

# Dense layers

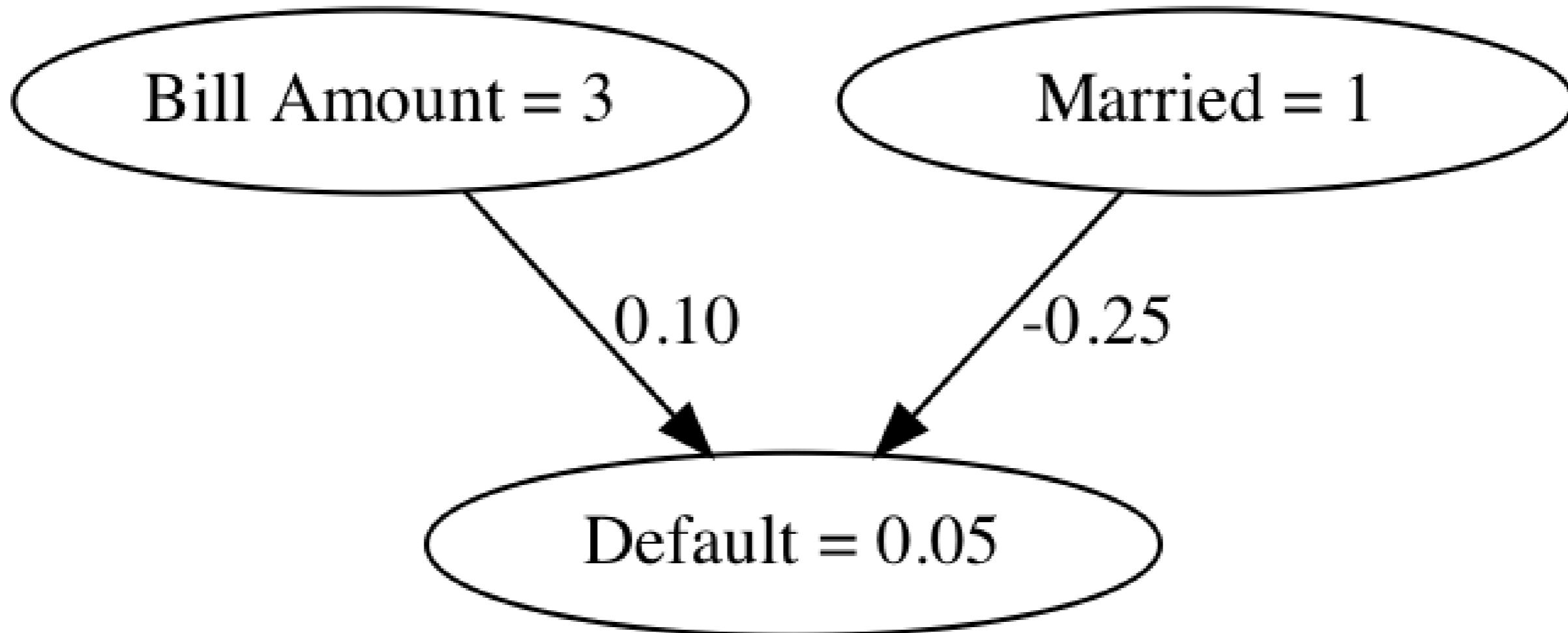
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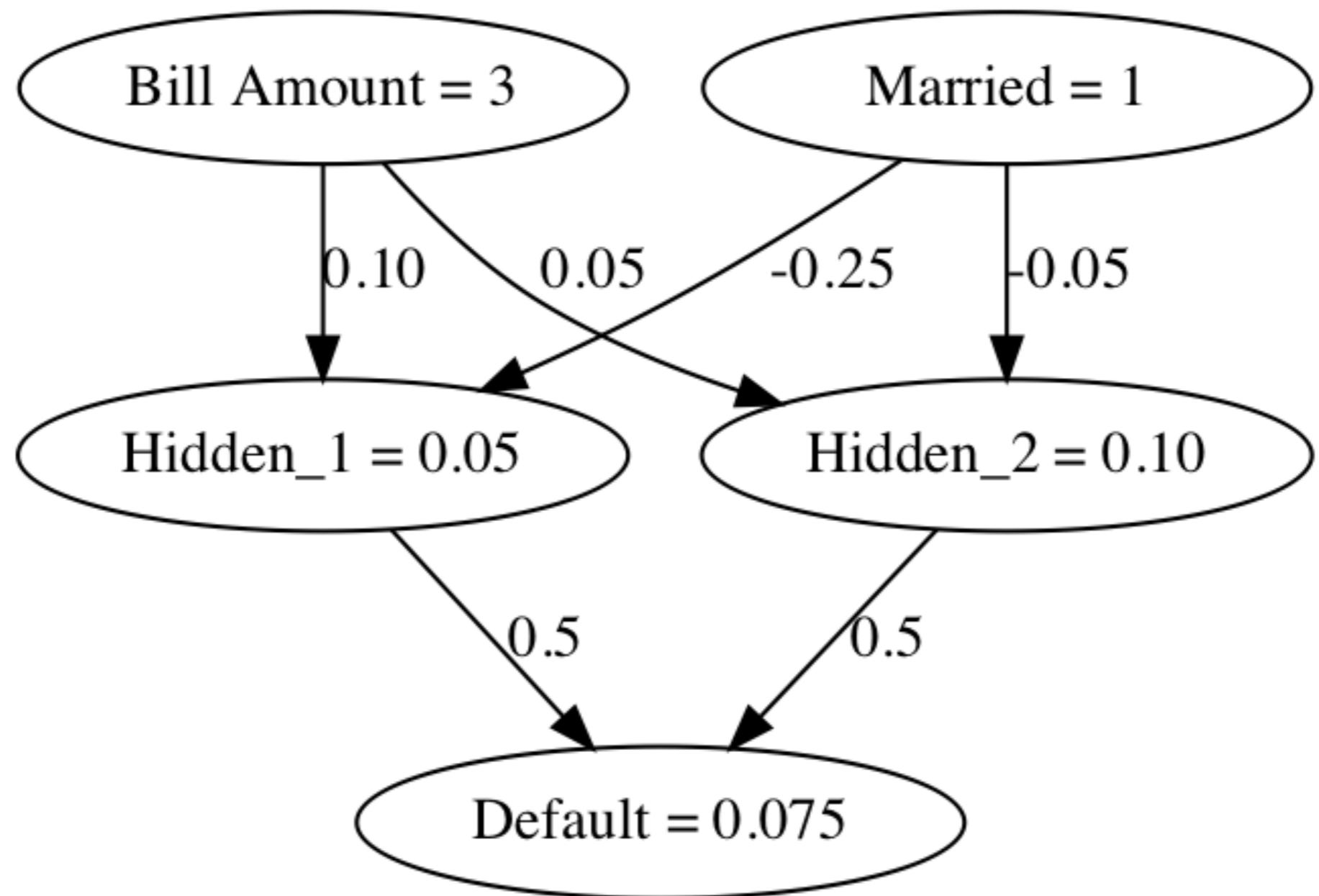
Isaiah Hull

