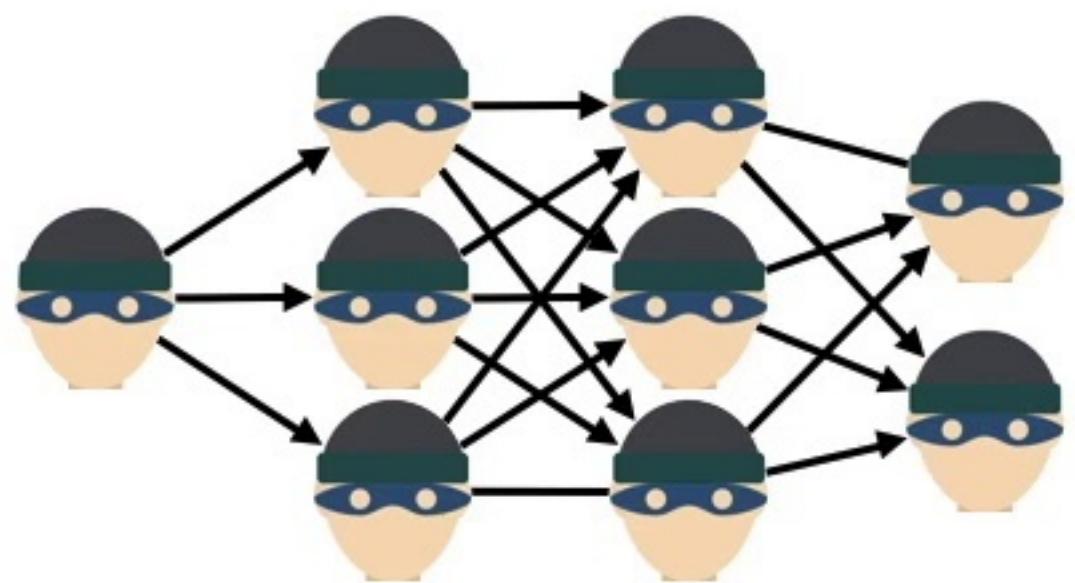


# Discriminator

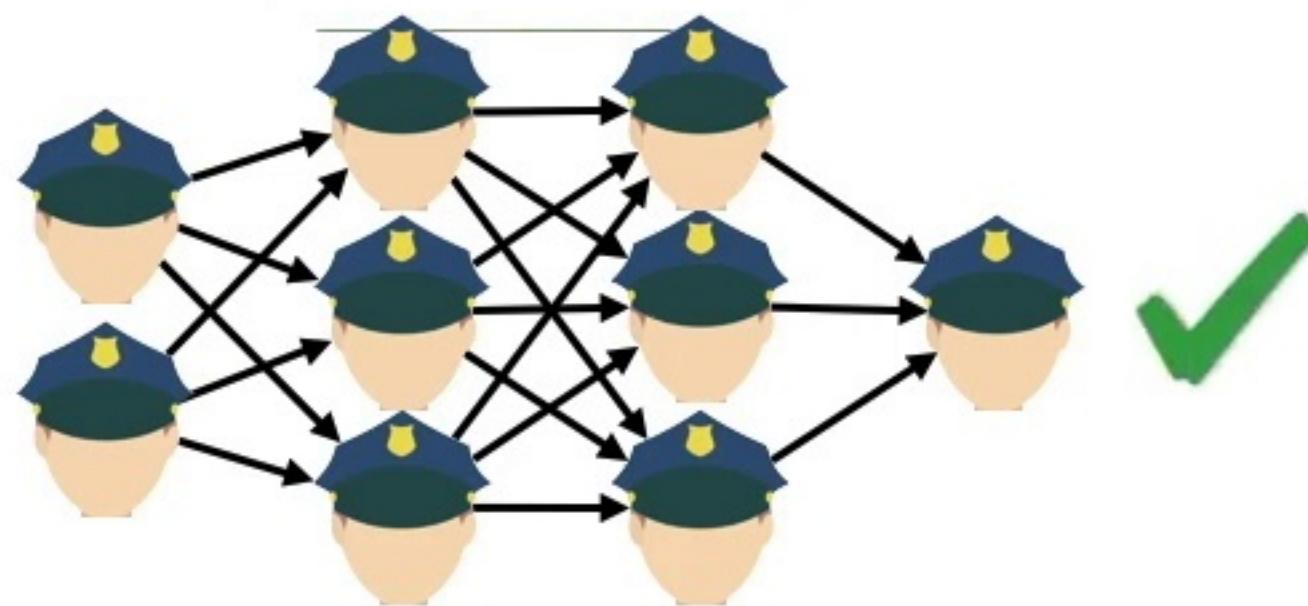


Real images

# Generator

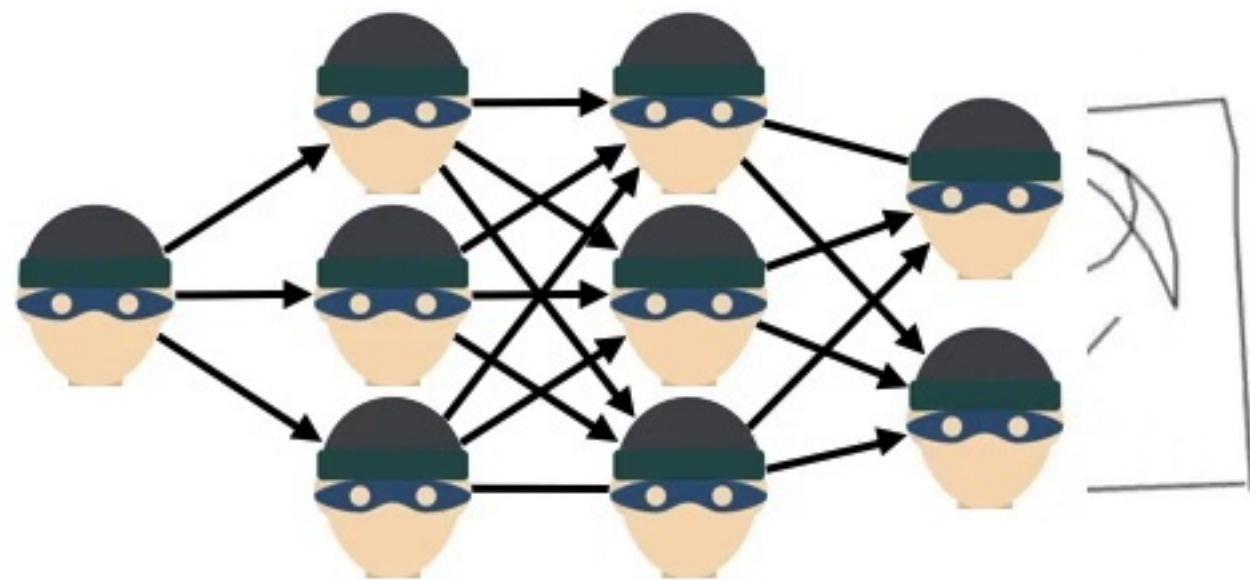


# Discriminator

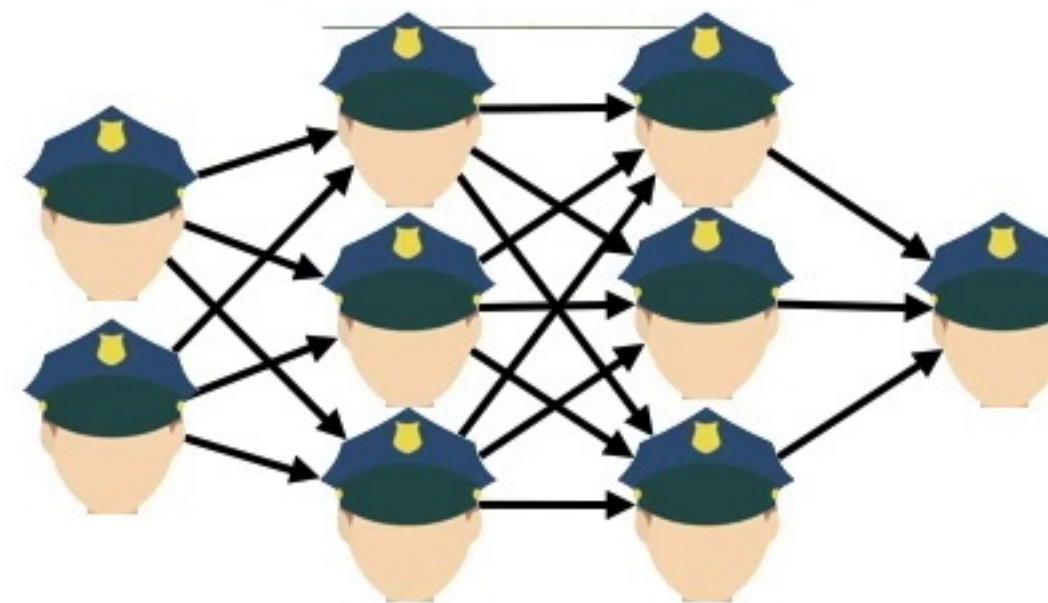


Real images

# Generator

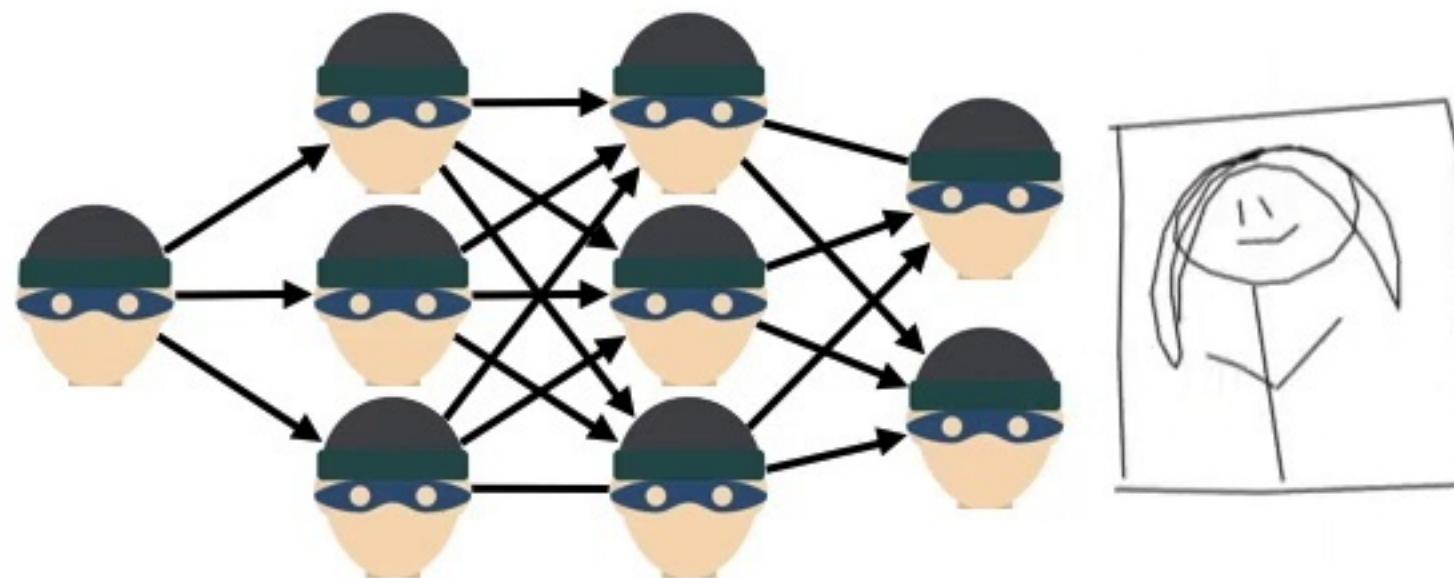


# Discriminator

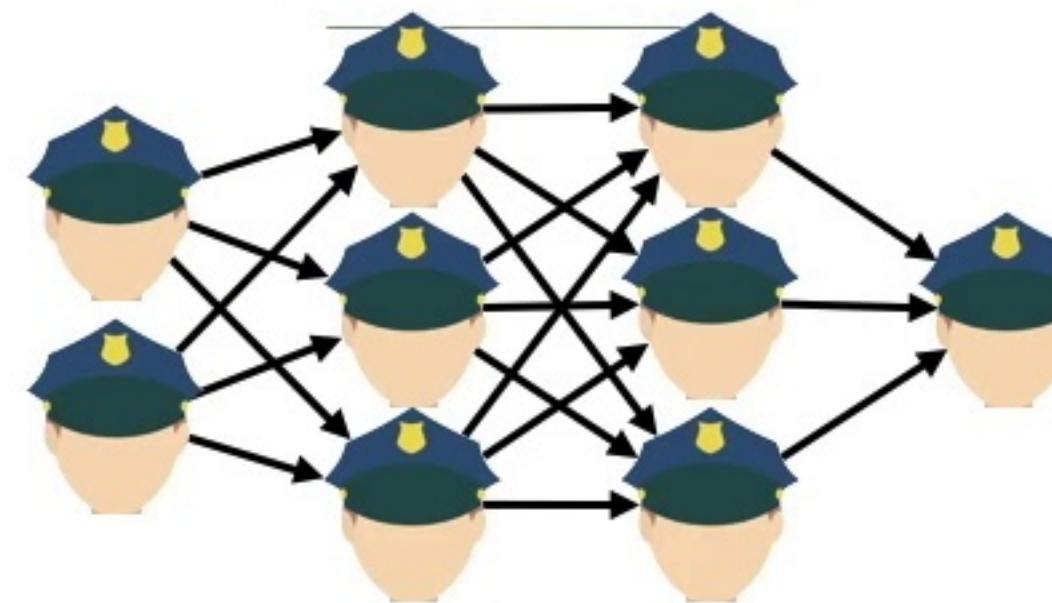


Real images

# Generator

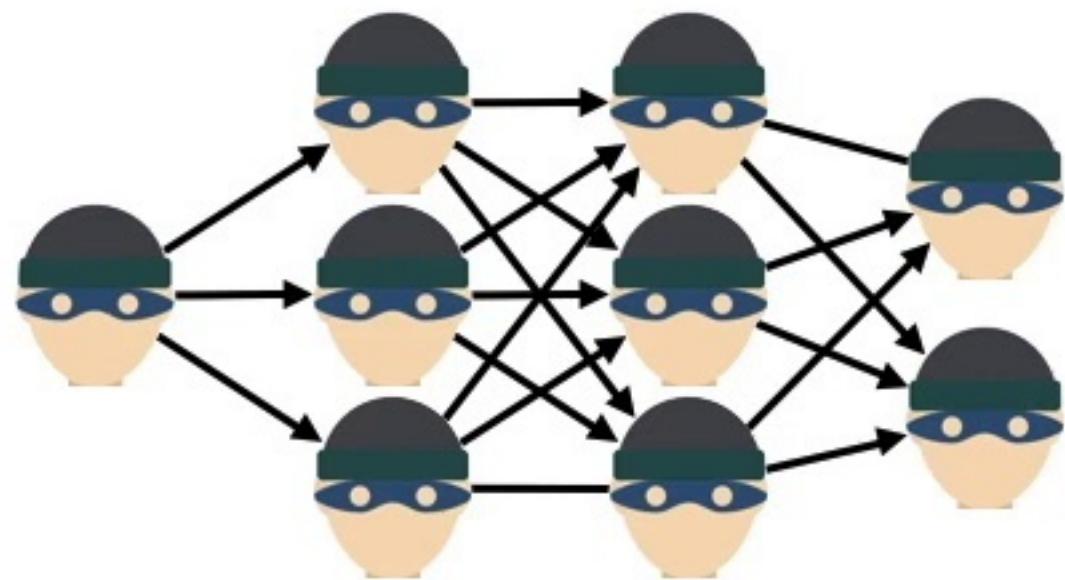


# Discriminator

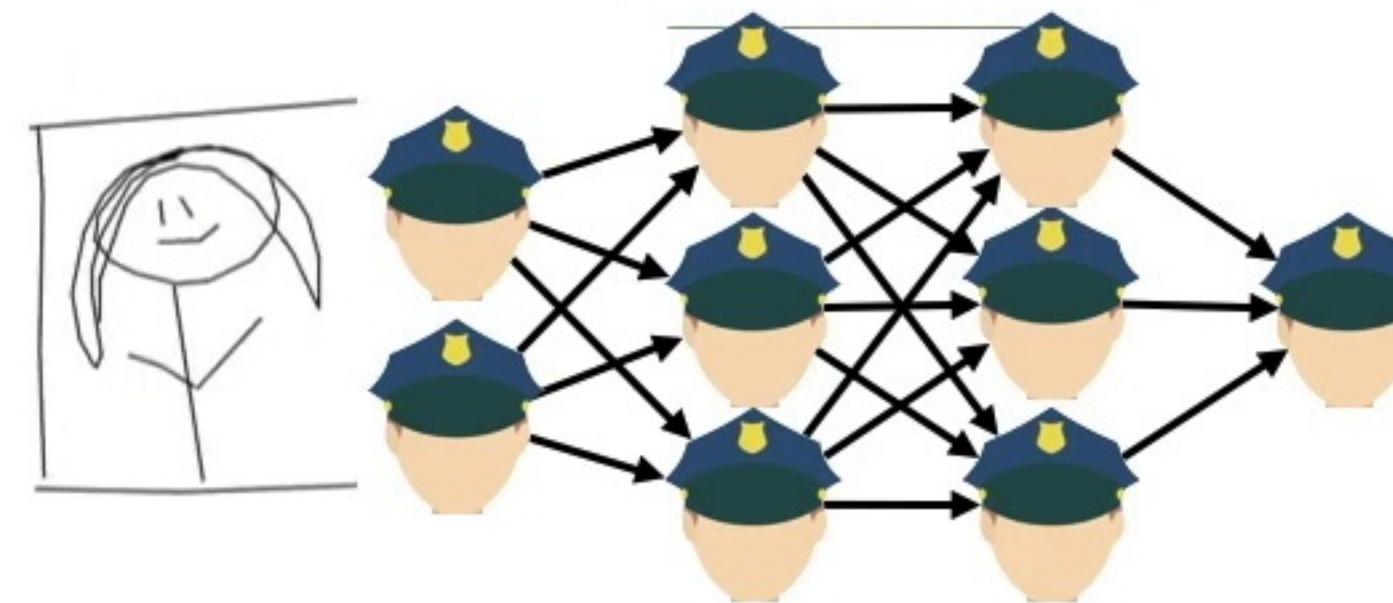


Real images

# Generator



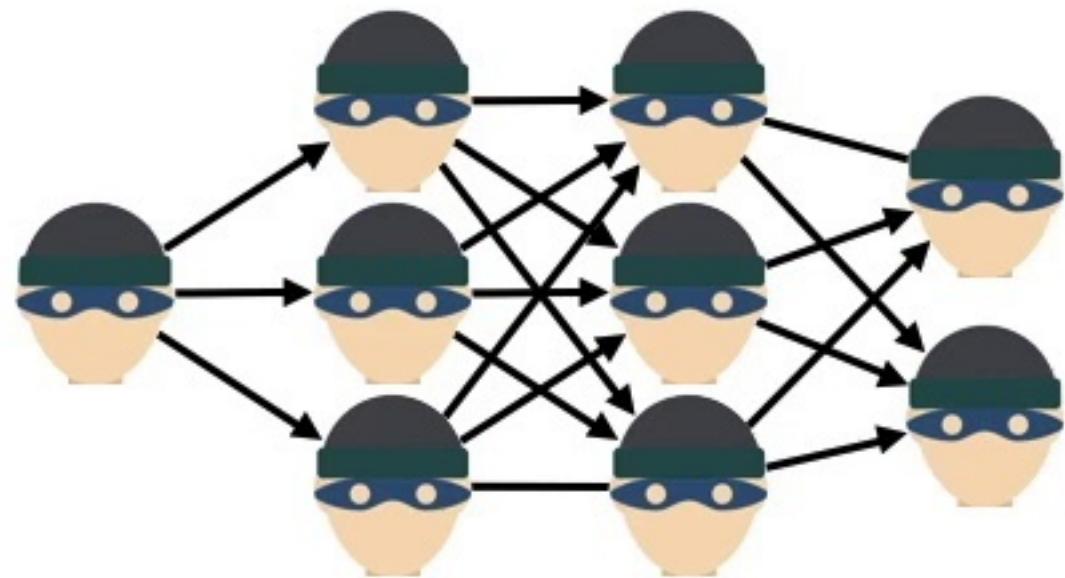
# Discriminator



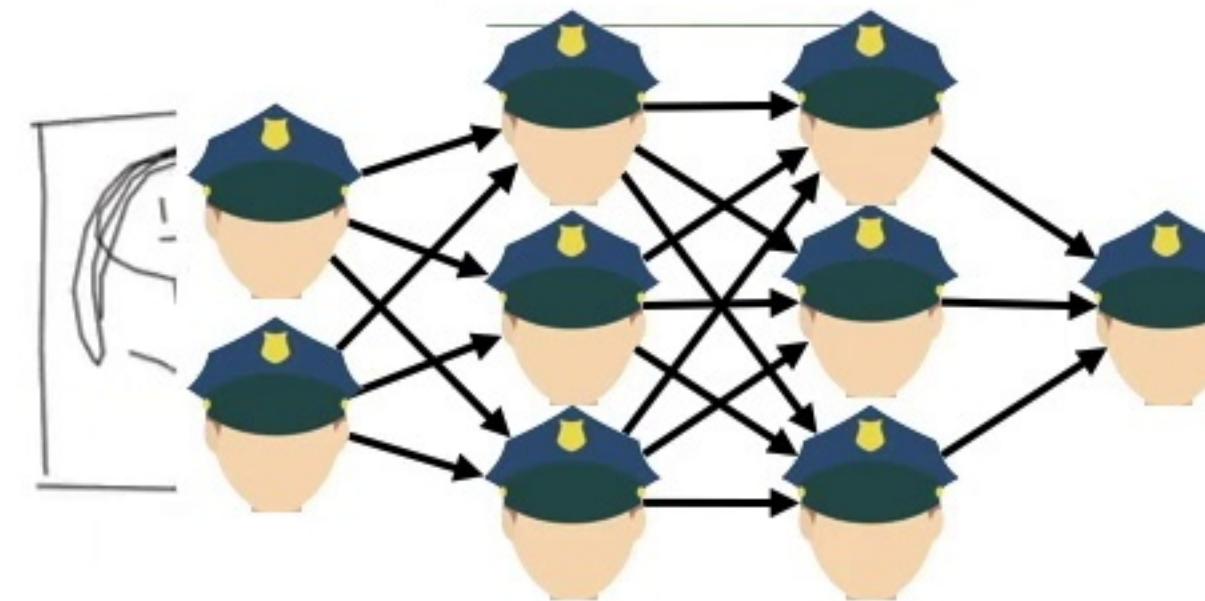
Real images

Fake images

# Generator

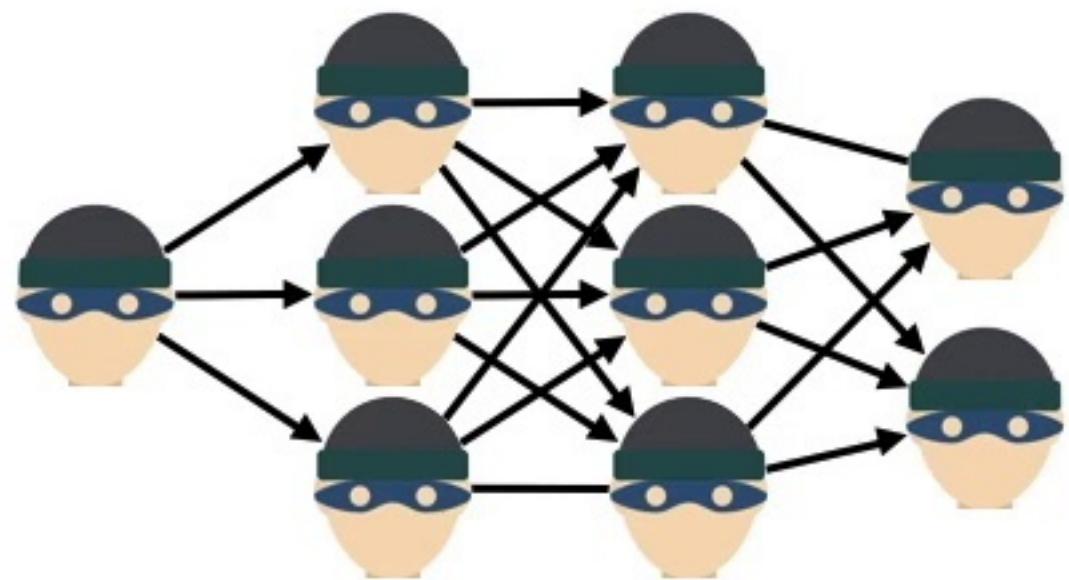


# Discriminator

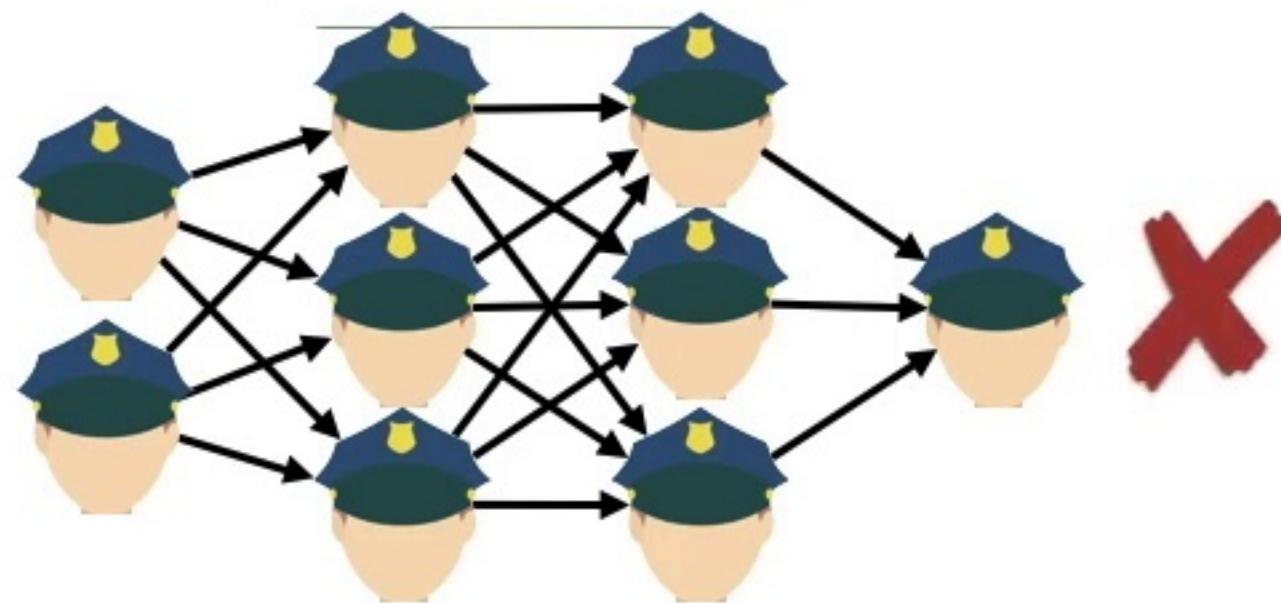


Real images

# Generator

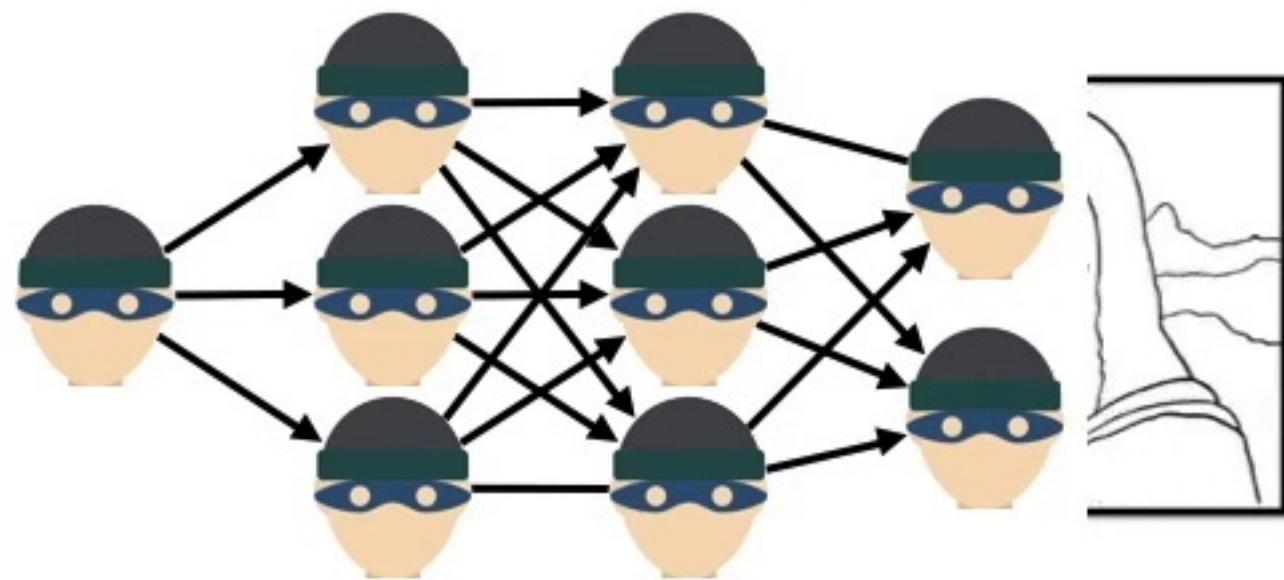


# Discriminator

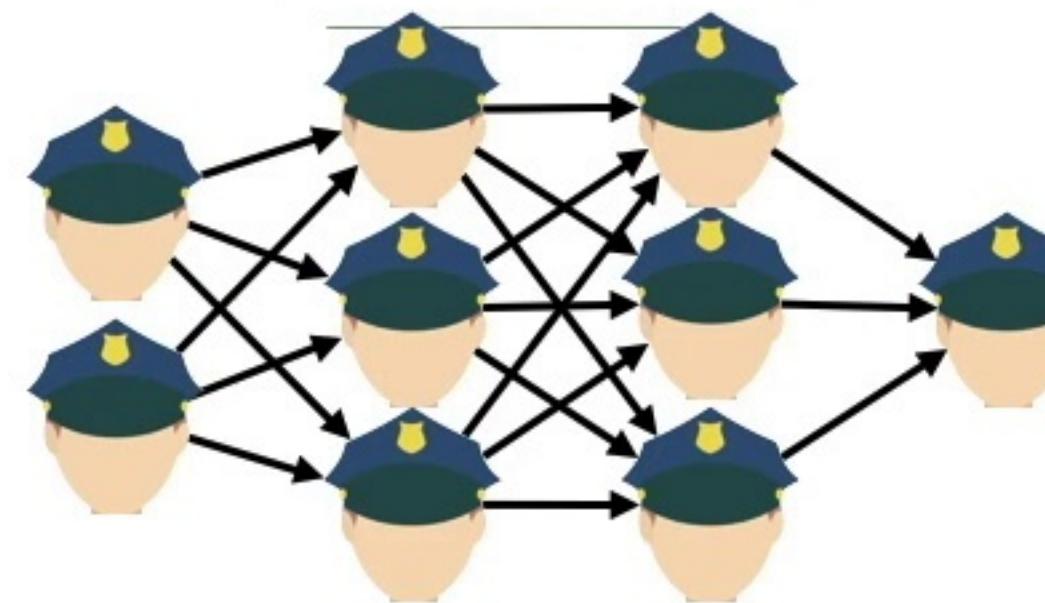


Real images

# Generator

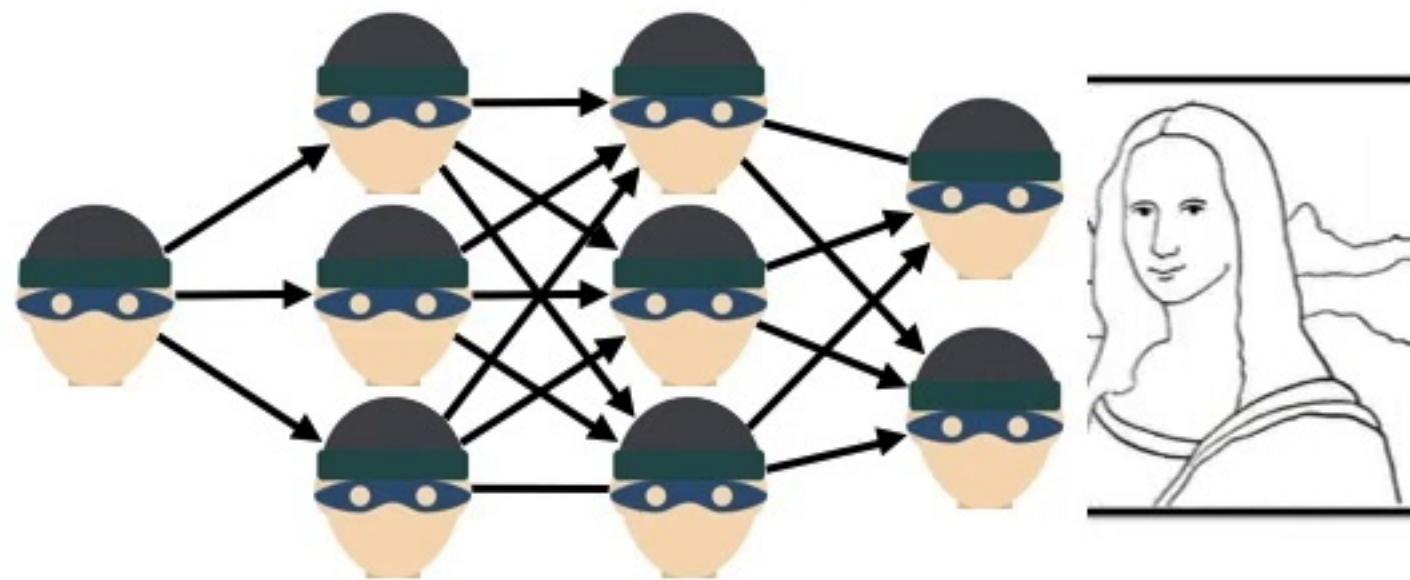


# Discriminator

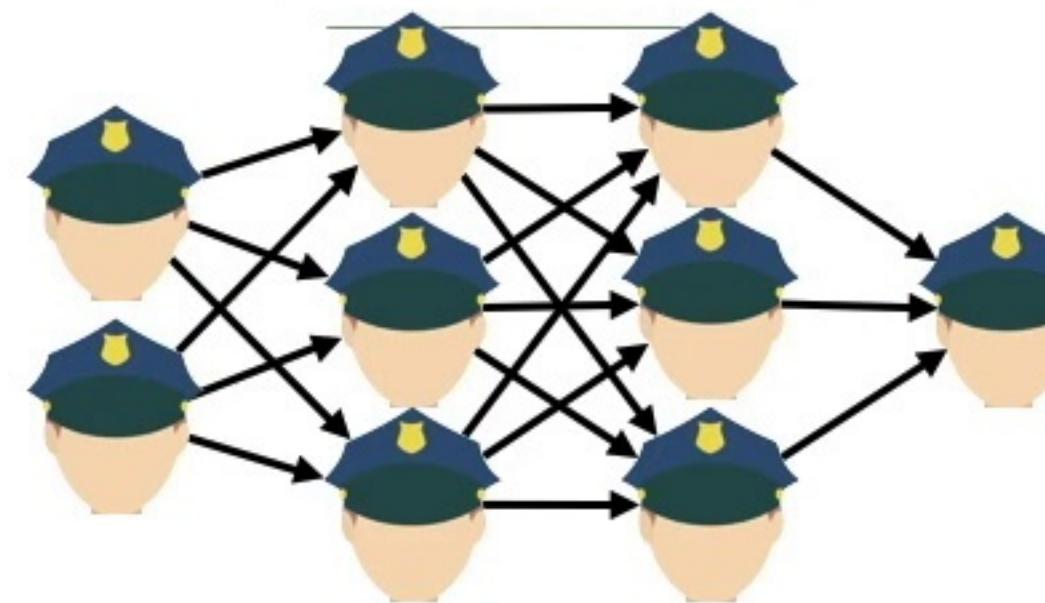


Real images

## Generator

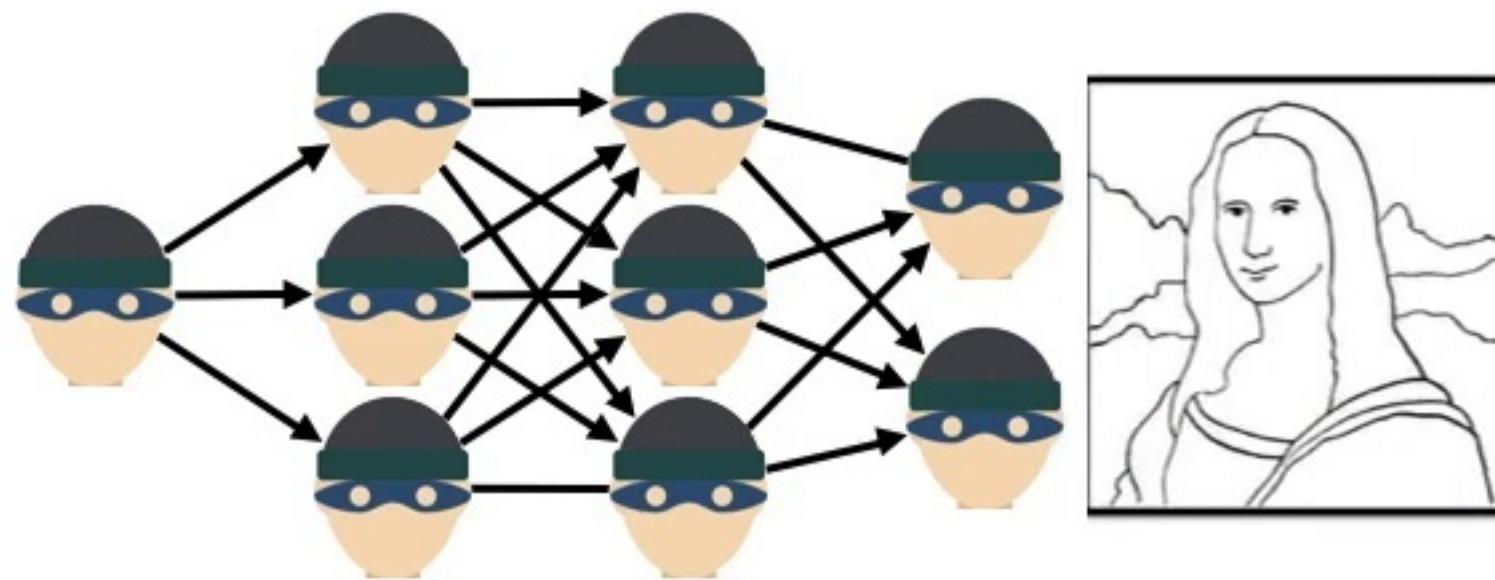


## Discriminator

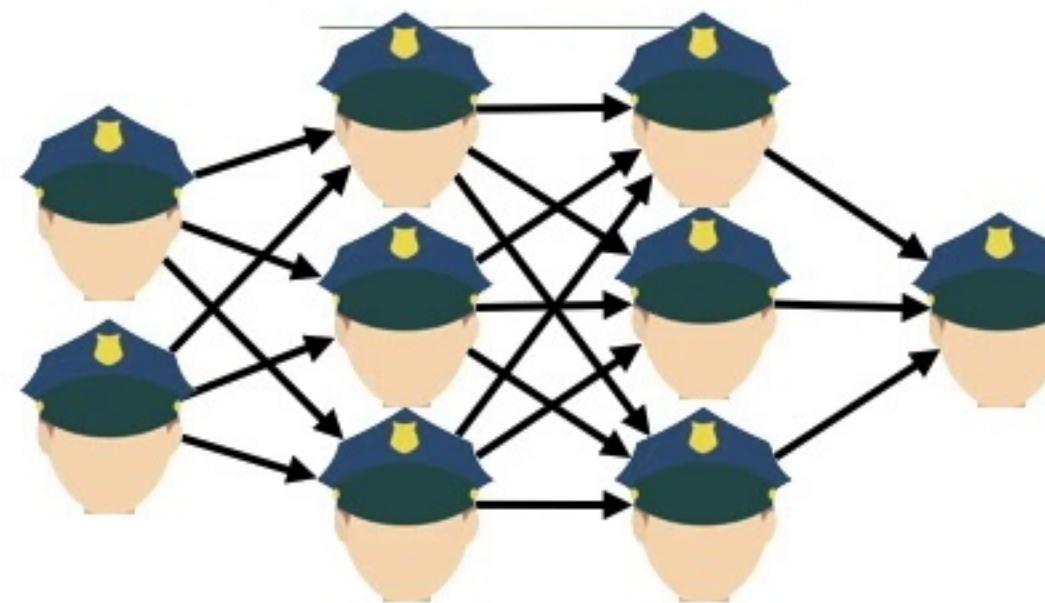


Real images

# Generator

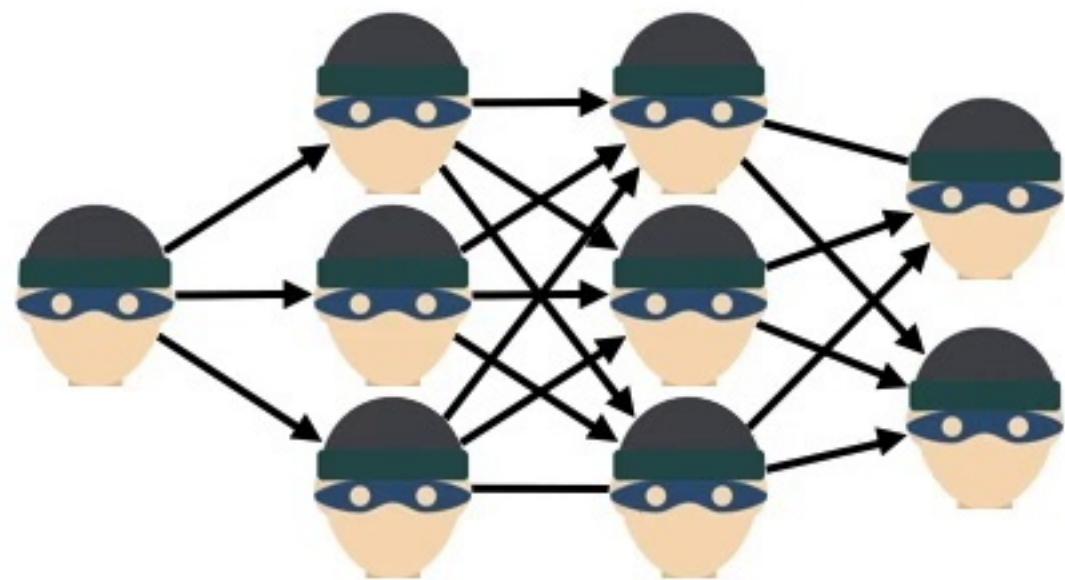


# Discriminator

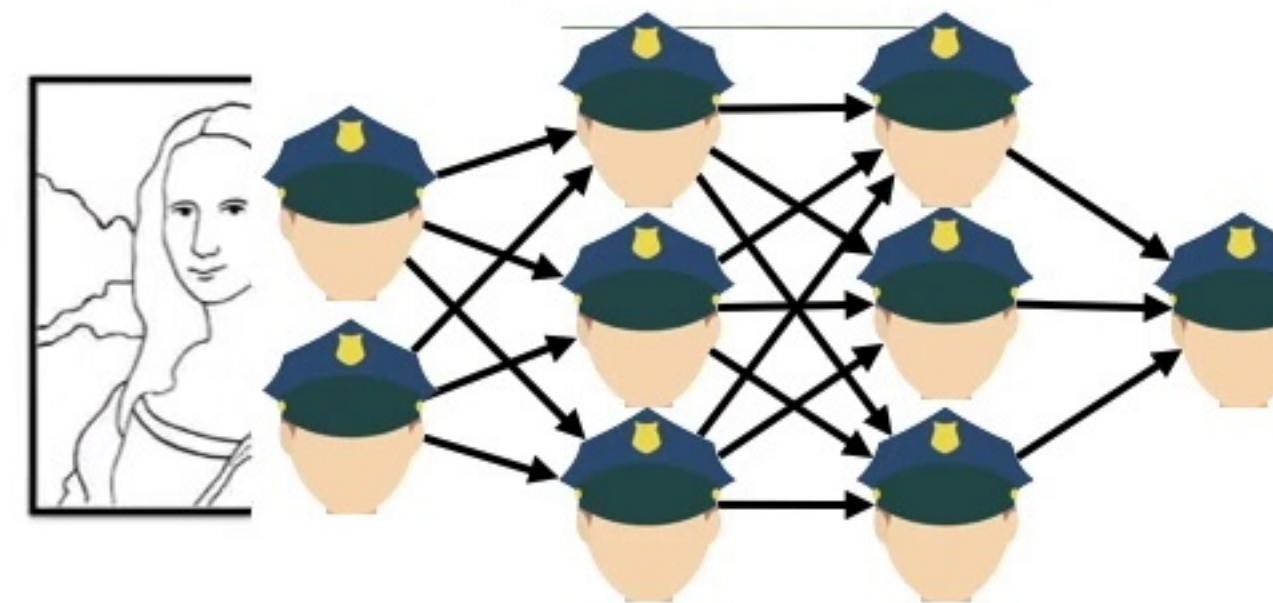


Real images

# Generator

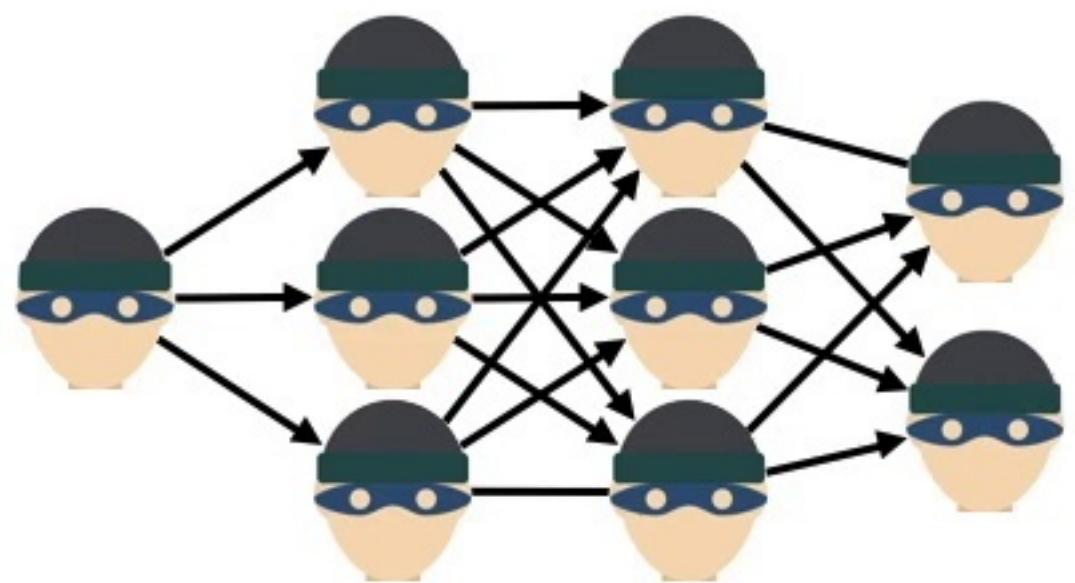


# Discriminator

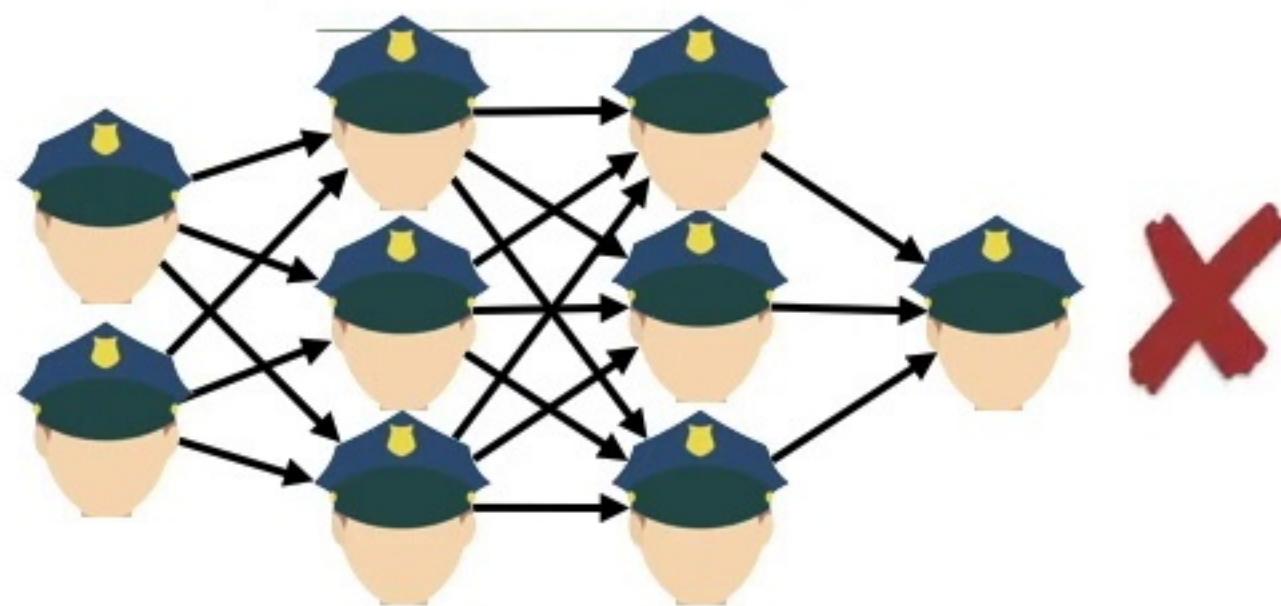


Real images

# Generator

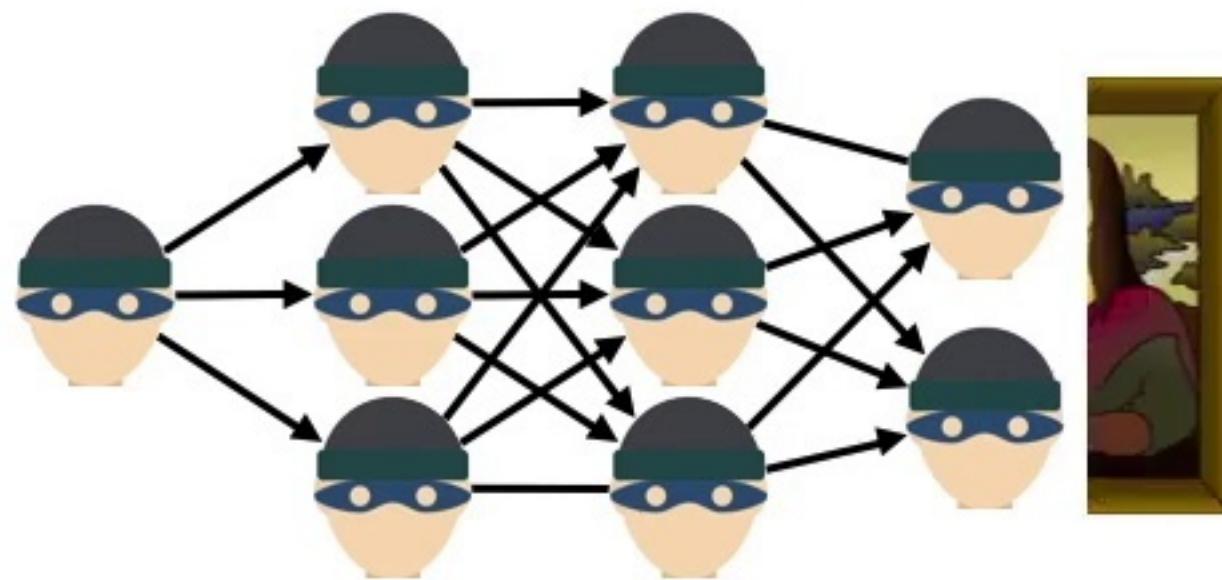


# Discriminator

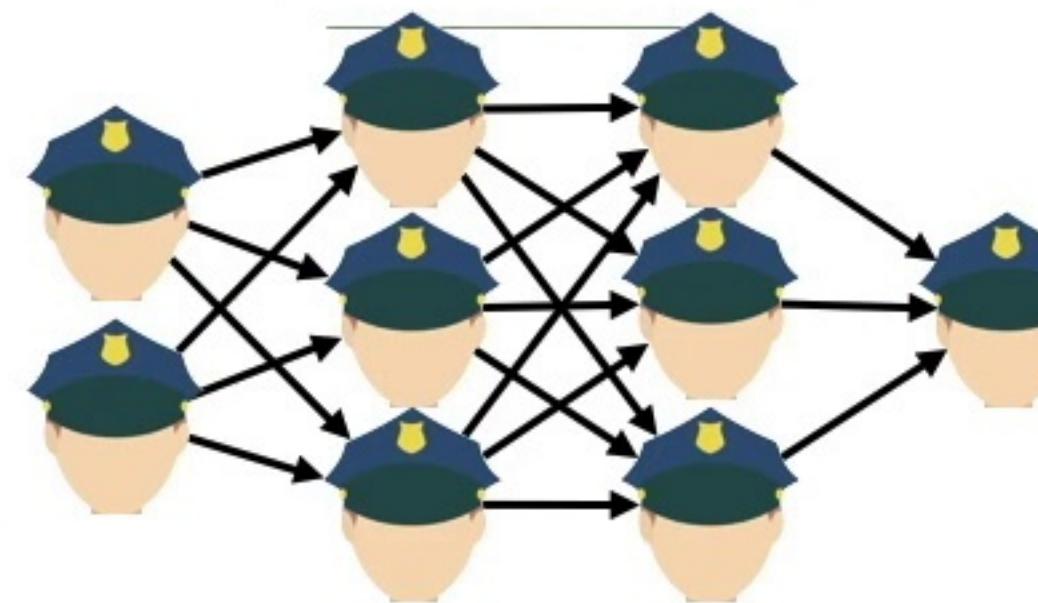


