Introduction to Deep Learning with TensorFlow

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Section 1

Deep learning

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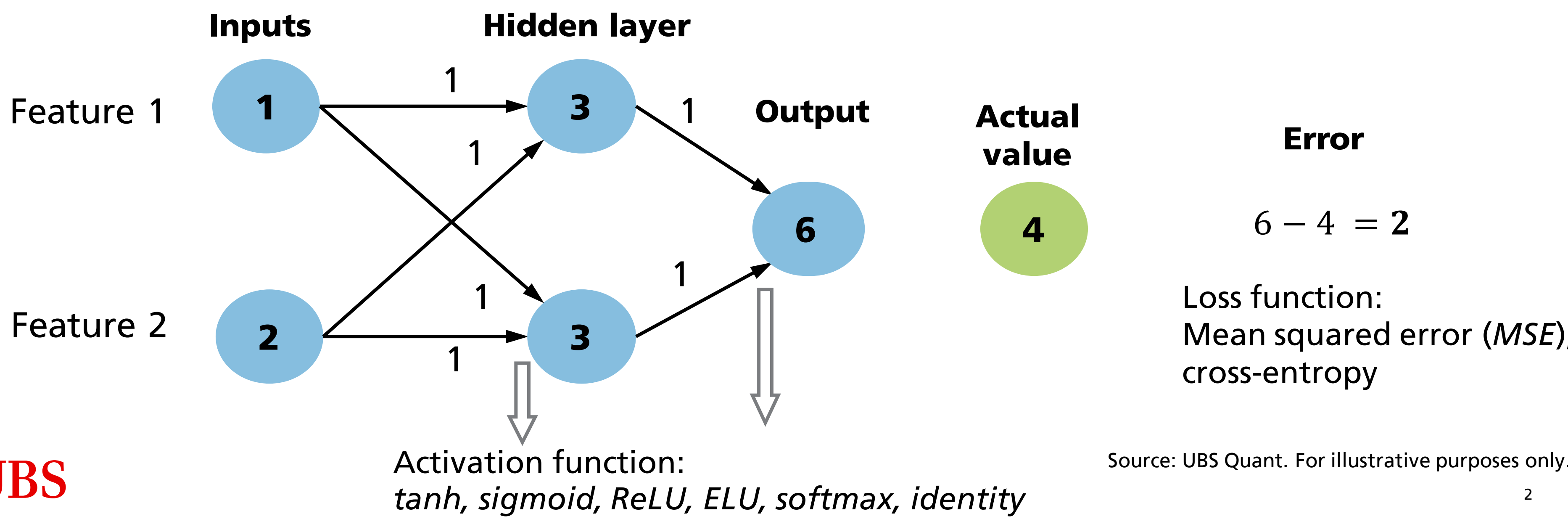
Overview

- Expert call [Introduction to Deep Learning]
- Class of machine learning algorithms
  - Use multiple hierarchical layers for feature extraction and transformation
  - Model complex, highly non-linear relationships between inputs and outputs
  - Learn "automatically" from data
- Fitting neural networks:
  - Forward propagation: make predictions given some weights
  - Back-propagation: optimise weights (gradient descent + chain rule)



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When does deep learning make sense?

- Focus is on **prediction**
- Establishing causality is not important
  - Can't map decisions back to individual features (unlike e.g. random forest)
- You have "a lot of data"
  - 100K+ samples, according to sklearn's guide to algorithms
- Unstructured data
  - Clear advantage over machine learning algorithms
- In general, the model you are fitting shouldn't be more complex than the data

Section 2

TensorFlow

What is TensorFlow?

- Open-source library for deep learning
- Operates on a **graph** representation of the underlying computational task
  - Specify mathematical operations as elements in a graph of data, variables and operations

- When should you use TensorFlow?
  - **High performance** – train across distributed GPUs
  - **Customisability** – non-standard network architectures
  - **A lot of Data**

- Basic objects
  - Constants, Placeholders, Variables
  - Layers
  - Optimisers and loss functions

⟹ **Introduce each of them with examples**

Deterministic Graphs

- **Placeholders**
  - Not specific values
  - Allows to create operations and computation graphs **without** the underlying data
- **Constants**
  - Things that don't change

```
import tensorflow as tf

x = tf.placeholder(dtype = tf.float32, shape = [None, 2], name = "x")
factor = tf.constant(7., name = "factor")

output = x * factor
print(output)
```

Not "standard" multiplication (calls `tf.multiply`*)*

```
Tensor("mul:0", shape=(?, 2), dtype=float32)
```

Output tensor has to be evaluated!