Economist

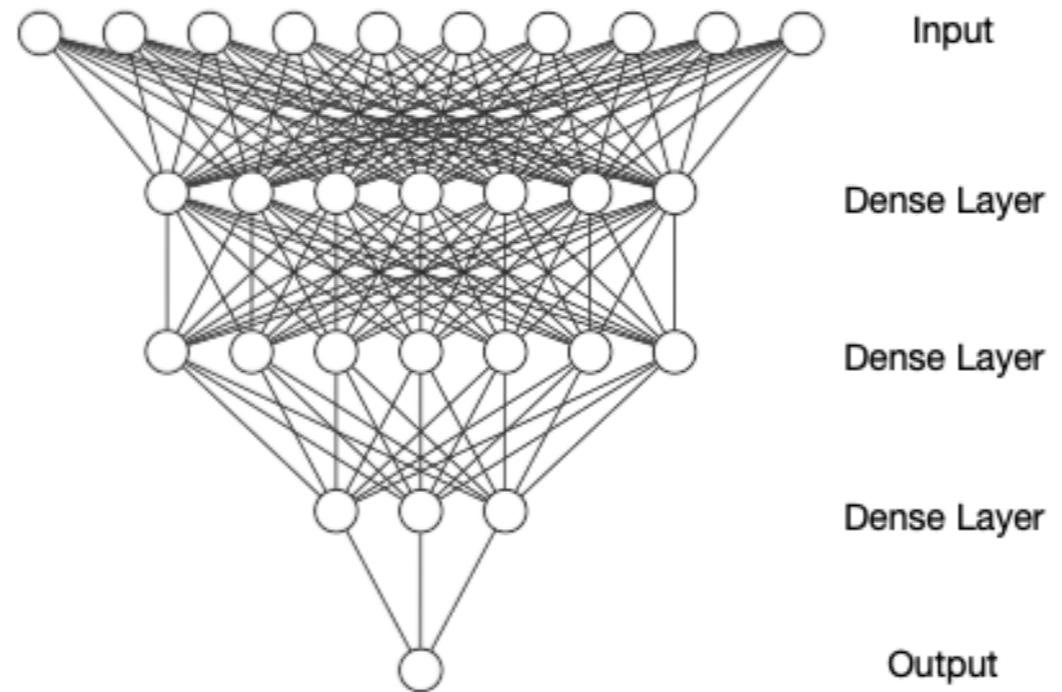
# The linear regression model



# What is a neural network?



# What is a neural network?



- A dense layer applies weights to all nodes from the previous layer.

# A simple dense layer

```
import tensorflow as tf
```

```
# Define inputs (features)
inputs = tf.constant([[1, 35]])
```

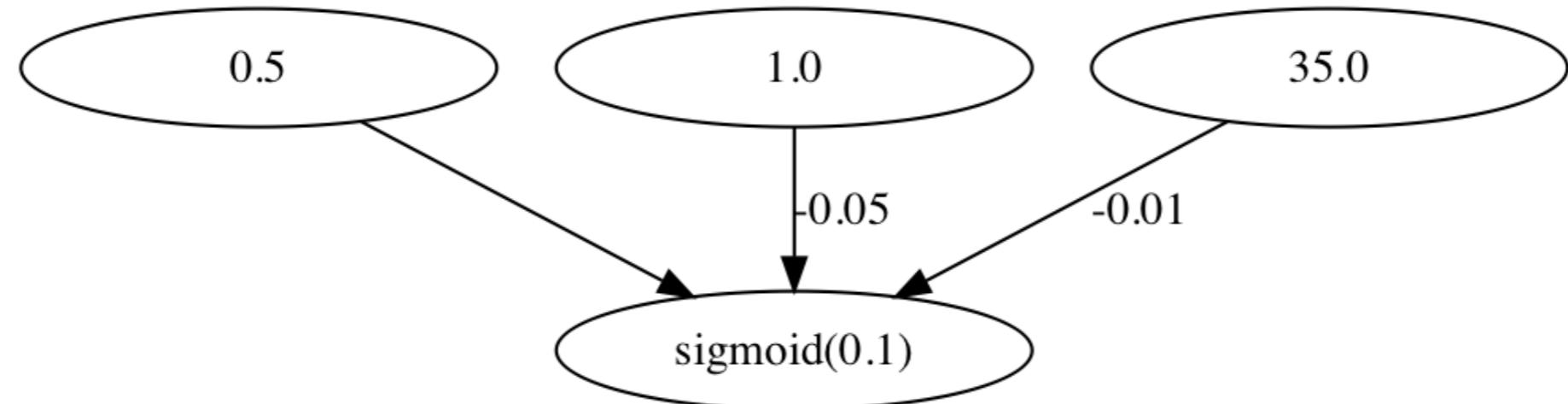
```
# Define weights
weights = tf.Variable([[-0.05], [-0.01]])
```

```
# Define the bias
bias = tf.Variable([0.5])
```

# A simple dense layer

```
# Multiply inputs (features) by the weights  
product = tf.matmul(inputs, weights)
```

```
# Define dense layer  
dense = tf.keras.activations.sigmoid(product+bias)
```



# Defining a complete model

```
import tensorflow as tf
```

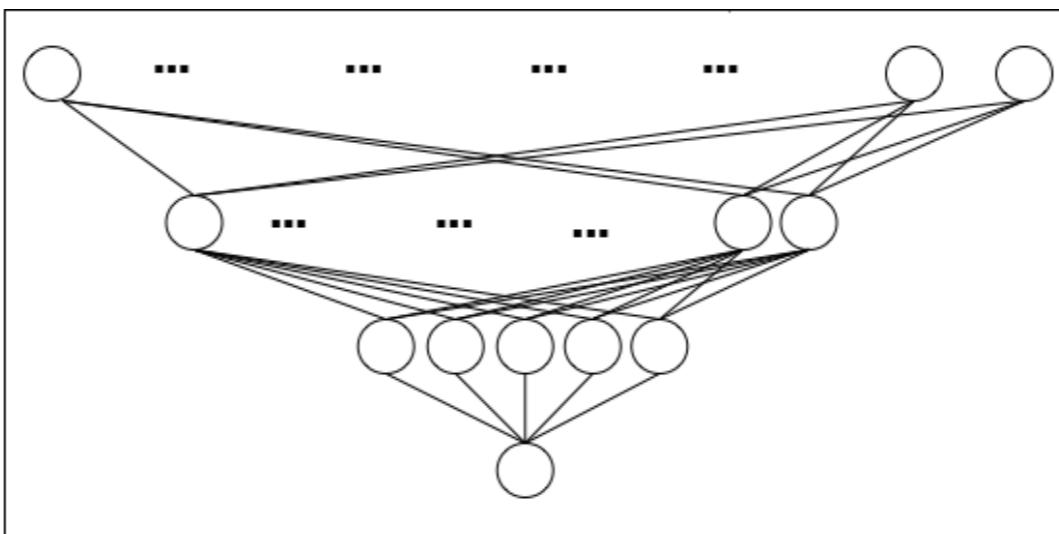
```
# Define input (features) layer  
inputs = tf.constant(data, tf.float32)
```

```
# Define first dense layer  
dense1 = tf.keras.layers.Dense(10, activation='sigmoid')(inputs)
```