Real images

# Generator

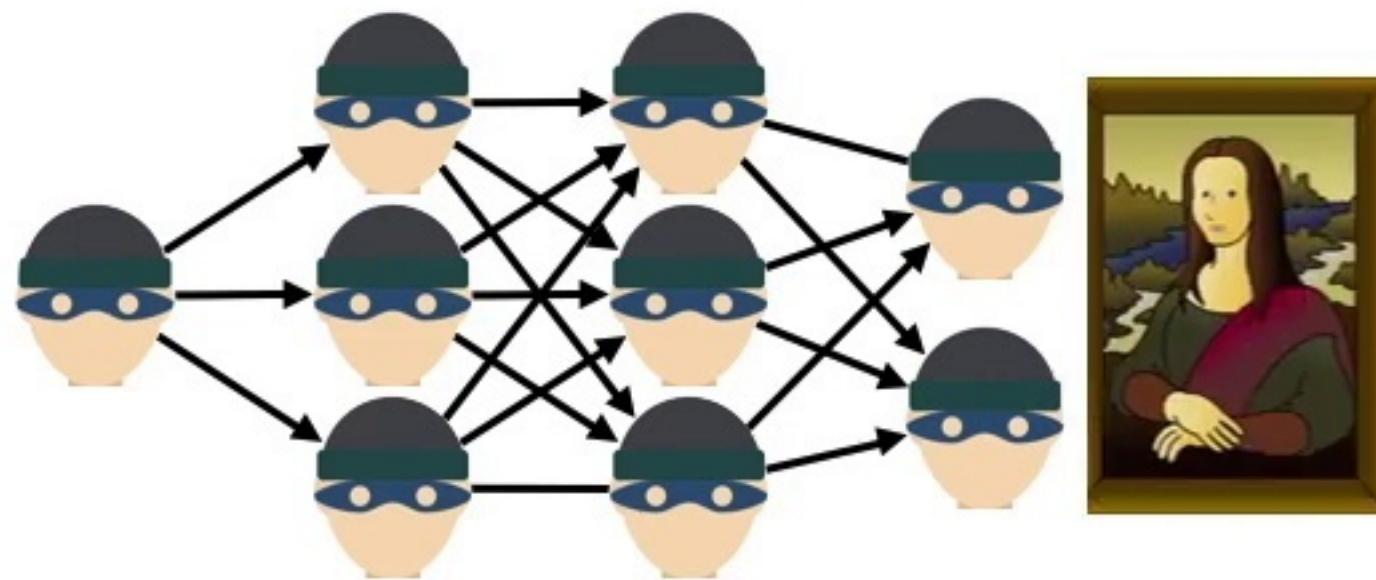


# Discriminator

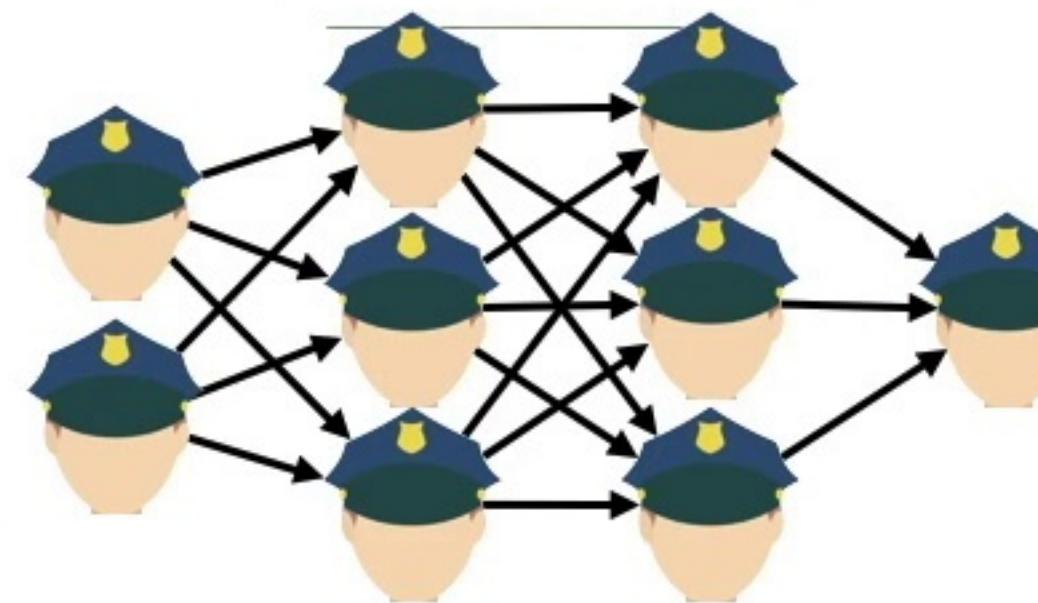


Real images

## Generator

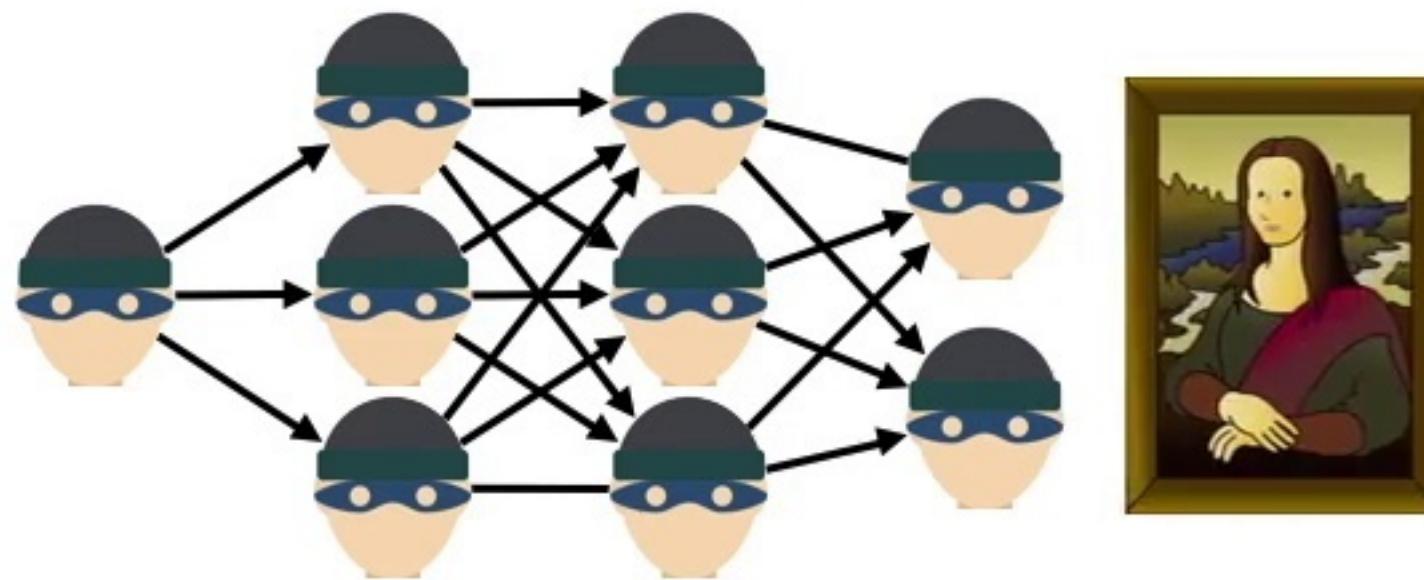


## Discriminator

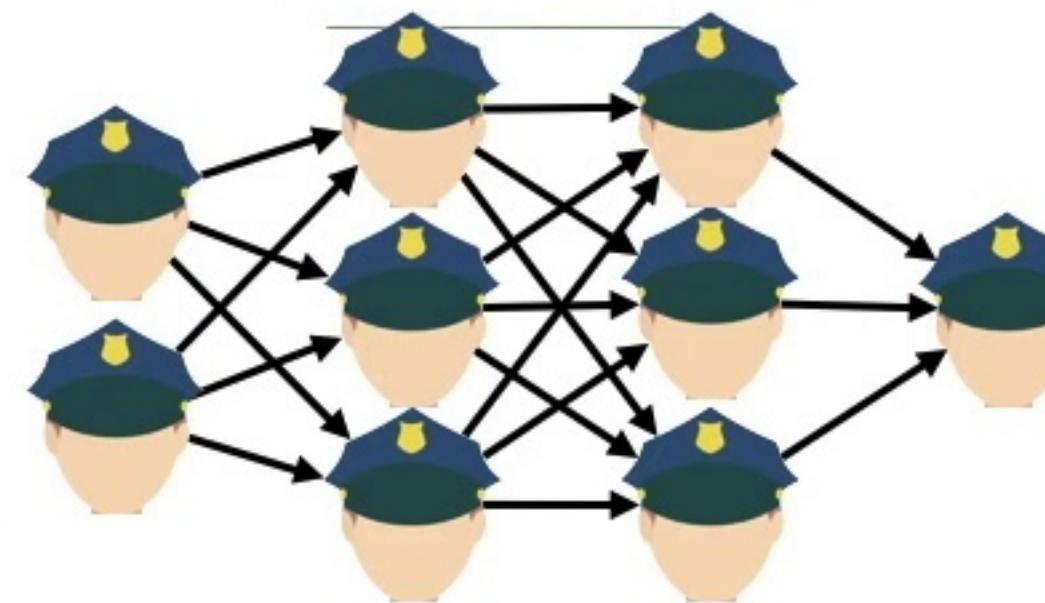


Real images

## Generator

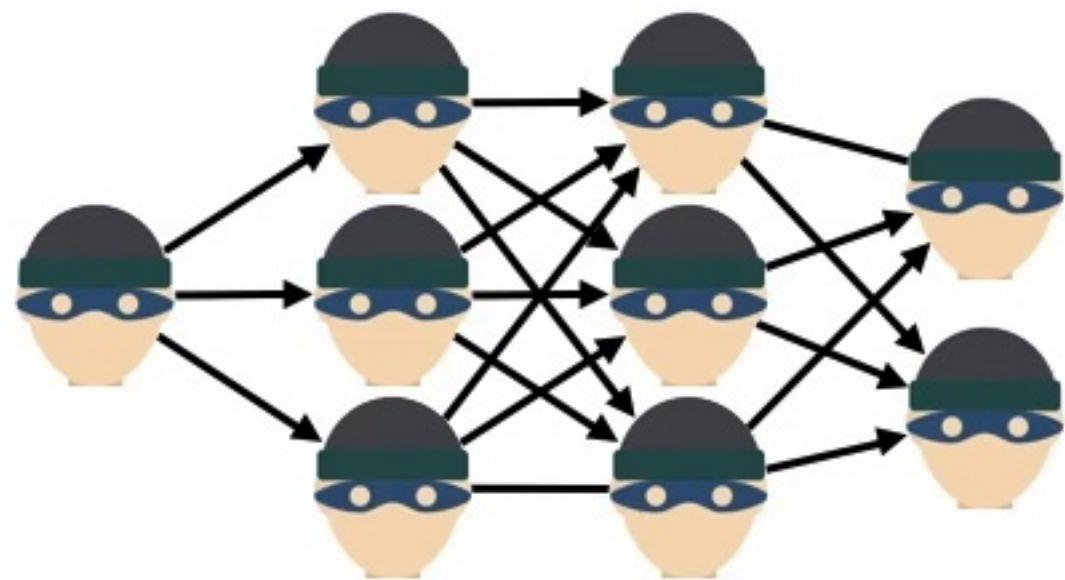


## Discriminator

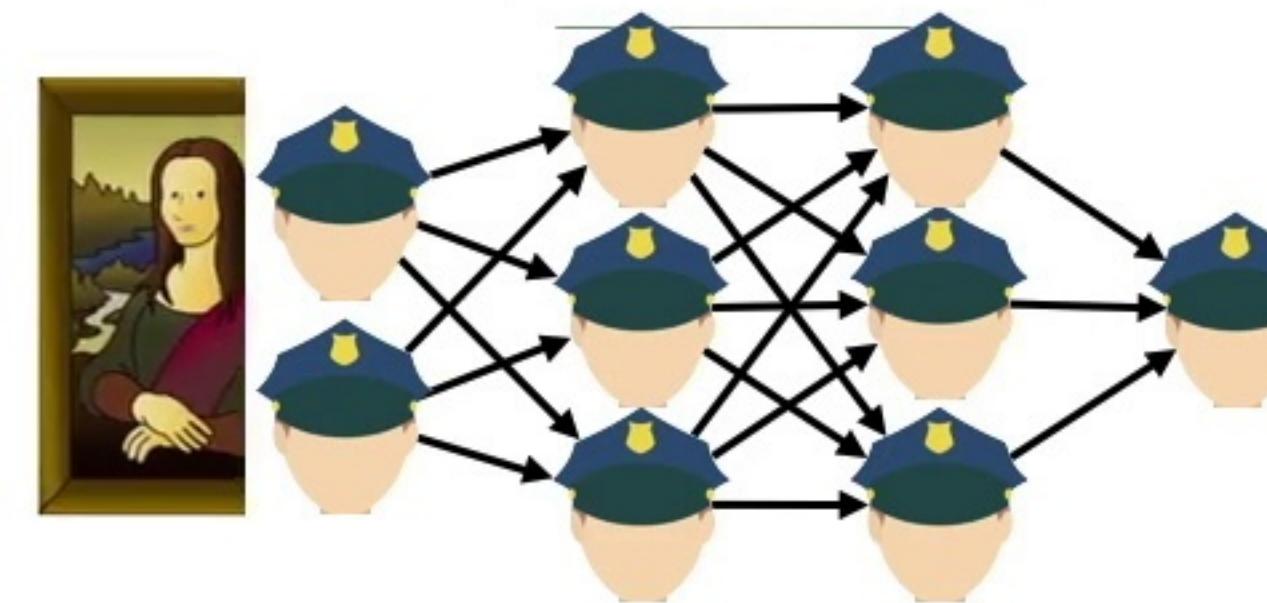


Real images

# Generator

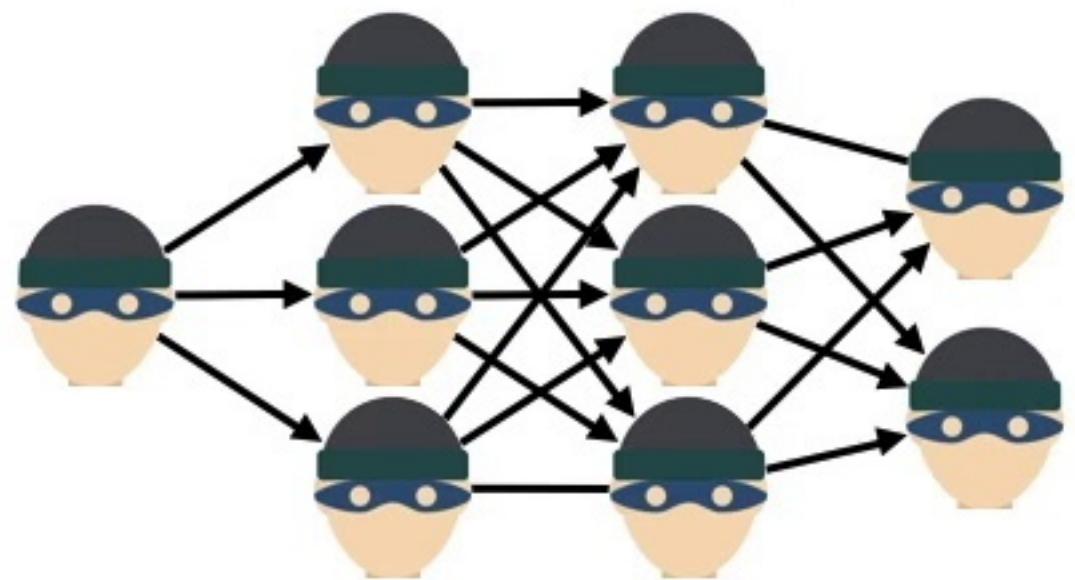


# Discriminator

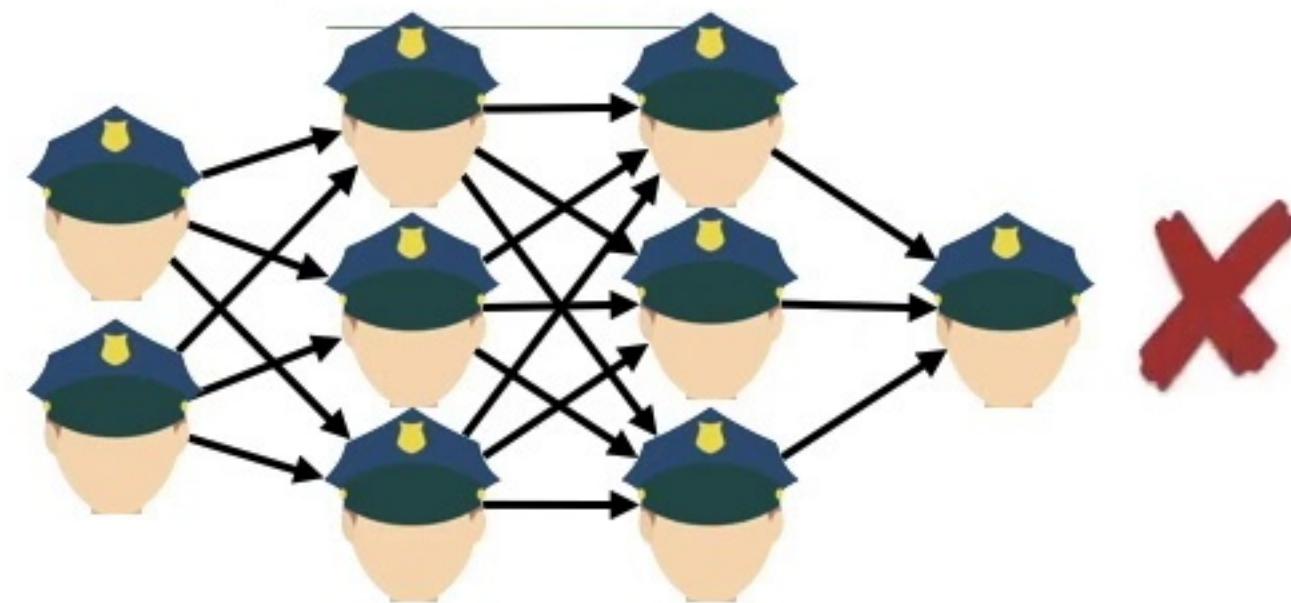


Real images

# Generator

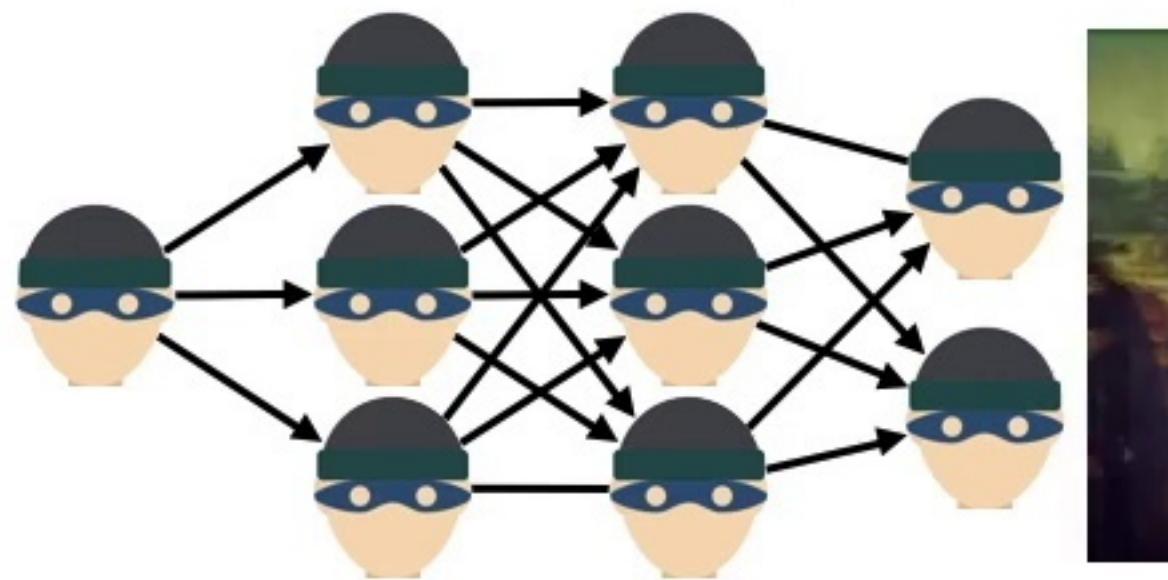


# Discriminator

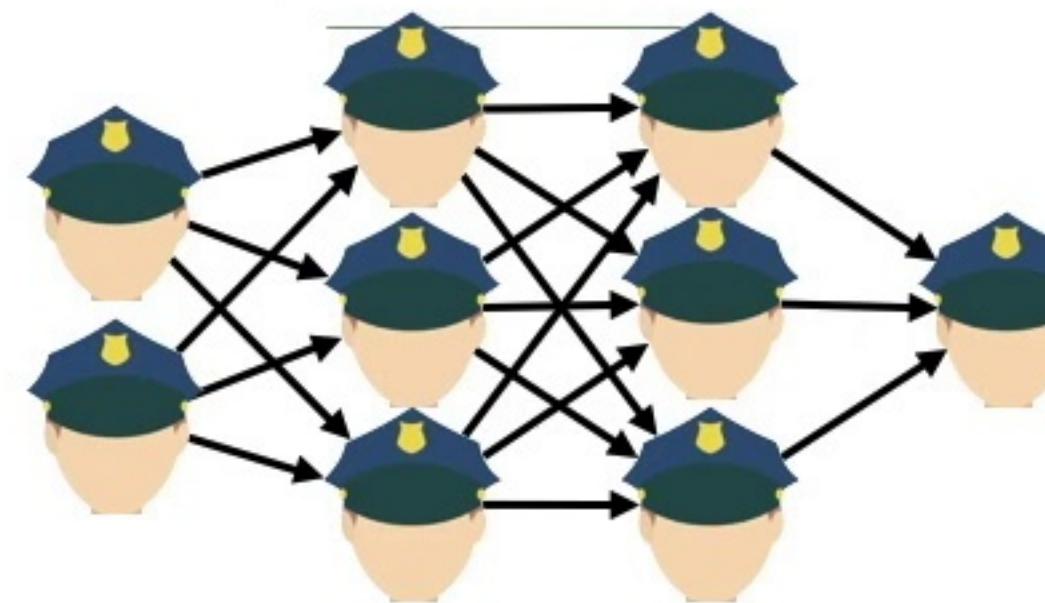


Real images

# Generator

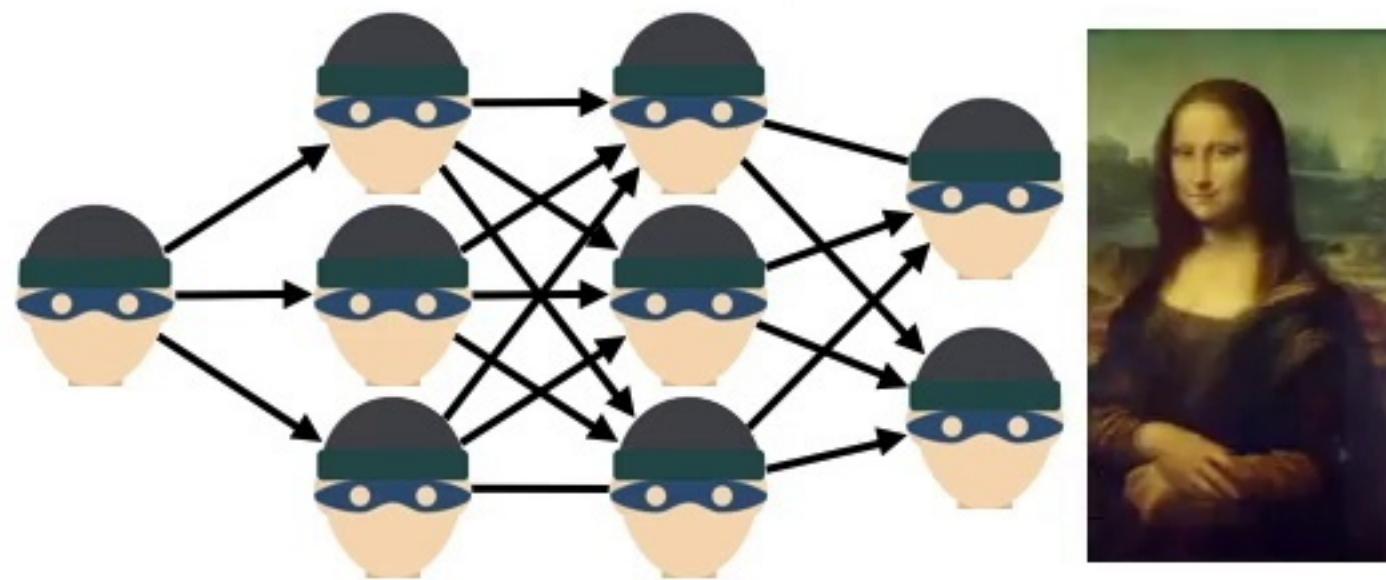


# Discriminator

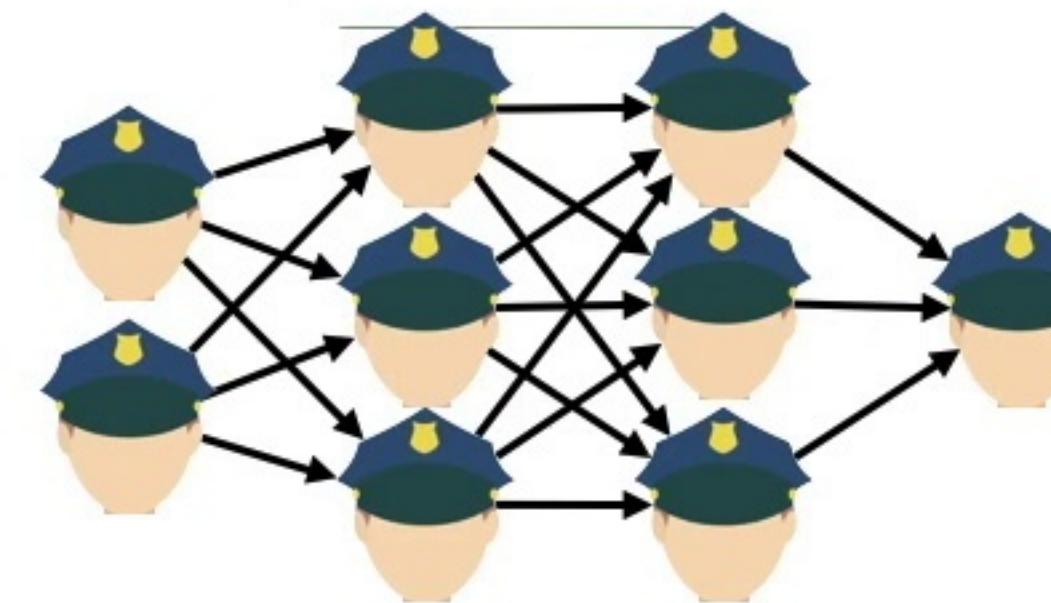


Real images

## Generator

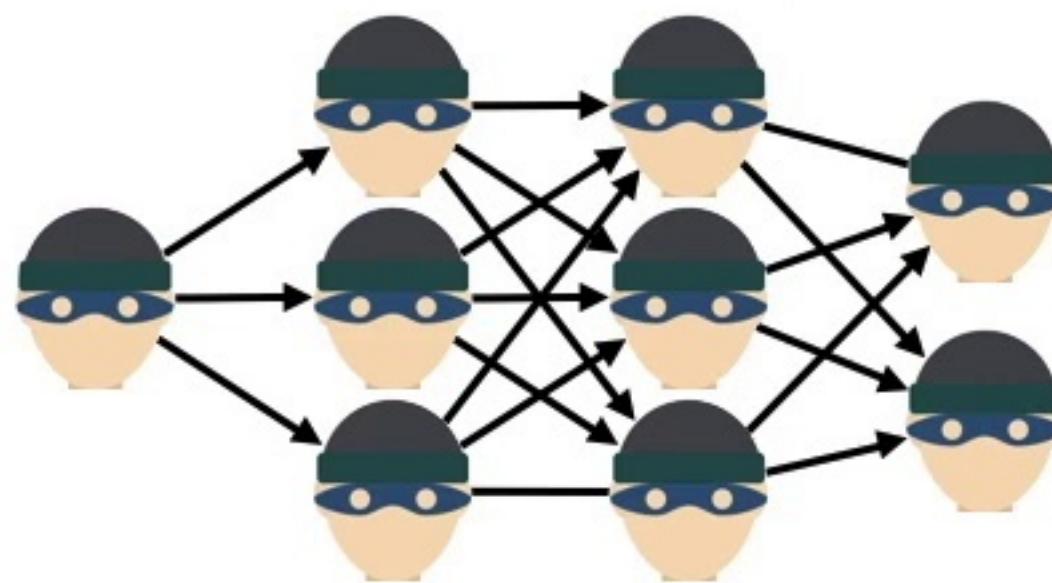


## Discriminator

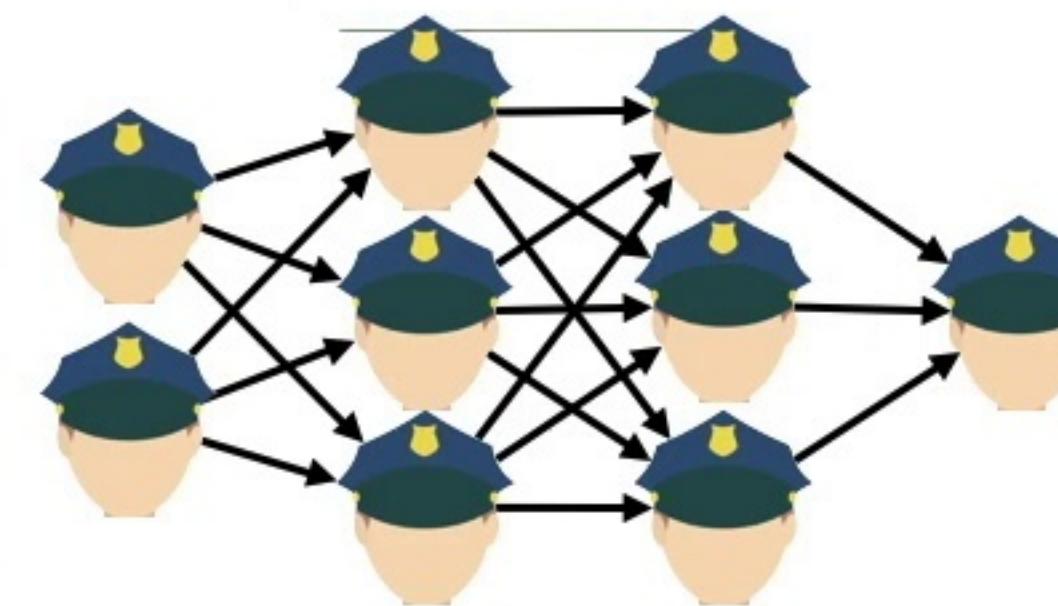


Real images

## Generator

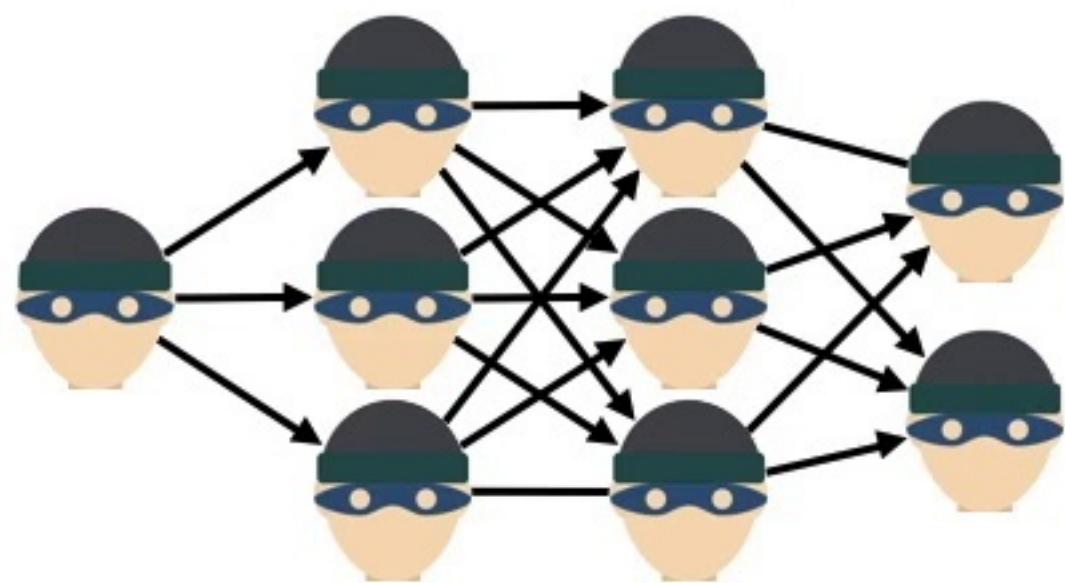


## Discriminator

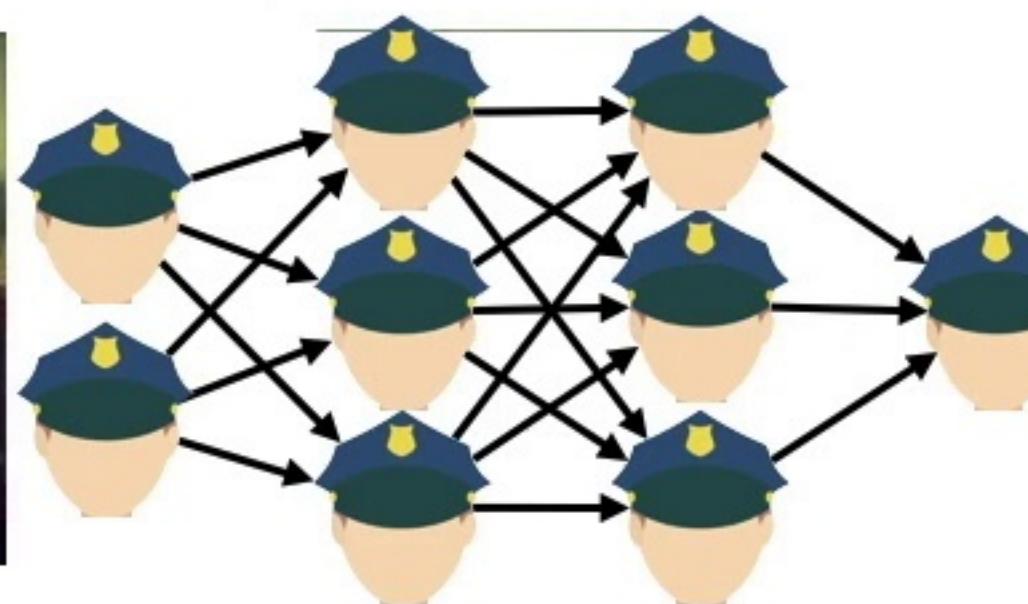


Real images

## Generator

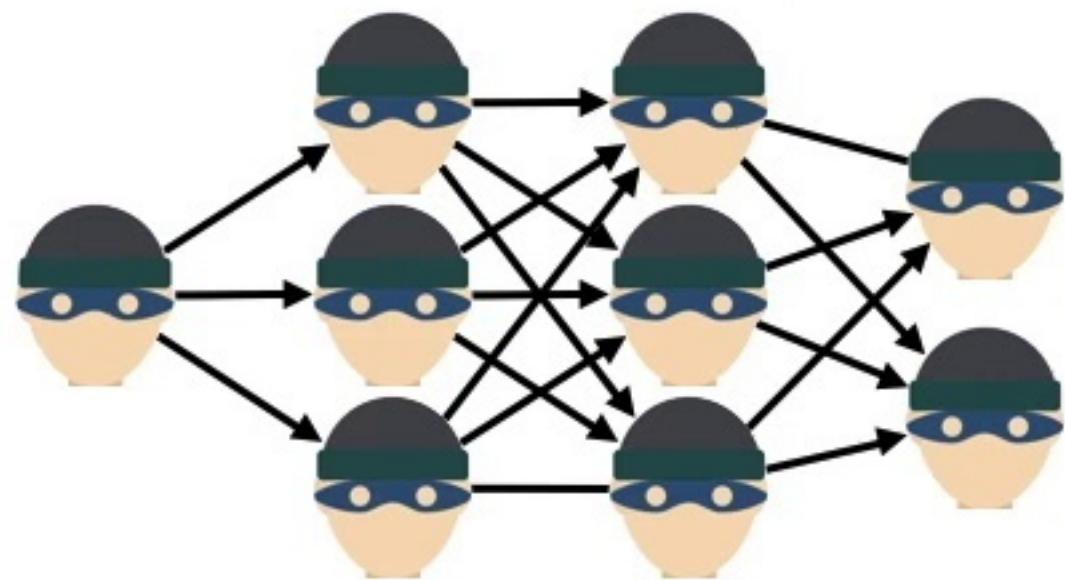


## Discriminator

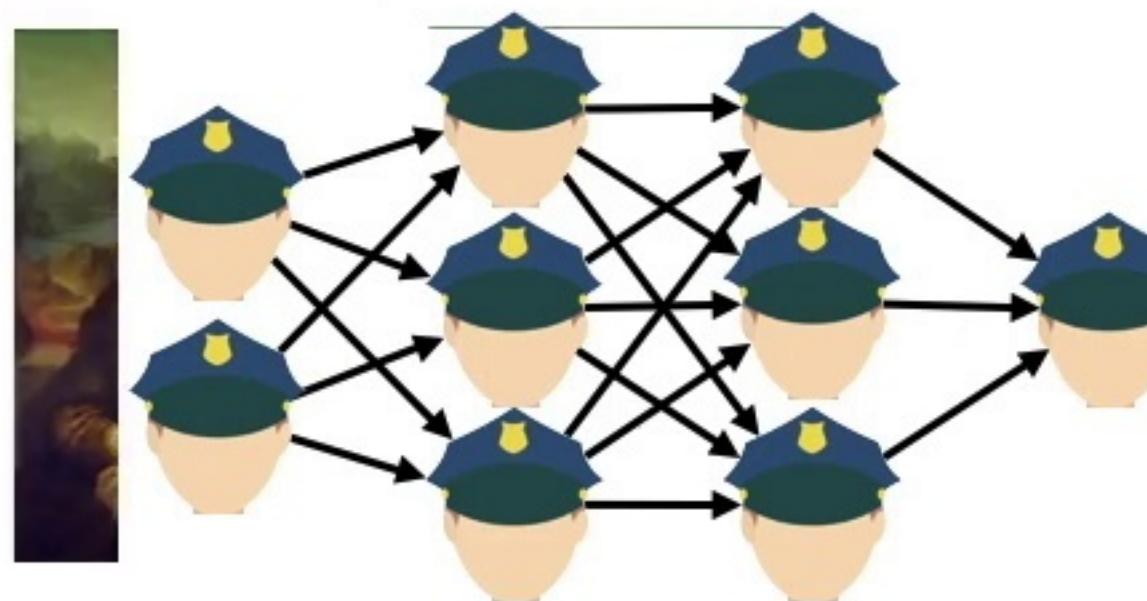


Real images

# Generator

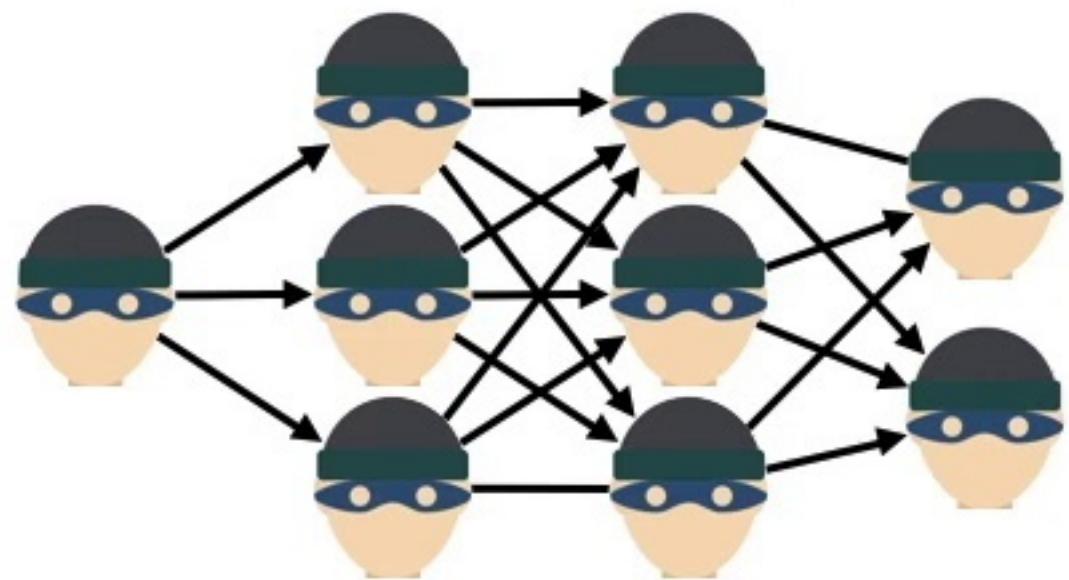


# Discriminator

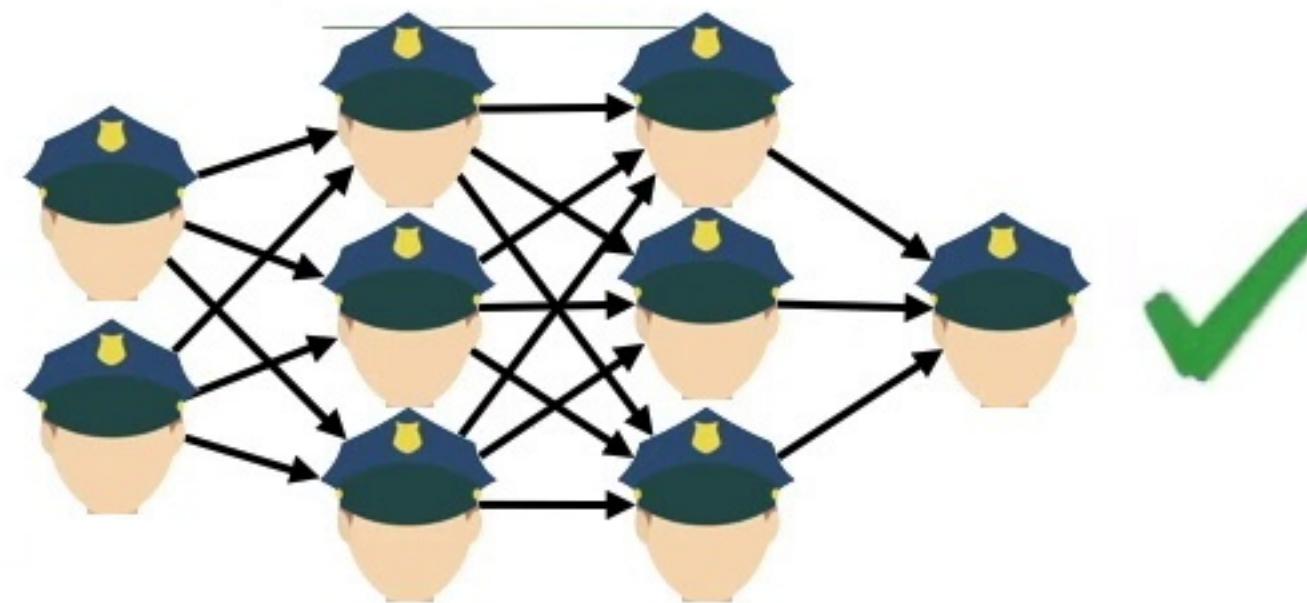


Real images

# Generator

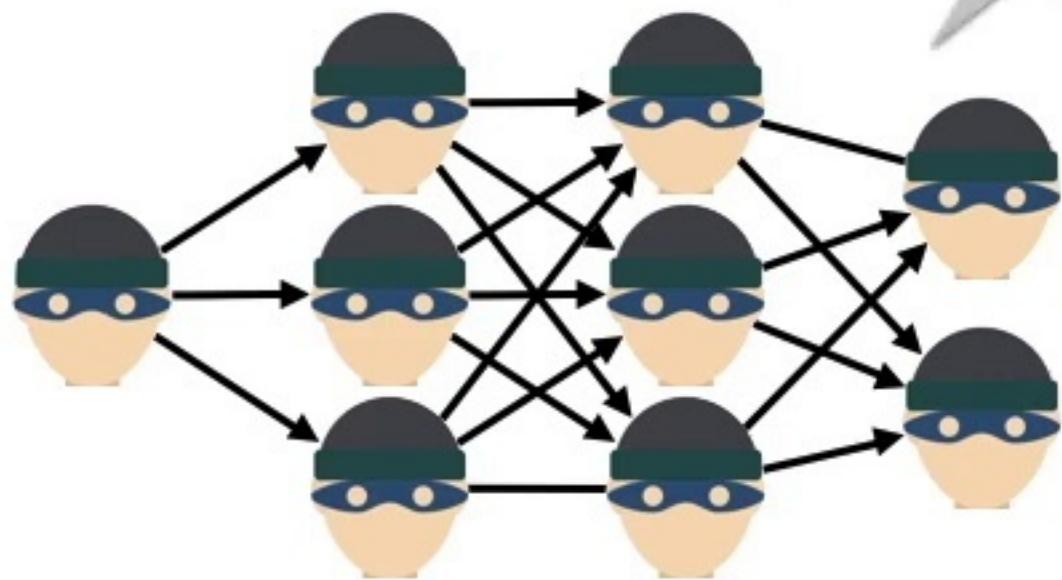


# Discriminator



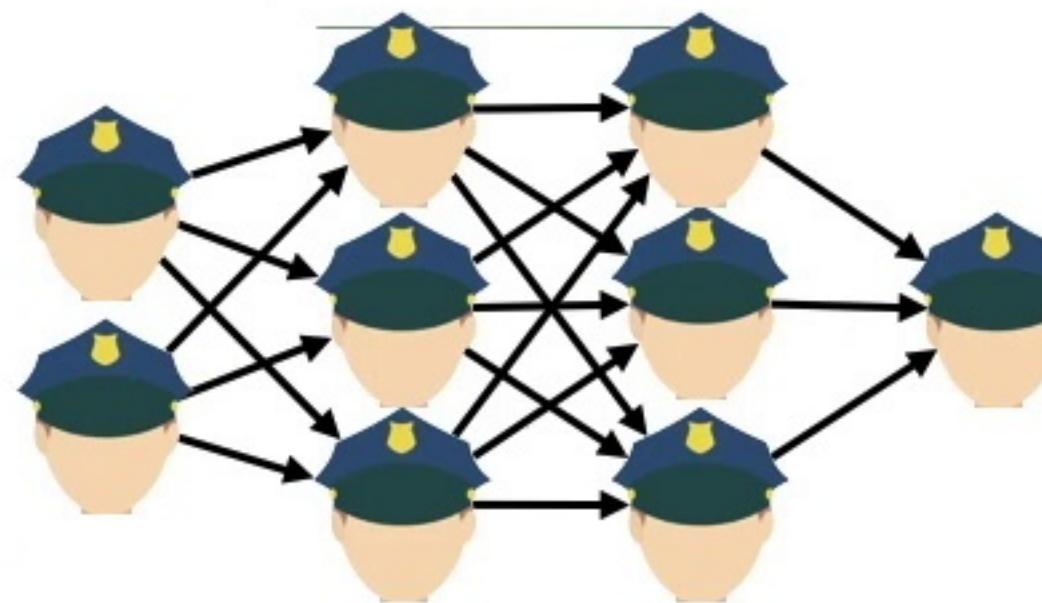
Real images

## Generator



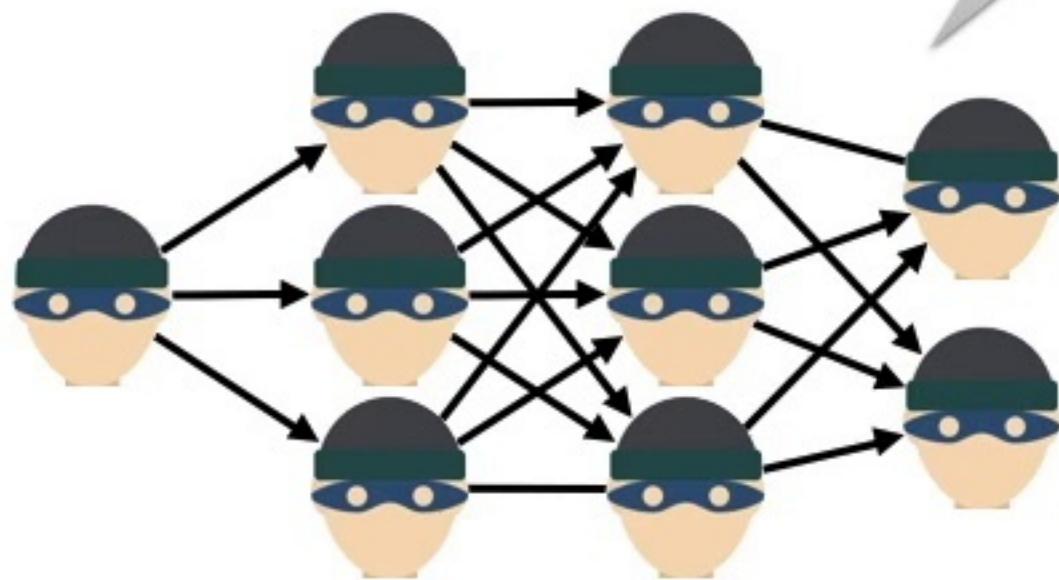