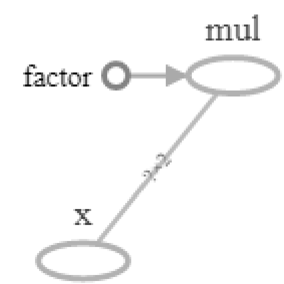
```
x_values = [[1, 2], [2, 3], [3, 4], [5, 6]]

with tf.Session() as sess:
    print(output.eval(feed_dict = {x: x_values}))
```

Pass values to ***all*** *placeholders in a dictionary*

```
[[  7.  14.]
 [ 14.  21.]
 [ 21.  28.]
 [ 35.  42.]]
```

Computation graph



Source: UBS Quant, generated with TensorBoard.

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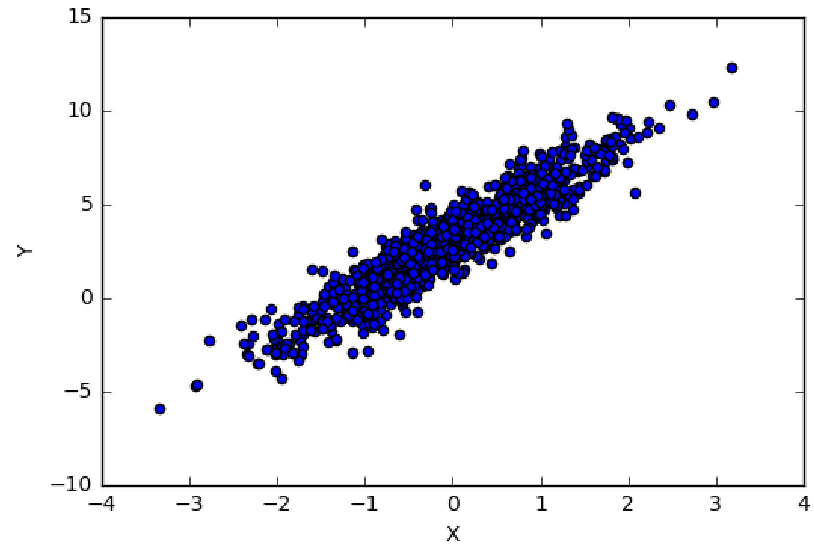
Linear regression with TensorFlow (1)

- Simple linear regression: $Y = \alpha + \beta X + \epsilon$
- True model: $Y = 3.14 + 2.72 \cdot X + N(0,1)$
  - Need to learn: $\alpha = 3.14$ and $\beta = 2.72$
- **Variables**
  - Usually parameters to optimise
  - In our case these are α and β




```
import tensorflow as tf

# Placeholders for X and Y (true)
x = tf.placeholder(dtype = tf.float32, shape = [None, 1], name = "x")
y_true = tf.placeholder(dtype = tf.float32, shape = [None, 1], name = "y_true")

# define two variables: a (intercept) and b (slope)
a = tf.Variable(initial_value = 1, name = "alpha", dtype = tf.float32)
b = tf.Variable(initial_value = 1, name = "beta", dtype = tf.float32)

# and define an initialiser
init = tf.global_variables_initializer()

# Specify the linear model
y = a + b * x
```