# Defining a complete model

```
# Define second dense layer  
dense2 = tf.keras.layers.Dense(5, activation='sigmoid')(dense1)
```

```
# Define output (predictions) layer  
outputs = tf.keras.layers.Dense(1, activation='sigmoid')(dense2)
```



# High-level versus low-level approach

- **High-level approach**
  - High-level API operations
- **Low-level approach**
  - Linear-algebraic operations

```
dense = keras.layers.Dense(10,\nactivation='sigmoid')
```

```
prod = matmul(inputs, weights)\ndense = keras.activations.sigmoid(prod)
```

# Let's practice!

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# Activation functions

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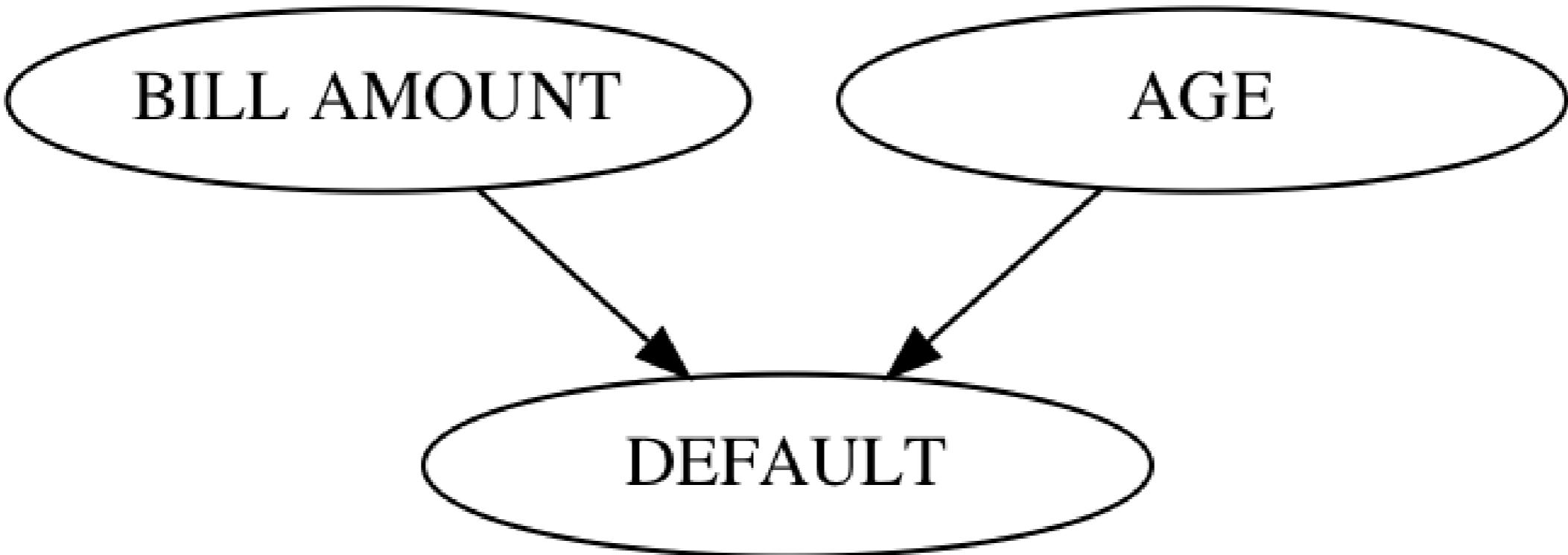
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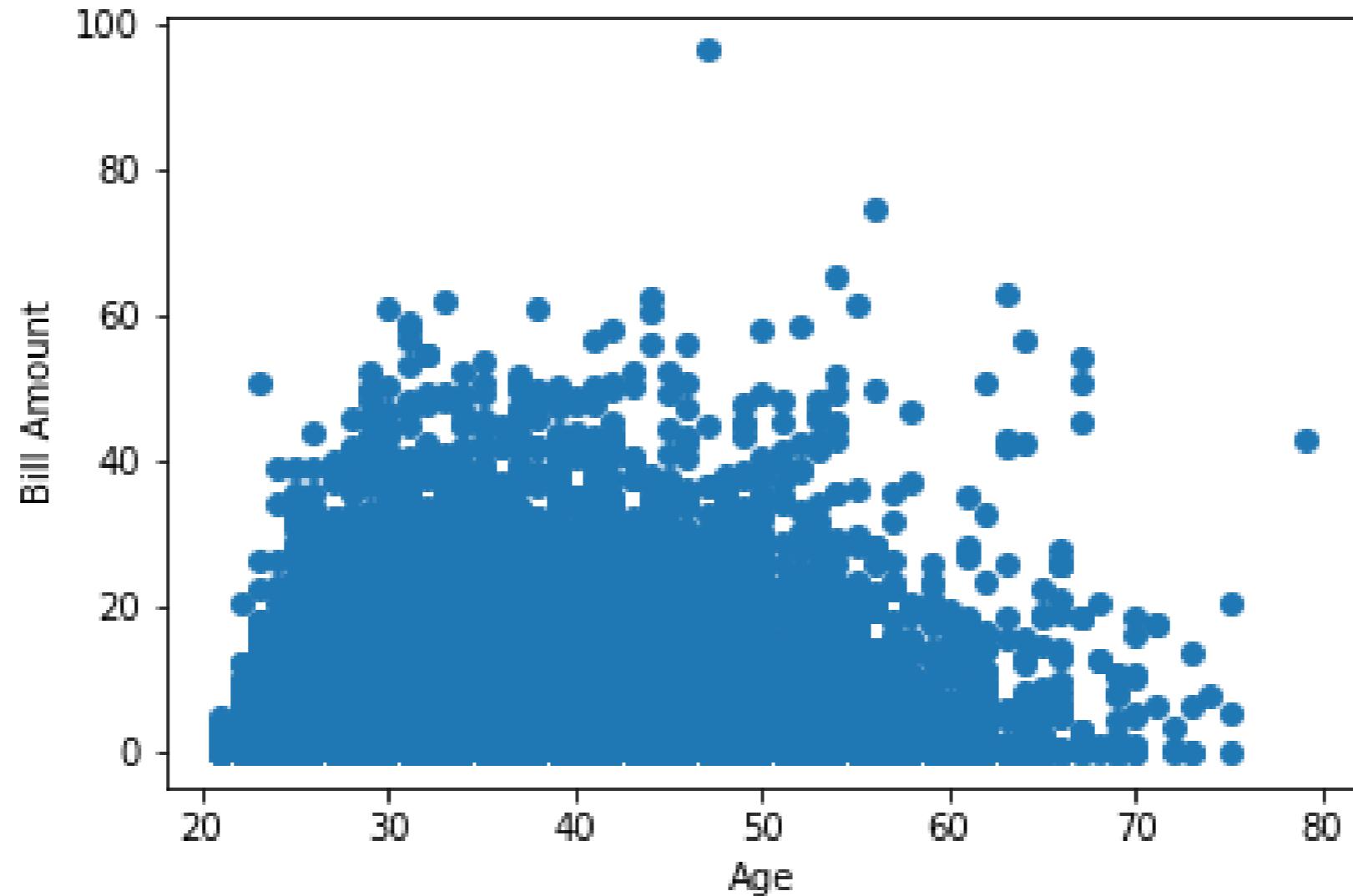
# What is an activation function?