AHA!!

## Discriminator



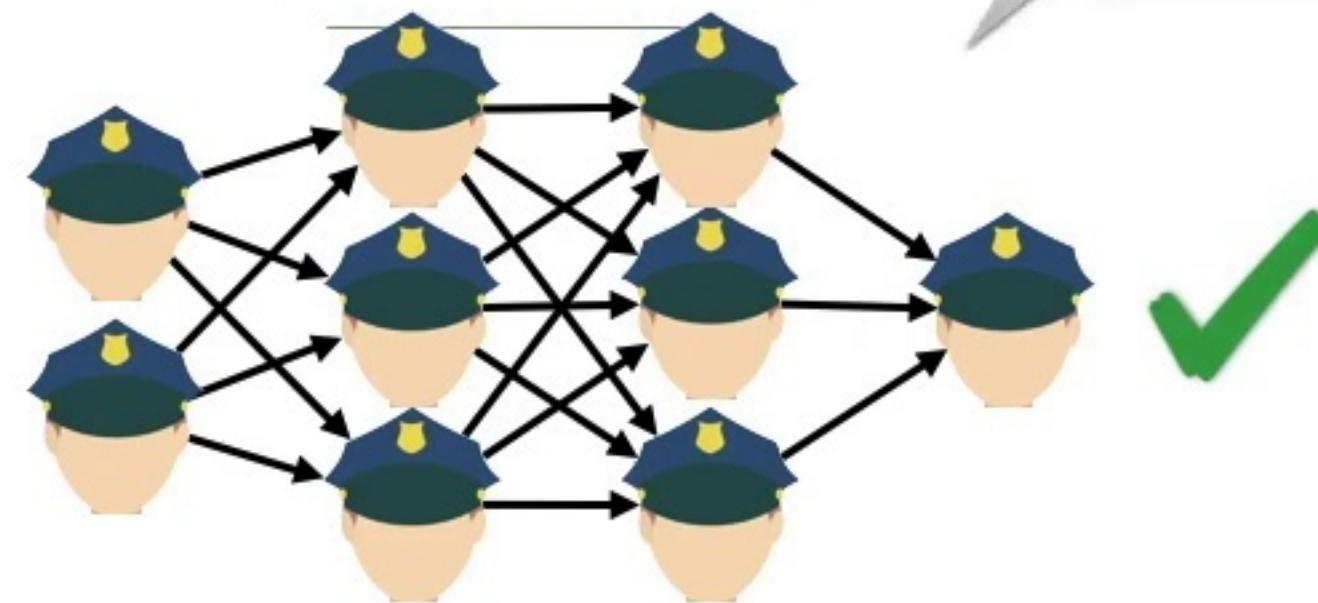
Real images

## Generator



AHA!!

## Discriminator



?

Real images

**Build the simplest GAN**

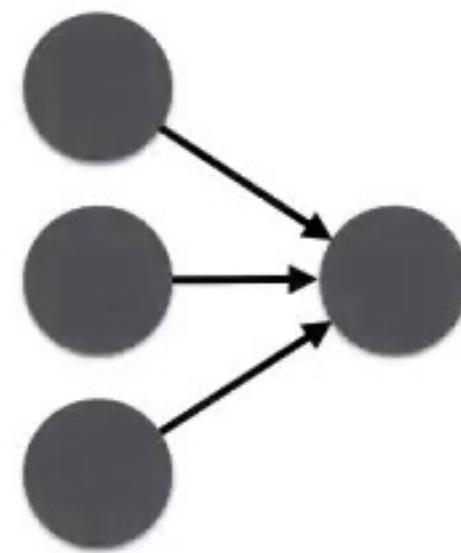
# Slanted Land



Slanted people

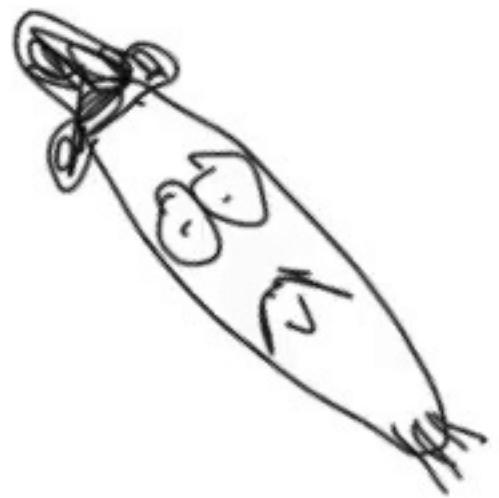
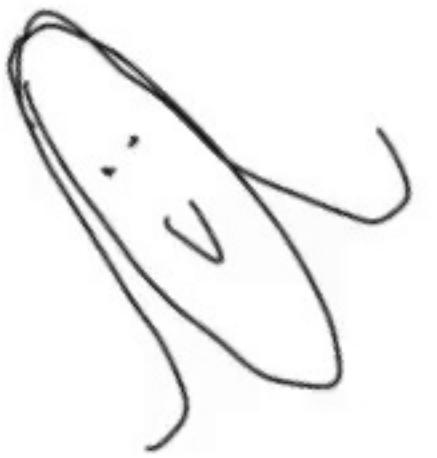
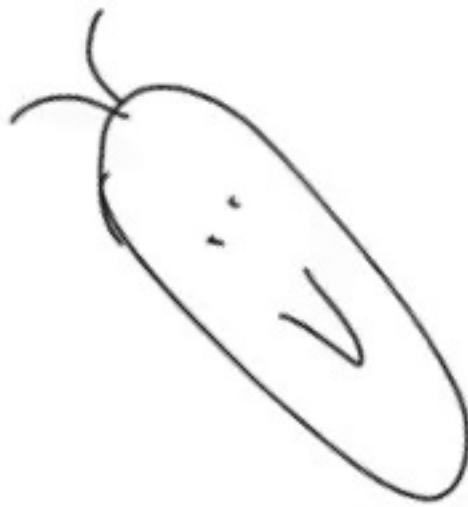


2x2 screens

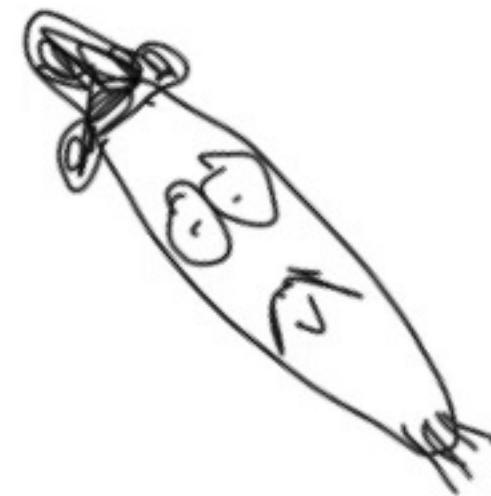
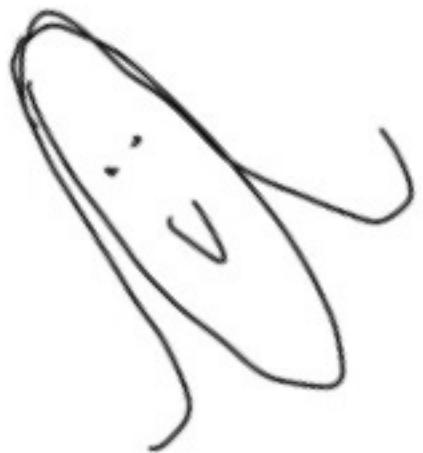
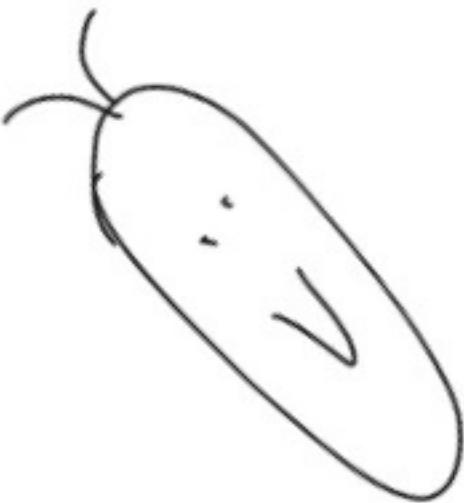


1-layer  
Neural networks

# Faces



# Faces



# No faces (noise)



Faces

0.75	0
0	0.75

1	0.25
0.25	0.75

1	0
0	1

0.75	0
0.25	0.75

Noise

0.25	0
1	0.75

0.25	1
0.5	0.75

0.75	0.5
0.75	0

1	1
0	0.75

0 1



# Building the Discriminator

# Building the discriminator

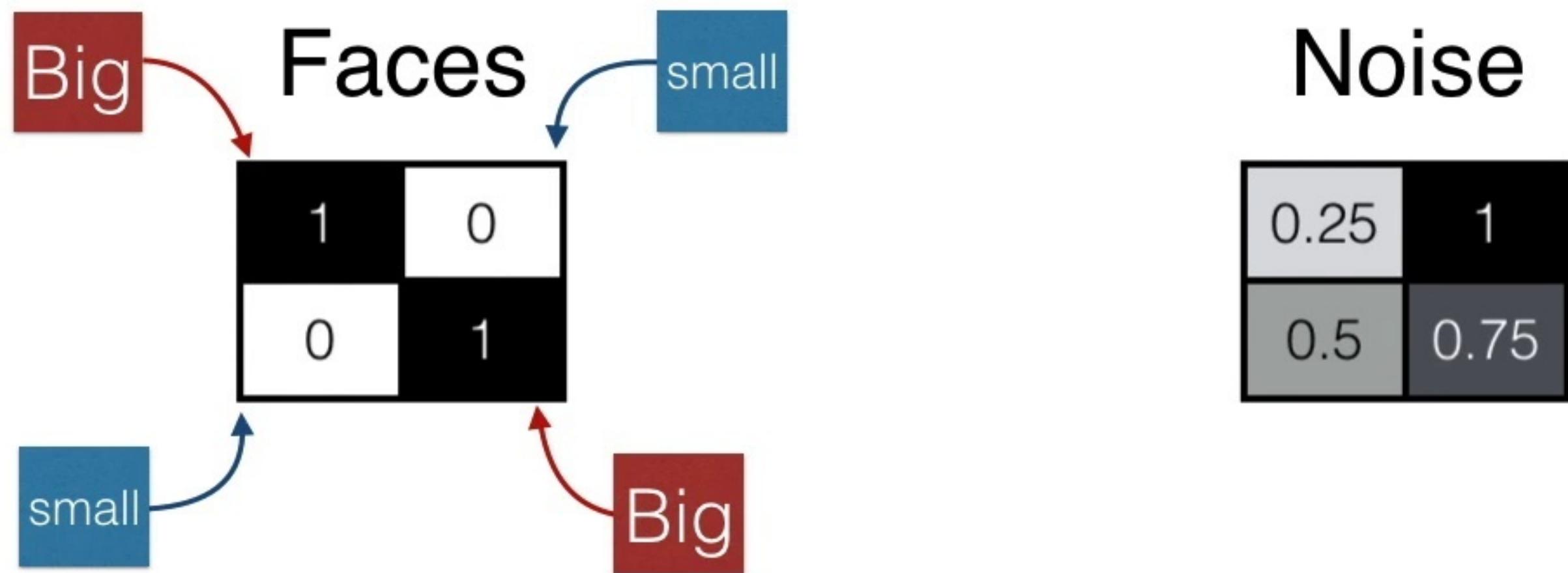
Faces

1	0
0	1

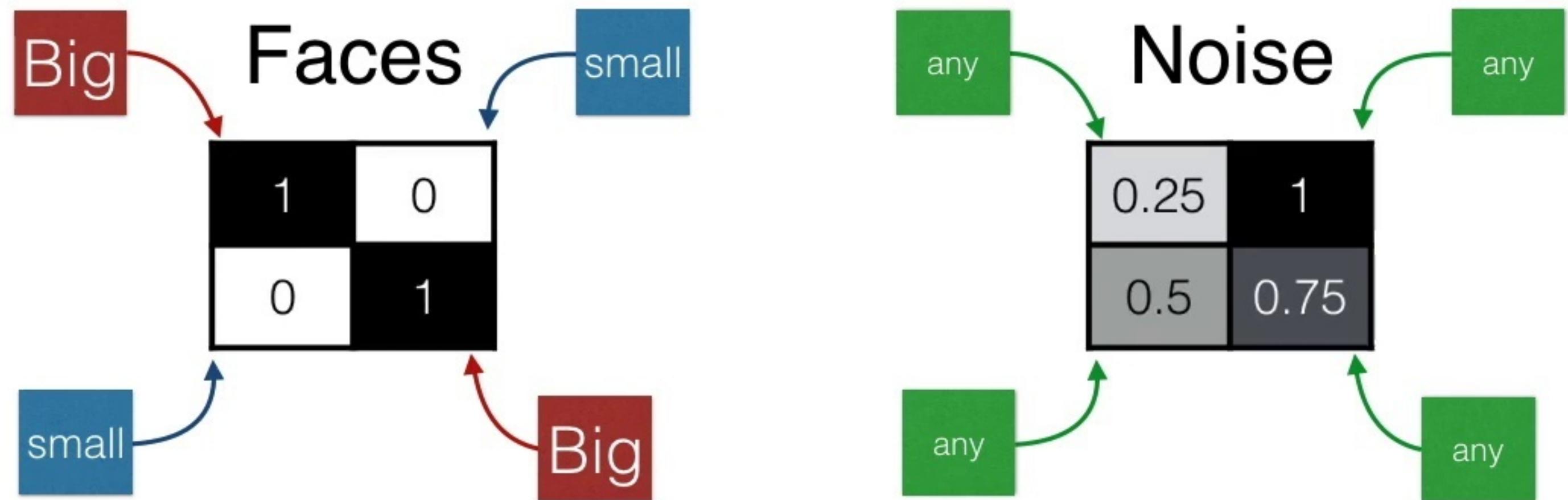
Noise

0.25	1
0.5	0.75

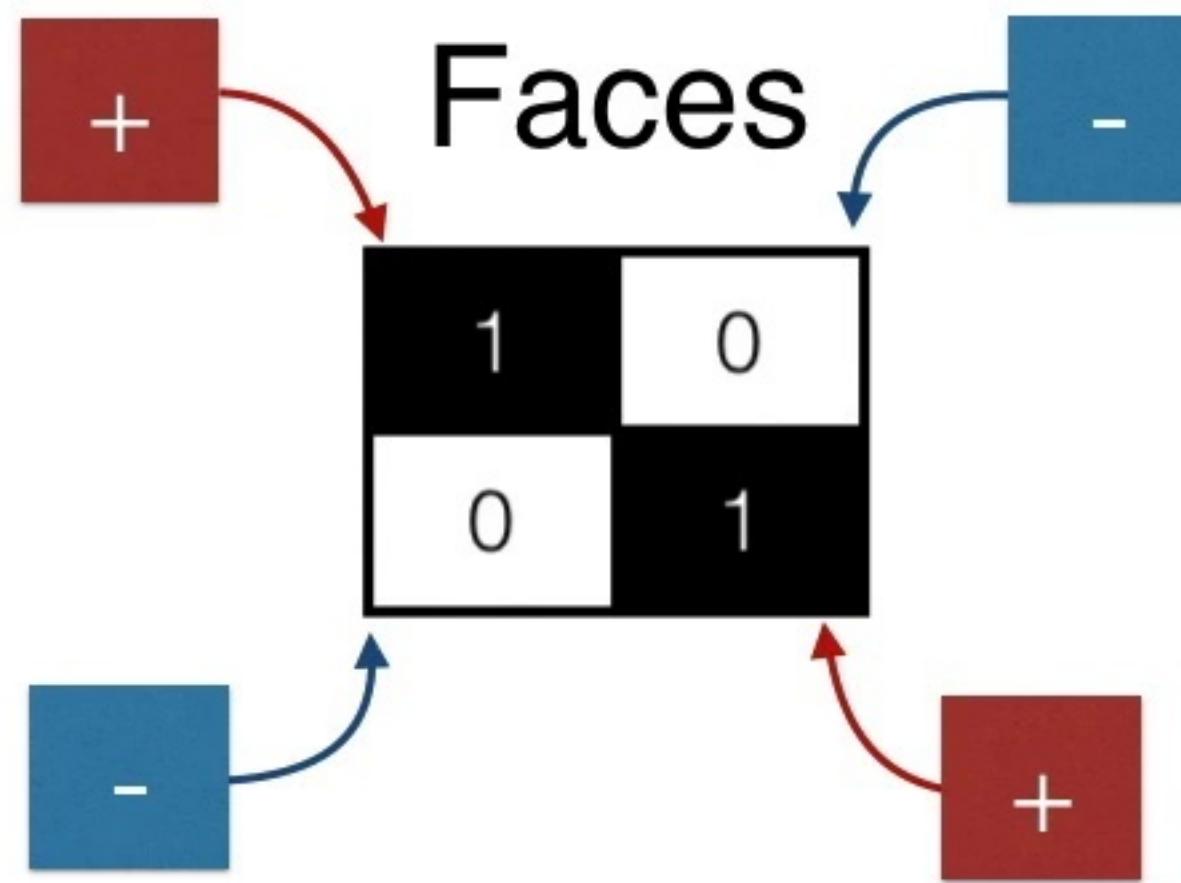
# Building the discriminator



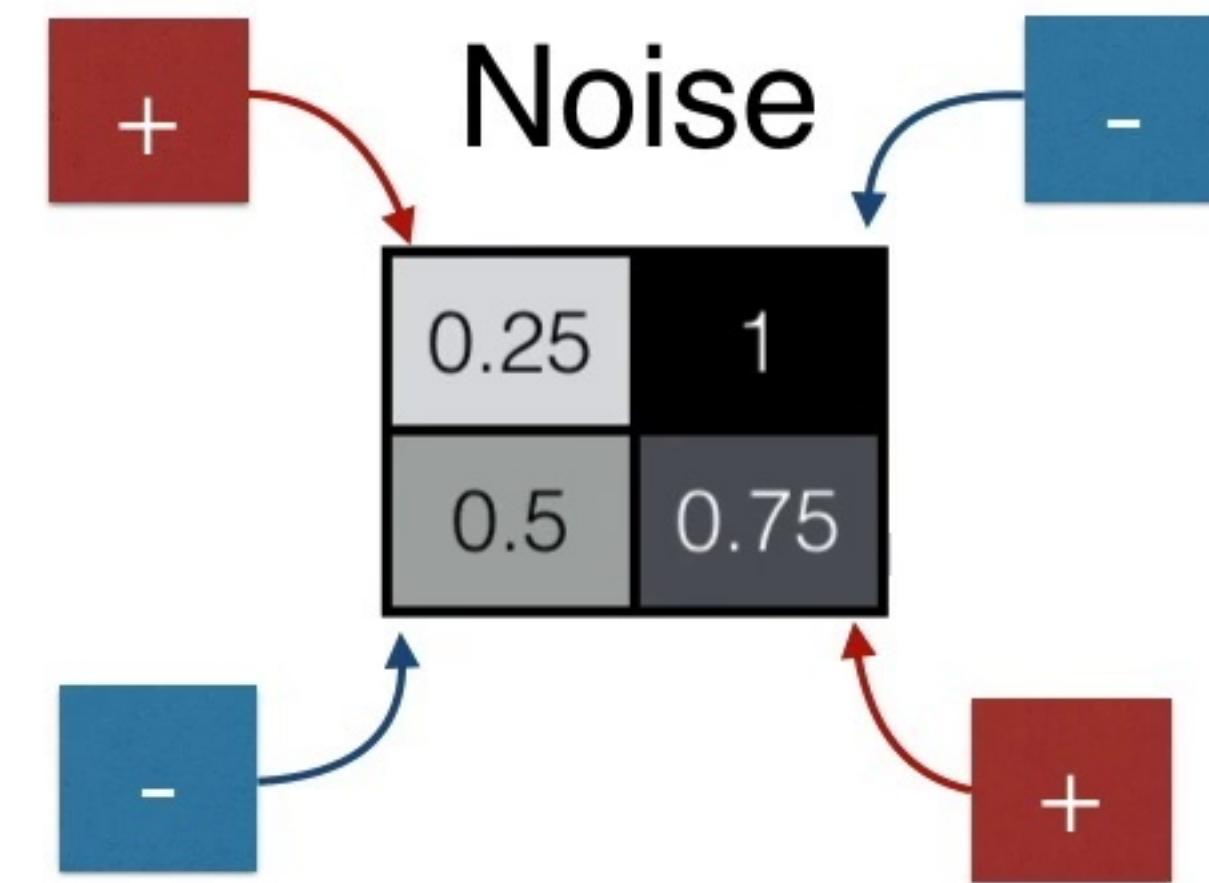
# Building the discriminator



# Building the discriminator

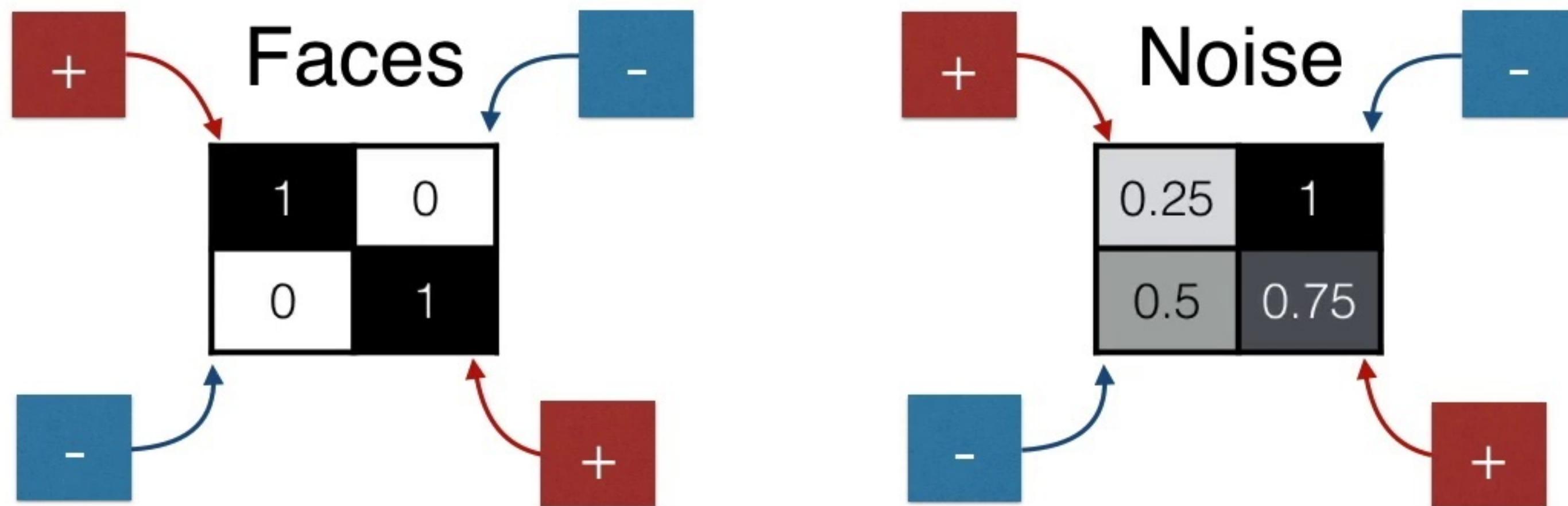


$$1 * \textcolor{red}{1} + 0 * \textcolor{blue}{(-1)} + 0 * \textcolor{blue}{(-1)} + 1 * \textcolor{red}{1} \\ = 2$$



$$0.25 * \textcolor{red}{1} + 1 * \textcolor{blue}{(-1)} + 0.5 * \textcolor{blue}{(-1)} + 0.75 * \textcolor{red}{1} \\ = -0.5$$

# Building the discriminator



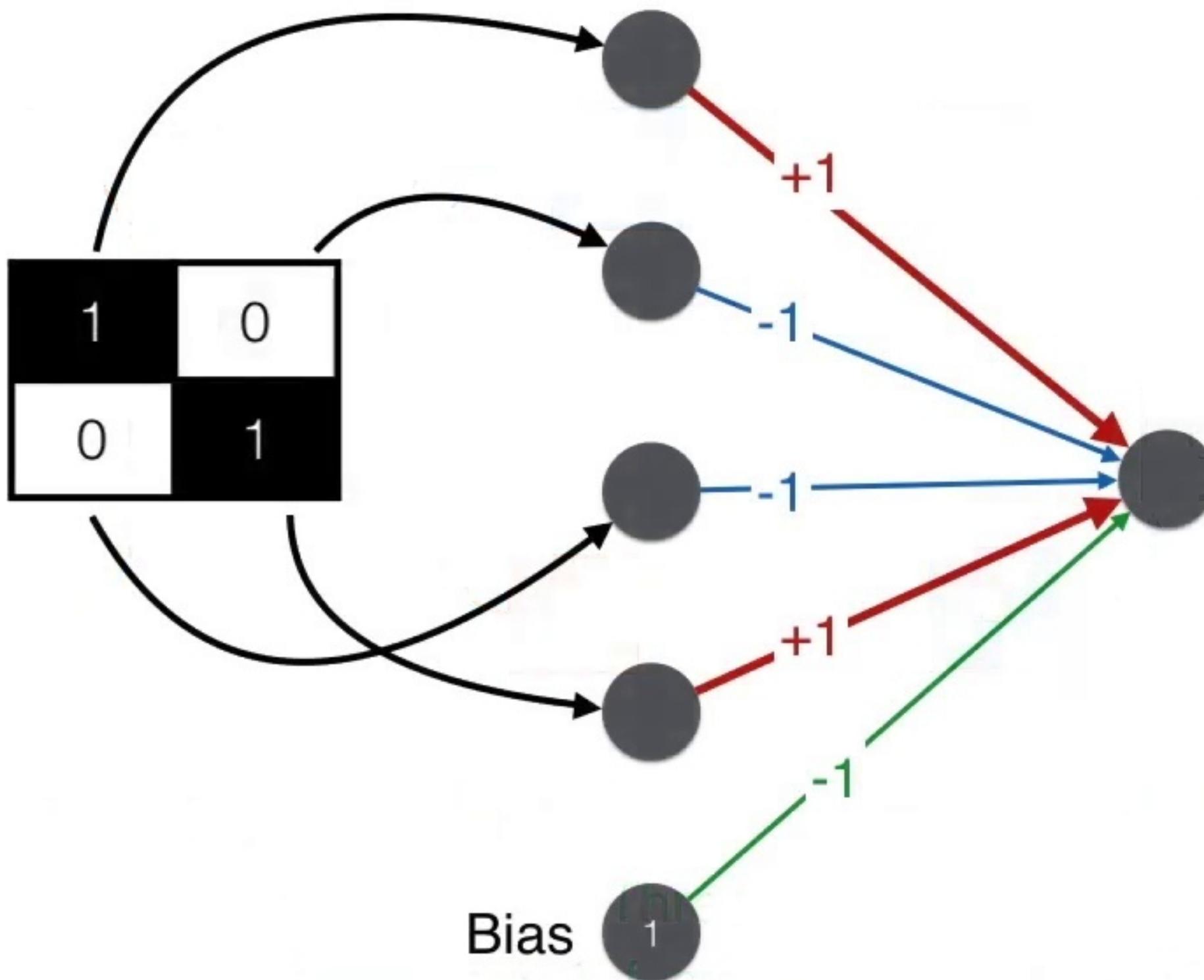
$$\begin{aligned} 1 * 1 + 0 * (-1) + 0 * (-1) + 1 * 1 \\ = 2 \end{aligned}$$