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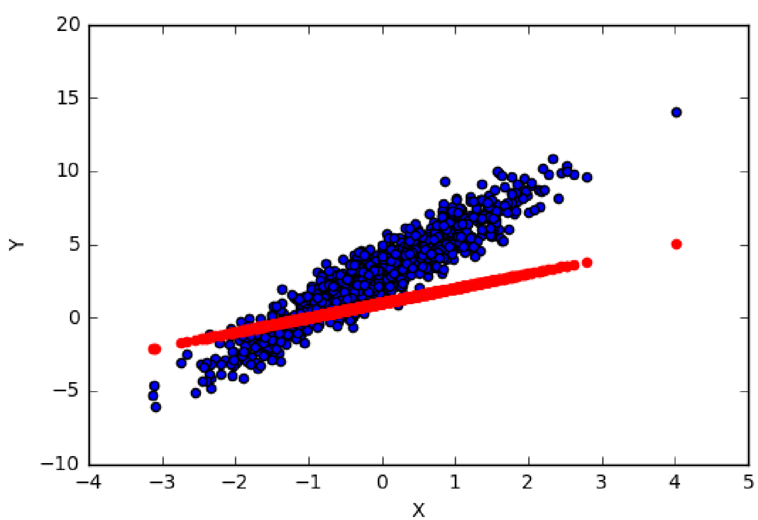
Linear regression with TensorFlow (2)

- We can evaluate the model with the initial values for of the parameters ($\alpha = 1,\ \beta = 1$)

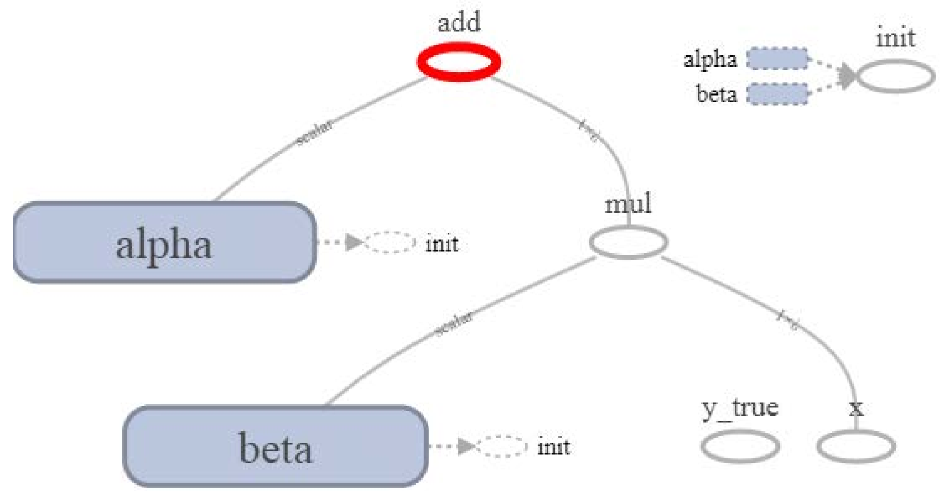
```
# Get some samples
batch_x, batch_y = get_training_samples()

with tf.Session() as sess:
    init.run() #  initialise a and b
    test_x = batch_x
    test_y = y.eval(feed_dict = {x: test_x})
```



Source: UBS Quant. For illustrative purposes only.
The true model is $Y = 3.14 + 2.72 \cdot X + N(0{,}1)$. Points in red are the fitted values with the initial values for the parameters ($\alpha = 1$ and $\beta = 1$)

Computation graph



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- Improving the model fit
  - **Loss function**
  - **Optimisation**

Linear regression with TensorFlow (3)