- Components of a typical hidden layer
  - Linear: Matrix multiplication
  - Nonlinear: Activation function

# Why nonlinearities are important



# Why nonlinearities are important



# A simple example

```
import numpy as np
import tensorflow as tf

# Define example borrower features
young, old = 0.3, 0.6
low_bill, high_bill = 0.1, 0.5
```

```
# Apply matrix multiplication step for all feature combinations
young_high = 1.0*young + 2.0*high_bill
young_low = 1.0*young + 2.0*low_bill
old_high = 1.0*old + 2.0*high_bill
old_low = 1.0*old + 2.0*low_bill
```

# A simple example

```
# Difference in default predictions for young  
print(young_high - young_low)
```

```
# Difference in default predictions for old  
print(old_high - old_low)
```

```
0.8
```

```
0.8
```

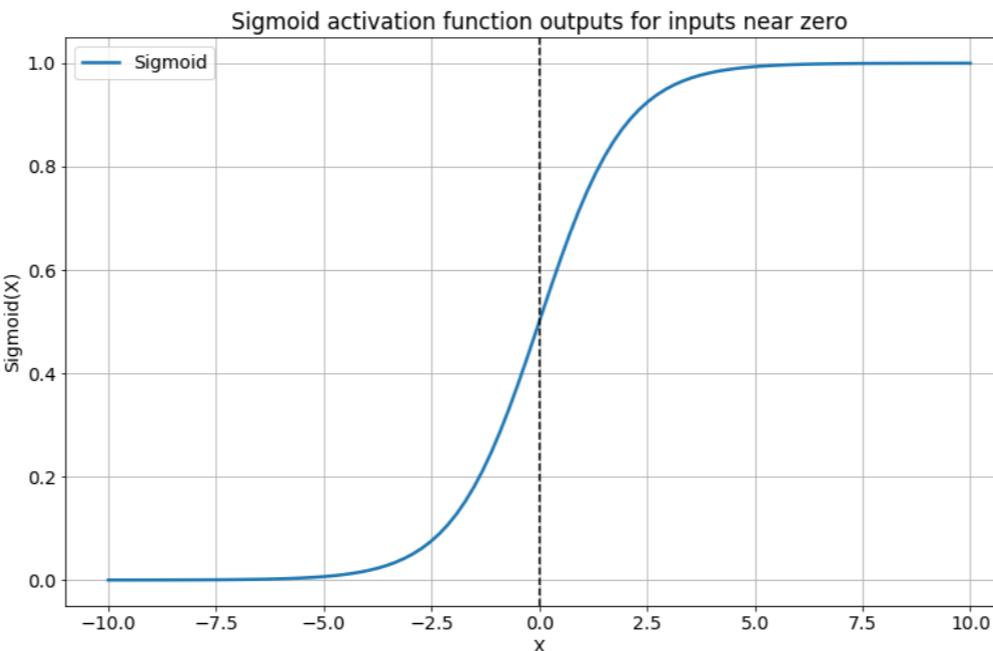
# A simple example

```
# Difference in default predictions for young  
print(tf.keras.activations.sigmoid(young_high).numpy() -  
tf.keras.activations.sigmoid(young_low).numpy())  
  
# Difference in default predictions for old  
print(tf.keras.activations.sigmoid(old_high).numpy() -  
tf.keras.activations.sigmoid(old_low).numpy())
```

```
0.16337568  
0.14204389
```

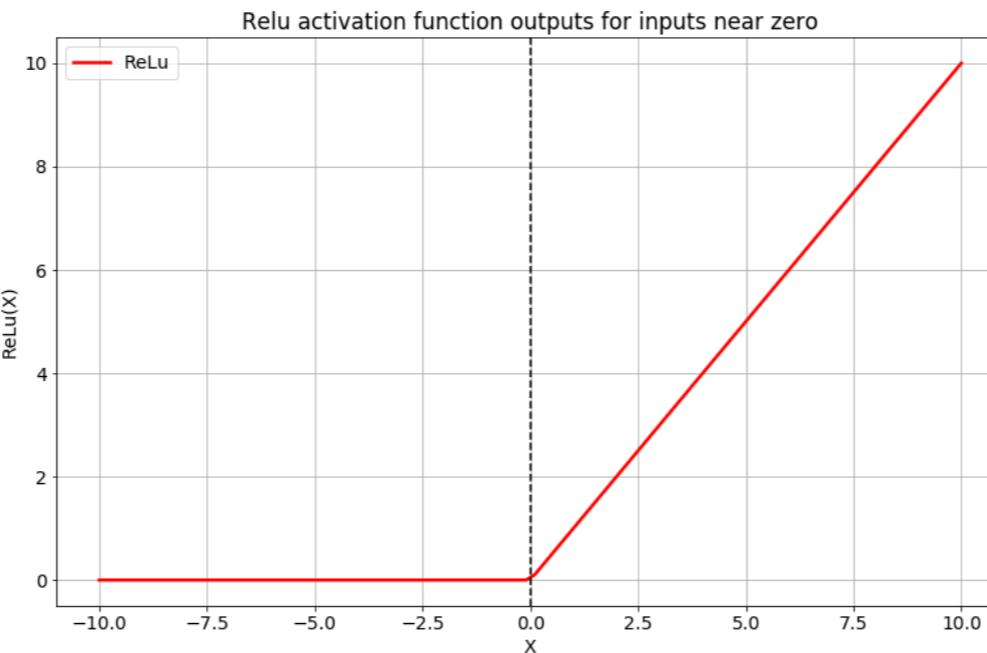
# The sigmoid activation function

- Sigmoid activation function
  - Binary classification
  - Low-level: `tf.keras.activations.sigmoid()`
  - High-level: `sigmoid`



# The relu activation function

- ReLu activation function
  - Hidden layers
  - Low-level: `tf.keras.activations.relu()`
  - High-level: `relu`



# The softmax activation function

- Softmax activation function
  - Output layer (>2 classes)
  - Low-level: `tf.keras.activations.softmax()`
  - High-level: `softmax`

# Activation functions in neural networks

```
import tensorflow as tf
```

```
# Define input layer  
inputs = tf.constant(borrower_features, tf.float32)
```

```
# Define dense layer 1  
dense1 = tf.keras.layers.Dense(16, activation='relu')(inputs)
```

```
# Define dense layer 2  
dense2 = tf.keras.layers.Dense(8, activation='sigmoid')(dense1)
```

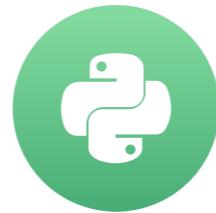
```
# Define output layer  
outputs = tf.keras.layers.Dense(4, activation='softmax')(dense2)
```