Threshold = 1

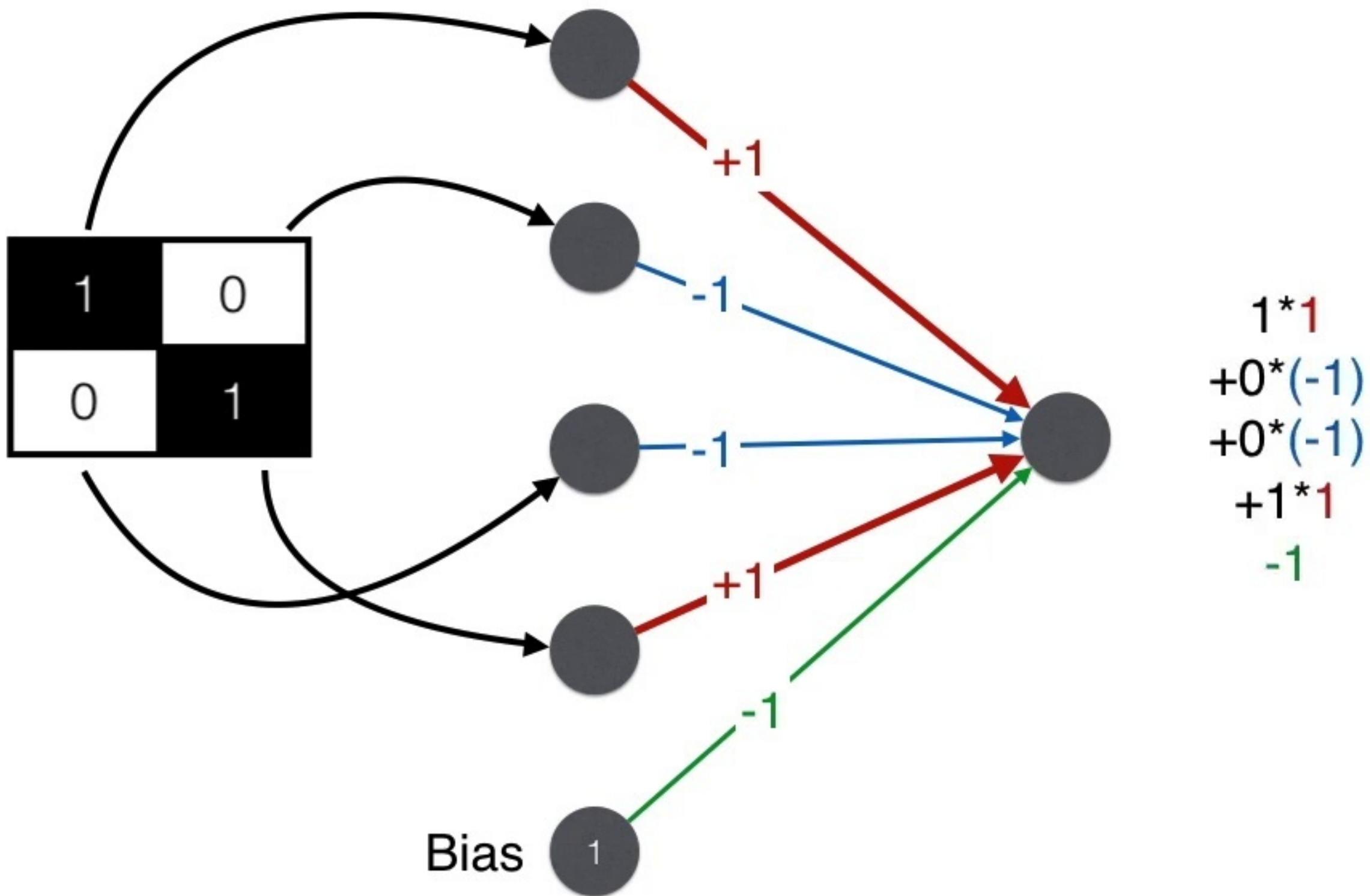
$$\begin{aligned} 0.25 * 1 + 1 * (-1) + 0.5 * (-1) + 0.75 * 1 \\ = -0.5 \end{aligned}$$

More than 1: face. Less than 1: no face

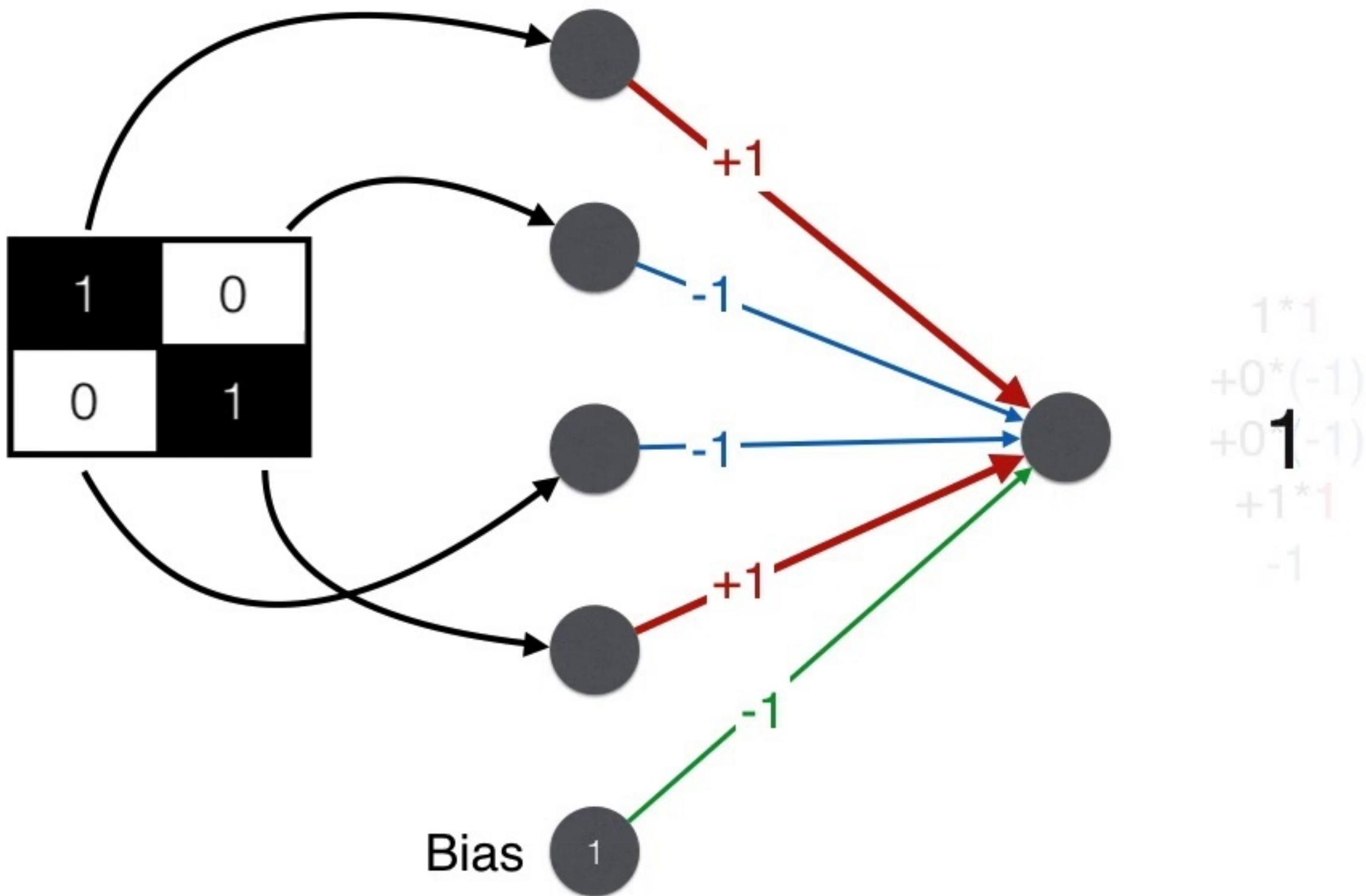
# Discriminator



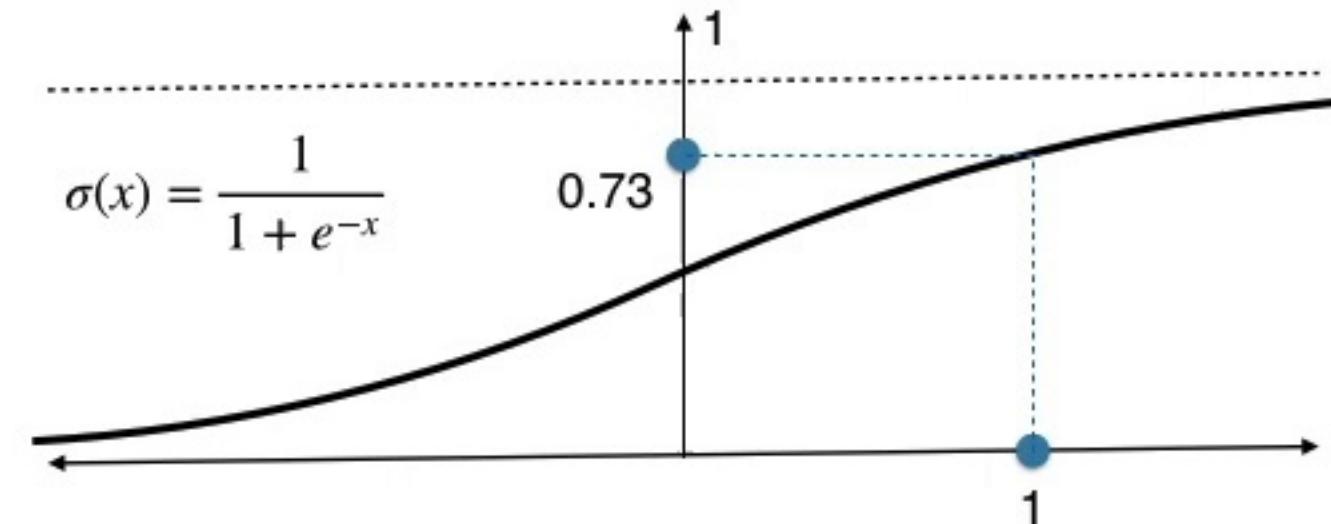
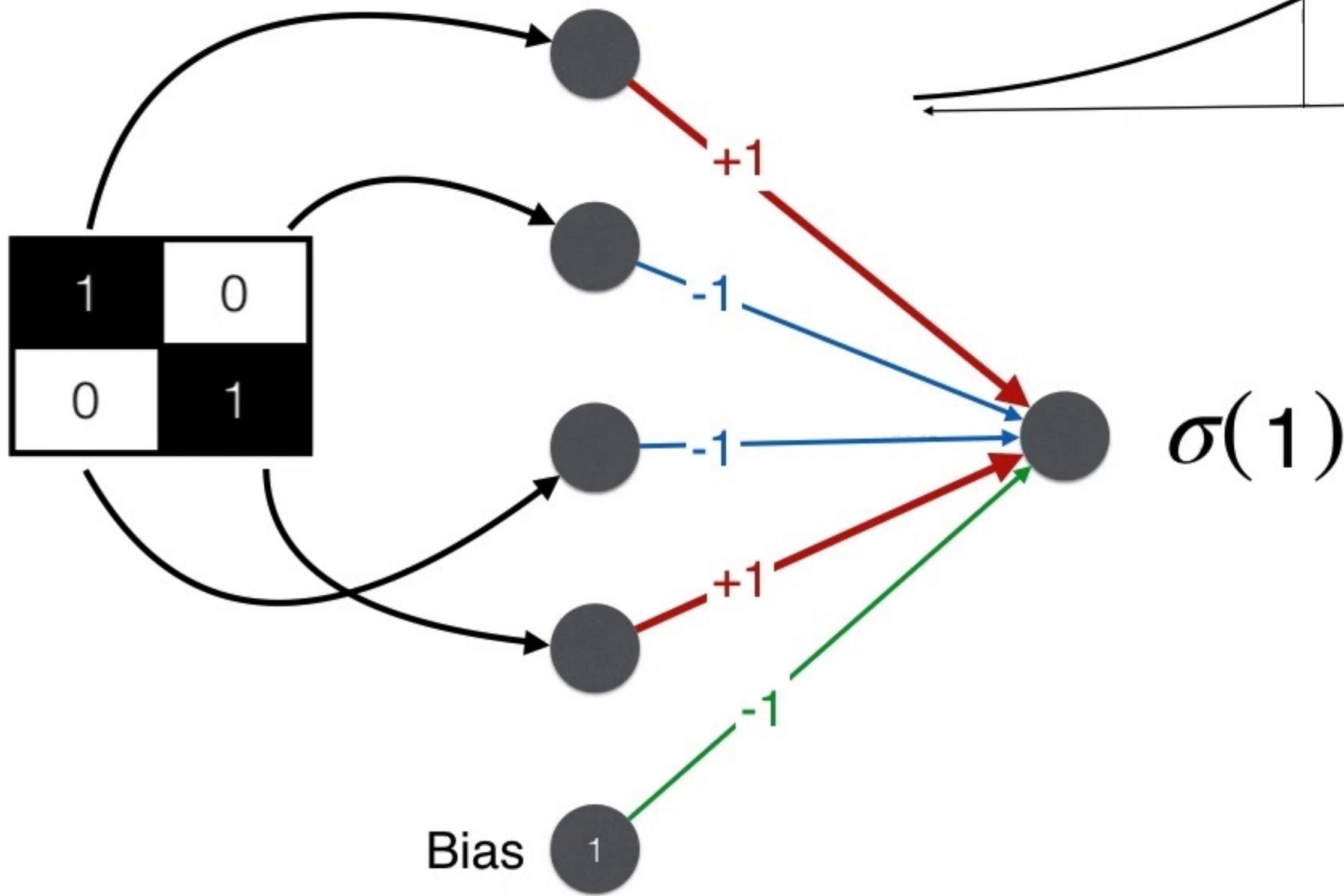
# Discriminator