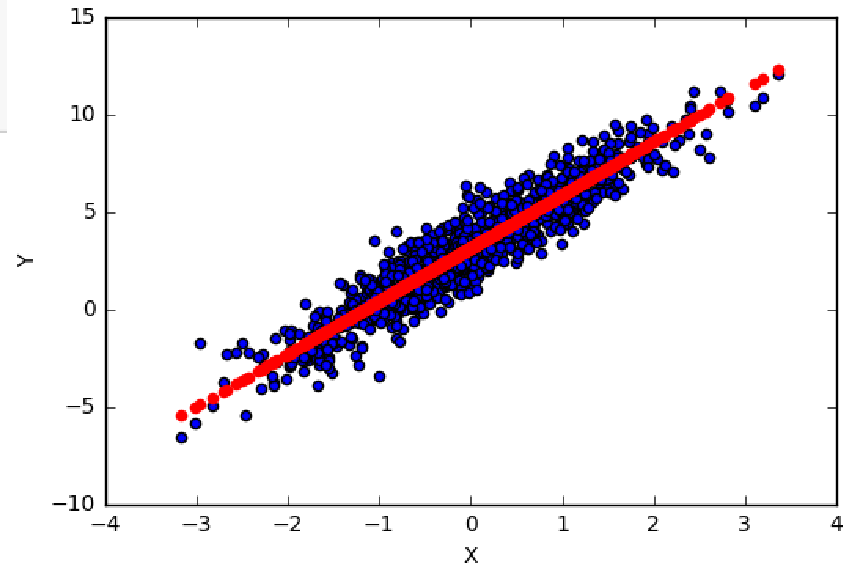
- **Loss**
  - Mean squared error (*MSE*) is appropriate for regression problems
  - Cross-entropy for classification
- **Optimiser**
  - Simple problem – generic gradient descent is fine
  - Deep networks – use an adaptive method (e.g. *Adam*, *Adagrad*)

```
# Loss function
loss = tf.losses.mean_squared_error(y, y_true)
# Optimiser
opti = tf.train.GradientDescentOptimizer(
    learning_rate = 0.01).minimize(loss = loss)
```

- Let's optimise:

```
with tf.Session() as sess:
    init.run()
    for i in range(1000):
        # generate samples
        batch_x, batch_y = get_training_samples()
        # calculate loss:
        opti.run(feed_dict = {x: batch_x, y_true: batch_y})
    print("{} {}".format(a.eval(), b.eval()))
```

```
3.141397714614868 2.716977119445801
```



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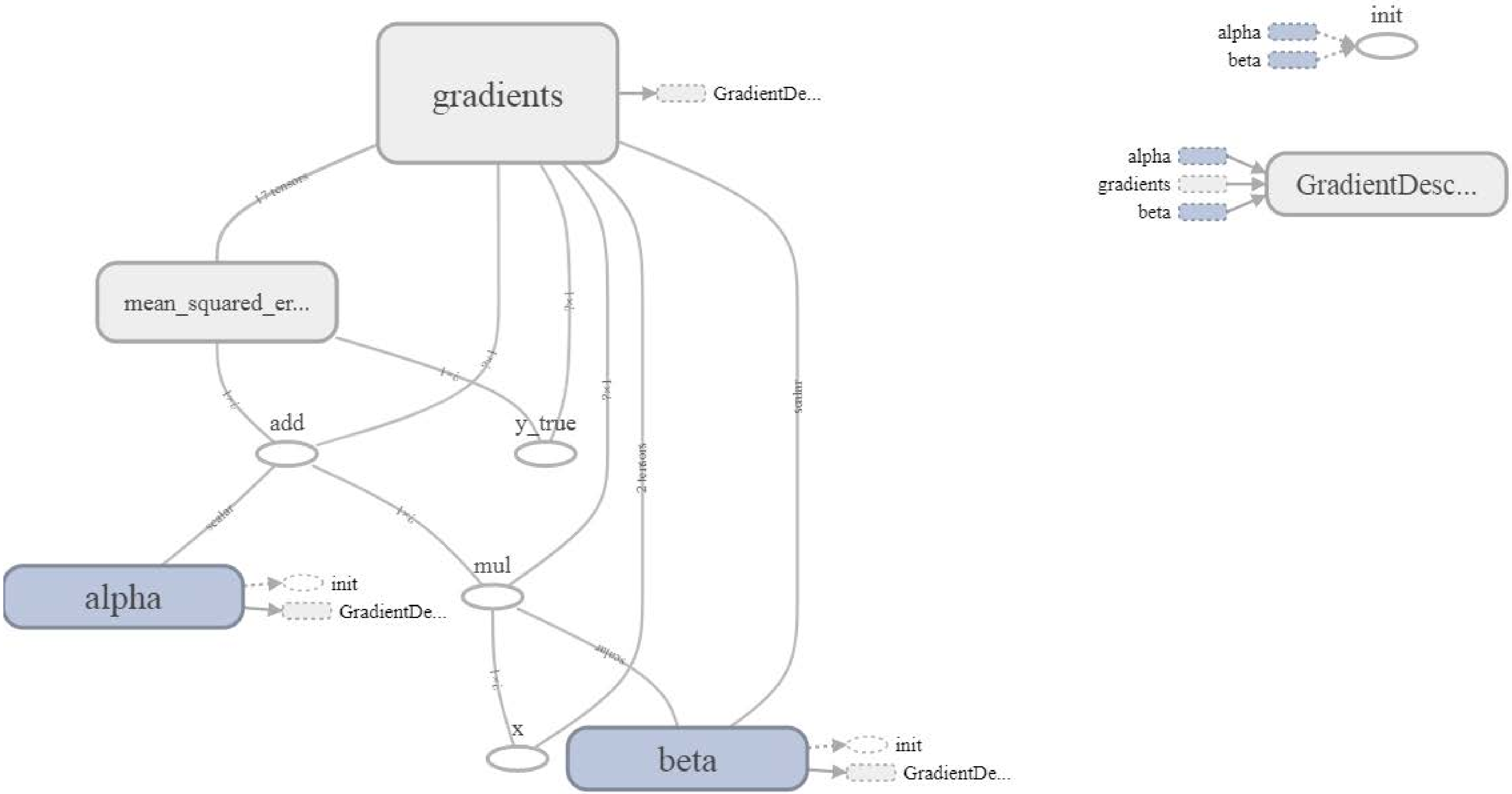
Computation graph of the linear model