# Let's practice!

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# Optimizers

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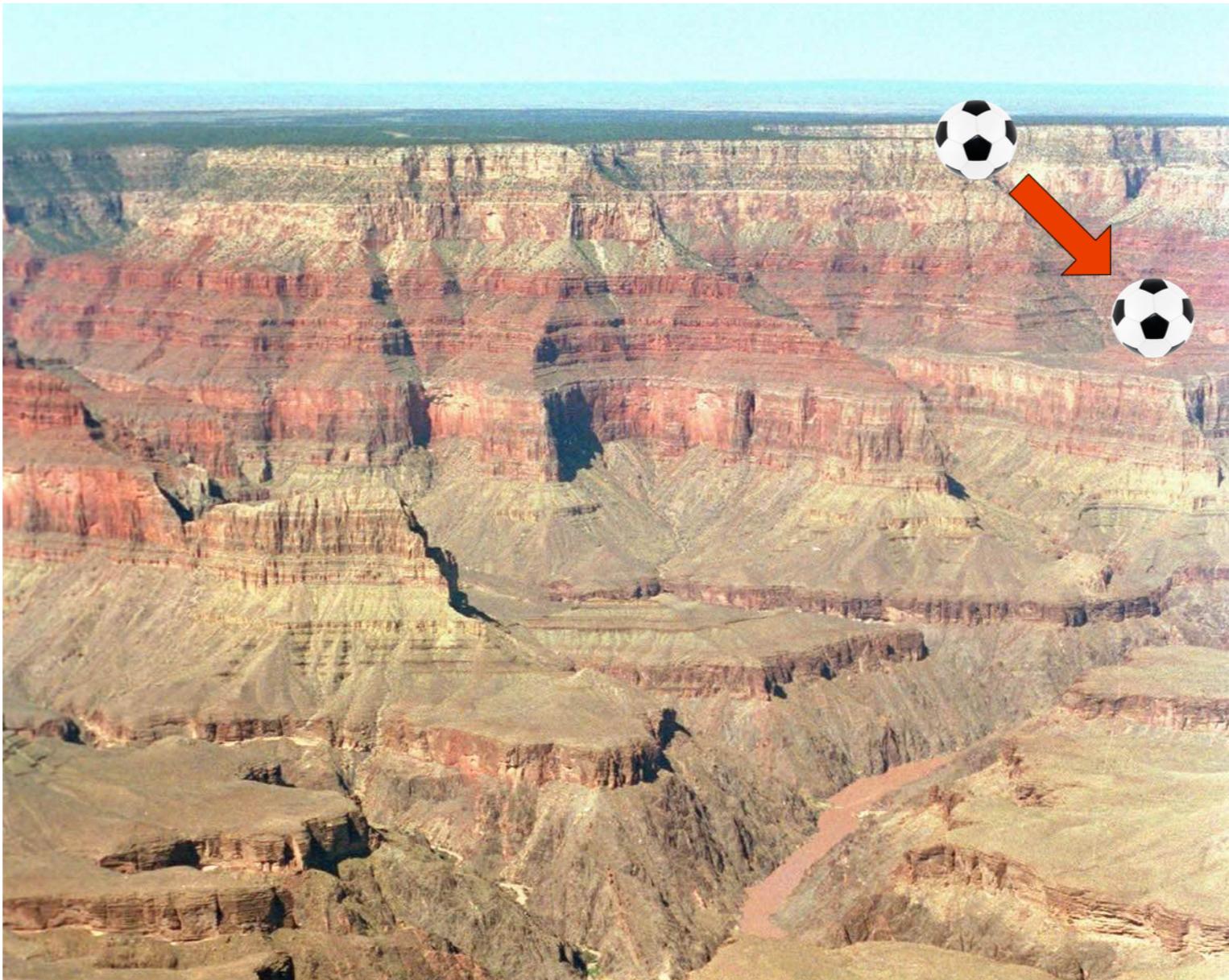
Isaiah Hull  
Economist

# How to find a minimum



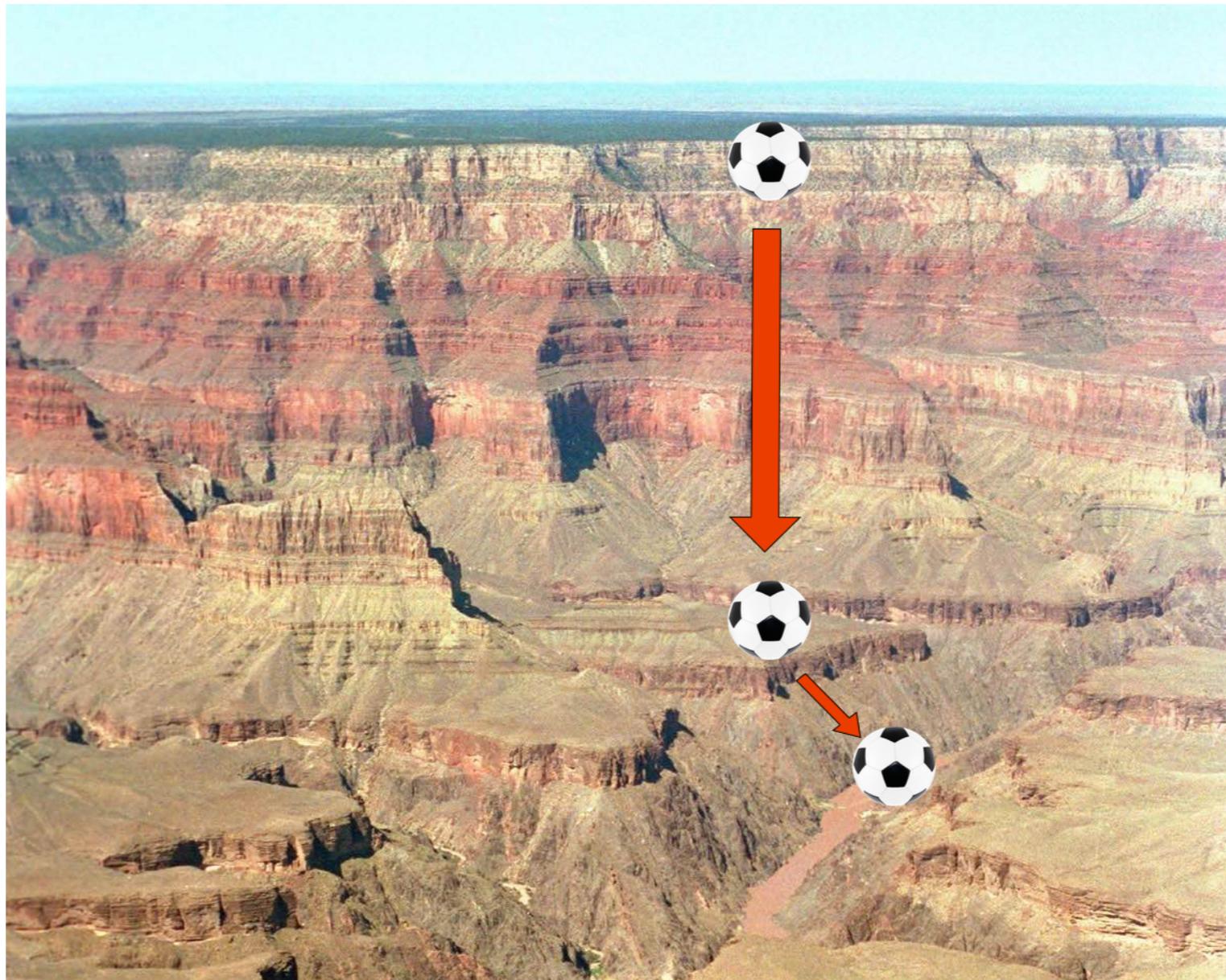
<sup>1</sup> Source: U.S. National Park Service