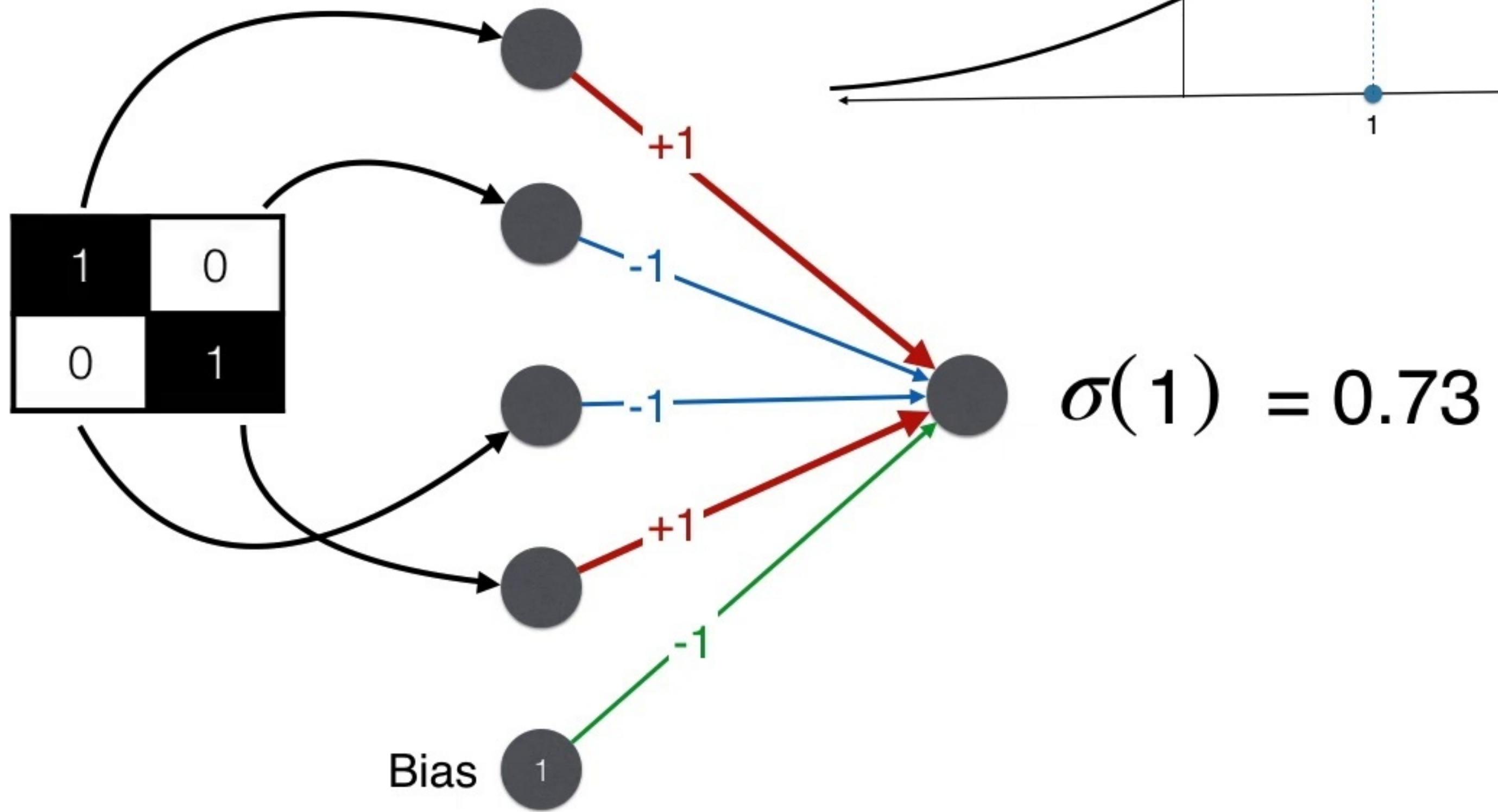
# Discriminator



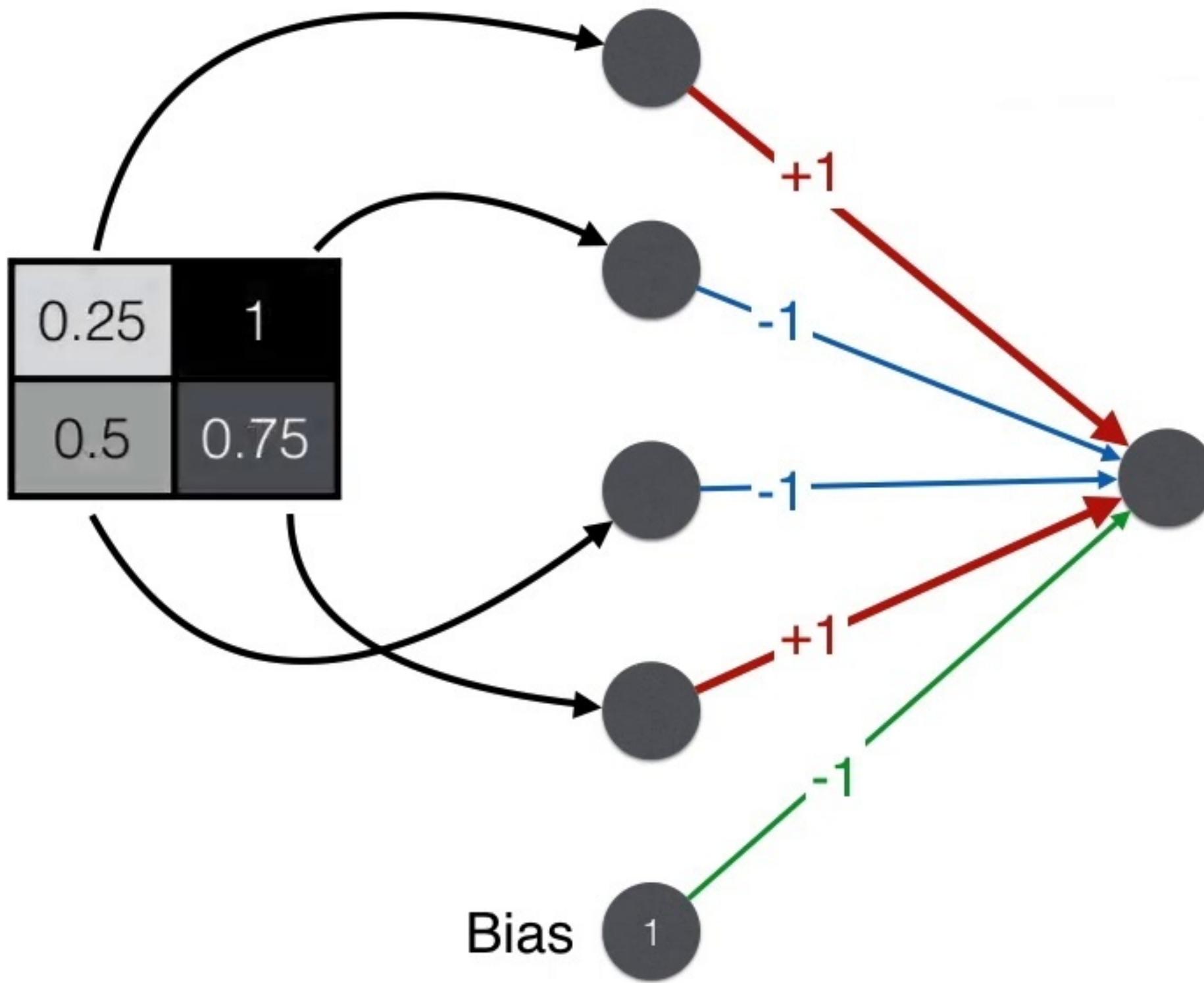
# Discriminator



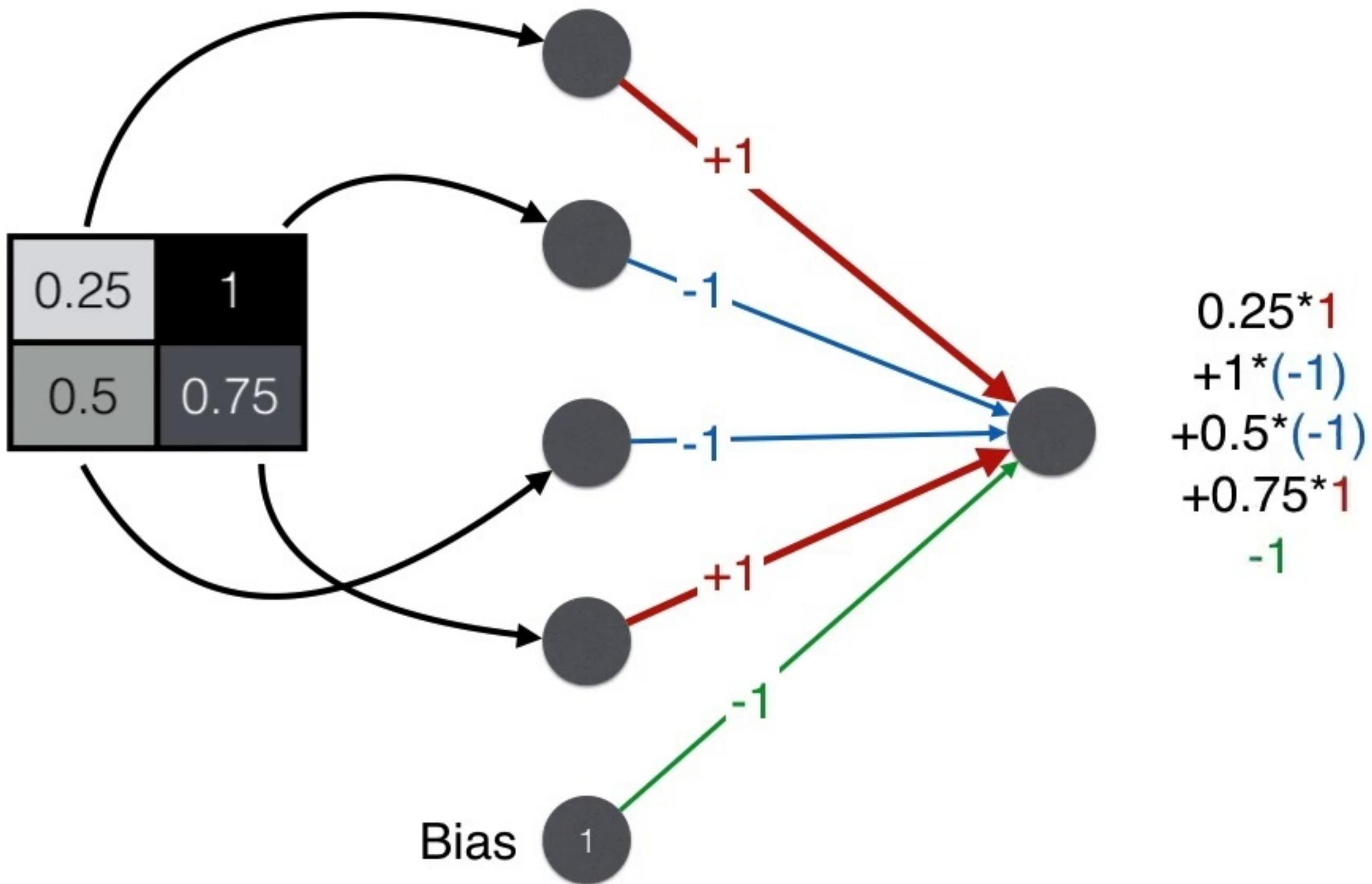
# Discriminator



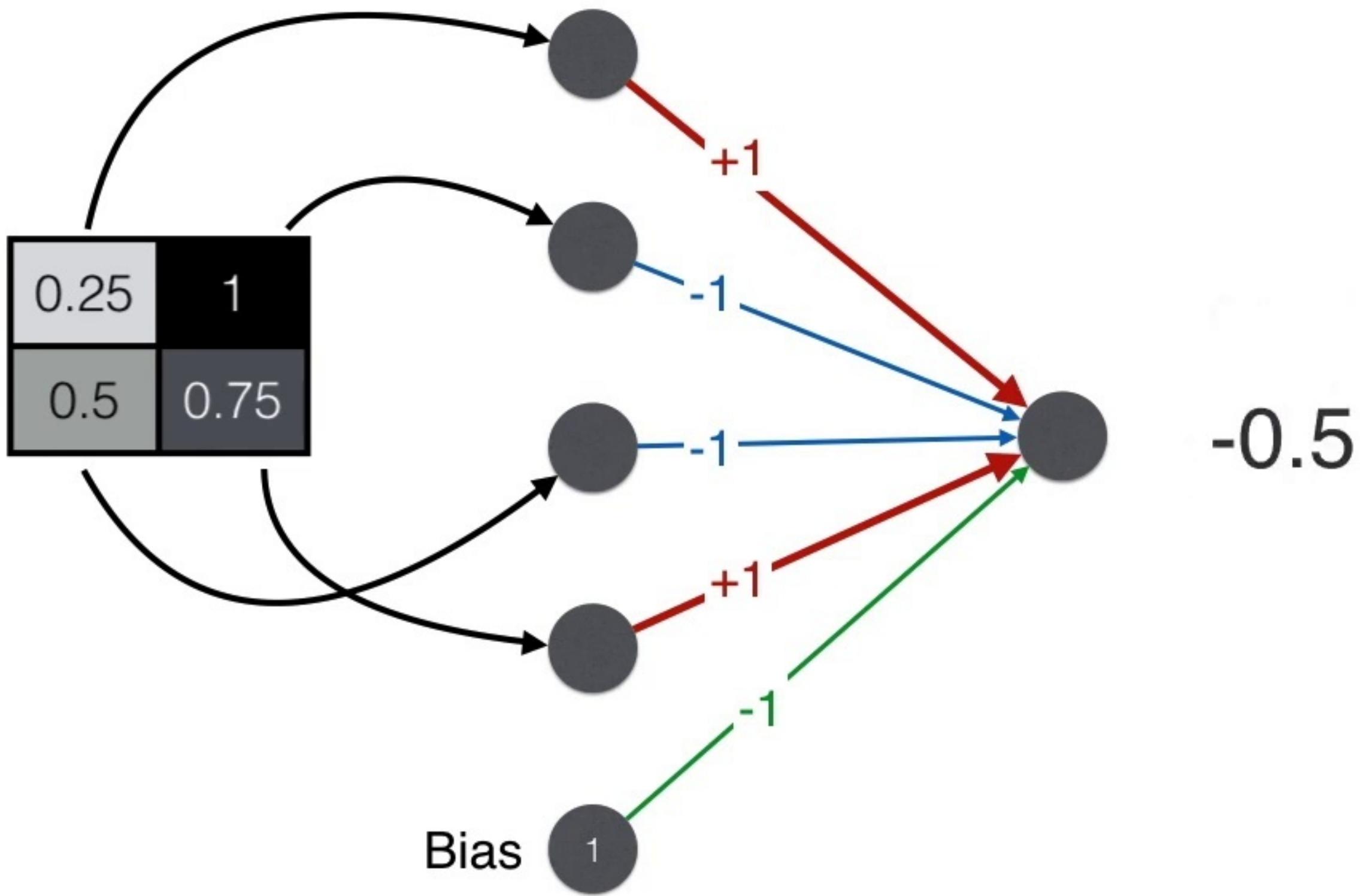
# Discriminator



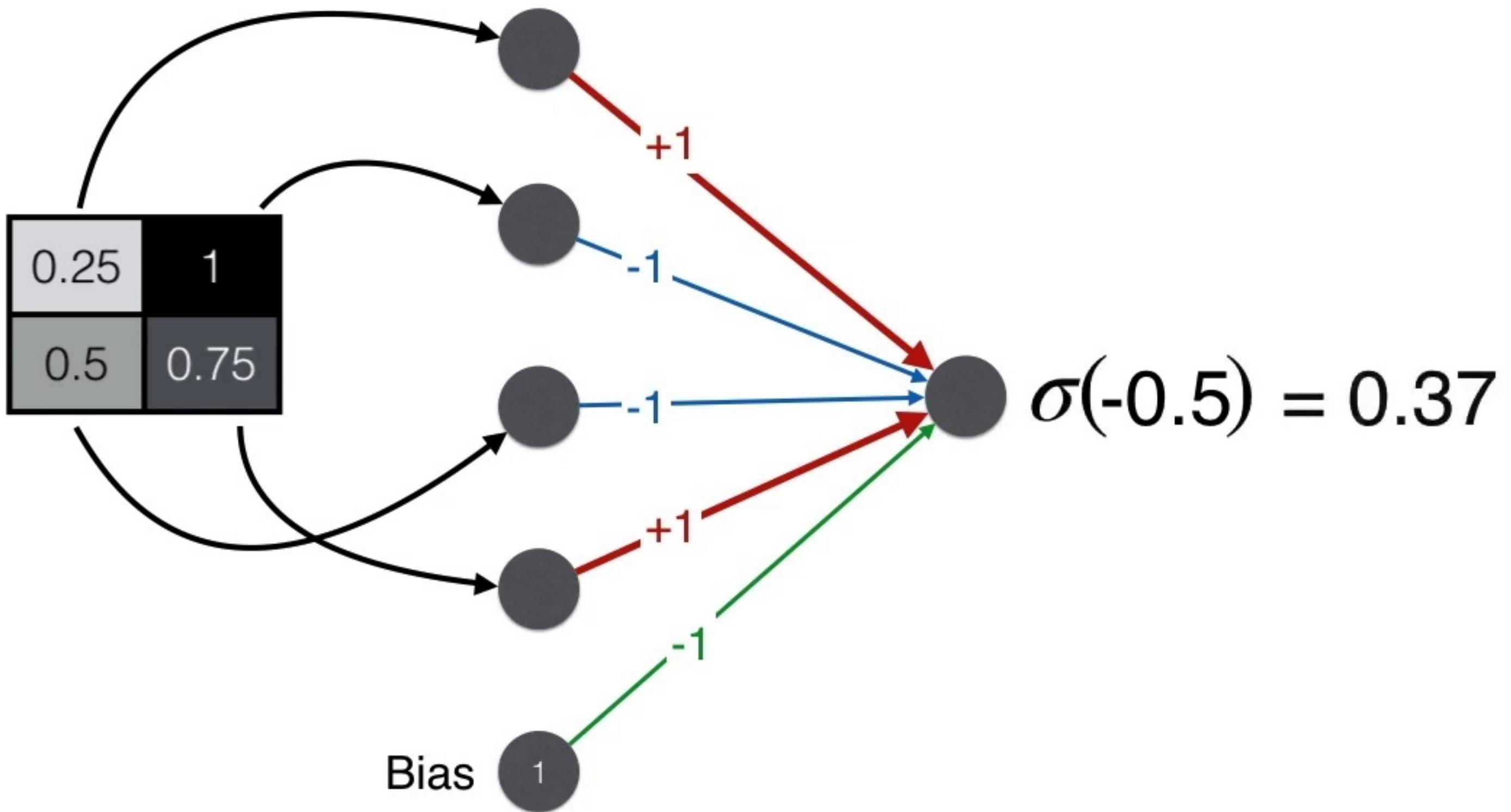
# Discriminator



# Discriminator

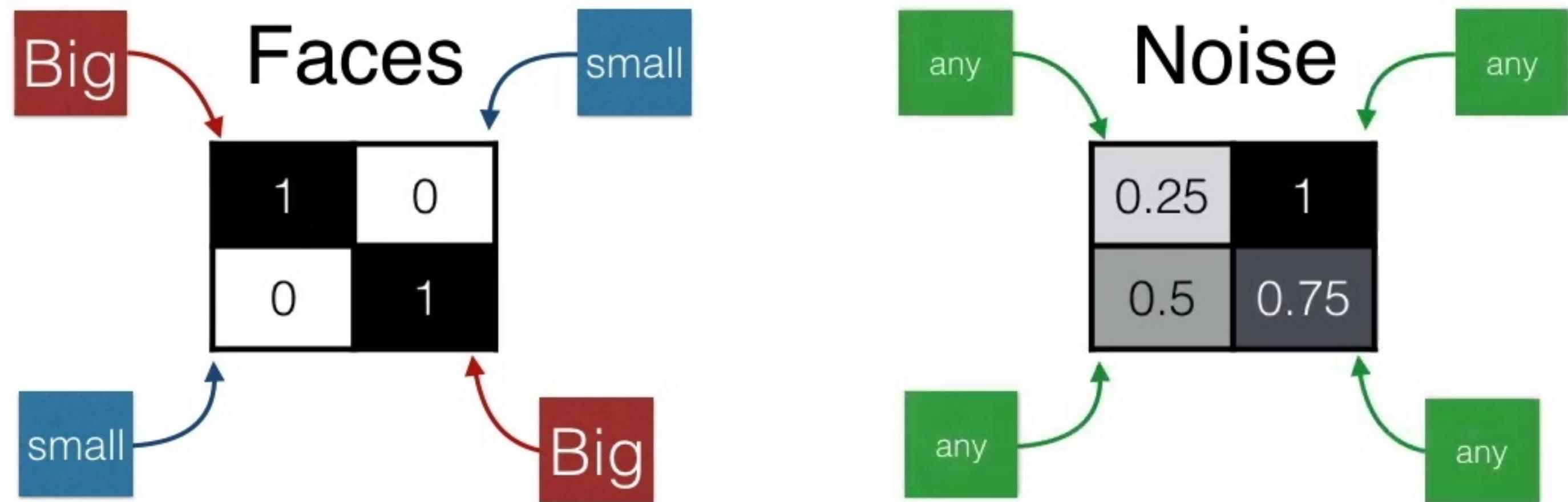


# Discriminator

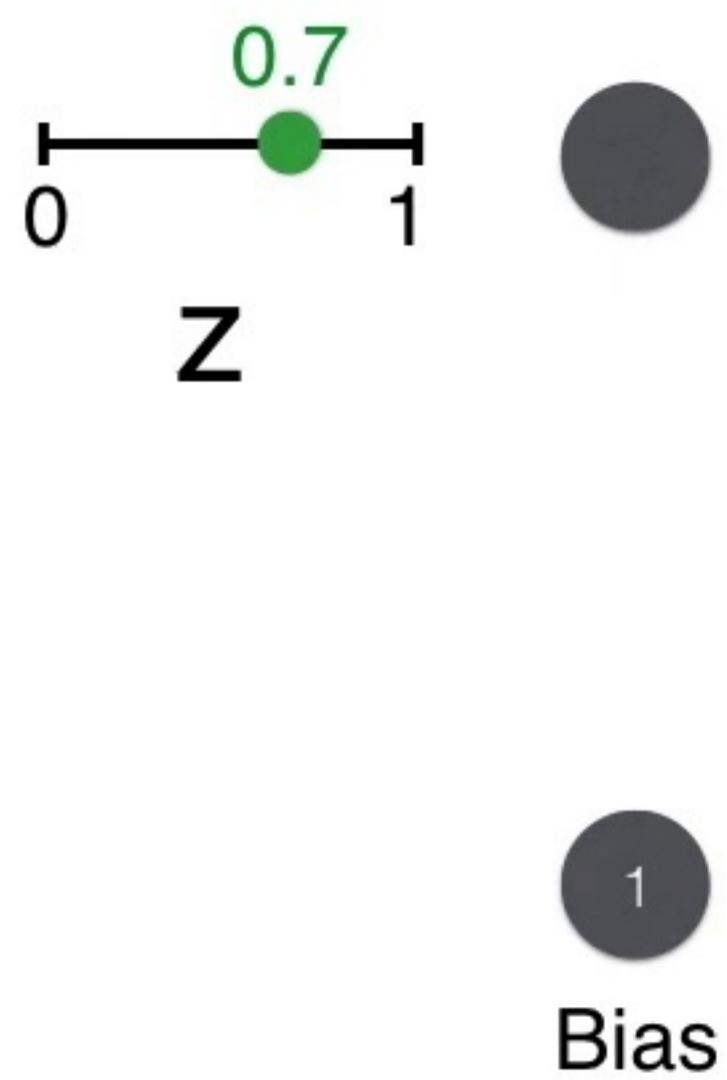


# Building the Generator

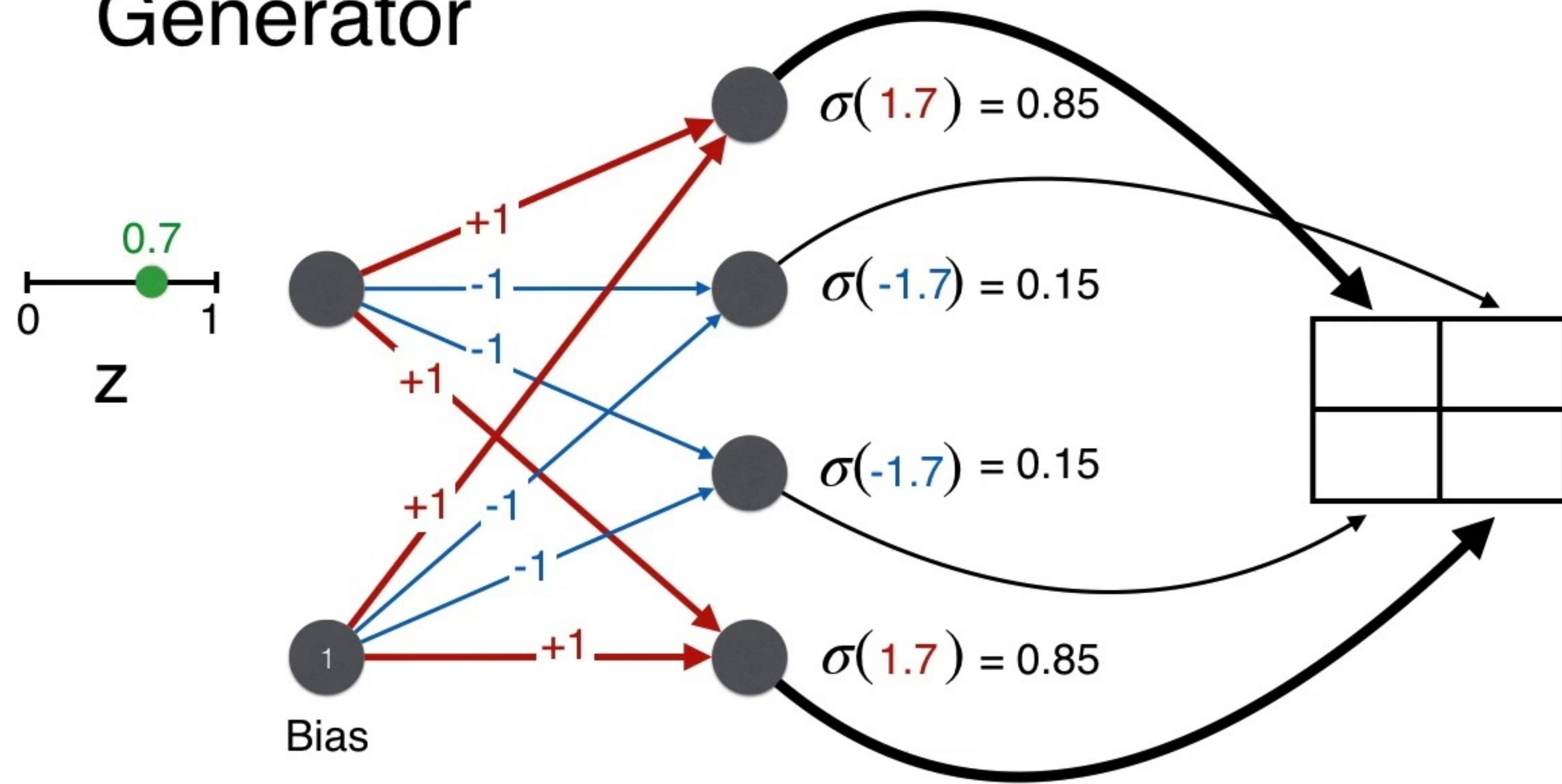
# Building the generator



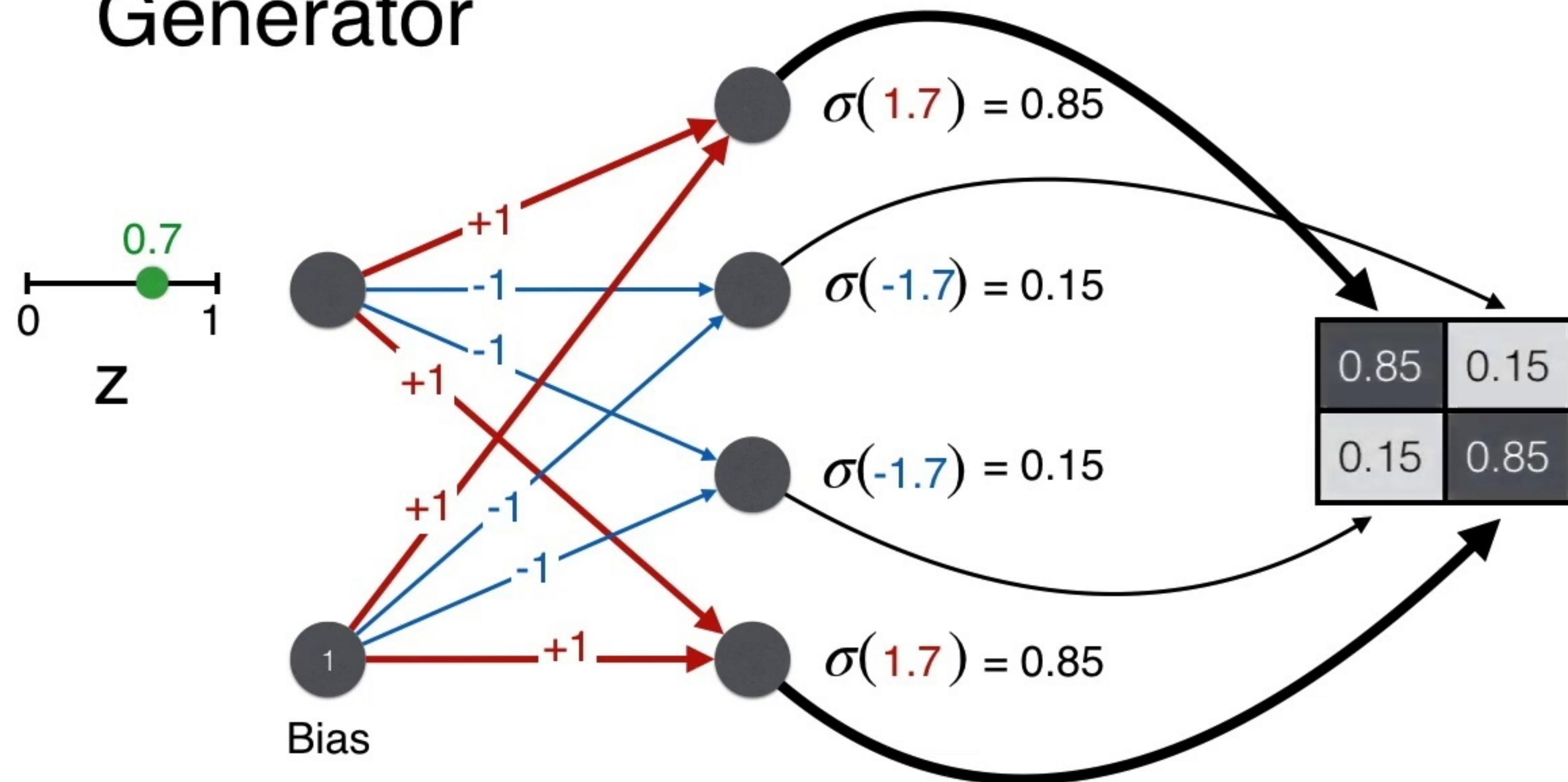
# Generator



# Generator



# Generator



# The training process: Error functions

# Log-loss error function

Label: 1  
Prediction: 0.1      Error: large

Label: 1  
Prediction: 0.9      Error: small

# Log-loss error function

$$\text{Error} = -\ln(\text{prediction})$$

Label: 1  
Prediction: 0.1

Error: large

$$-\ln(0.1) = 2.3$$

Label: 1  
Prediction: 0.9

Error: small

$$-\ln(0.9) = 0.1$$

# Log-loss error function

Label: 0 Prediction: 0.1	Error: small
Label: 0 Prediction: 0.9	Error: large

# Log-loss error function

$$\text{Error} = -\ln(1 - \text{prediction})$$

Label: 0  
Prediction: 0.1

Error: small

$$-\ln(0.9) = 0.1$$

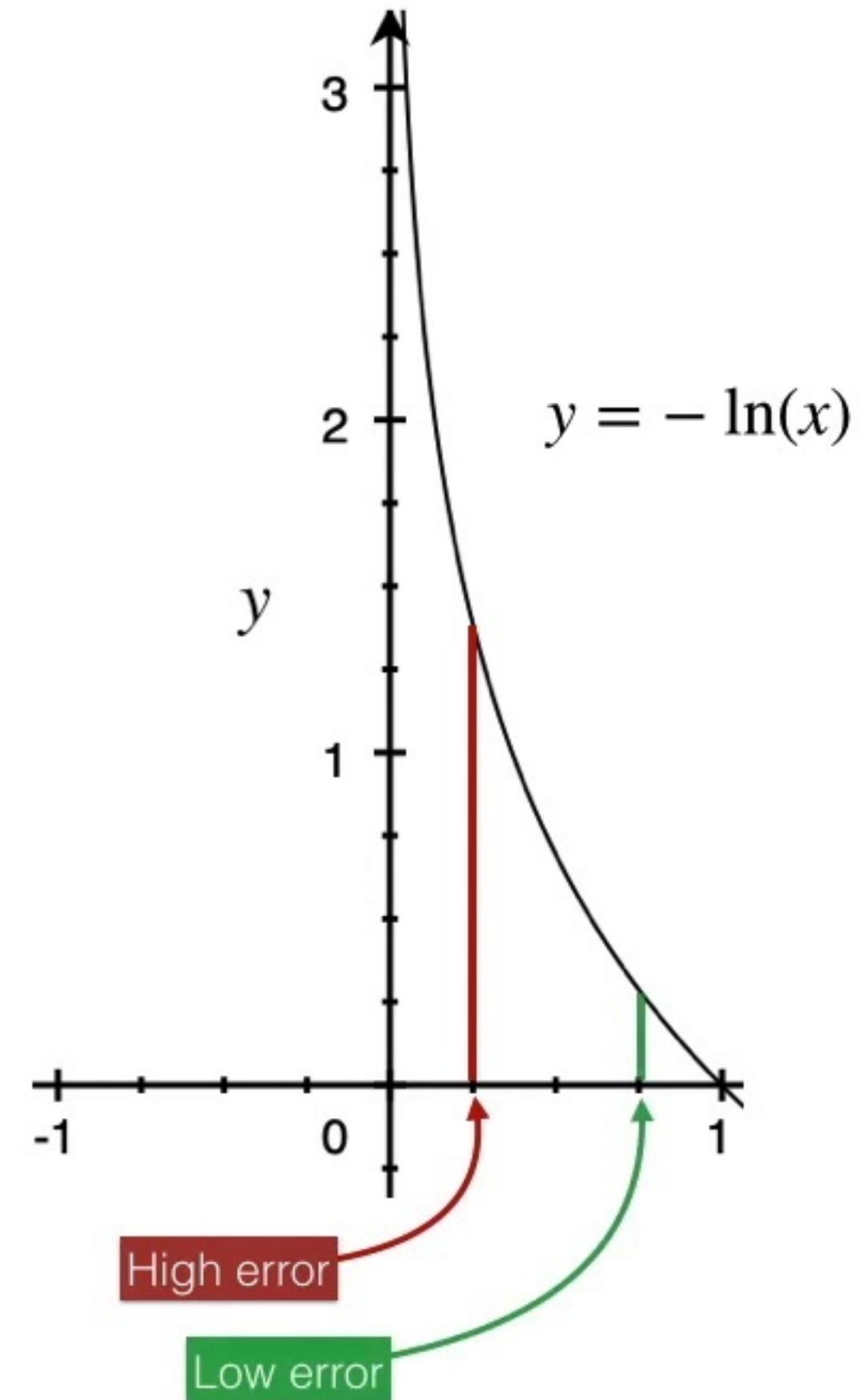
Label: 0  
Prediction: 0.9

Error: large

$$-\ln(0.1) = 2.3$$

# Summary

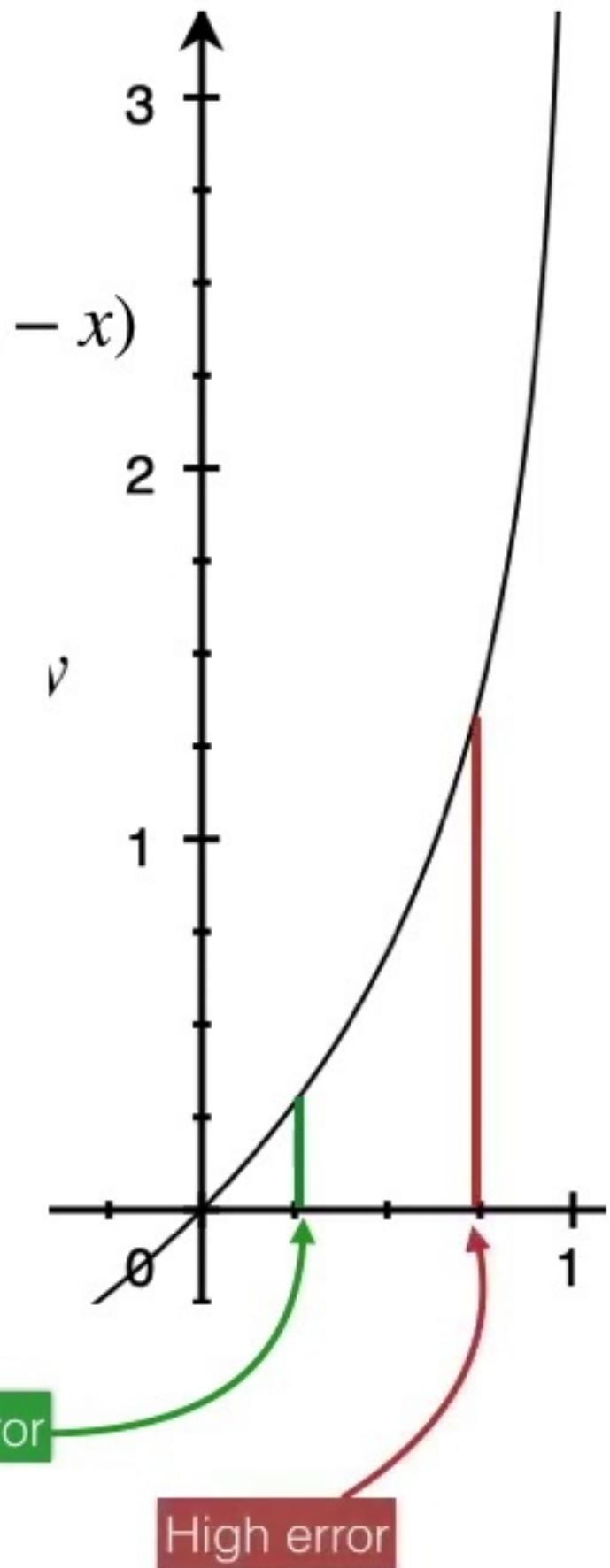
If we want a prediction to be 1:  
Log-loss =  $-\ln(\text{prediction})$



# Summary

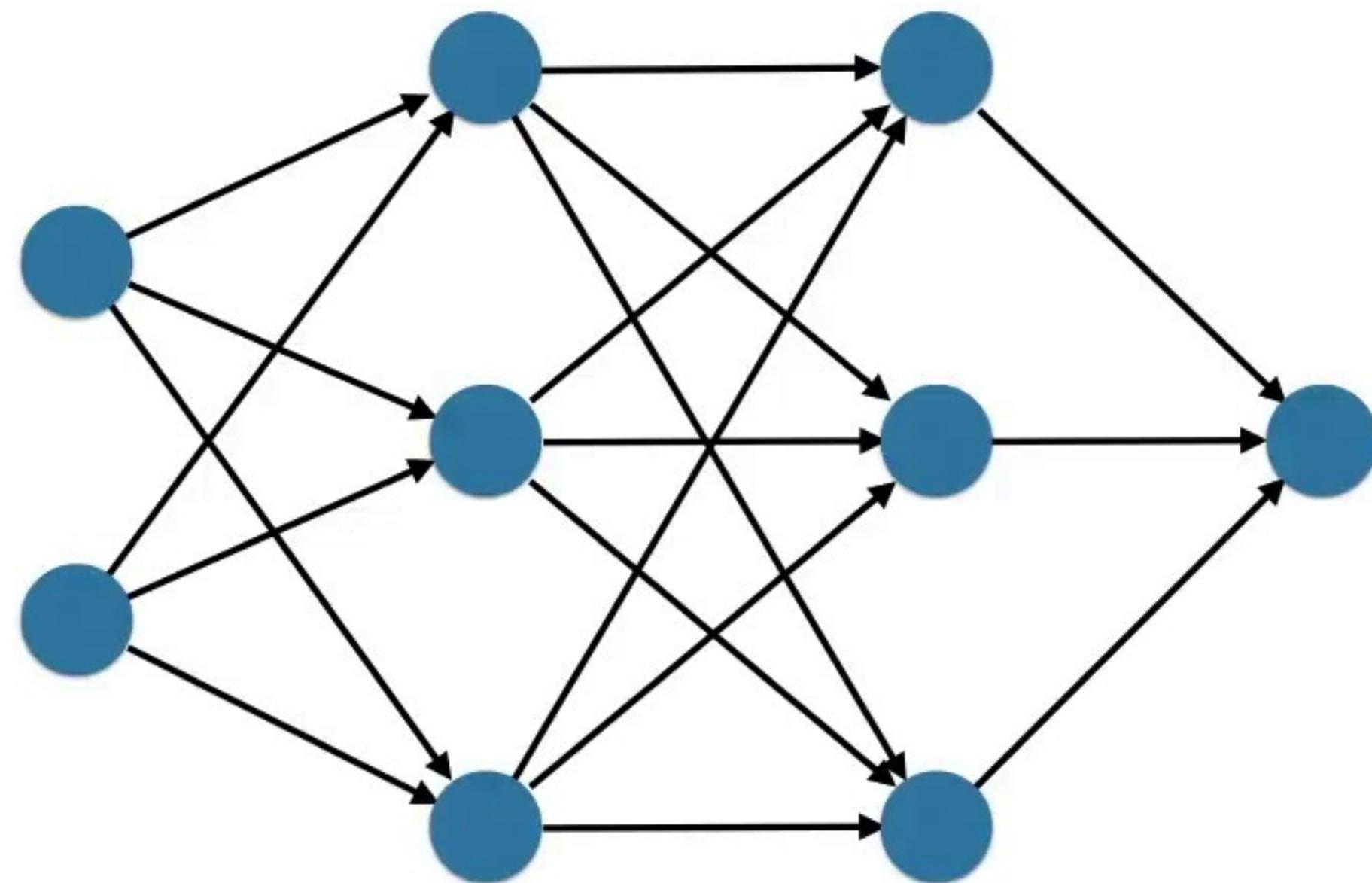
$$y = -\ln(1 - x)$$

If we want a prediction to be 0:  
Log-loss =  $-\ln(1 - \text{prediction})$

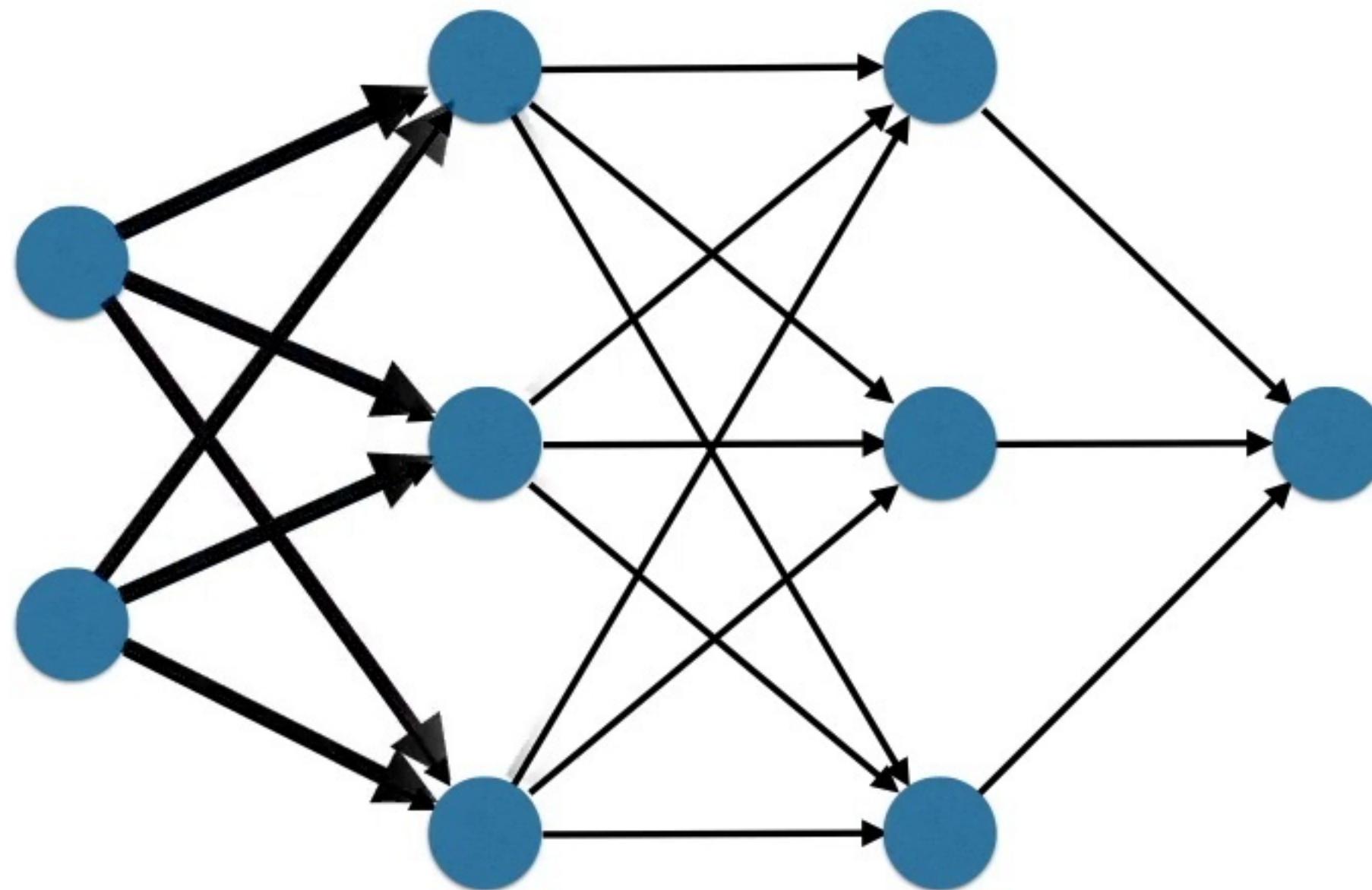


# The training process: Backpropagation

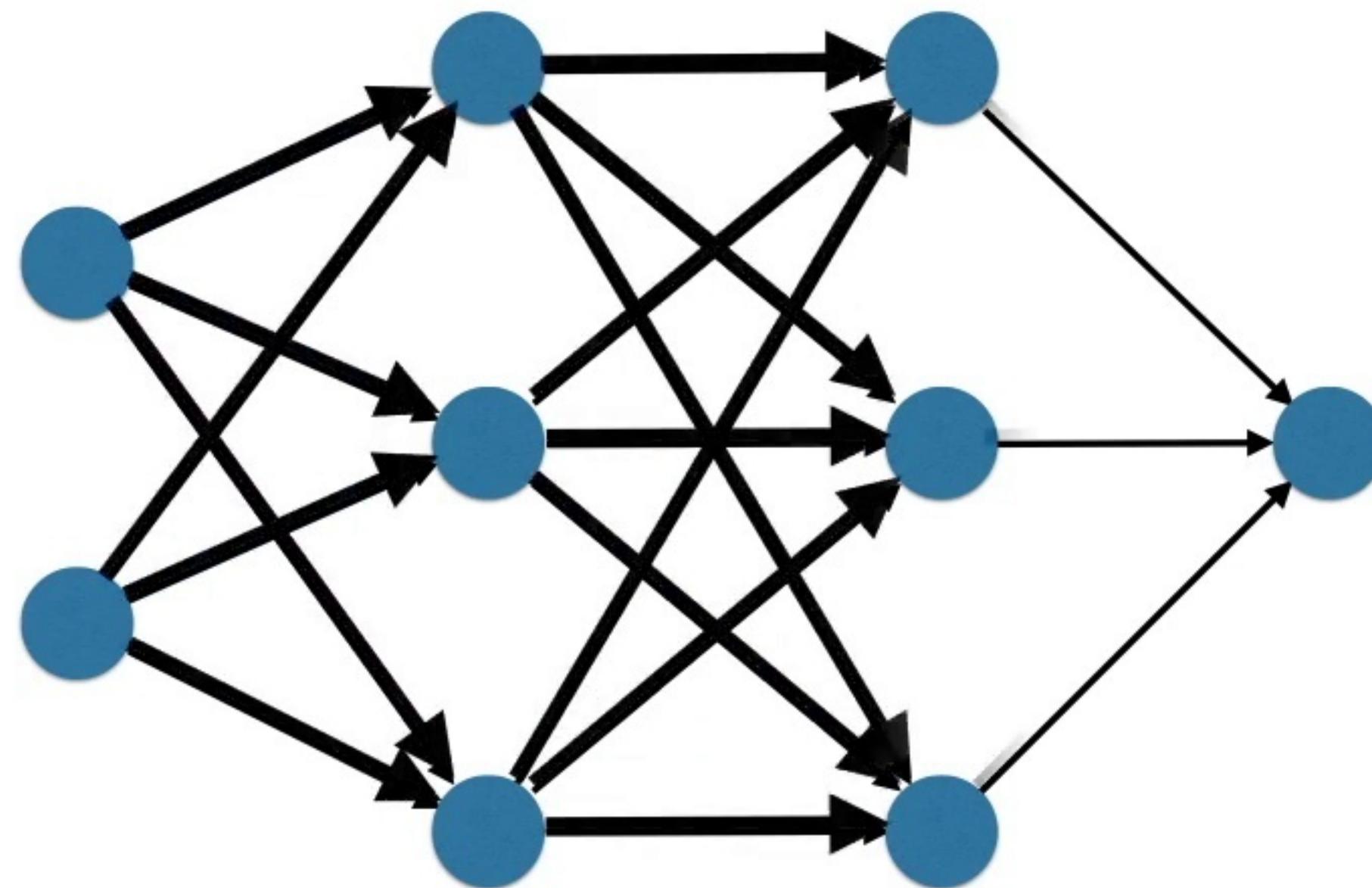
# Backpropagation



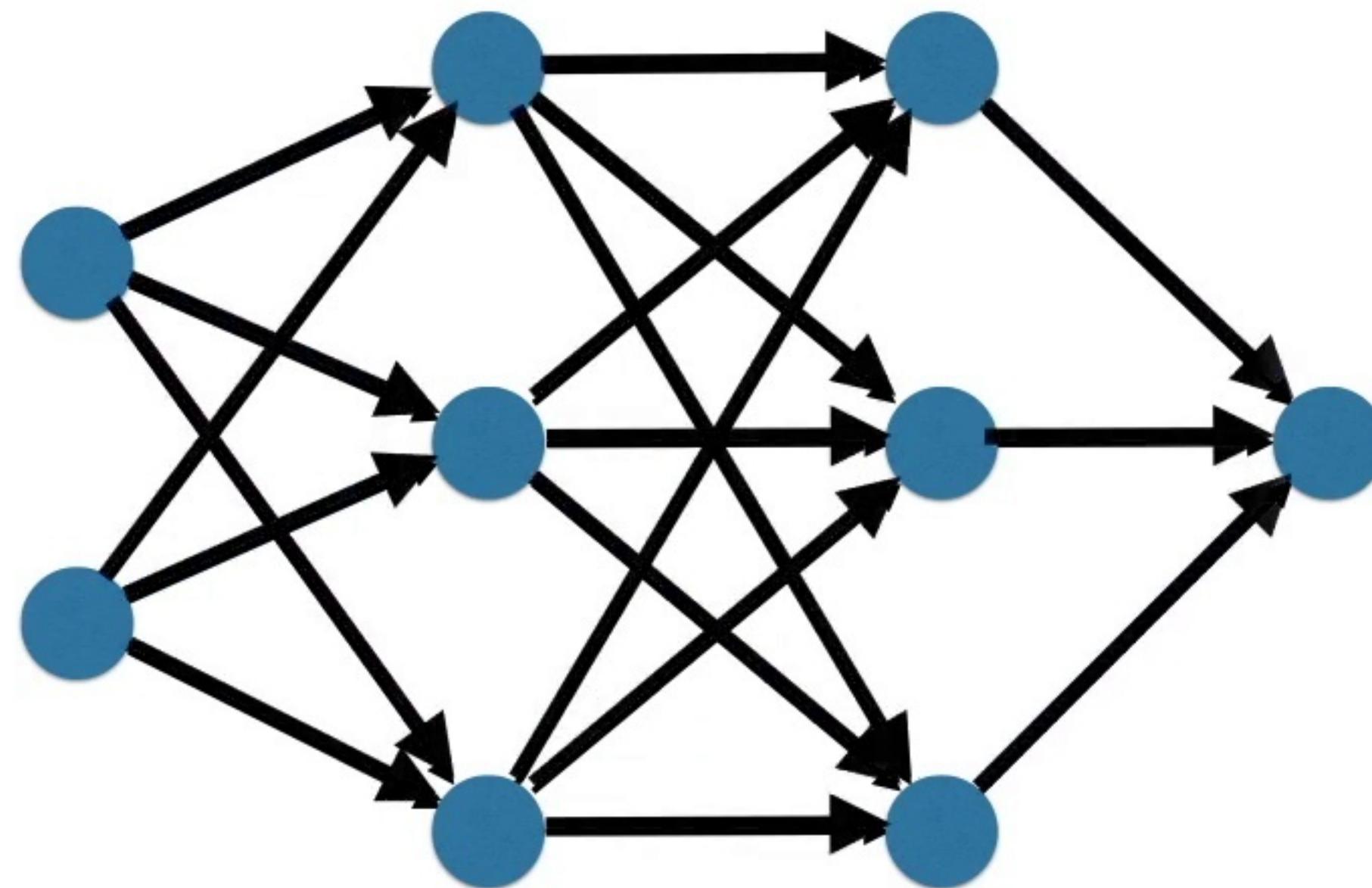
# Backpropagation



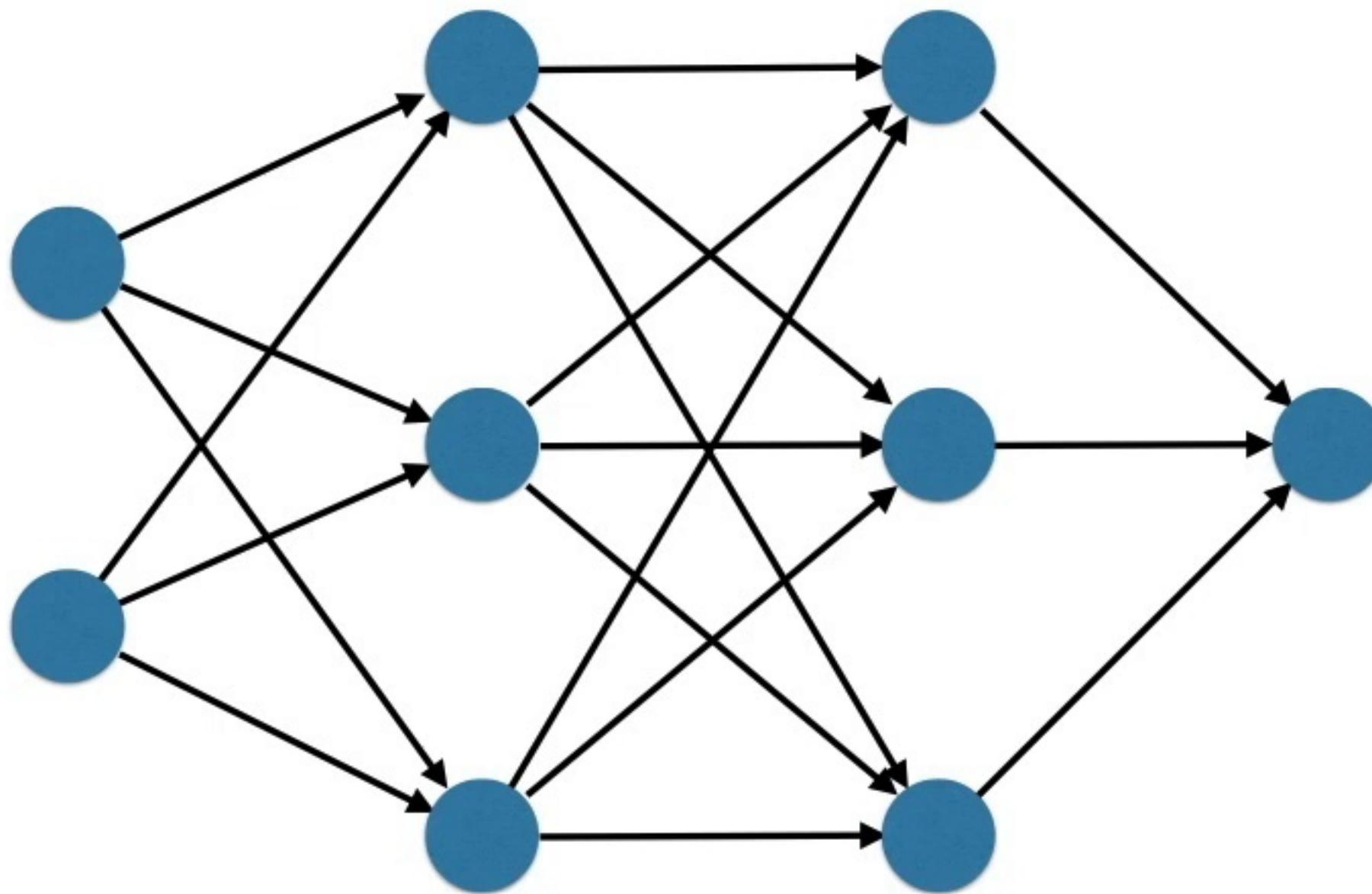
# Backpropagation



# Backpropagation

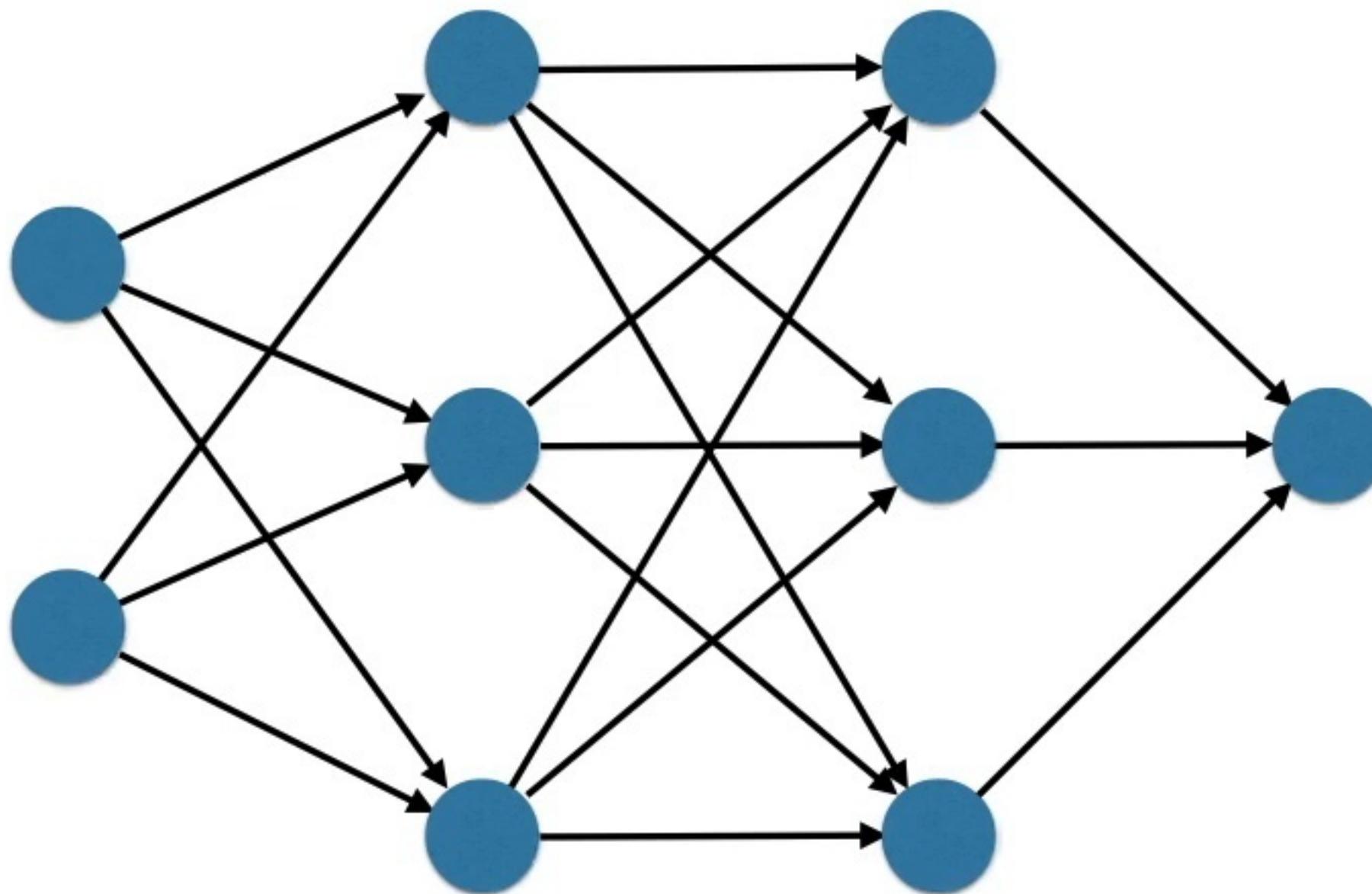


# Backpropagation



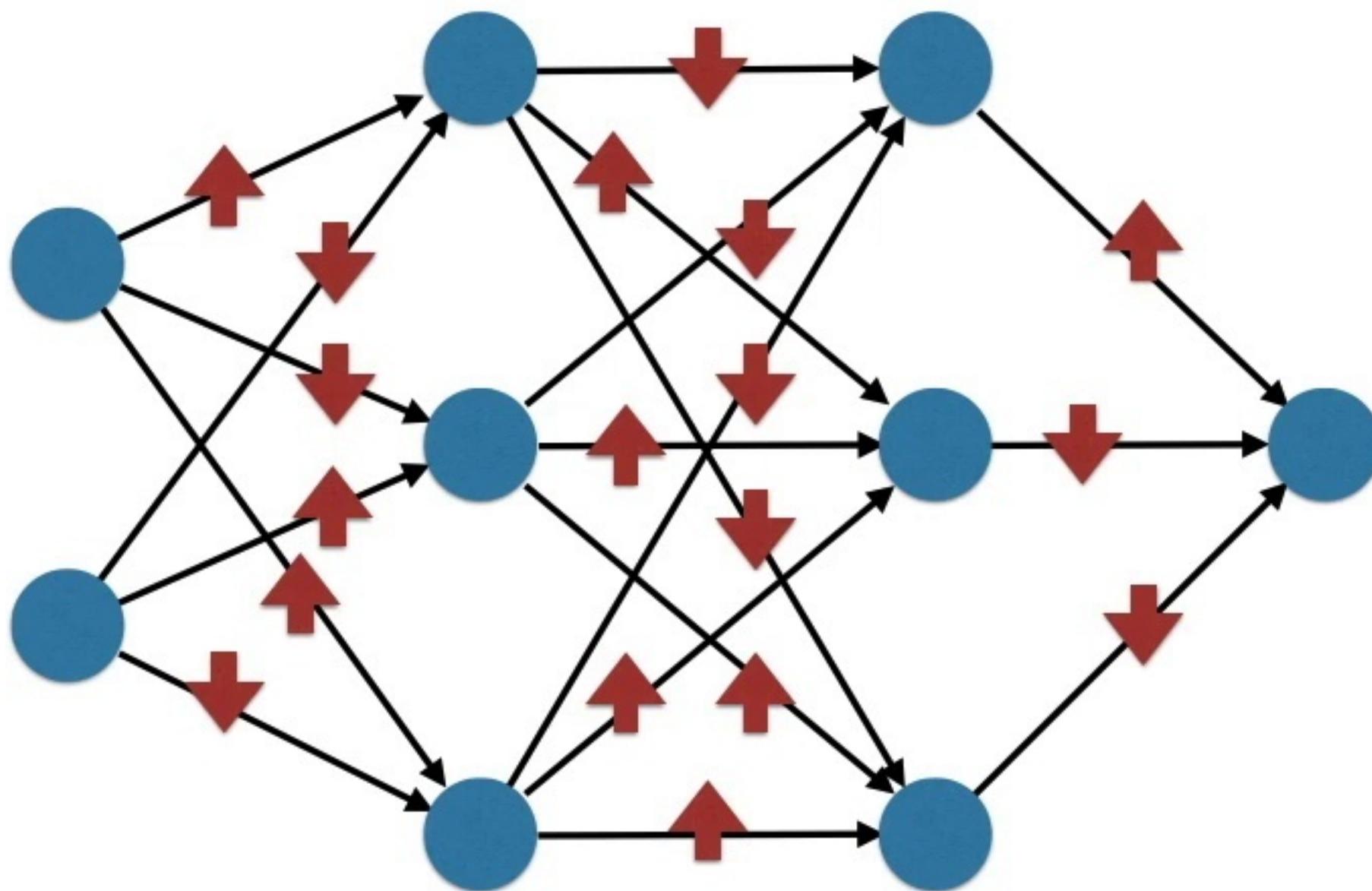
Prediction  
Error

# Backpropagation



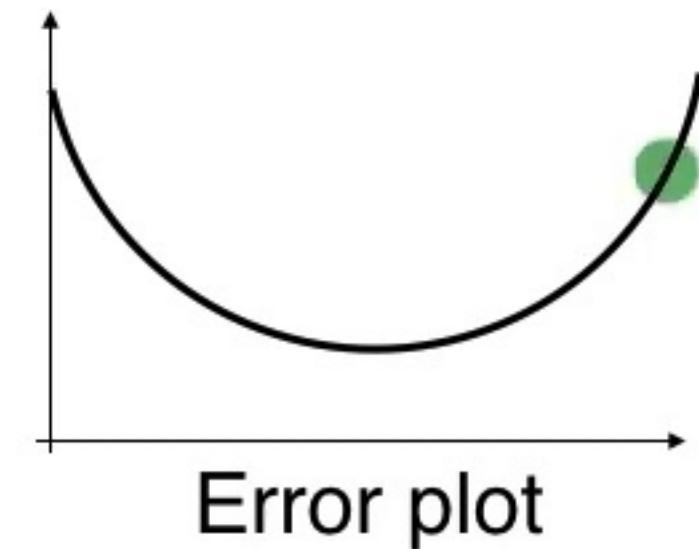
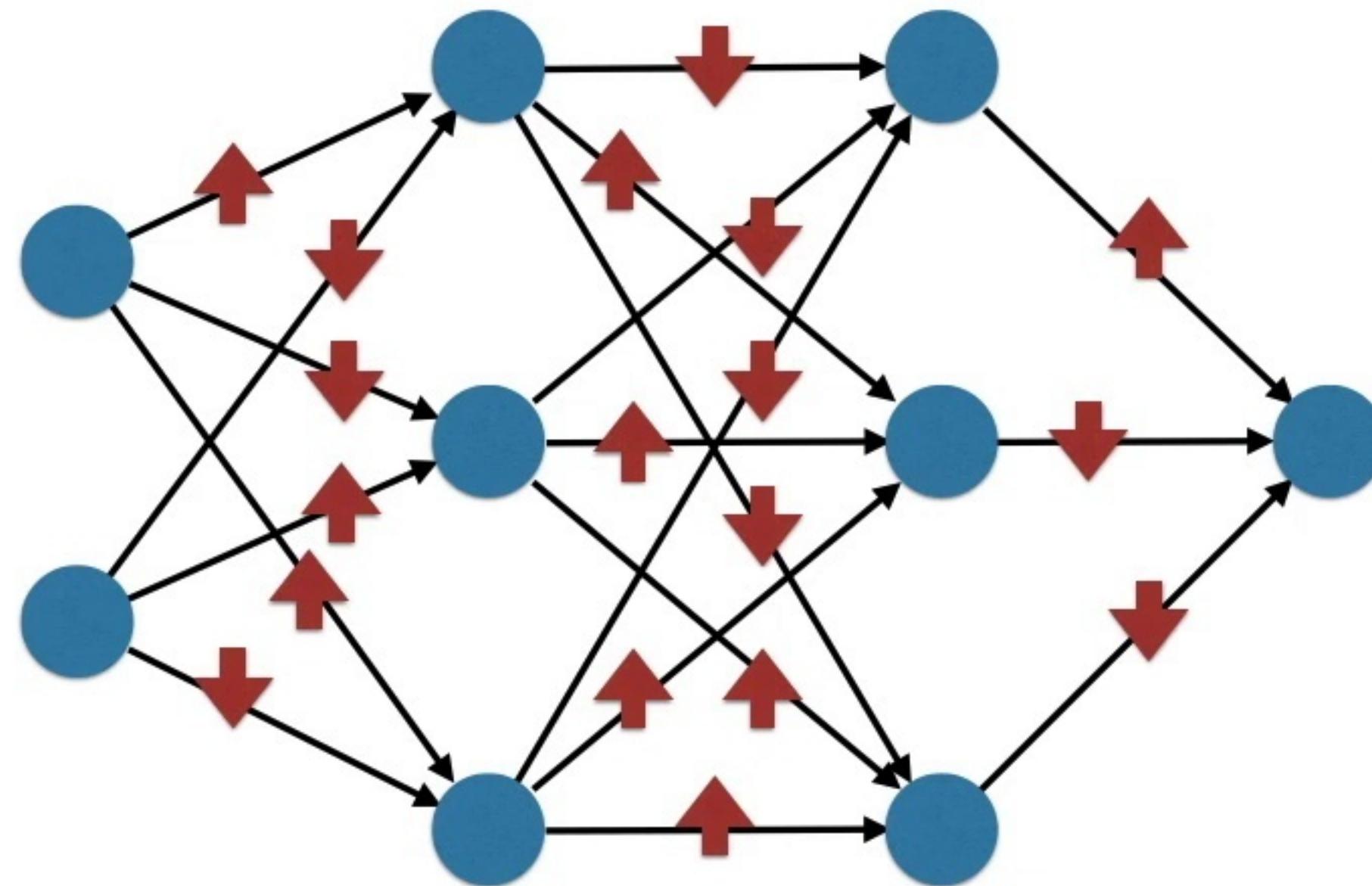
Prediction  
Error ↓

# Backpropagation



Prediction  
Error

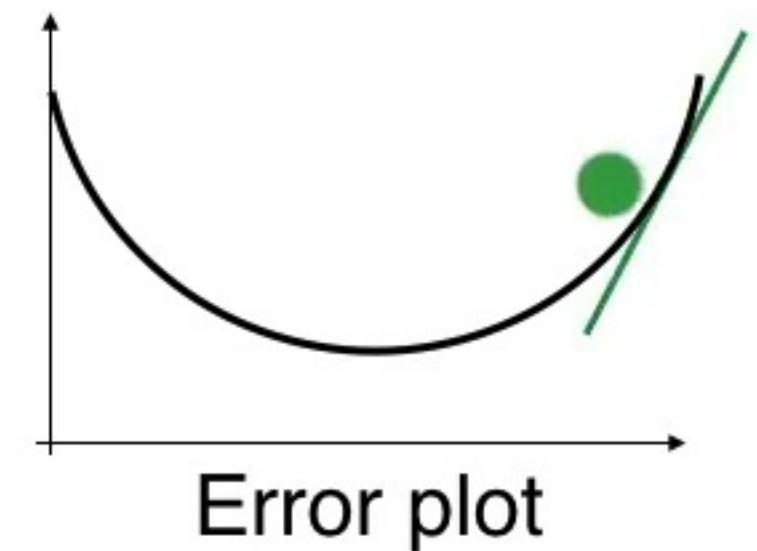
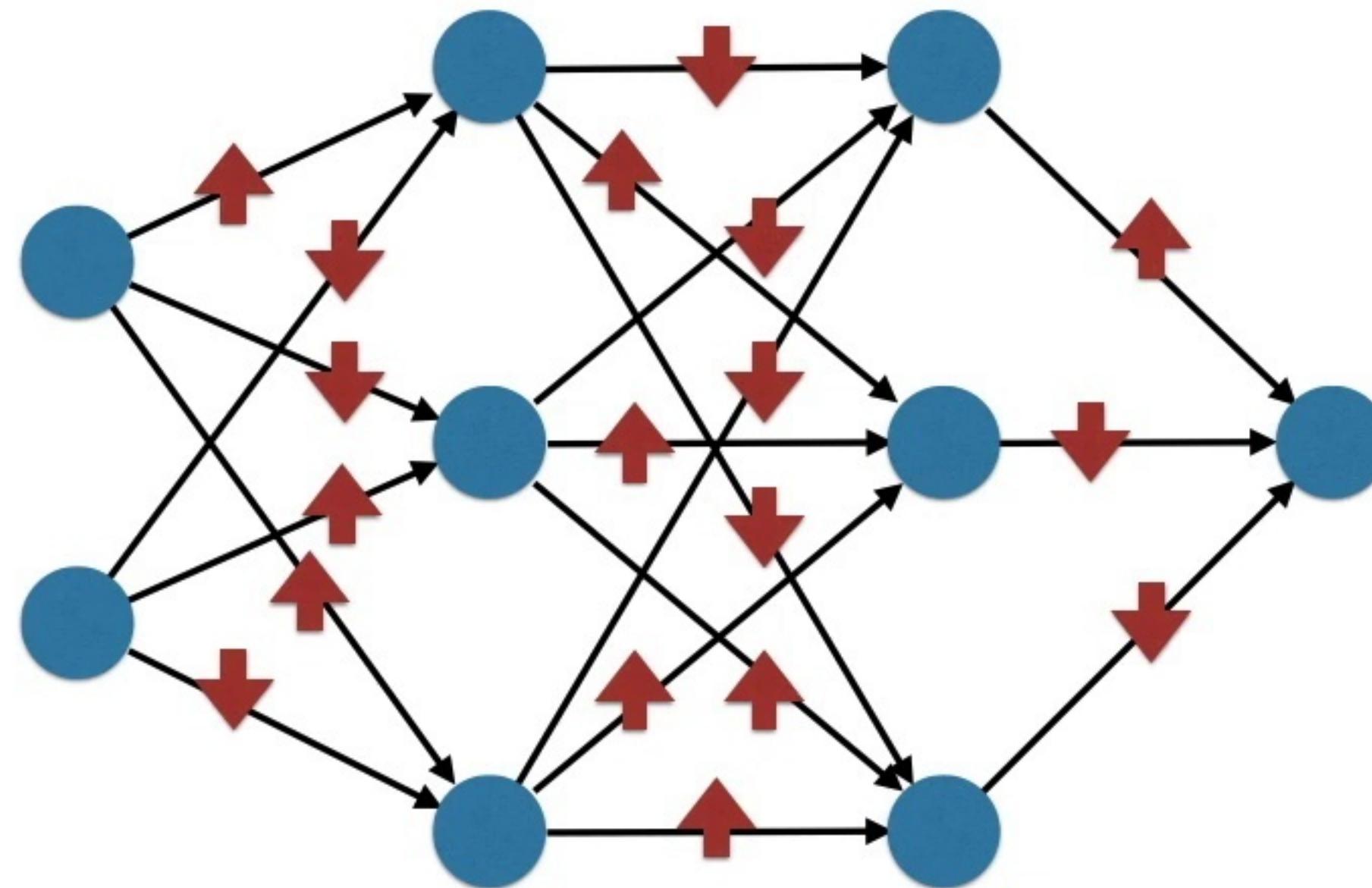
# Backpropagation