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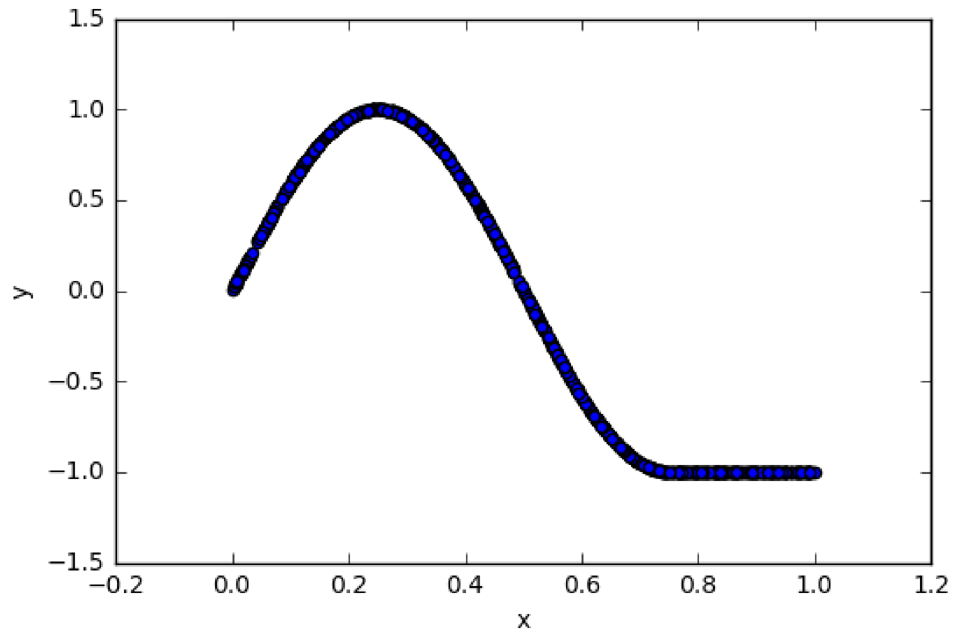
Neural networks

- Non-linear function we'd like to learn:

$$Y(x) = \begin{cases} \sin(2\pi x) & \text{for } 0 \leq x \leq 0.75 \\ -1 & \text{for } x > 0.75 \end{cases}$$