# How to find a minimum



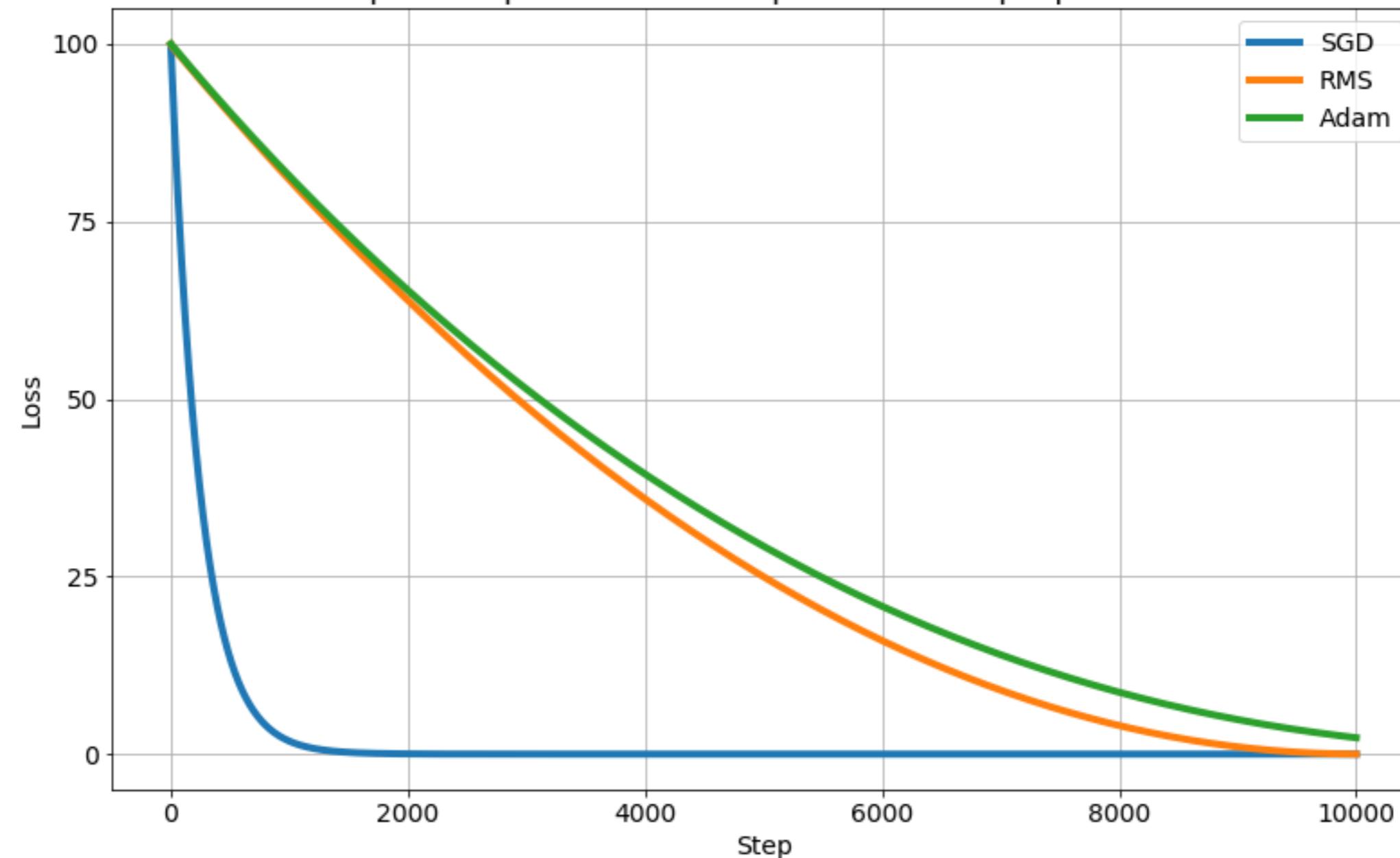
<sup>1</sup> Source: U.S. National Park Service

# How to find a minimum



<sup>1</sup> Source: U.S. National Park Service

### Optimizer performance comparison for simple problem



# The gradient descent optimizer

- Stochastic gradient descent (SGD) optimizer
  - `tf.keras.optimizers.SGD()`
  - `learning_rate`
- Simple and easy to interpret

# The RMS prop optimizer

- Root mean squared (RMS) propagation optimizer
  - Applies different learning rates to each feature
  - `tf.keras.optimizers.RMSprop()`
  - `learning_rate`
  - `momentum`
  - `decay`
- Allows for momentum to both build and decay

# The adam optimizer

- Adaptive moment (adam) optimizer
  - `tf.keras.optimizers.Adam()`
  - `learning_rate`
  - `beta1`
- Performs well with default parameter values

# A complete example

```
import tensorflow as tf

# Define the model function
def model(bias, weights, features = borrower_features):
    product = tf.matmul(features, weights)
    return tf.keras.activations.sigmoid(product+bias)
```

```
# Compute the predicted values and loss
def loss_function(bias, weights, targets = default, features = borrower_features):
    predictions = model(bias, weights)
    return tf.keras.losses.binary_crossentropy(targets, predictions)
```

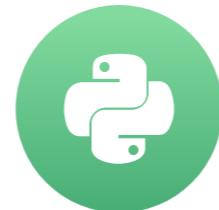
```
# Minimize the loss function with RMS propagation
opt = tf.keras.optimizers.RMSprop(learning_rate=0.01, momentum=0.9)
opt.minimize(lambda: loss_function(bias, weights), var_list=[bias, weights])
```

# Let's practice!

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# Training a network in TensorFlow