Prediction

Error

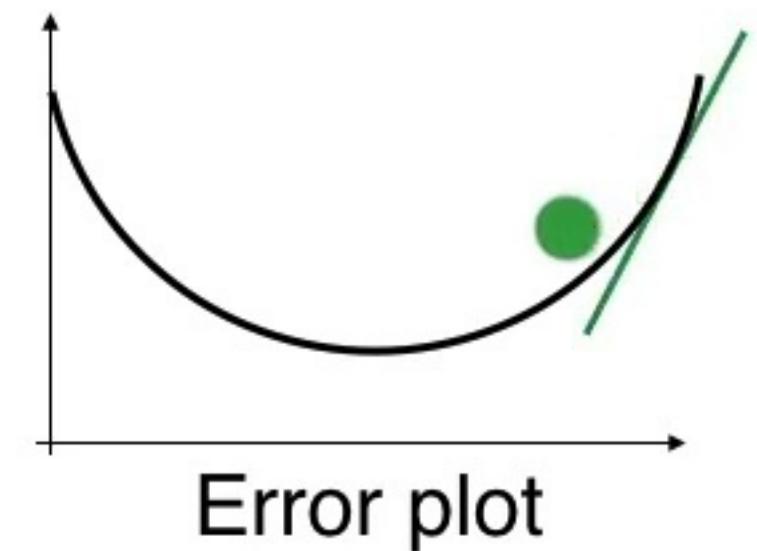
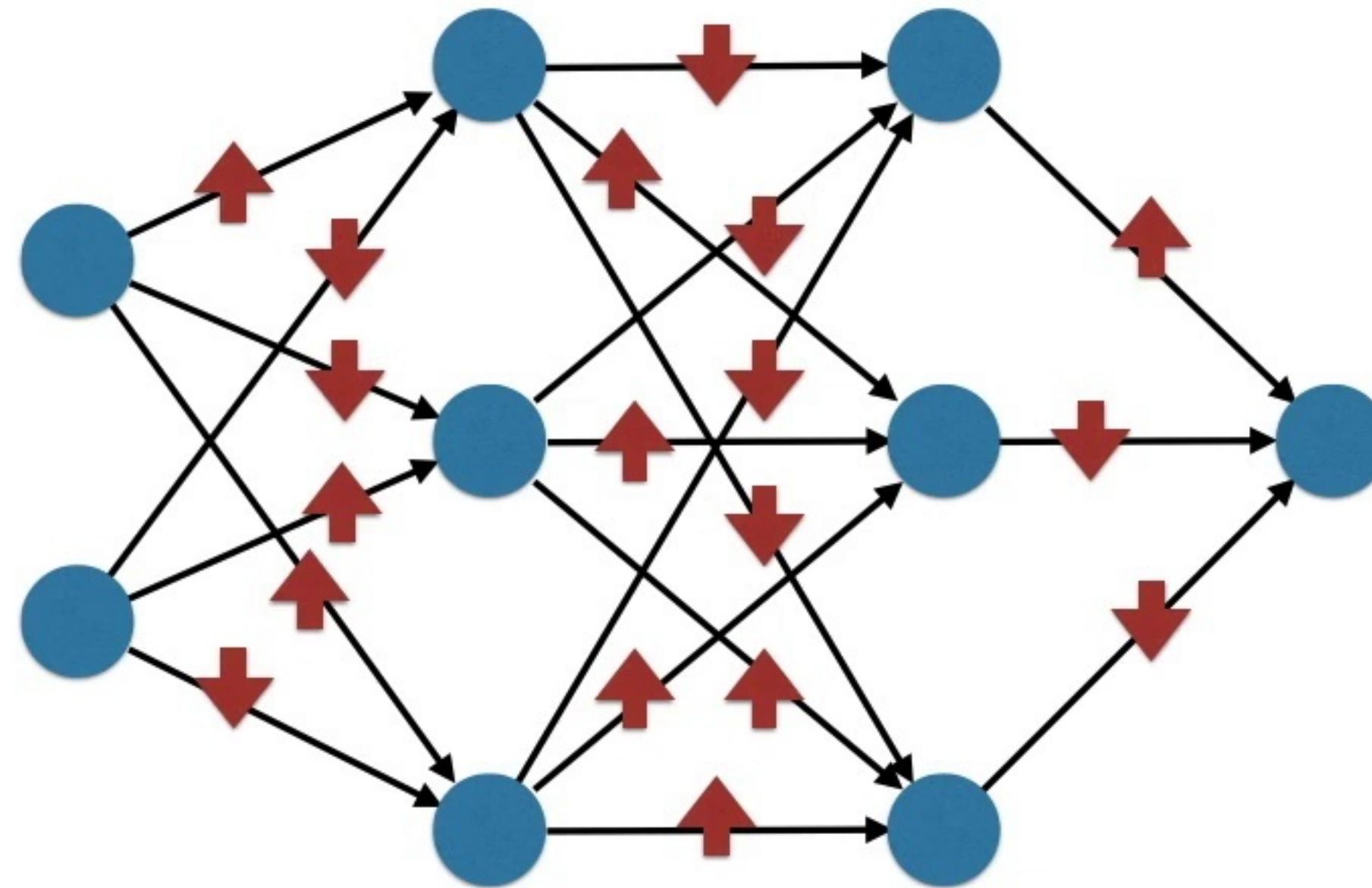
# Backpropagation



Prediction

Error

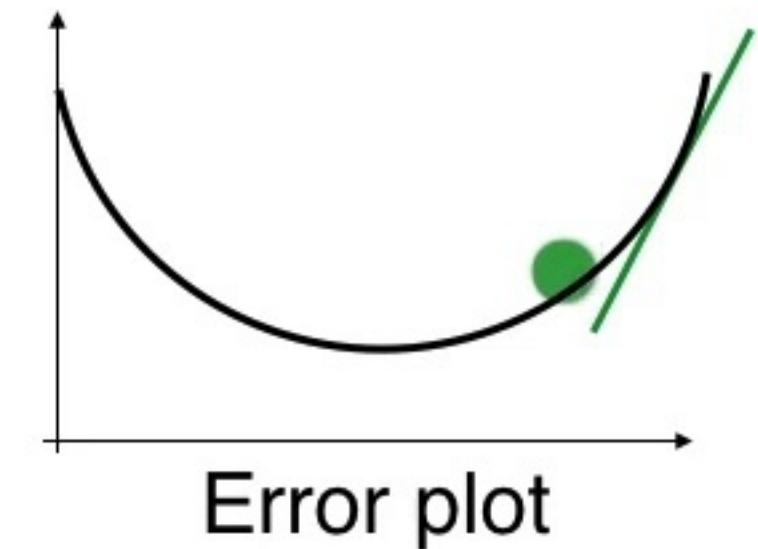
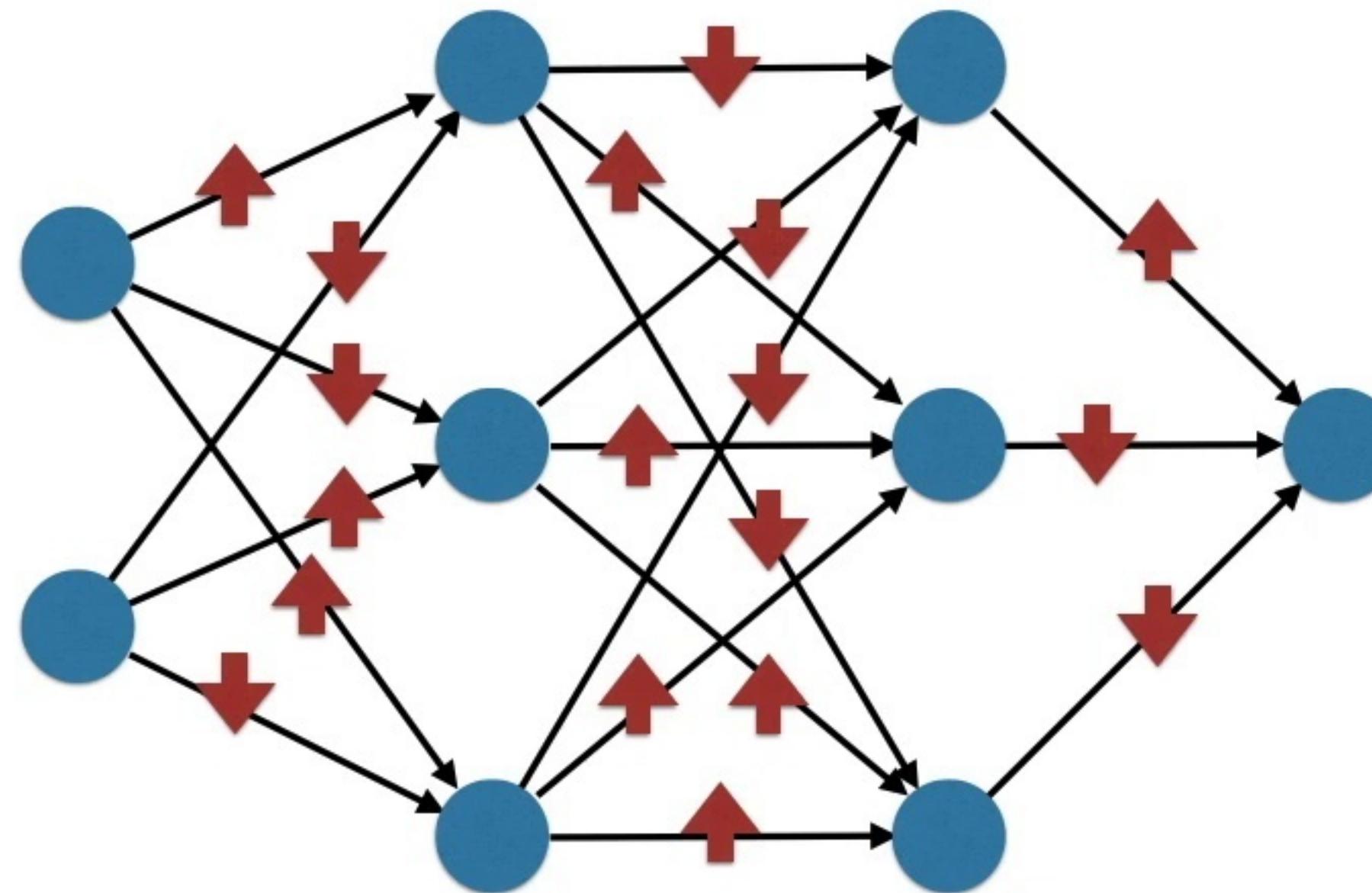
# Backpropagation



Prediction

Error

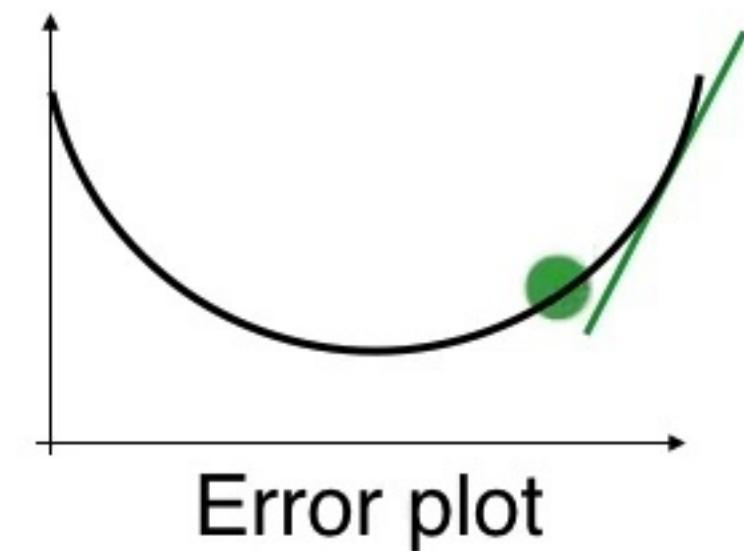
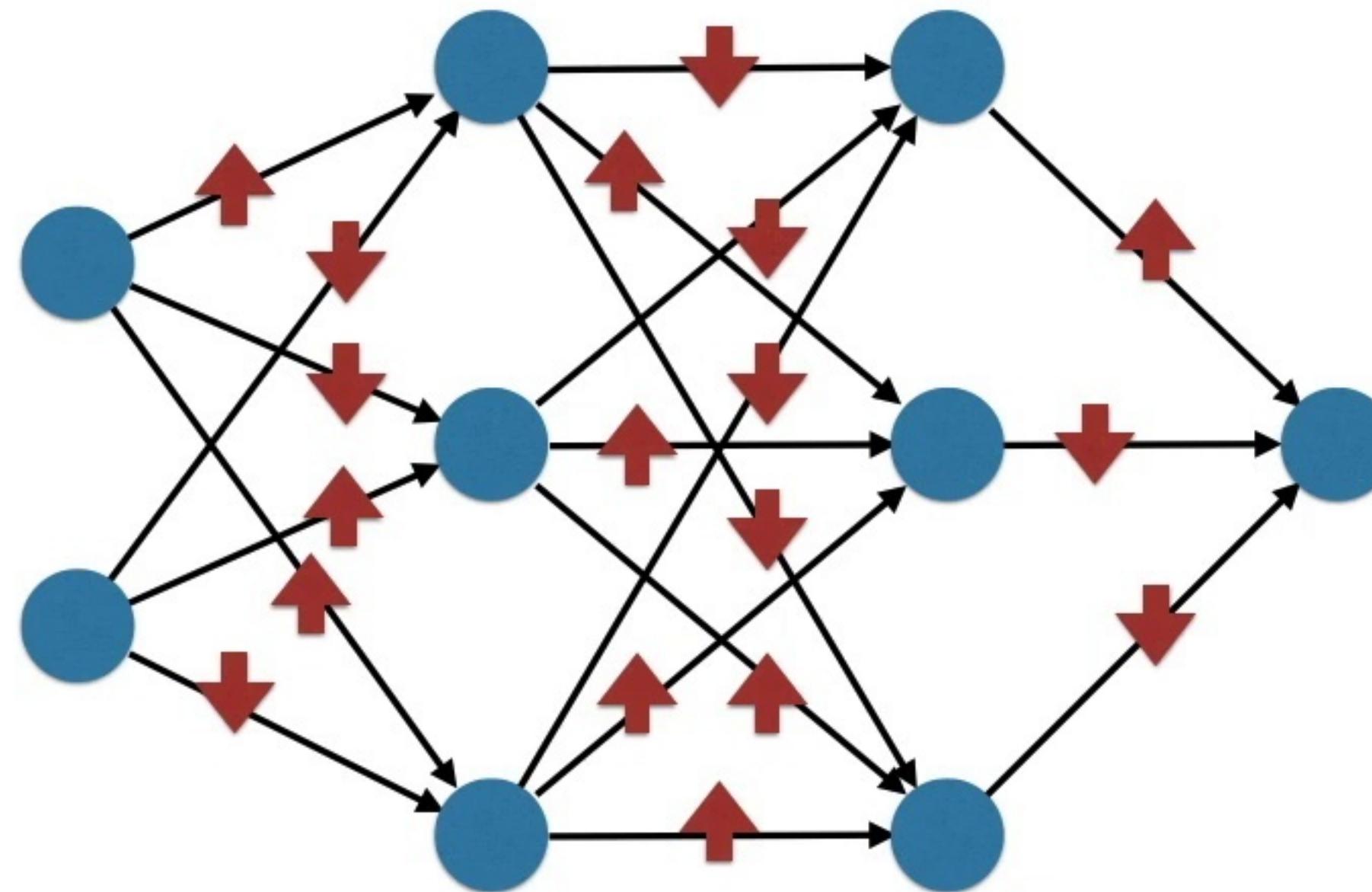
# Backpropagation



Prediction

Error

# Backpropagation

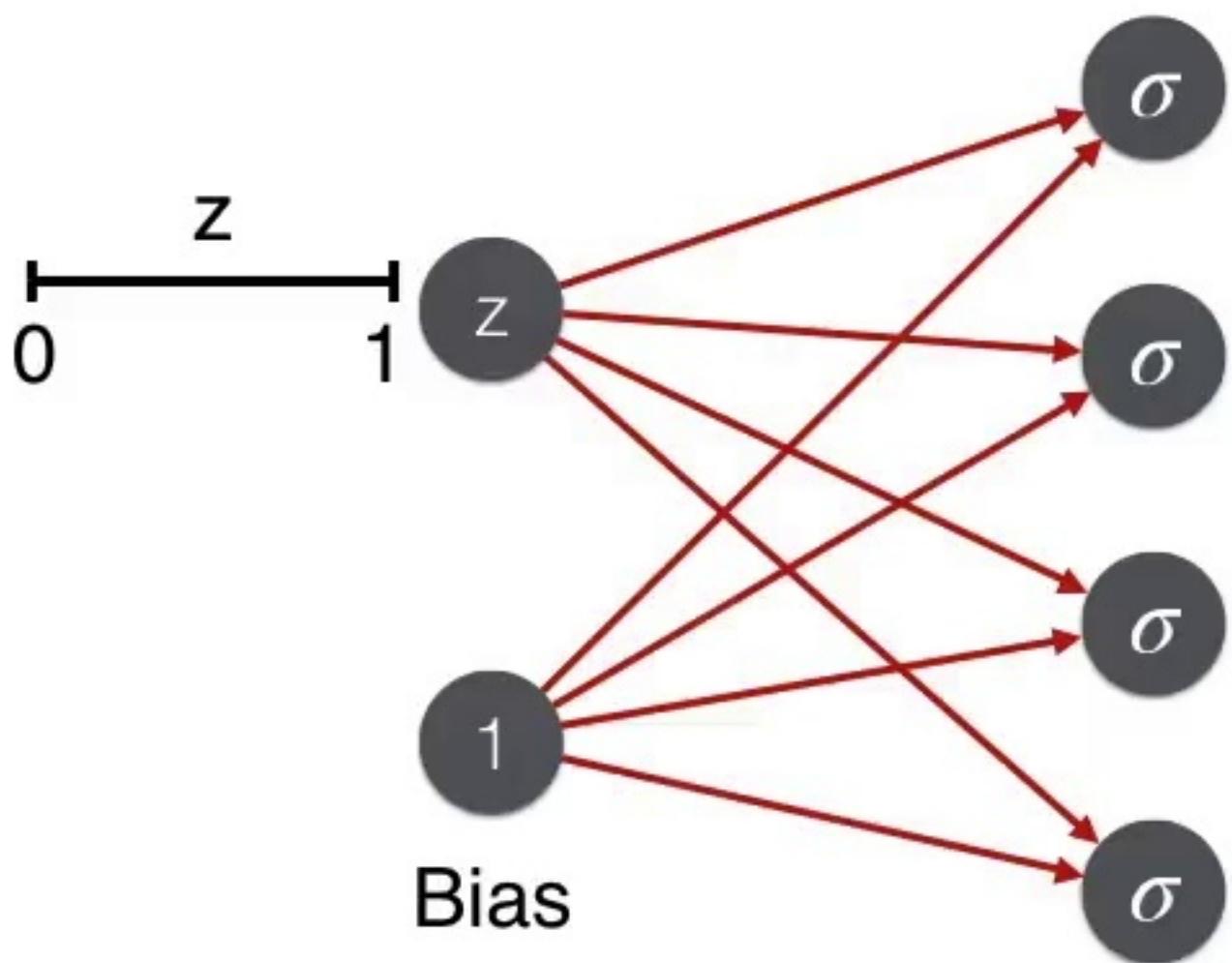


Prediction

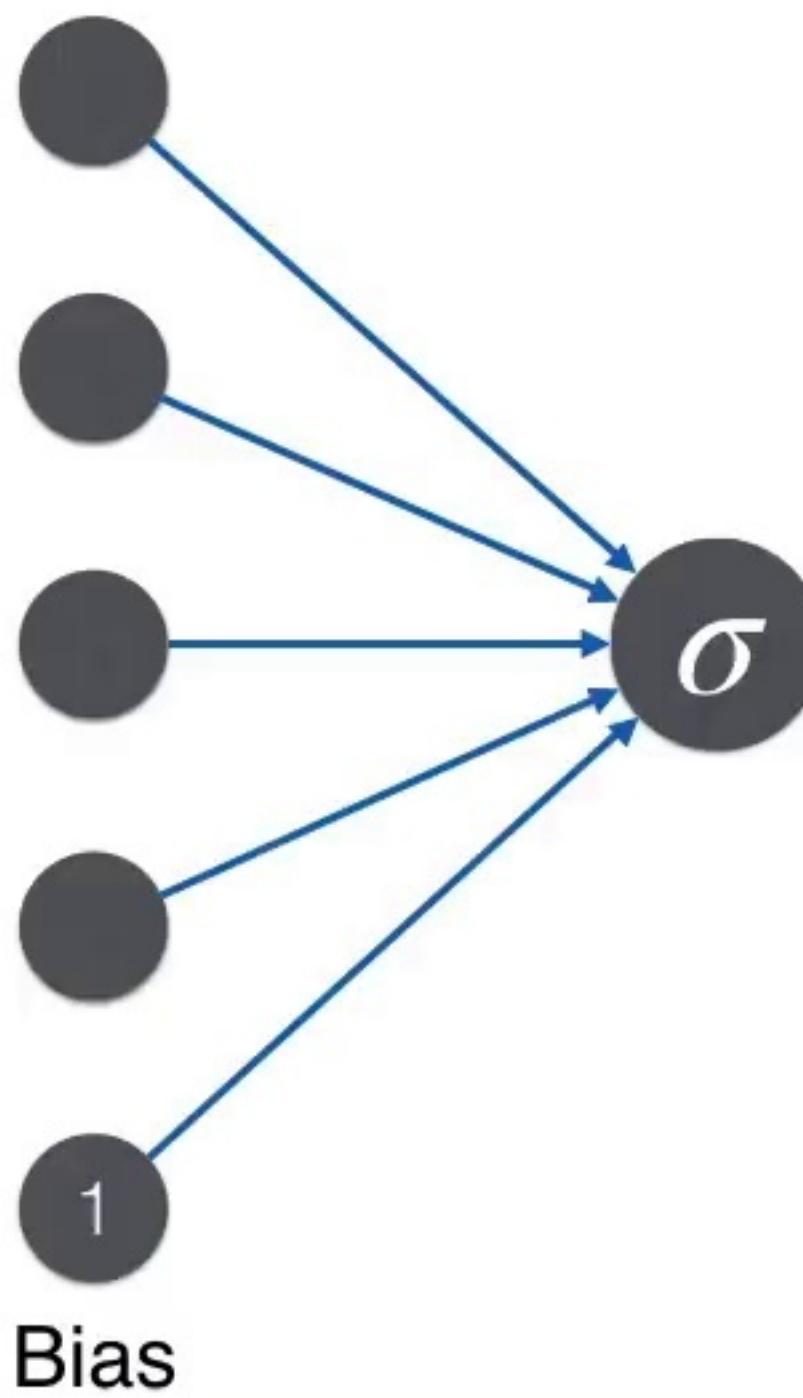
Error

# Training the generator and the discriminator

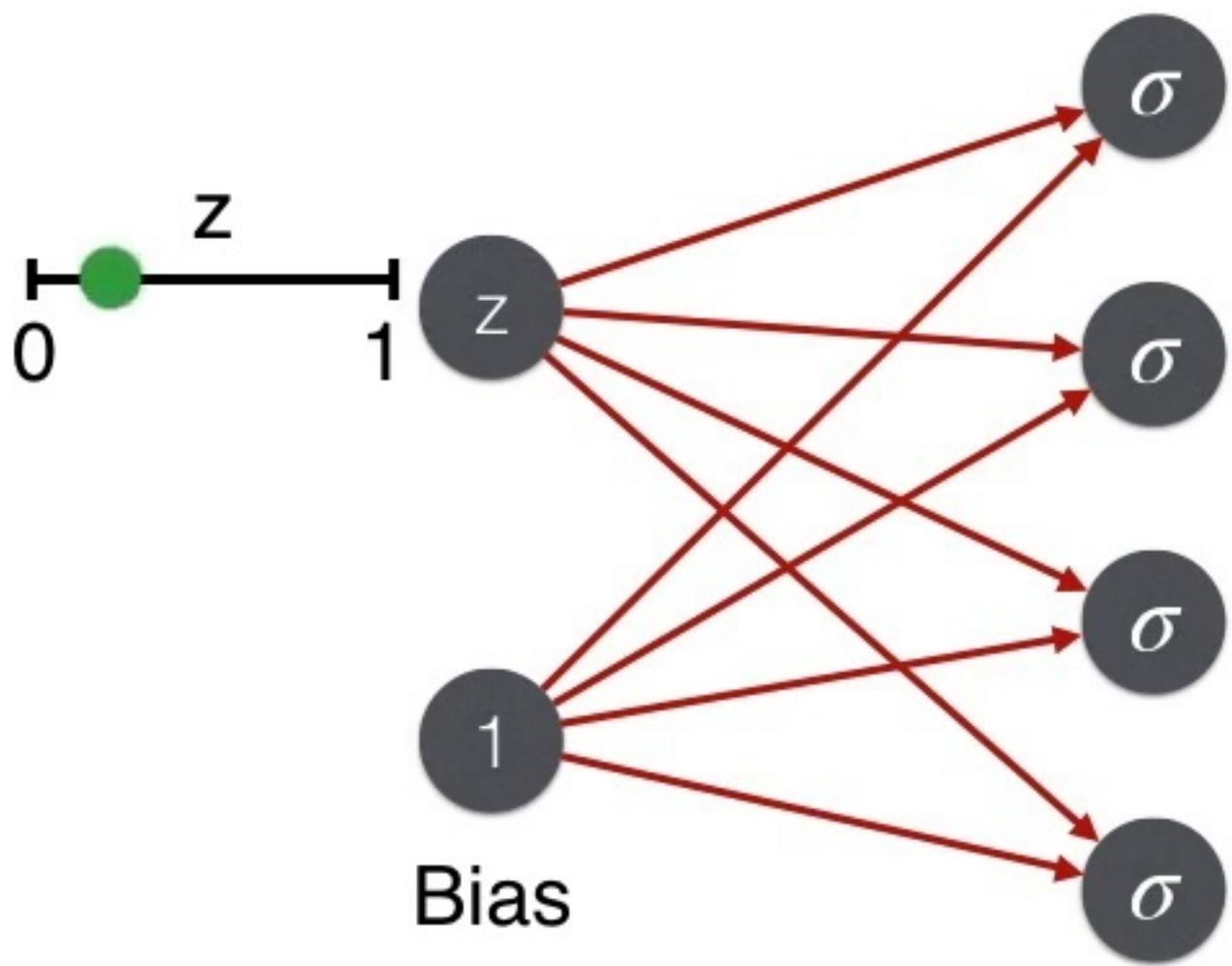
## Generator



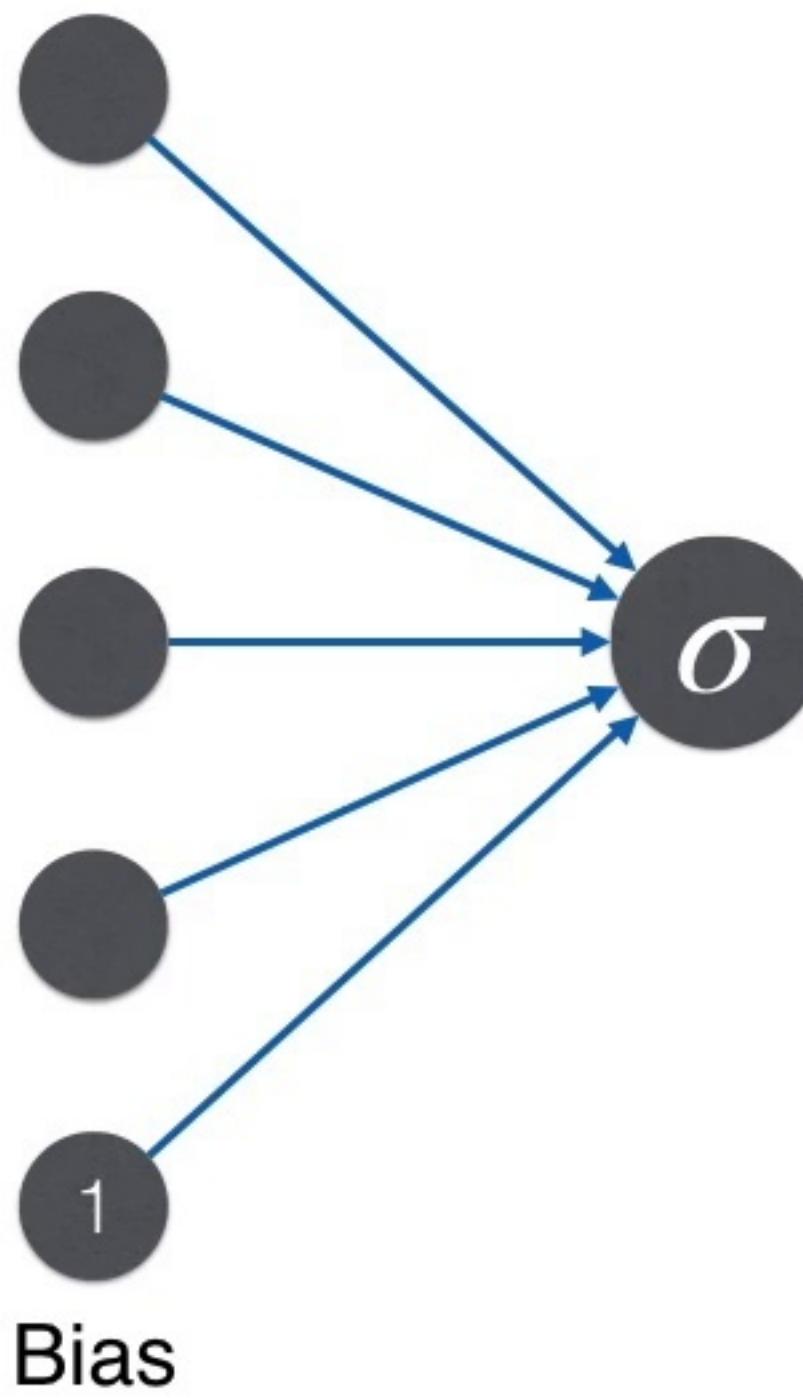
## Discriminator

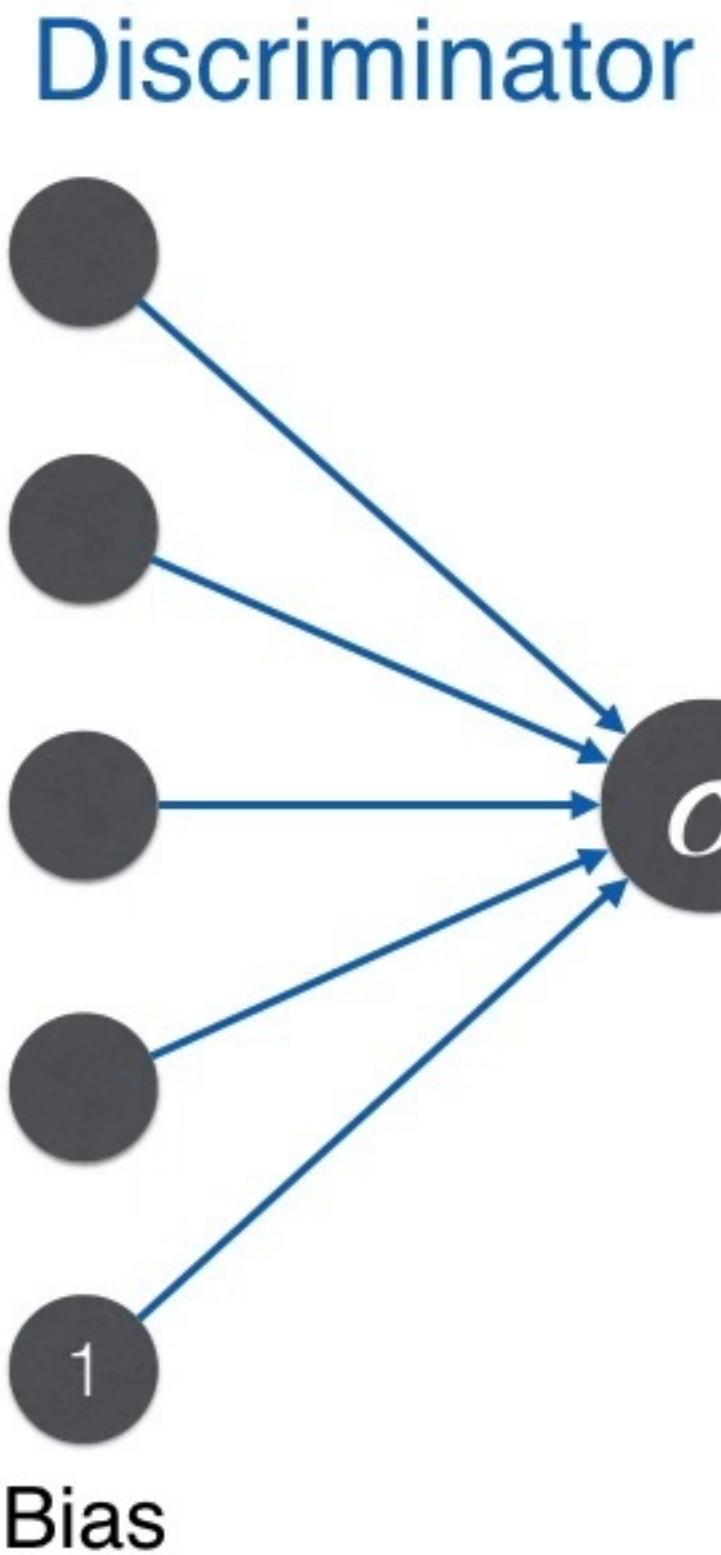
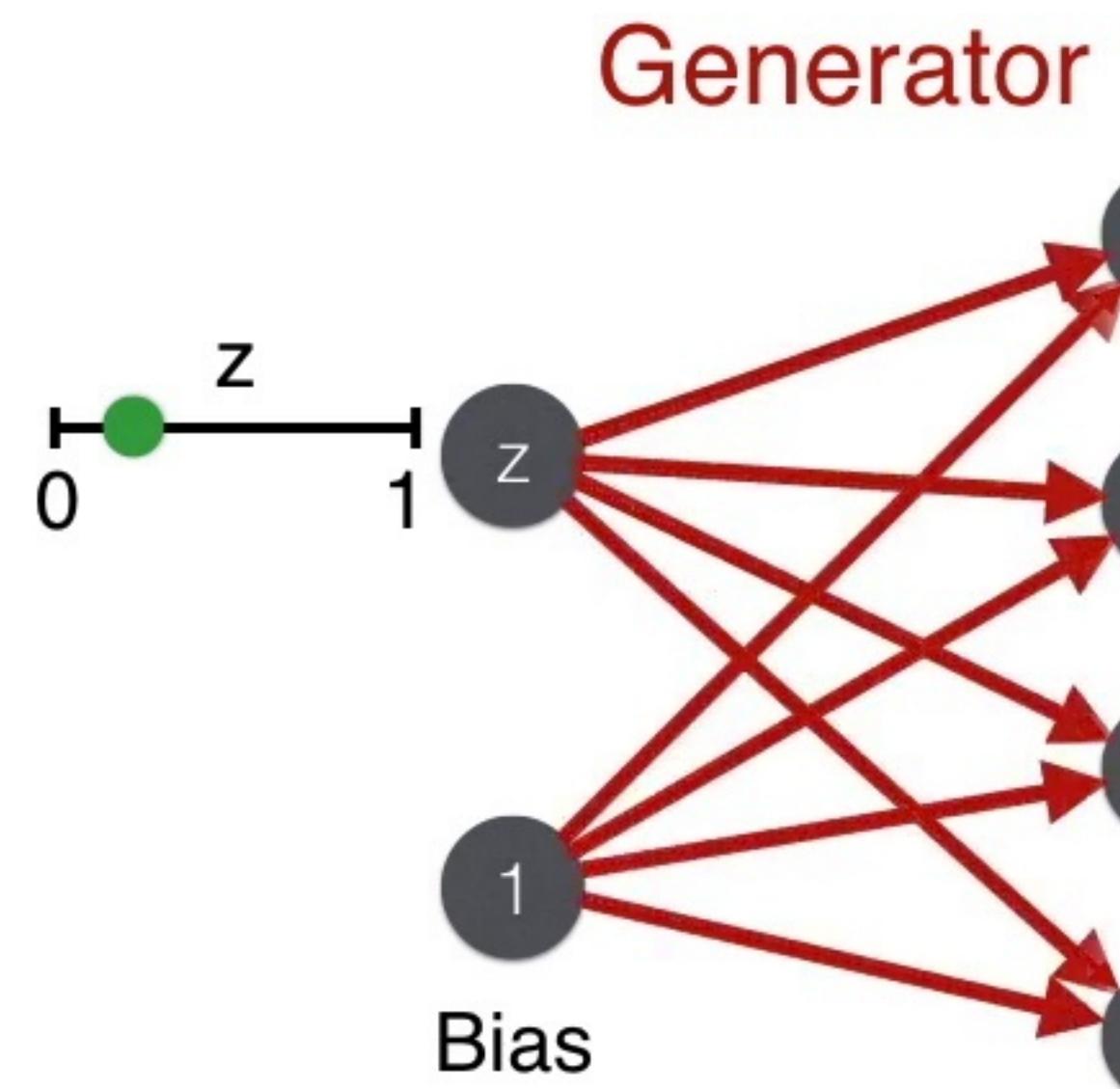