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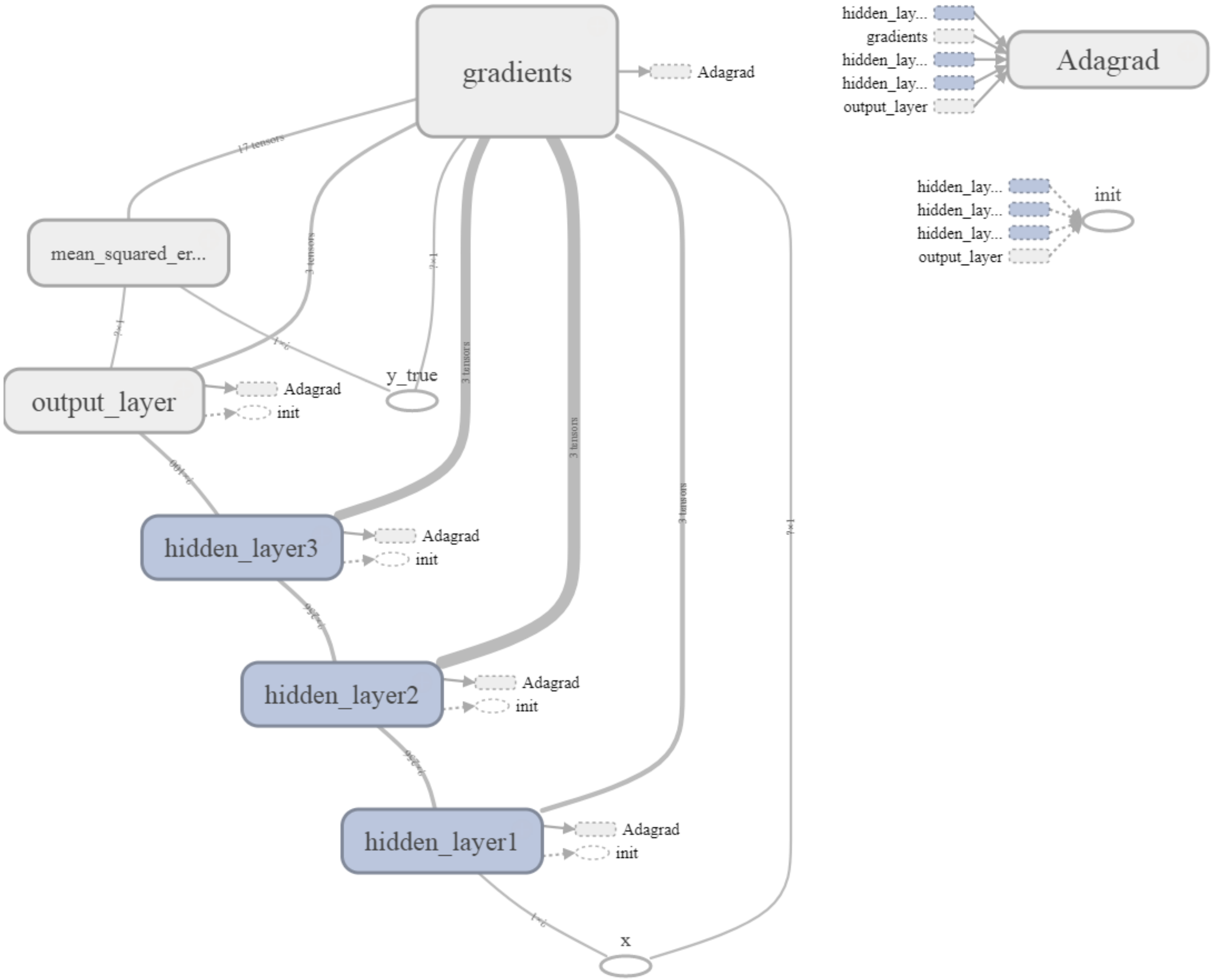
Neural networks with TensorFlow

```python
import numpy as np
import tensorflow as tf
import scipy as sp
import matplotlib.pyplot as plt

def get_training_samples(n = 1000):
    x = sp.rand(n, 1) #  random uniforms
    y = np.sin(x * 2 * np.pi)
    y[x > 0.75] = -1
    return(x, y)

## Neural Network Setup
x = tf.placeholder(tf.float32, shape = [None, 1], name = "x")
y_true = tf.placeholder(tf.float32, shape = [None, 1])
# Hidden layers
hl_1 = tf.layers.dense(inputs = x, units = 256, activation = tf.nn.relu)
hl_2 = tf.layers.dense(inputs = hl_1, units = 128, activation = tf.nn.relu)
hl_3 = tf.layers.dense(inputs = hl_2, units = 64, activation = tf.nn.relu)
# Output layer
y_pred = tf.layers.dense(inputs = hl_3, units = 1, activation = tf.nn.tanh)

loss = tf.losses.mean_squared_error(y_true, y_pred)
opti = tf.train.AdagradOptimizer(learning_rate = 0.01).minimize(loss)
init = tf.global_variables_initializer()

## Run the model
with tf.Session() as sess:
    init.run()
    for i in range(15000):
        batch_x, batch_y = get_training_samples(250)
        opti.run(feed_dict = {y_true: batch_y, x: batch_x})
    # Plot
    plt.scatter(batch_x, y_pred.eval({x: batch_x}))
    plt.show()
```