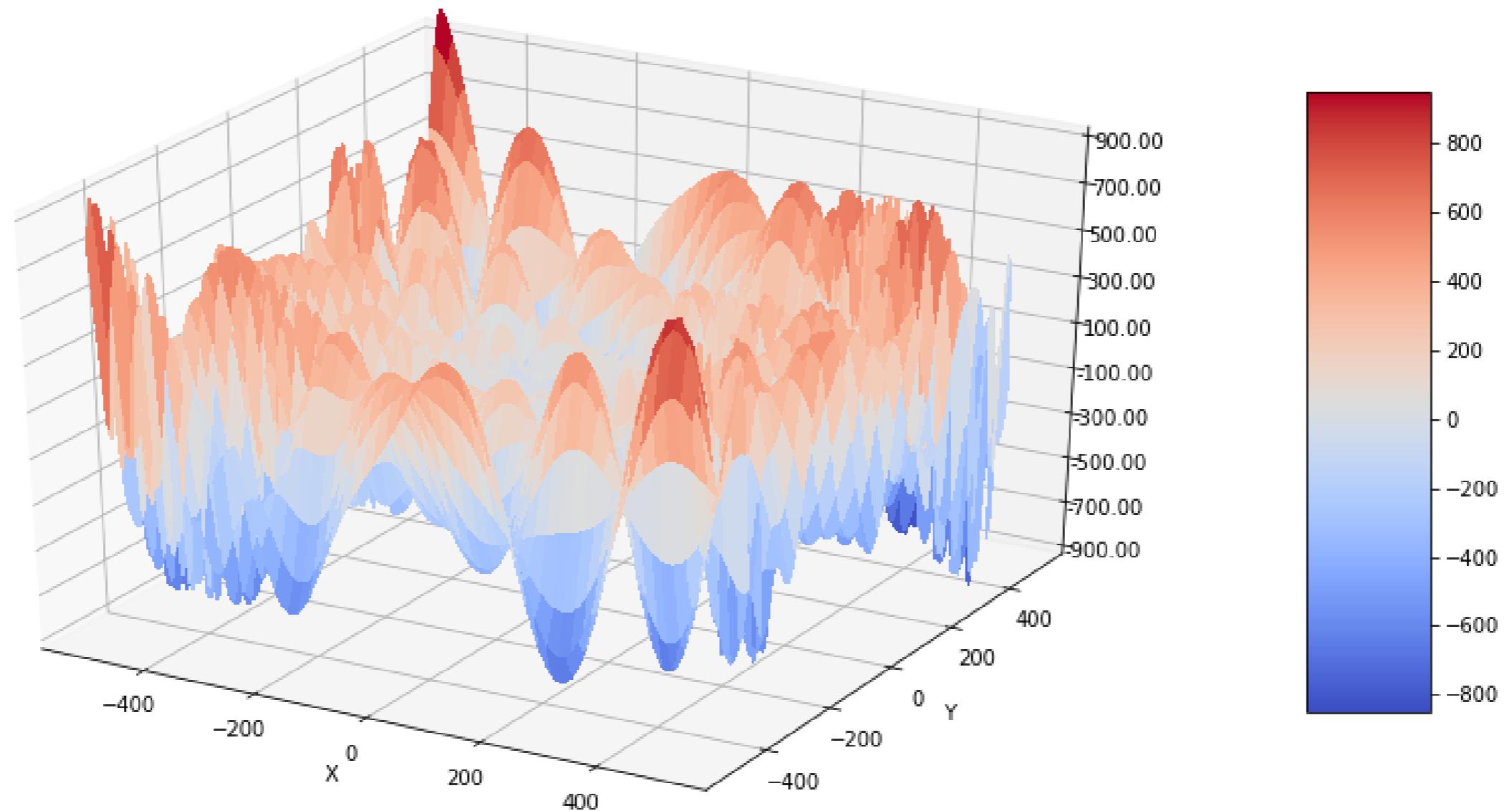
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Isaiah Hull

Economist

## The Eggholder Function



# Random initializers

- Often need to initialize thousands of variables
  - `tf.ones()` may perform poorly
  - Tedious and difficult to initialize variables individually
- Alternatively, draw initial values from distribution
  - Normal
  - Uniform
  - Glorot initializer