## Generator

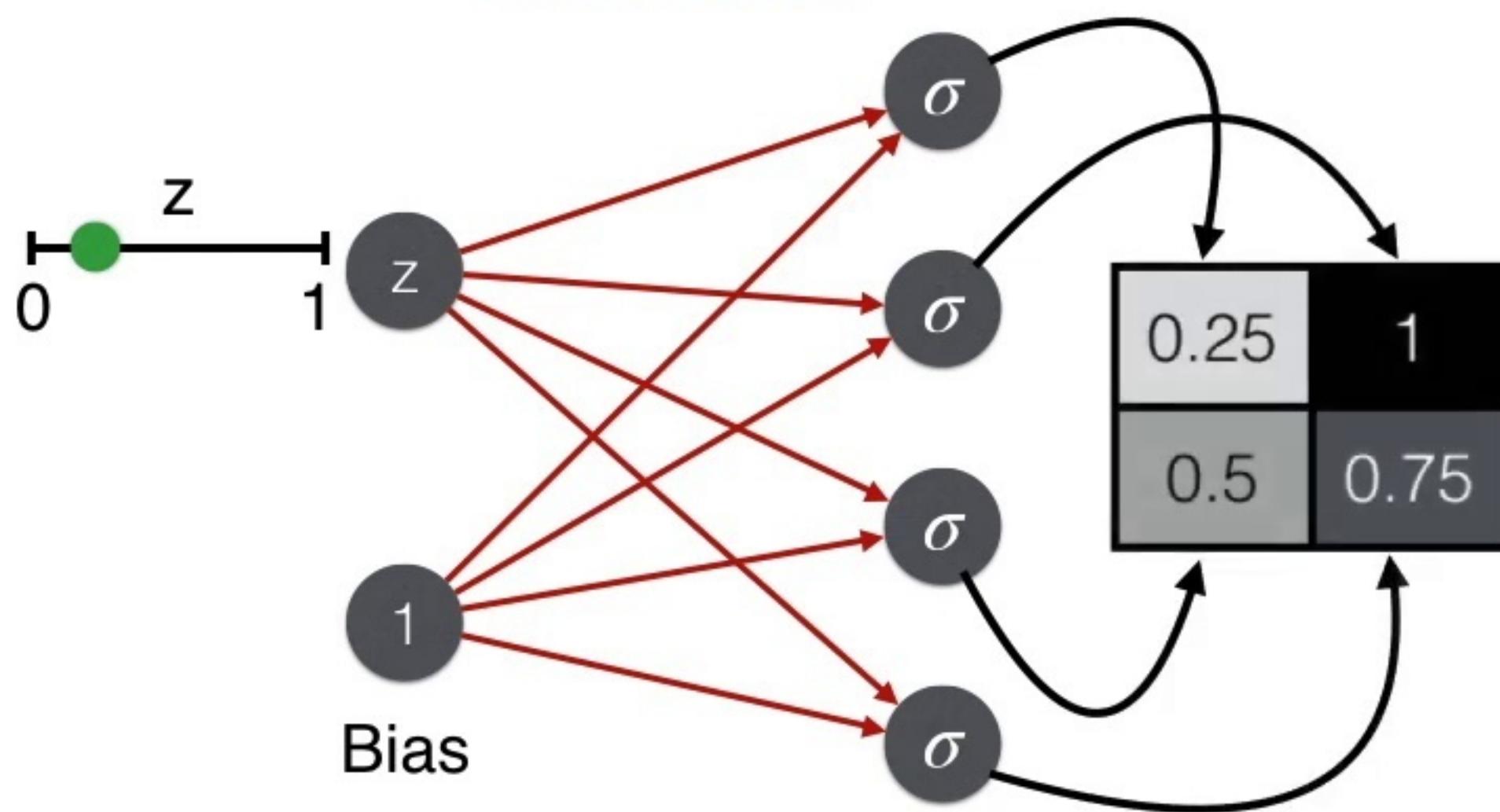


## Discriminator

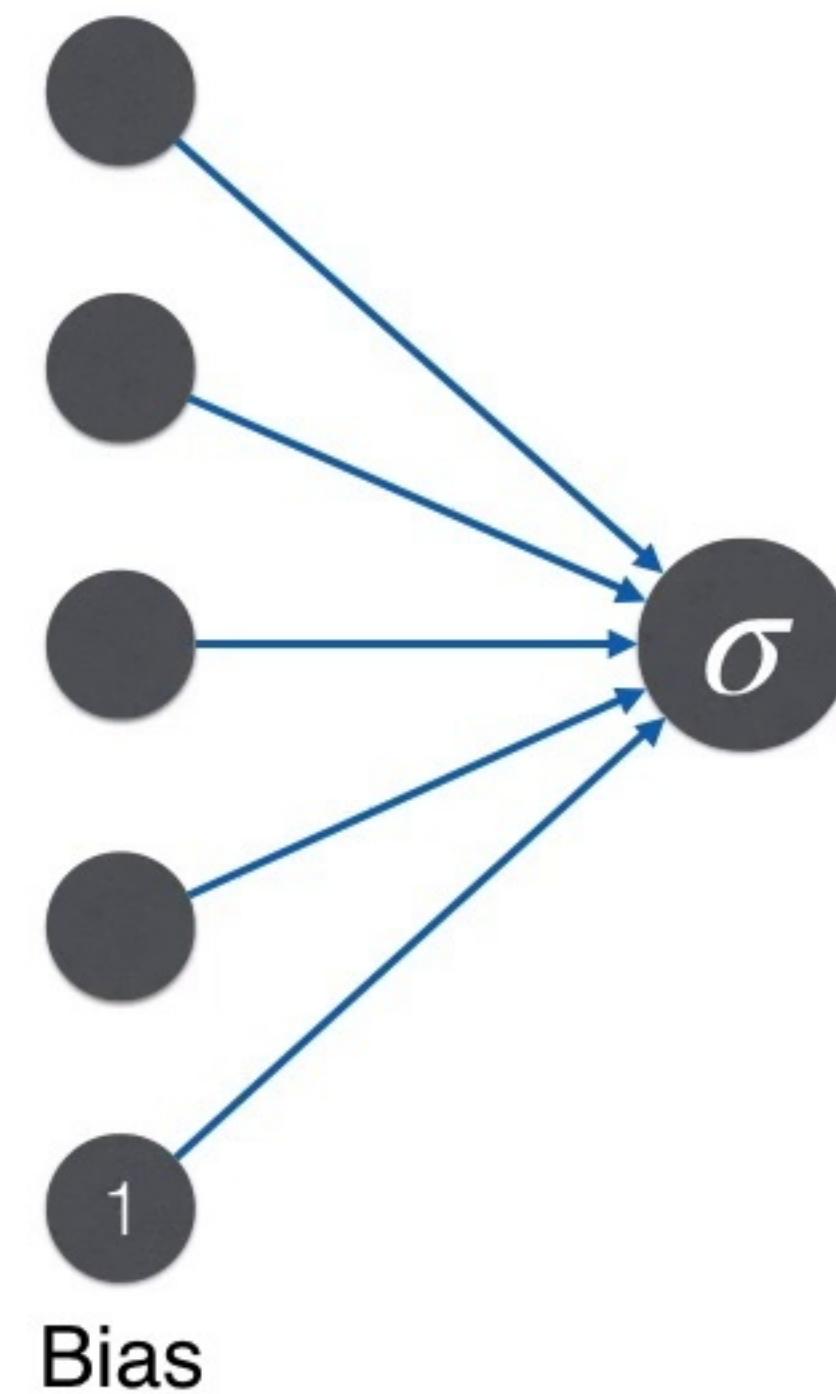




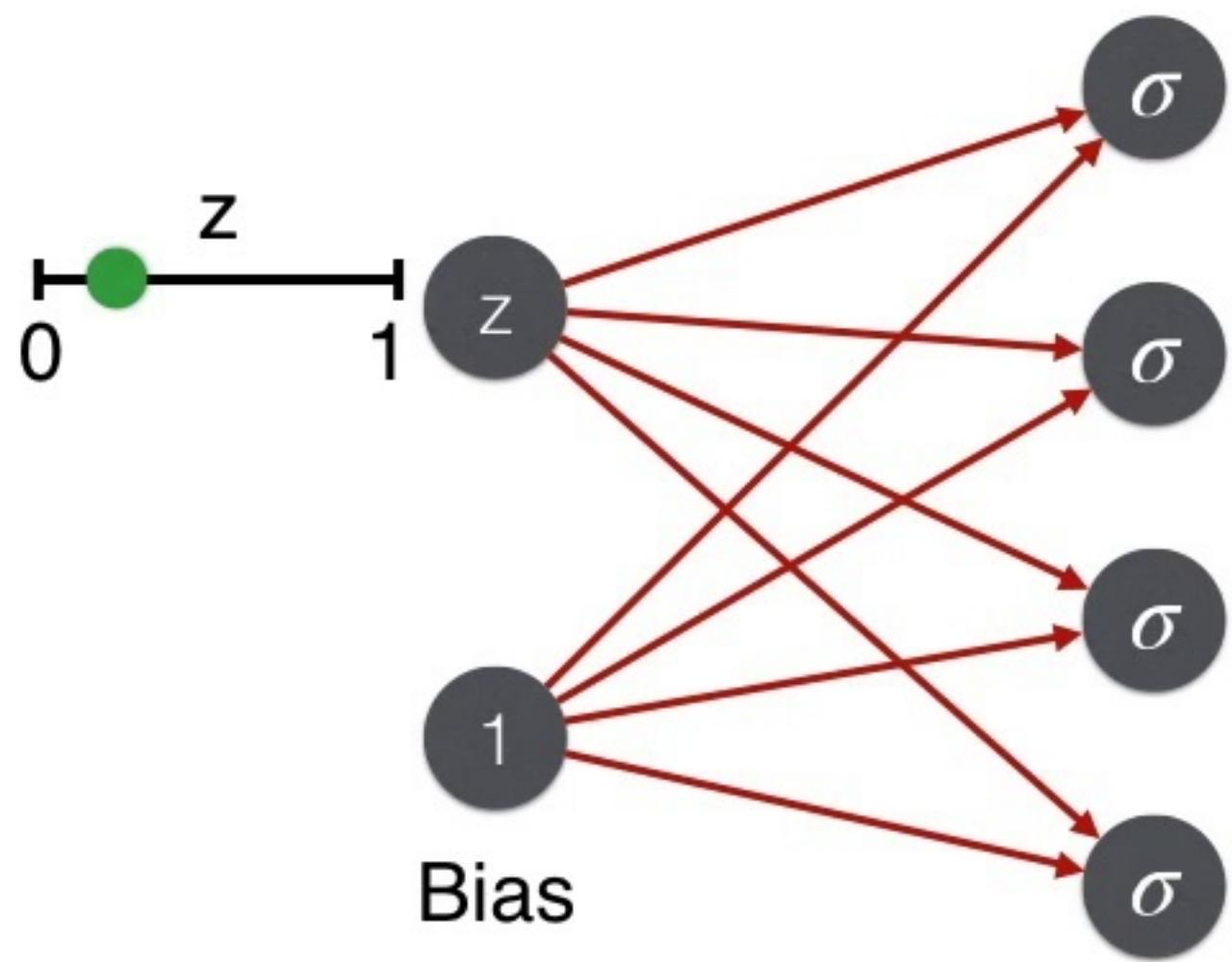
## Generator



## Discriminator



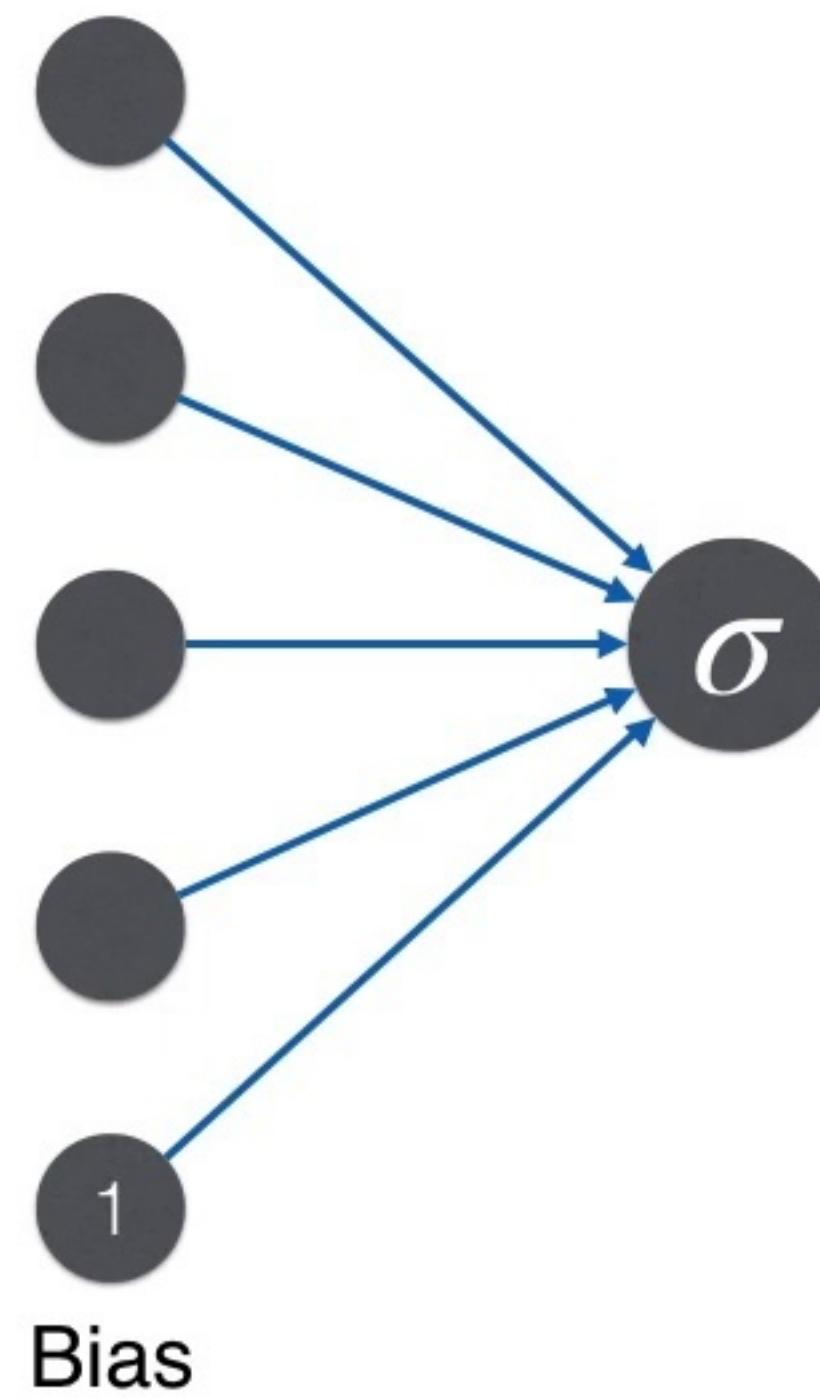
## Generator

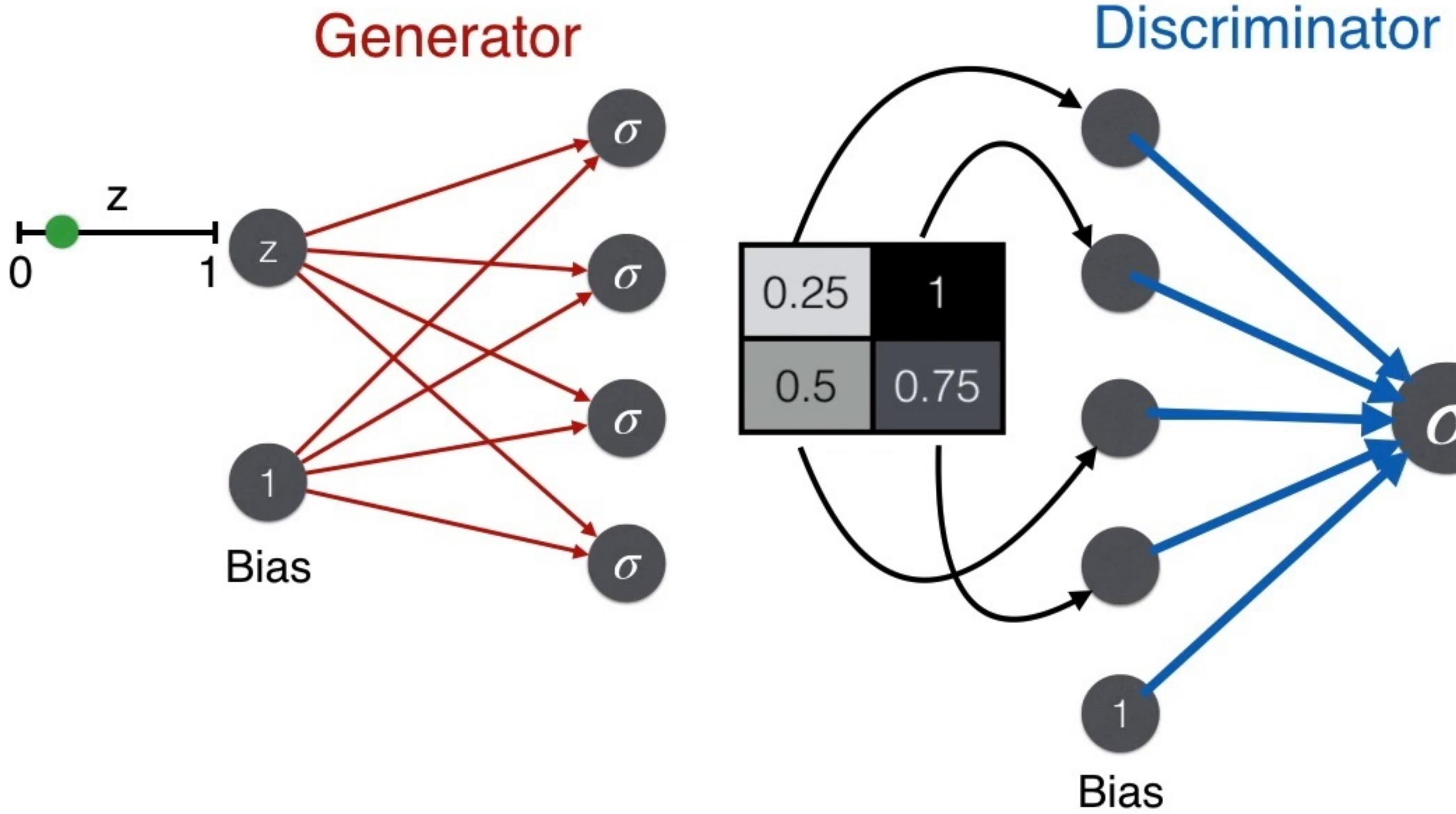


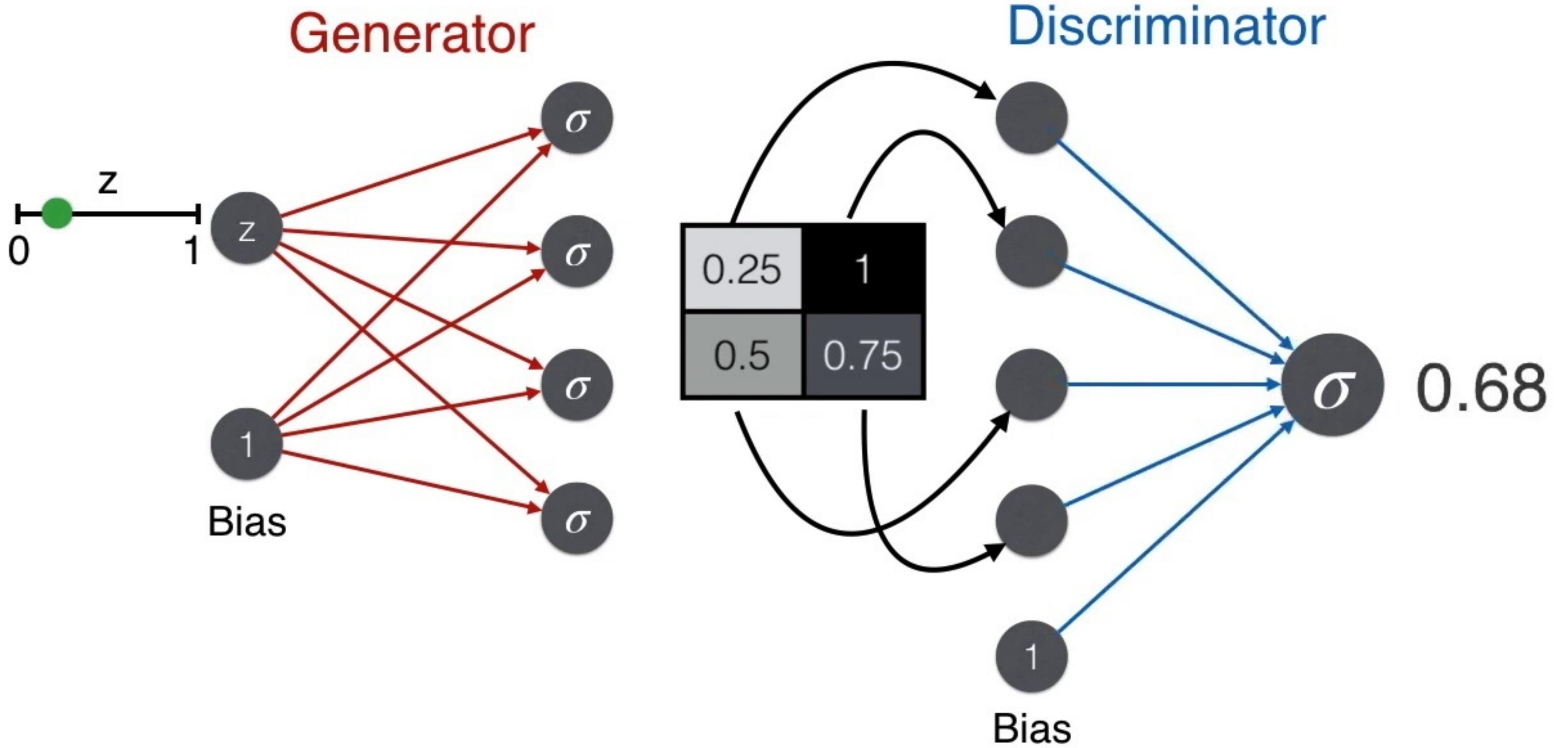
Generated  
image

0.25	1
0.5	0.75

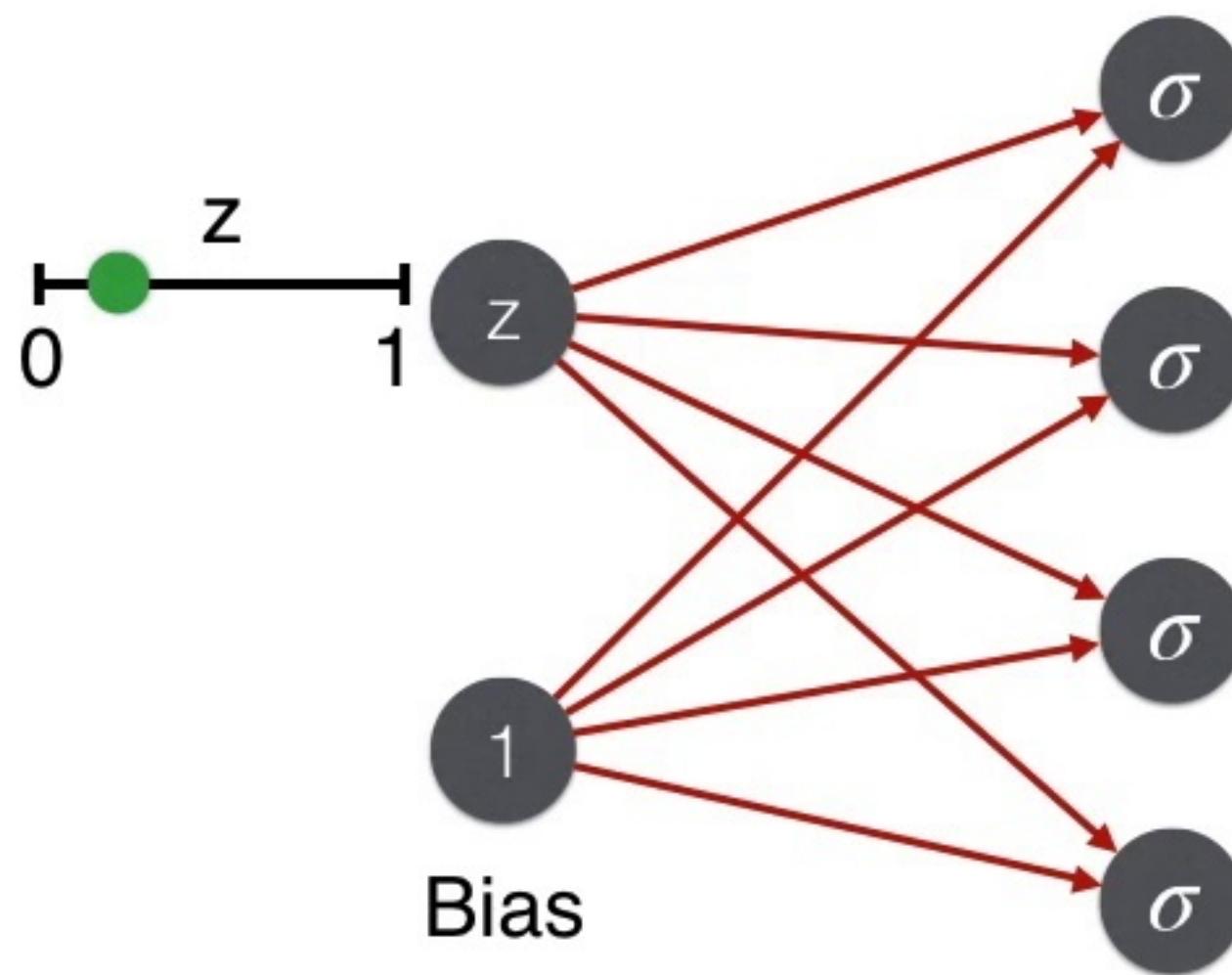
## Discriminator



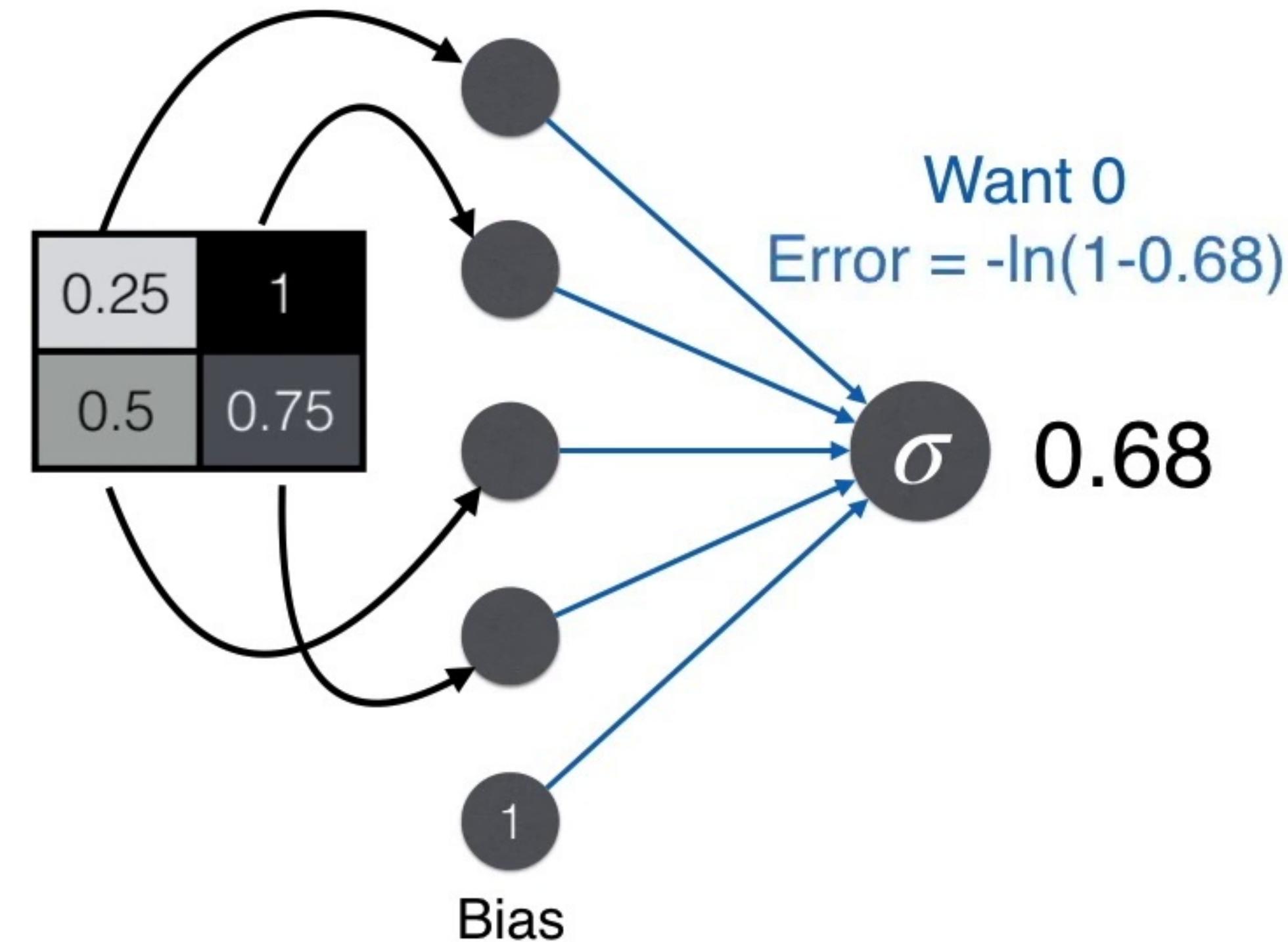


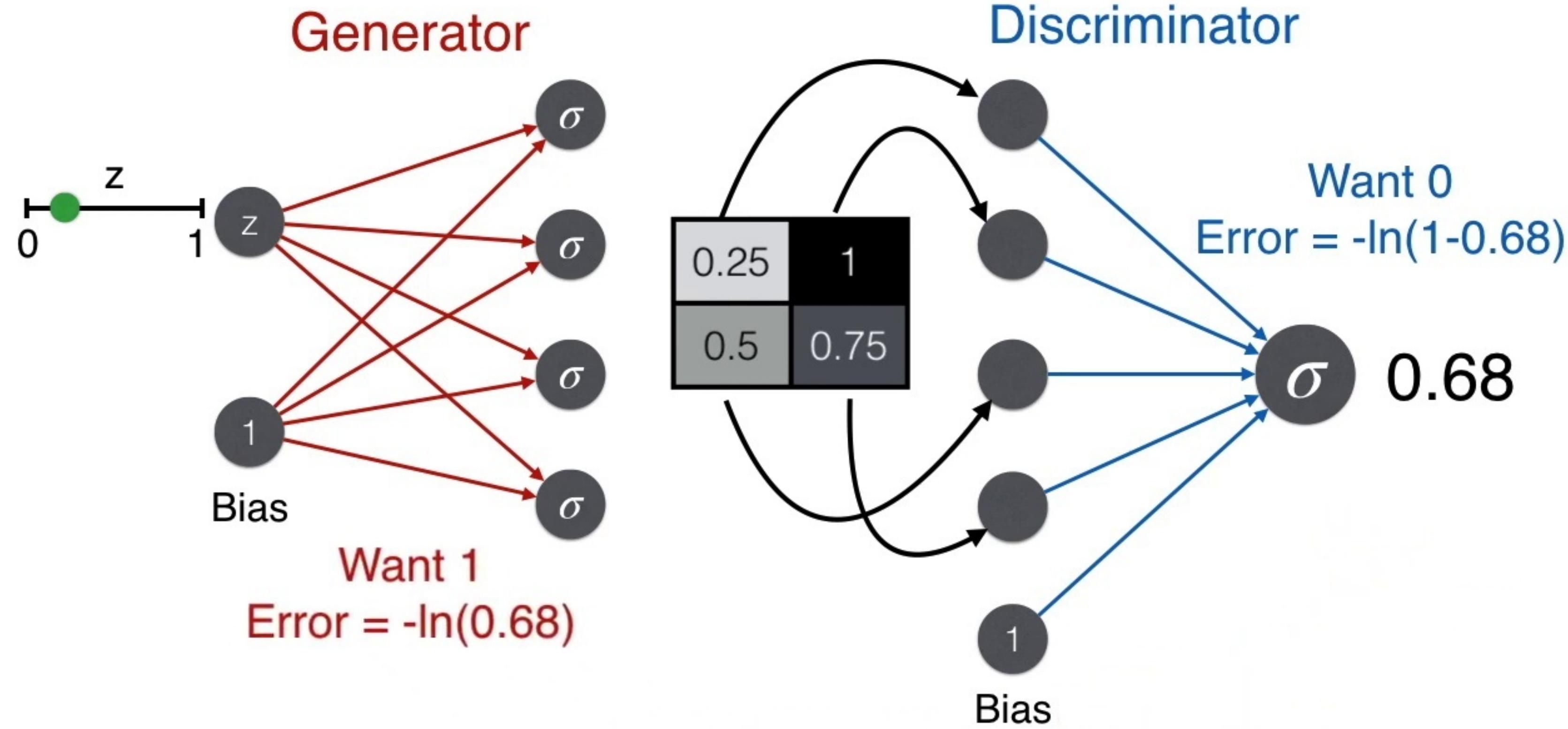


## Generator

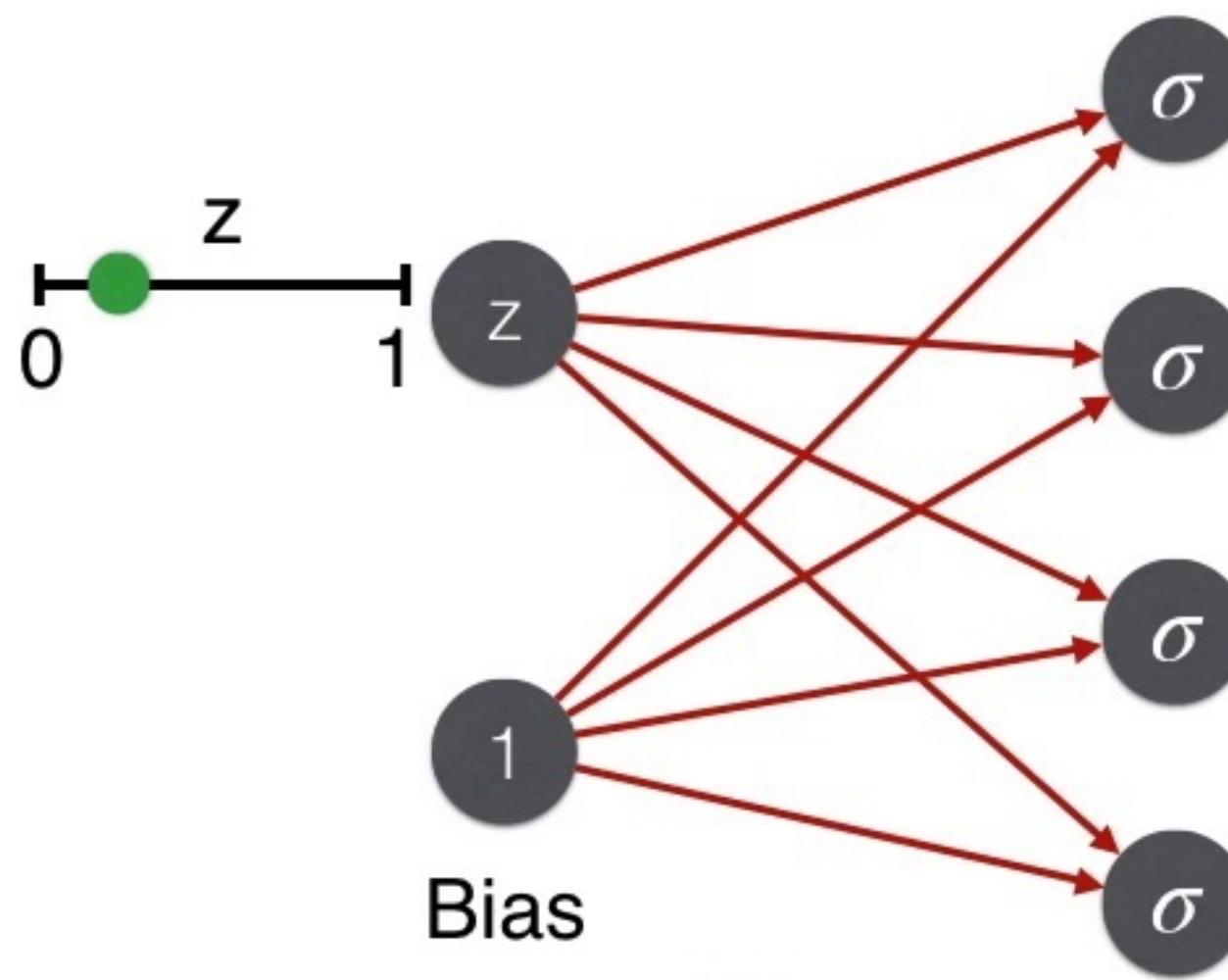


## Discriminator





## Generator

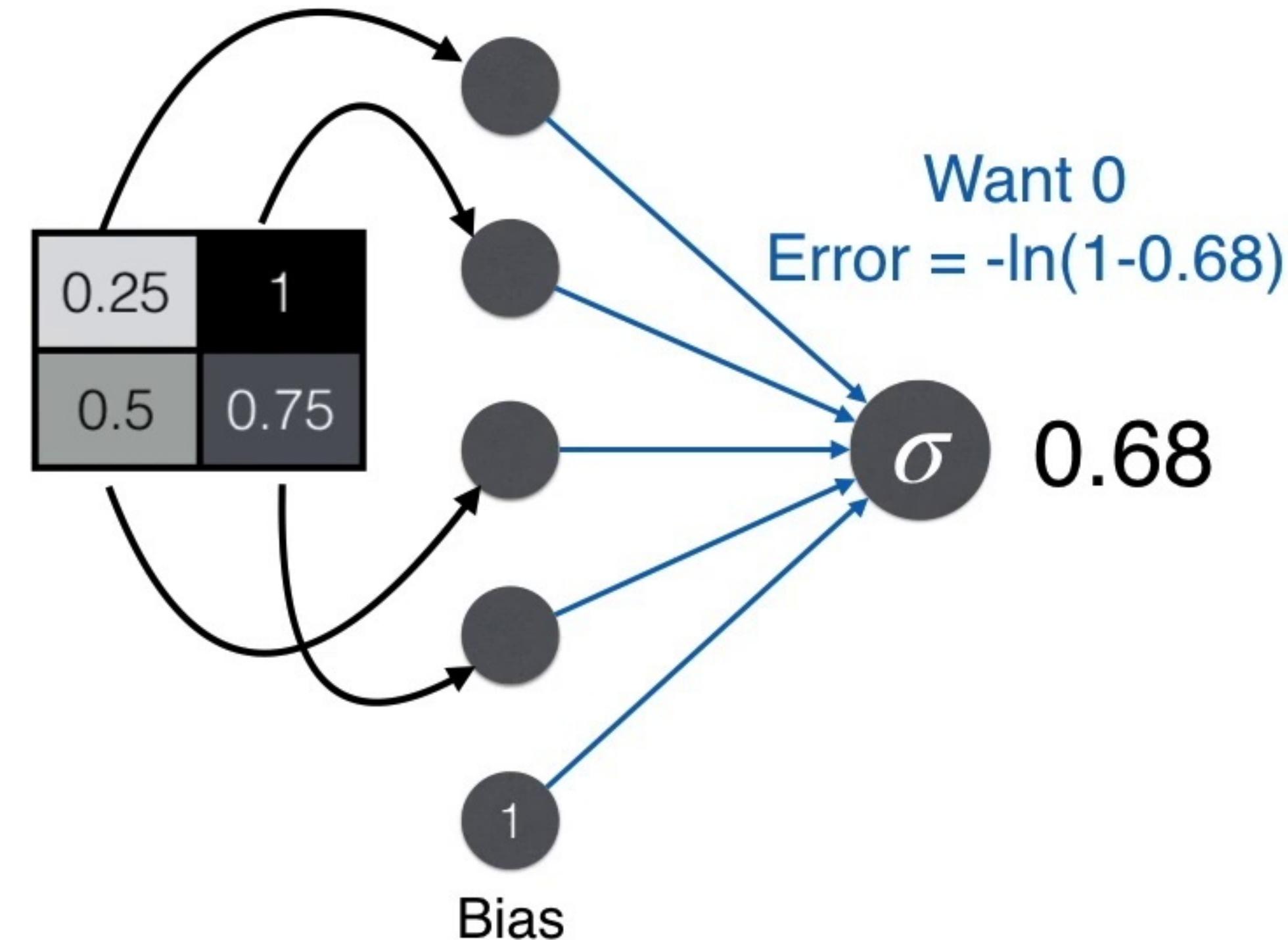


Want 1

Error =  $-\ln(0.68)$

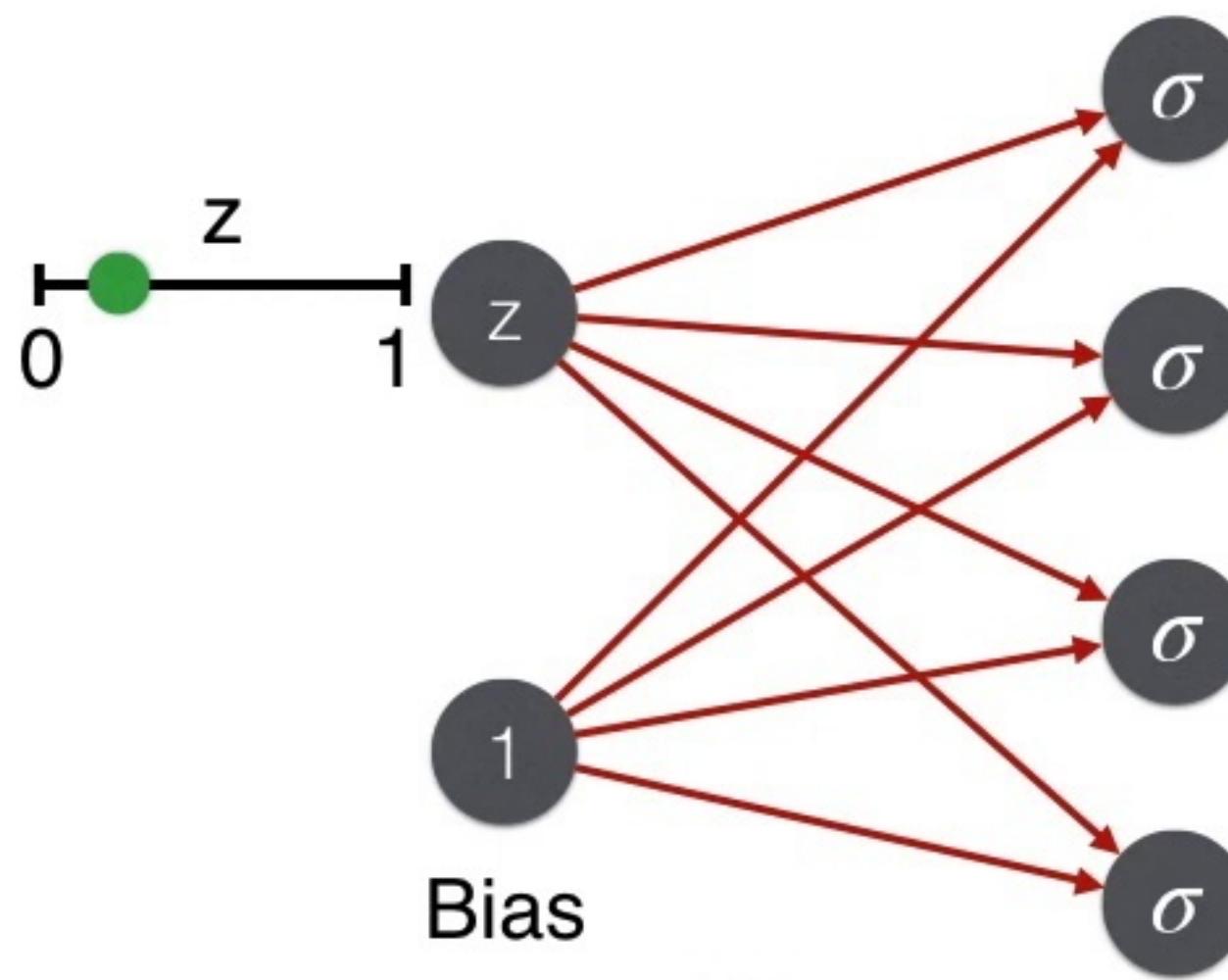
$$-\ln(D(G(z)))$$

## Discriminator



0.68

## Generator

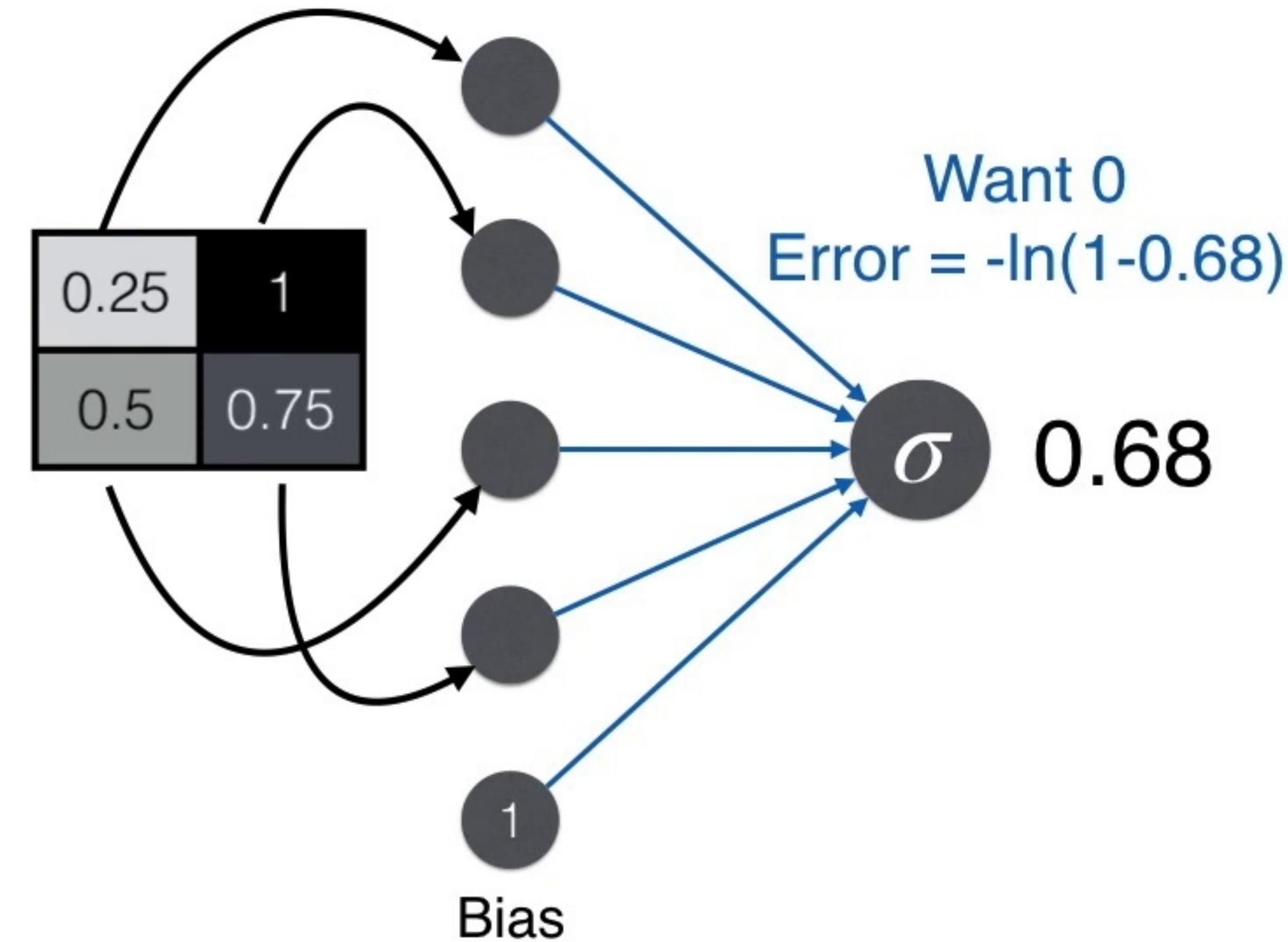


Want 1

Error =  $-\ln(0.68)$

$$-\ln(D(G(z)))$$

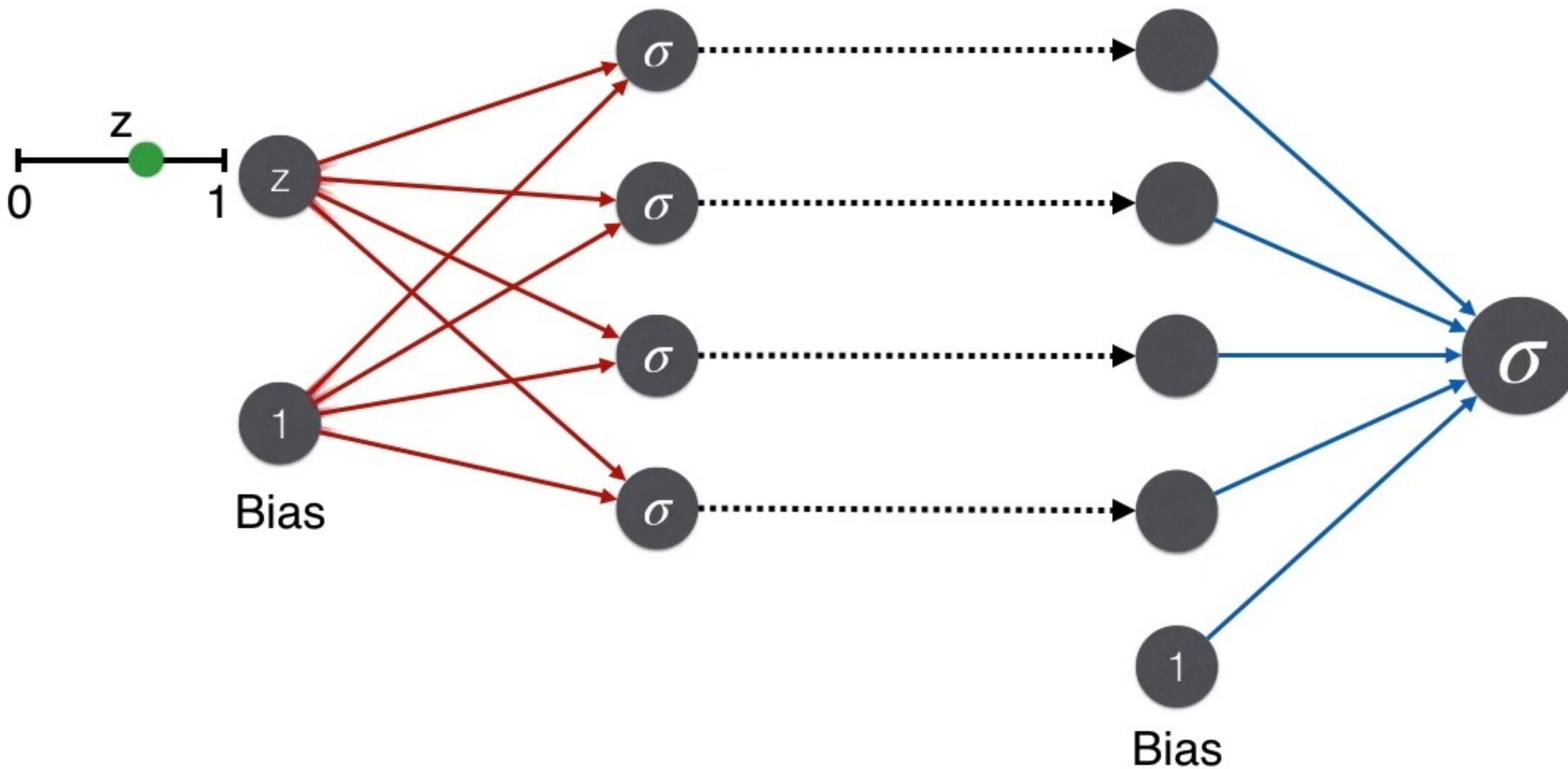
## Discriminator



$$-\ln(1 - D(G(z)))$$

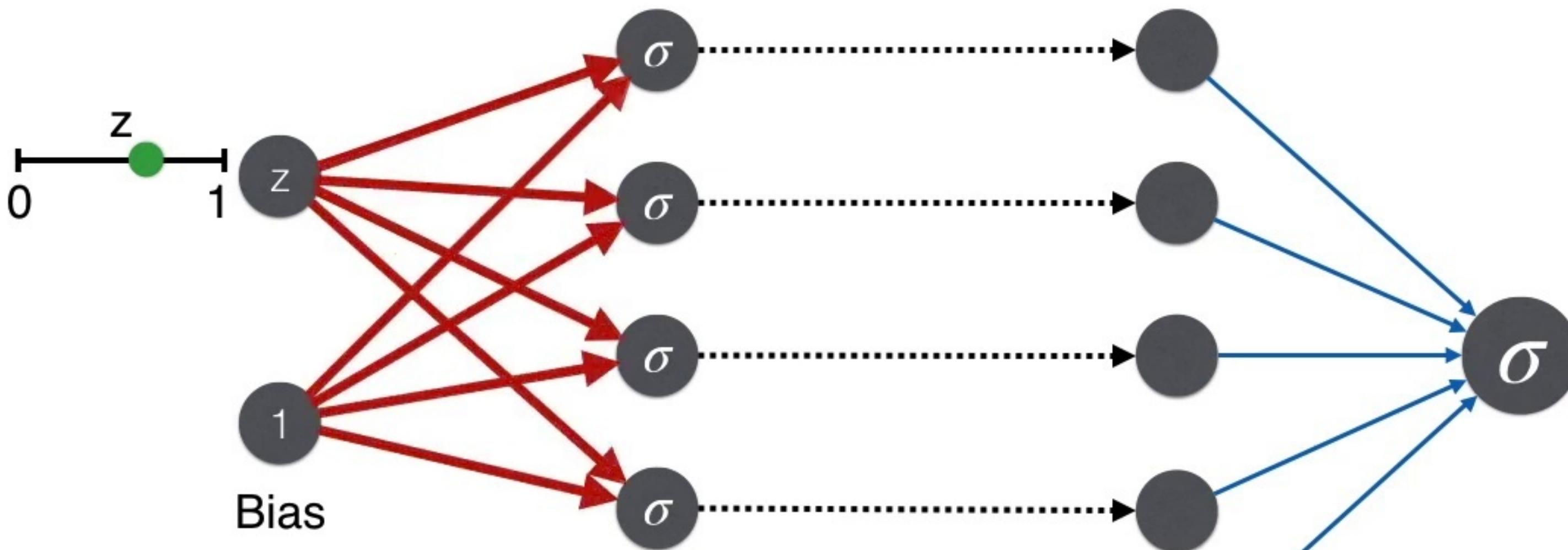
Repeat many times...