Source: UBS Quant.

Computation graph of feed-forward NN



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Section 3

Example: Portfolio returns

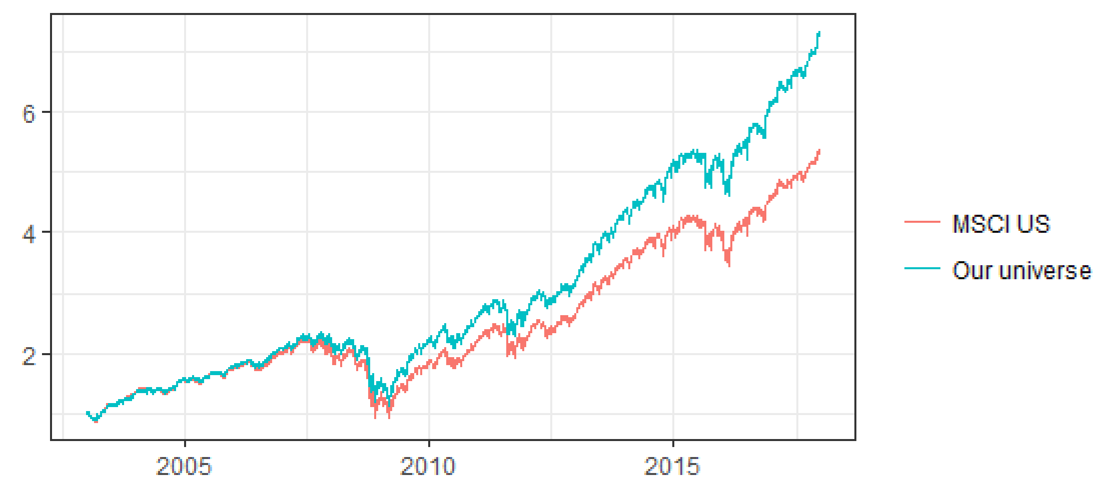
Setup (1)

- Example from [Introduction to Deep Learning]
  - n stocks, equally weighted in portfolio

$$r_p(t) = \sum_{i=1}^{n} \frac{1}{n} r_i(t)$$

  - Learn the relationship between all previous stock returns and directional change in the portfolio return
  - Observed data: historical daily returns, $\{X_t\}_{t=1}^{T}$, $X_t = r_1(t), \ldots r_n(t)$
  - The universe is MSCI US, restricted to those companies that have price data throughout the period from January 2003 through Nov 2017 (look-ahead + survival bias)

Cumulative return



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Setup (2)

- Inputs: daily returns of 215 stocks
- Target:

$$Y_t = \begin{cases} 1, & r_p(t+1) > \epsilon \\ 0, & |r_p(t+1)| < \epsilon \\ -1, & r_p(t+1) < -\epsilon \end{cases}$$

  – ϵ is determined from the training data to avoid class imbalance

- Standardise the inputs (based on the training data)
- One-hot encode the target
  – Example:

$$Y_t = \{0,\ 1,\ 1, -1\} \quad \Longrightarrow \quad \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