# Initializing variables in TensorFlow

```
import tensorflow as tf

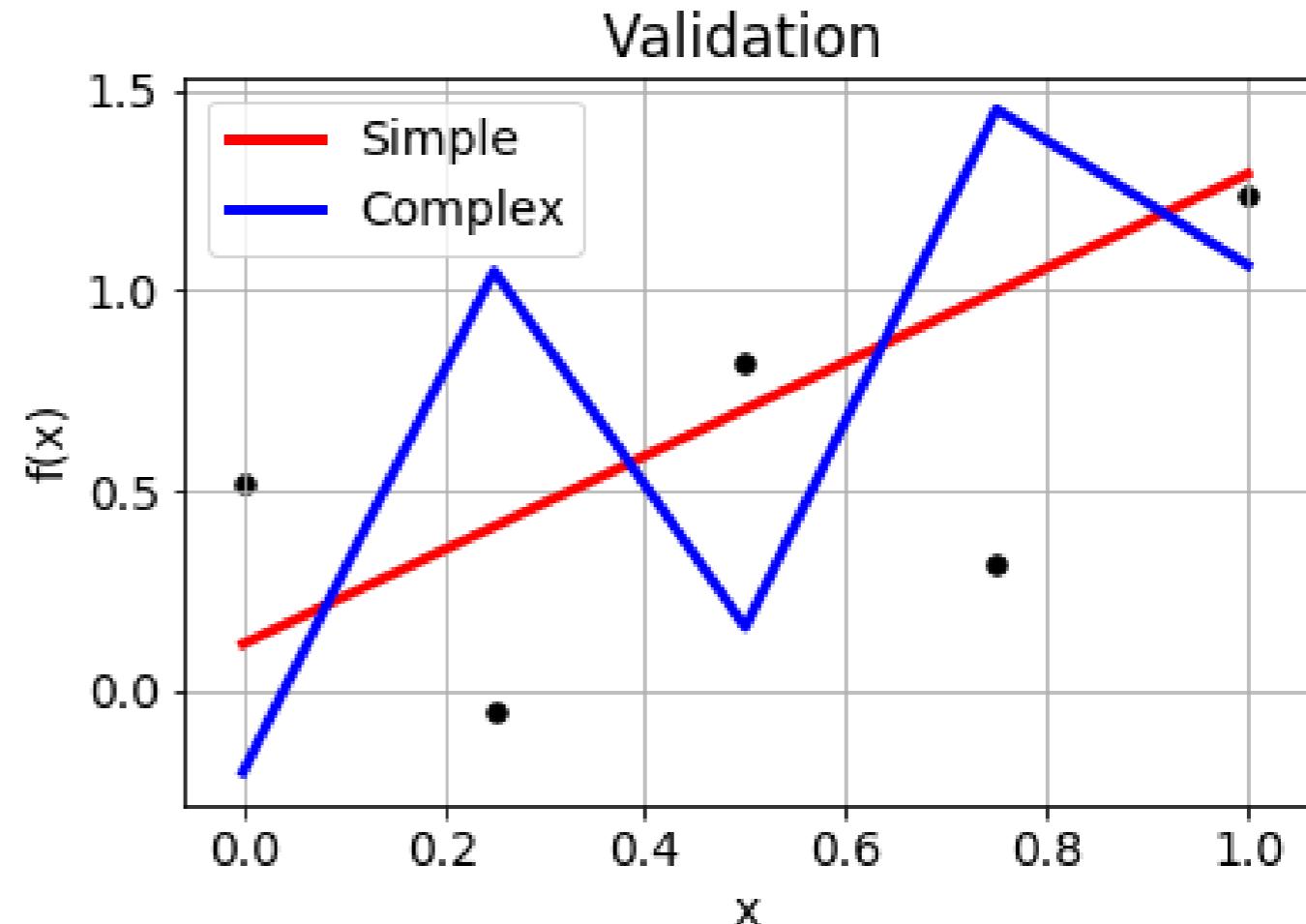
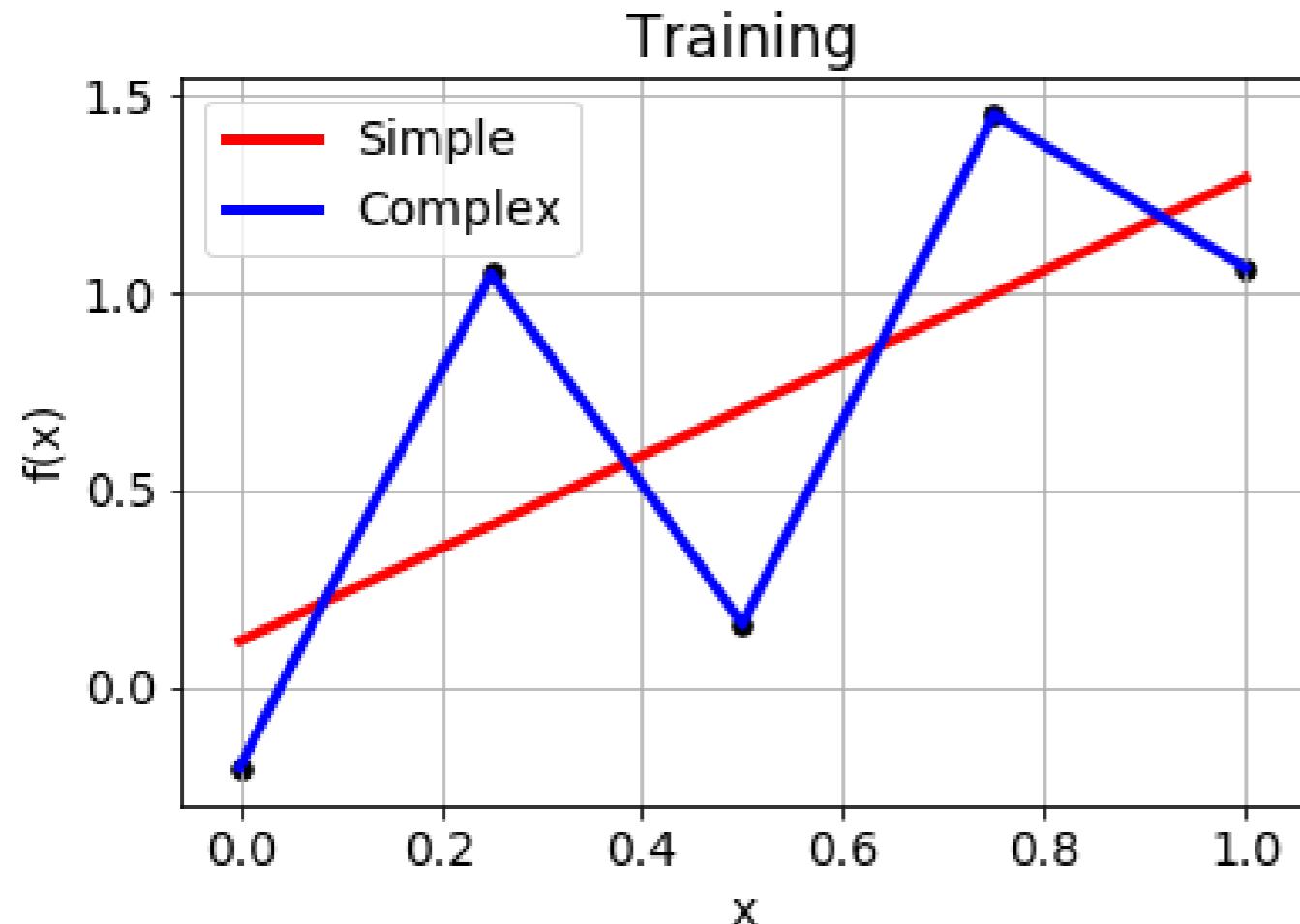
# Define 500x500 random normal variable
weights = tf.Variable(tf.random.normal([500, 500]))

# Define 500x500 truncated random normal variable
weights = tf.Variable(tf.random.truncated_normal([500, 500]))
```

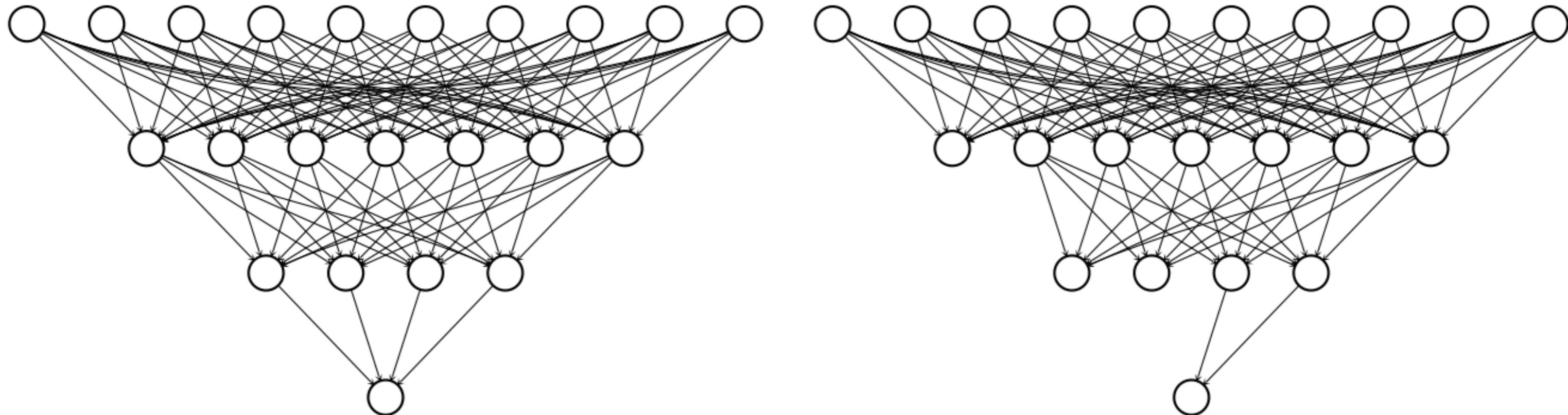
# Initializing variables in TensorFlow

```
# Define a dense layer with the default initializer  
dense = tf.keras.layers.Dense(32, activation='relu')  
  
# Define a dense layer with the zeros initializer  
dense = tf.keras.layers.Dense(32, activation='relu', \  
    kernel_initializer='zeros')
```

# Neural networks and overfitting



# Applying dropout



# Implementing dropout in a network

```
import numpy as np  
import tensorflow as tf  
  
# Define input data  
inputs = np.array(borrower_features, np.float32)
```

```
# Define dense layer 1  
dense1 = tf.keras.layers.Dense(32, activation='relu')(inputs)
```

# Implementing dropout in a network

```
# Define dense layer 2  
dense2 = tf.keras.layers.Dense(16, activation='relu')(dense1)
```

```
# Apply dropout operation  
dropout1 = tf.keras.layers.Dropout(0.25)(dense2)
```

```
# Define output layer  
outputs = tf.keras.layers.Dense(1, activation='sigmoid')(dropout1)
```

# Let's practice!

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