## Generator

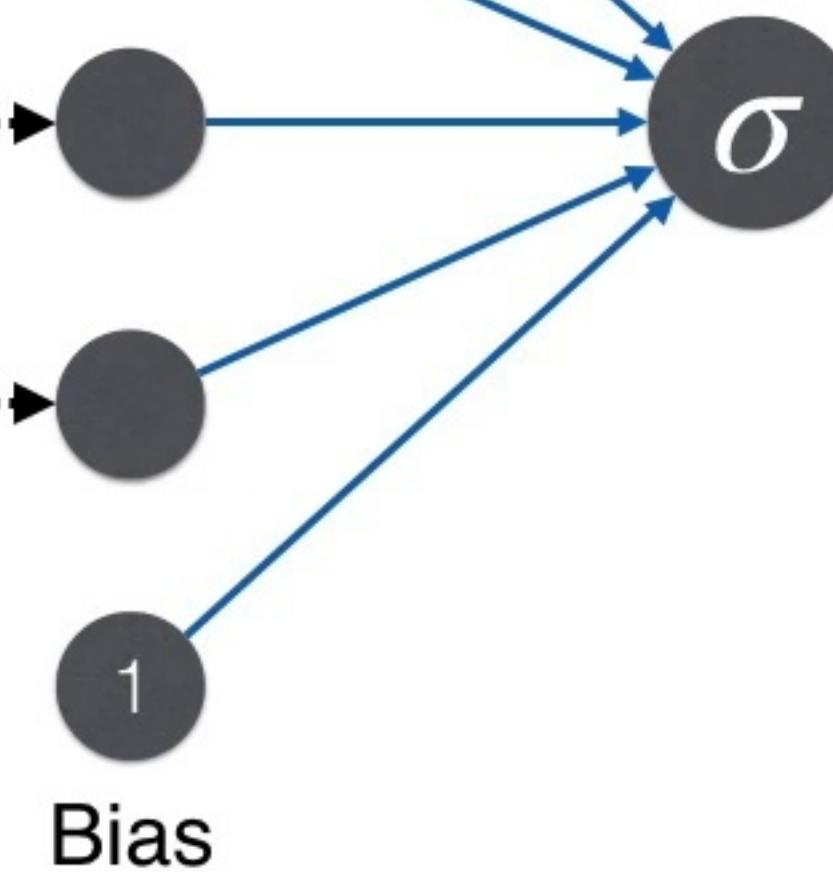


## Discriminator

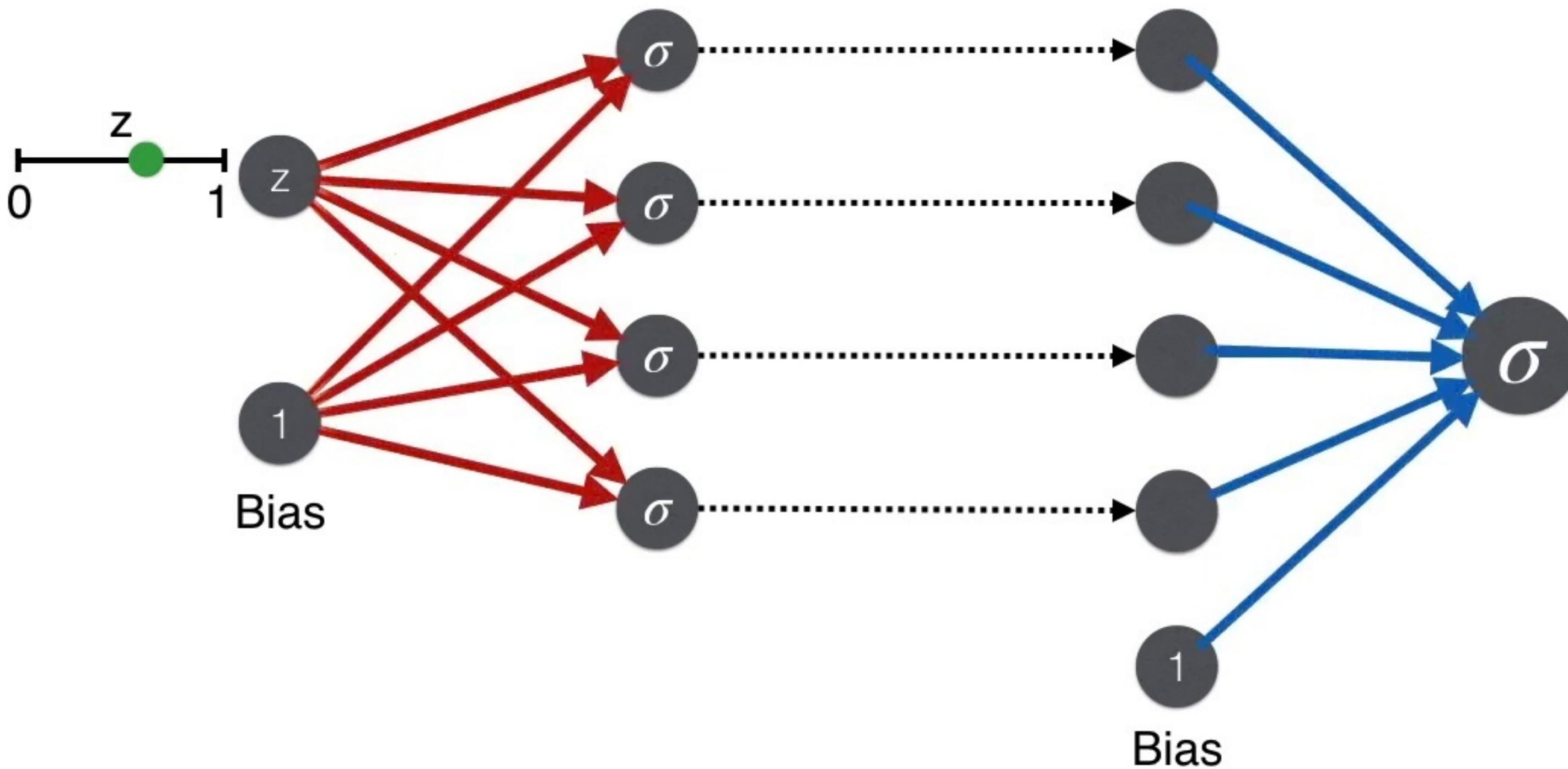
## Generator



## Discriminator

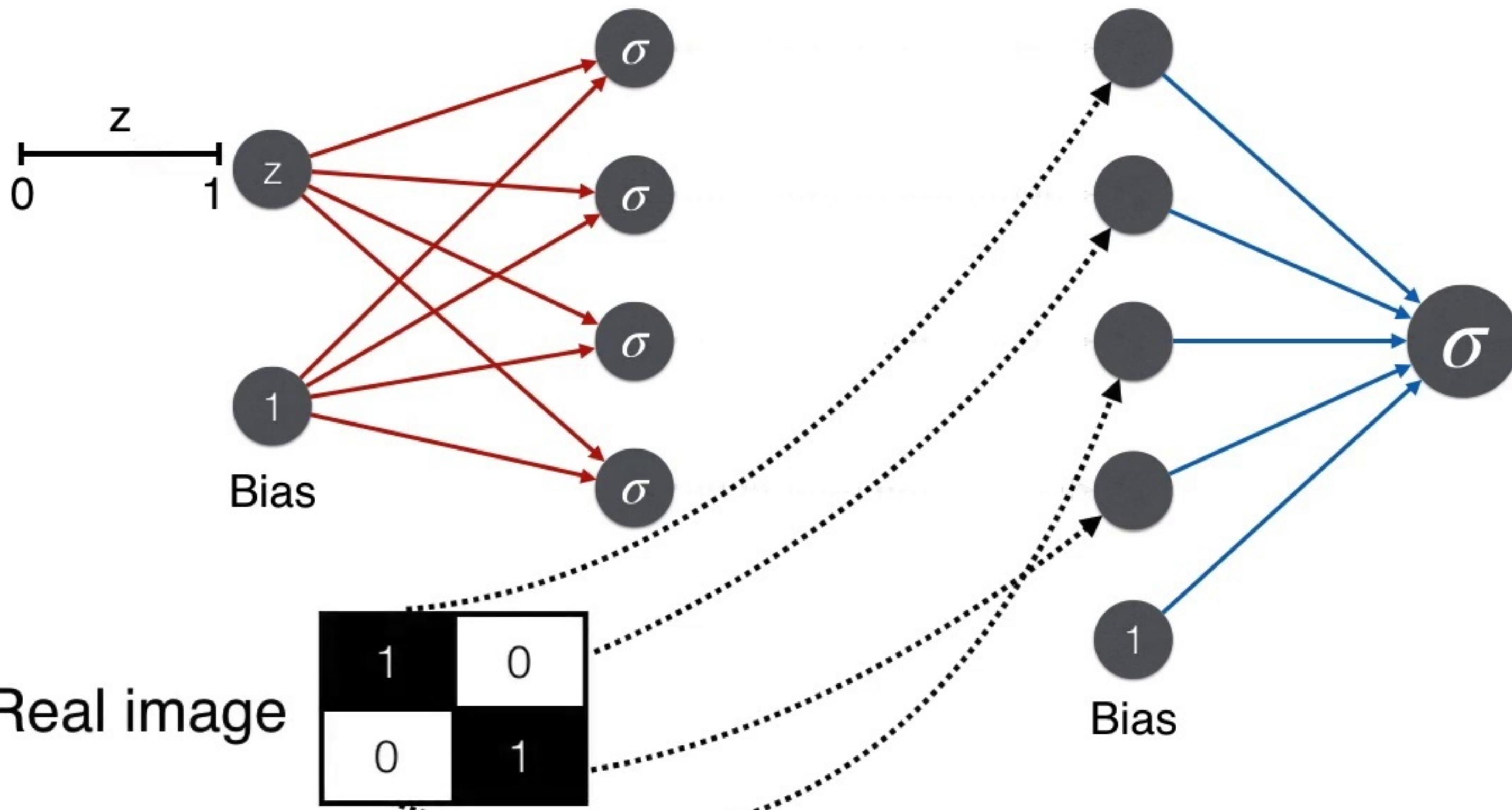


## Generator



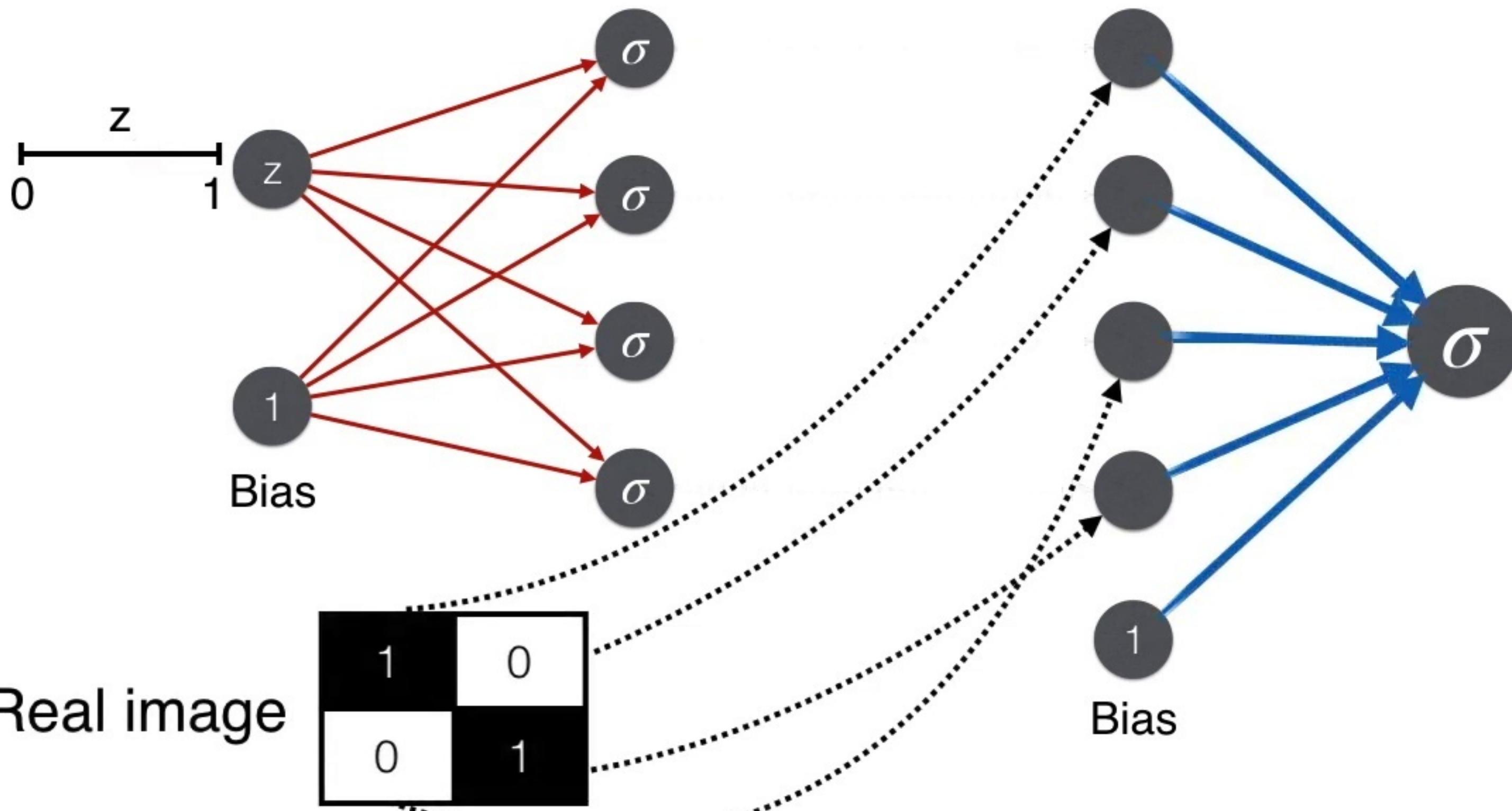
## Discriminator

## Generator



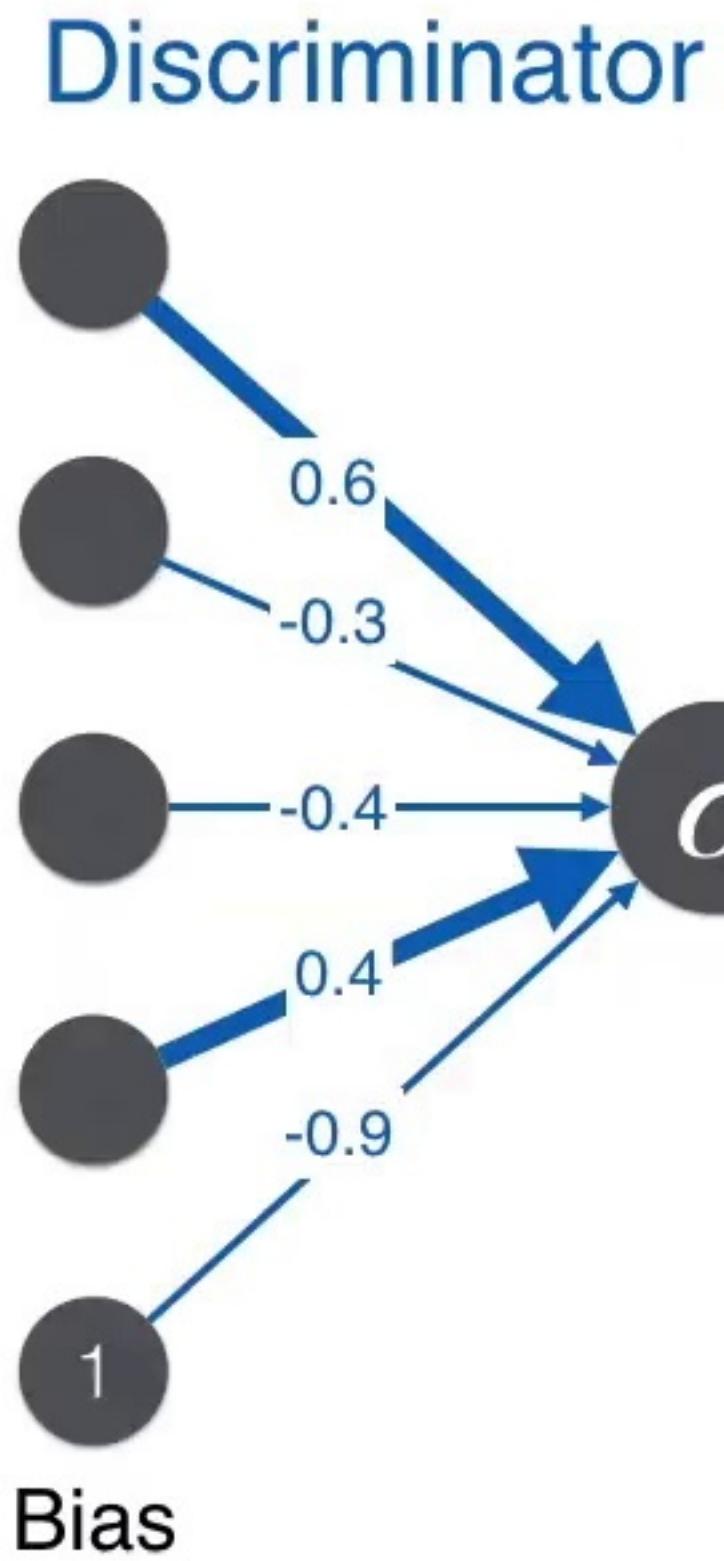
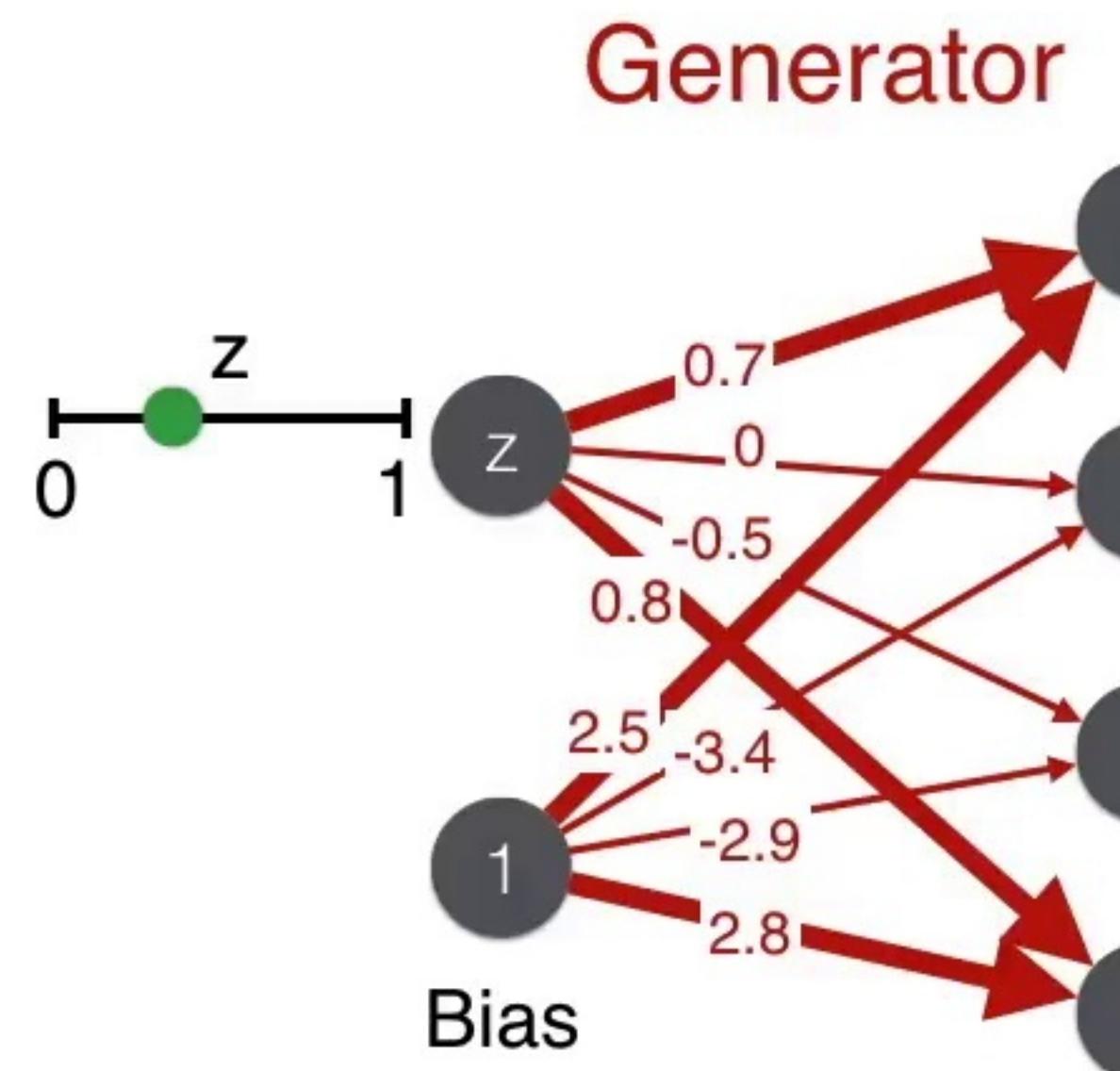
## Discriminator

## Generator

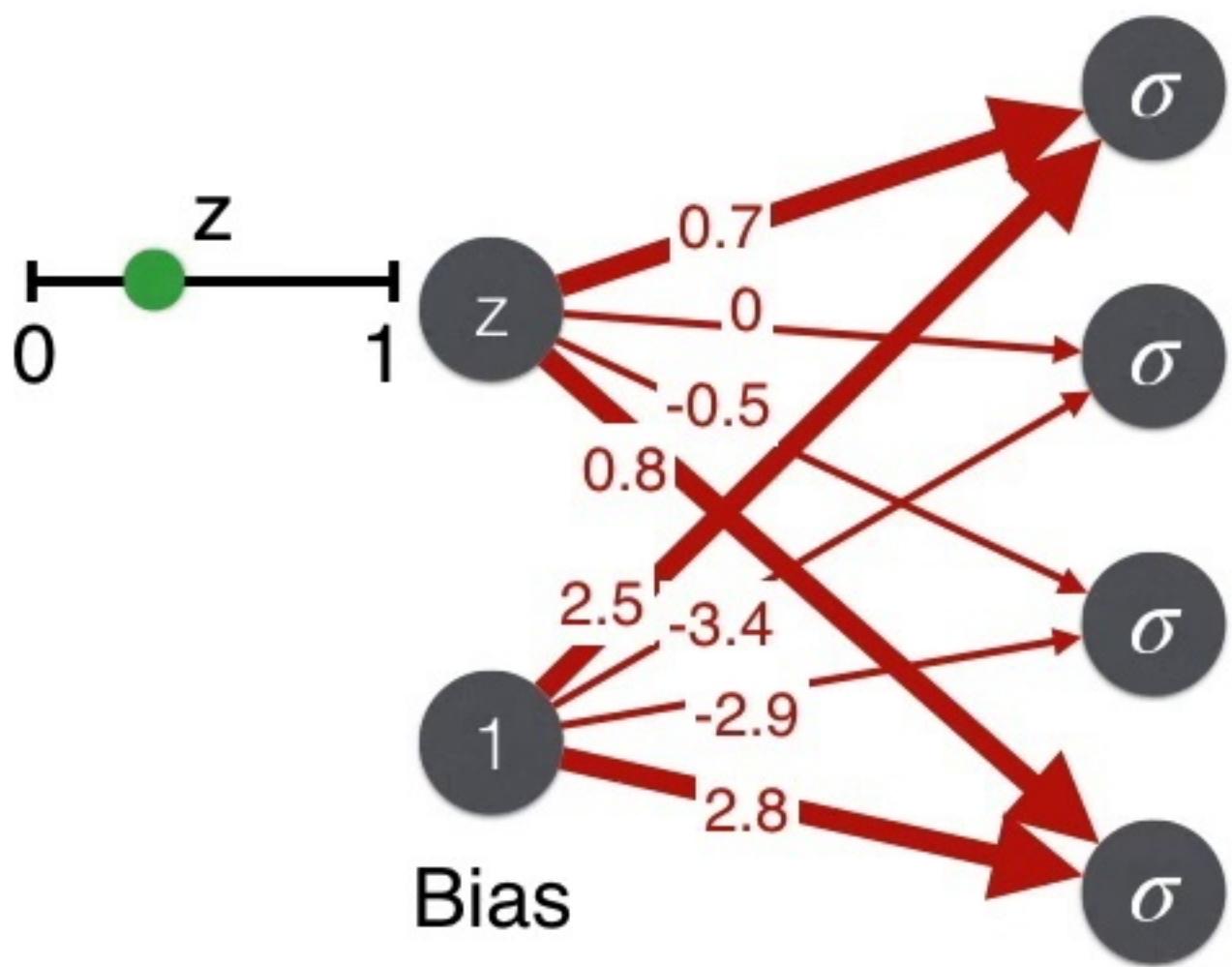


## Discriminator

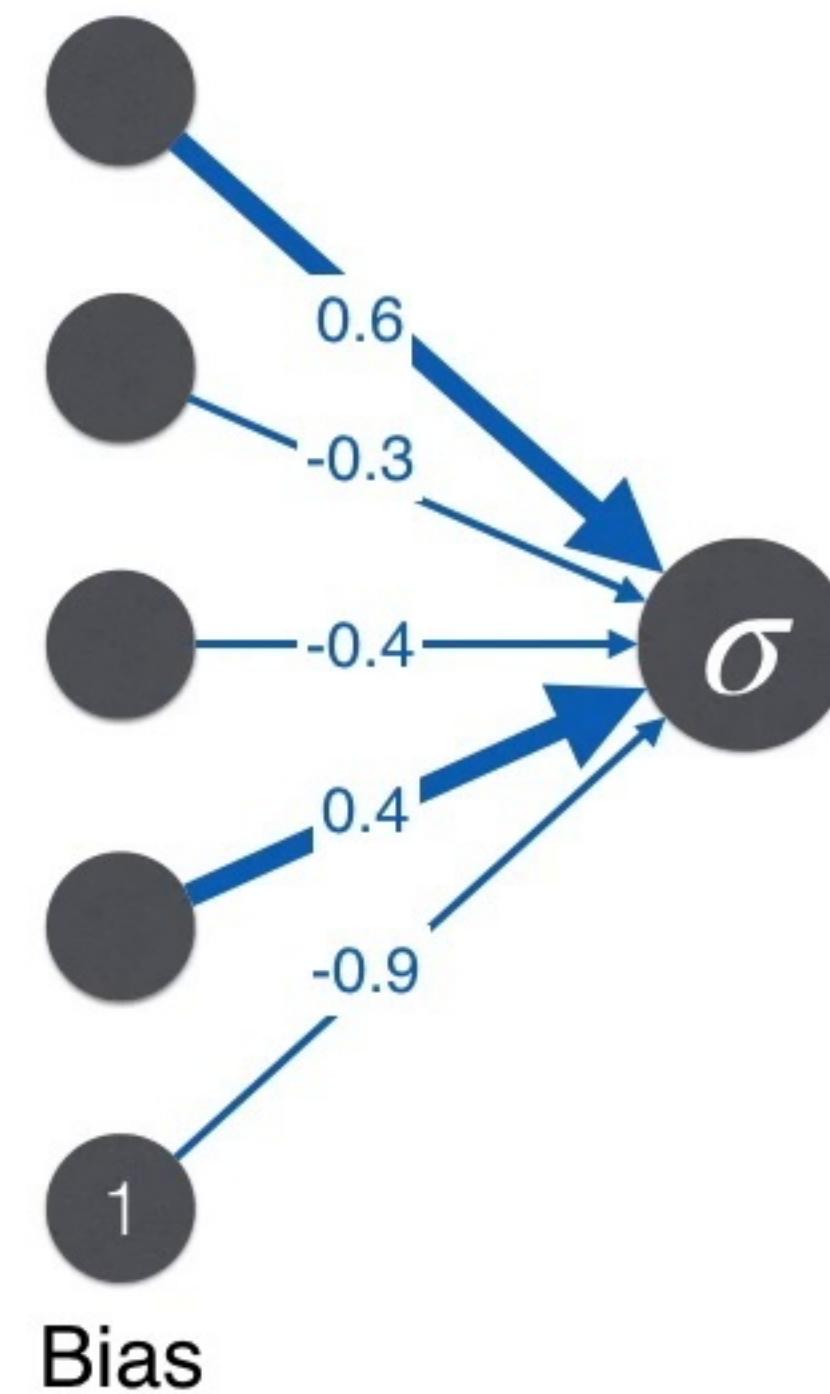
After many of these iterations (epochs)



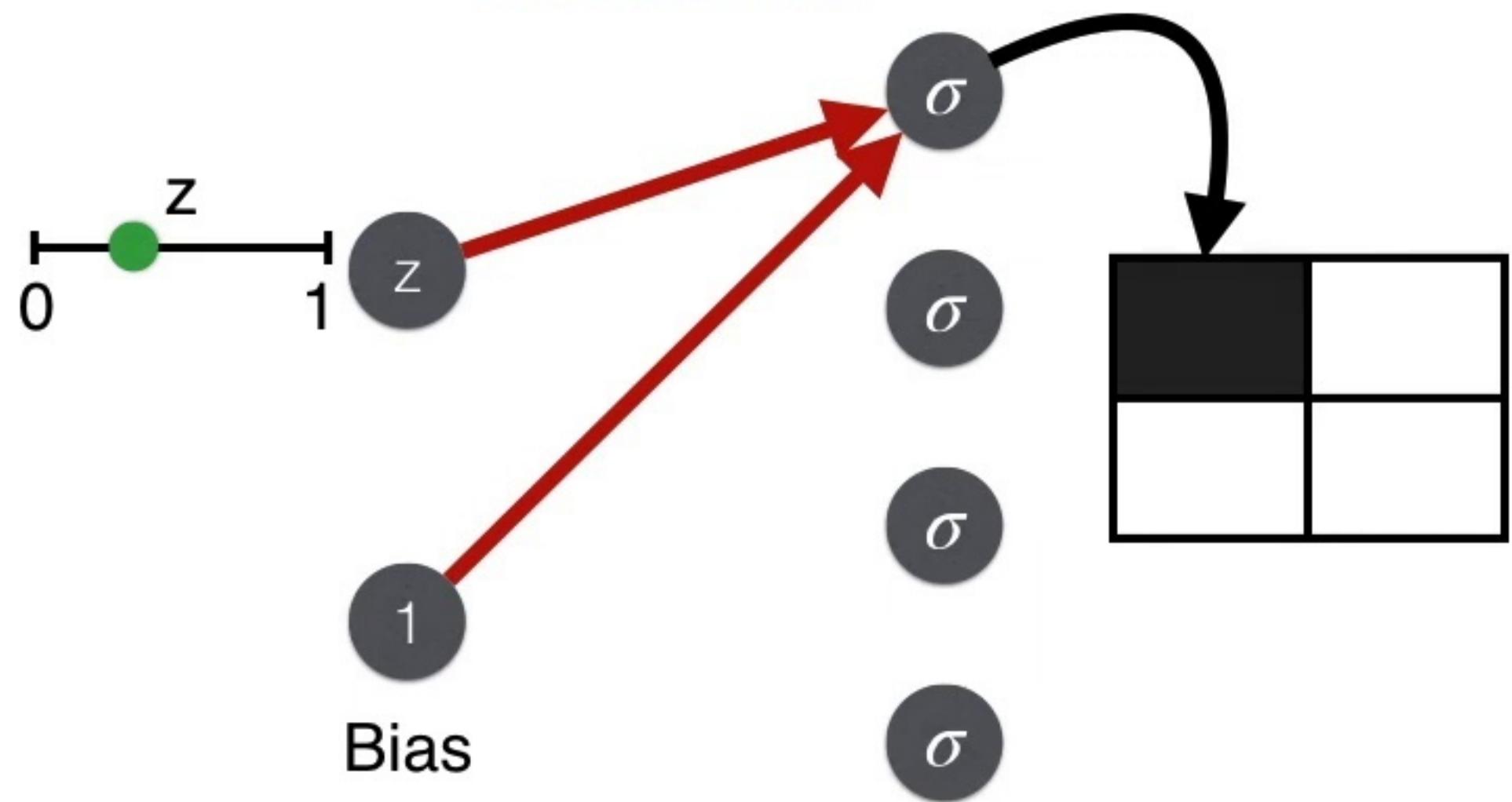
## Generator



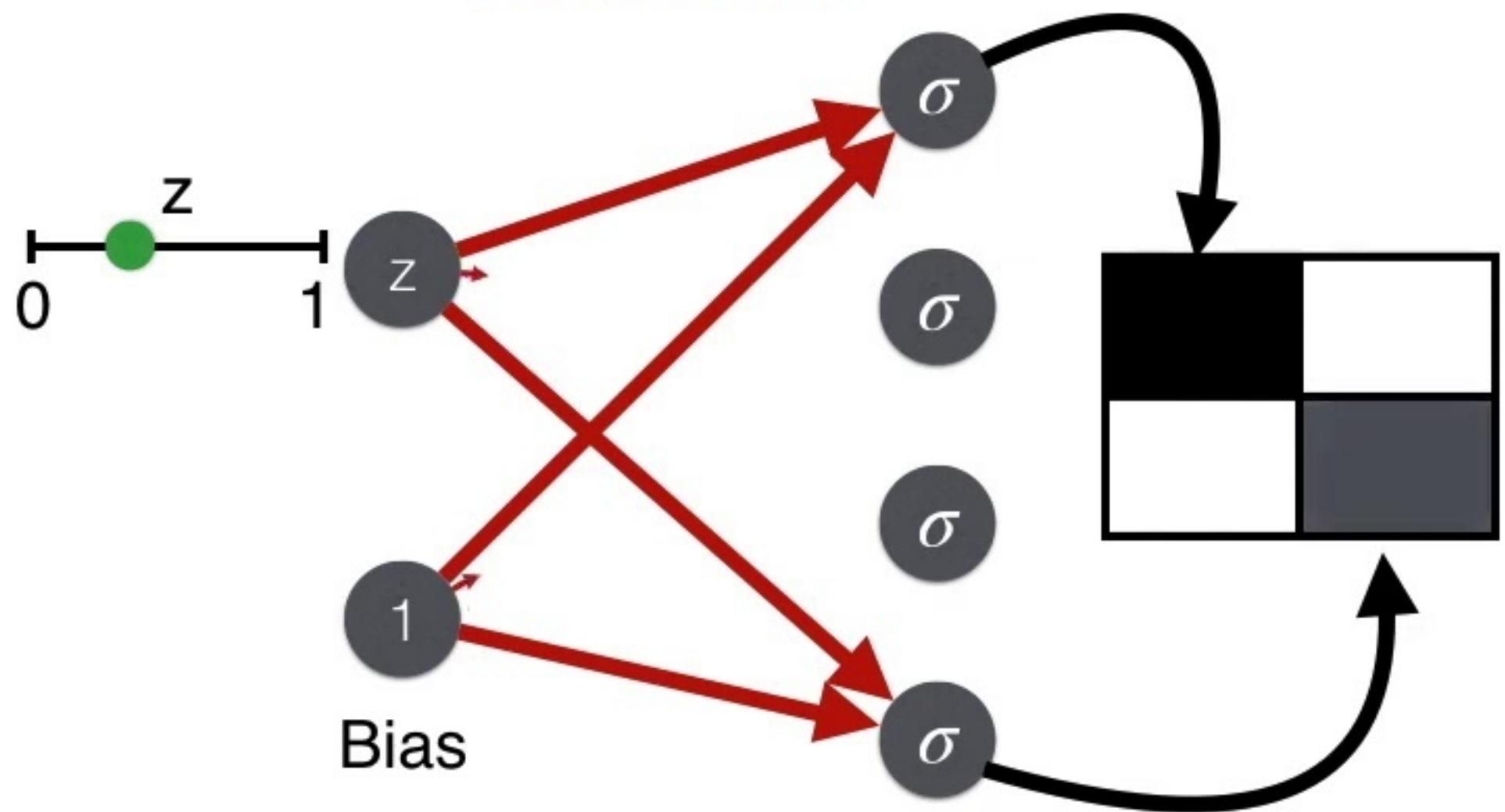
## Discriminator



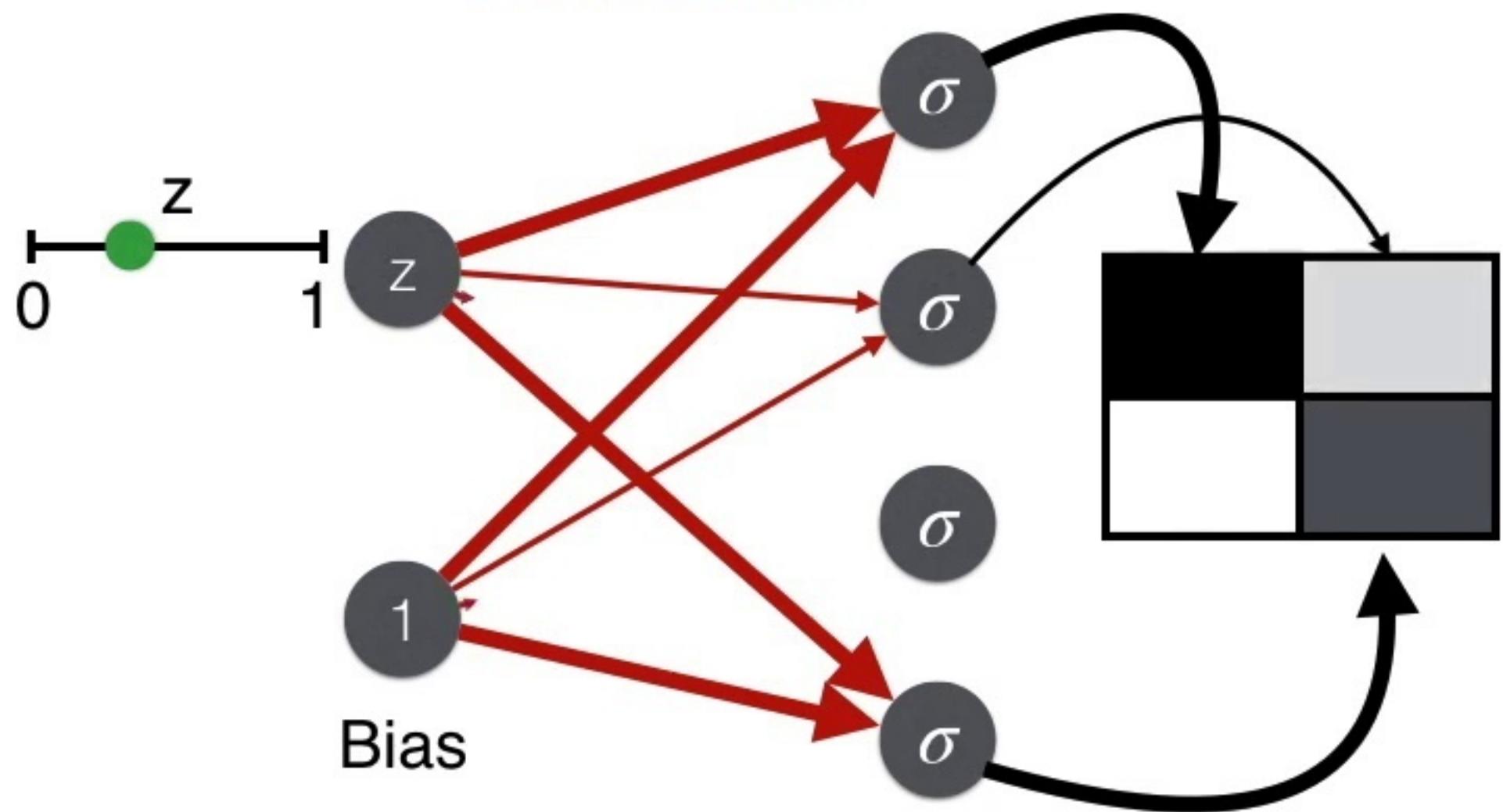
# Generator



# Generator



# Generator



# Generator