- Training over 3500 data points, forecast one step ahead

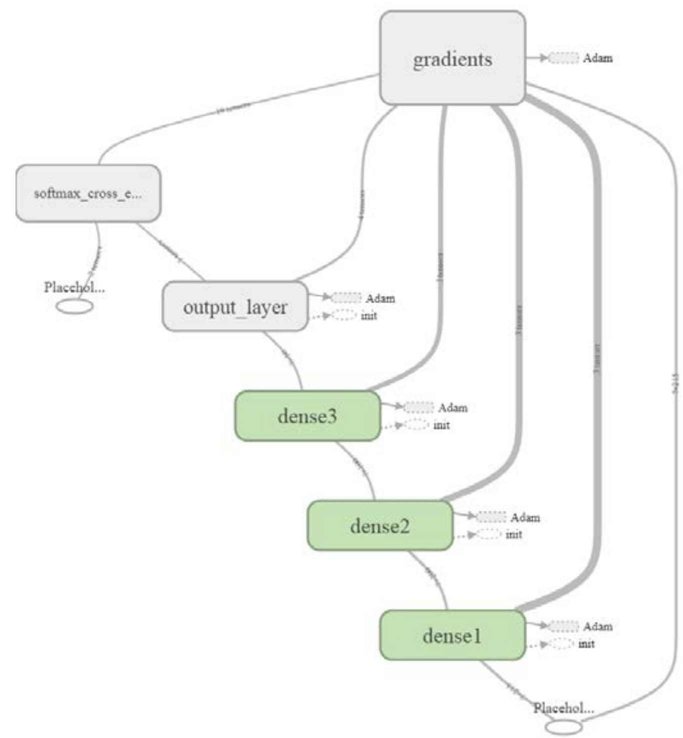
Network architecture

– Fully connected feed-forward

– 3 hidden layers with 200, 100 and 50 neurons and *ReLU* activation function

– Output layer consists of 3 neurons (one for each class), *softmax* activation

– *Cross-entropy* loss function



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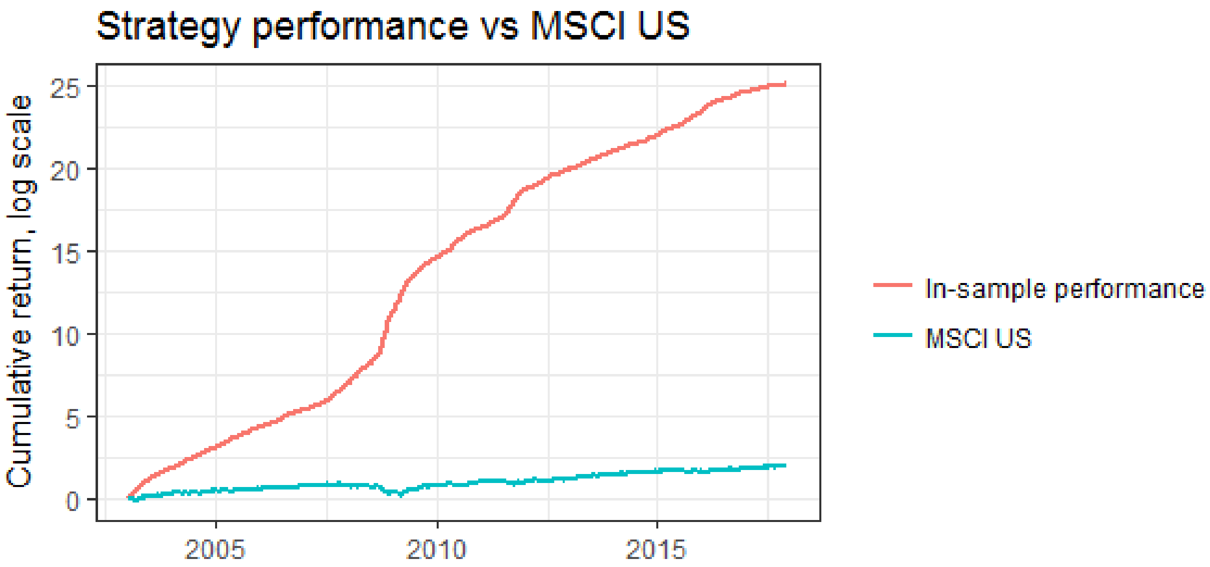
In-sample results

- We train the network on the entire dataset, mini-batch size of 100, 20 epochs (trained with *keras* + *TensorFlow* backend)
- In-sample accuracy: **93%**



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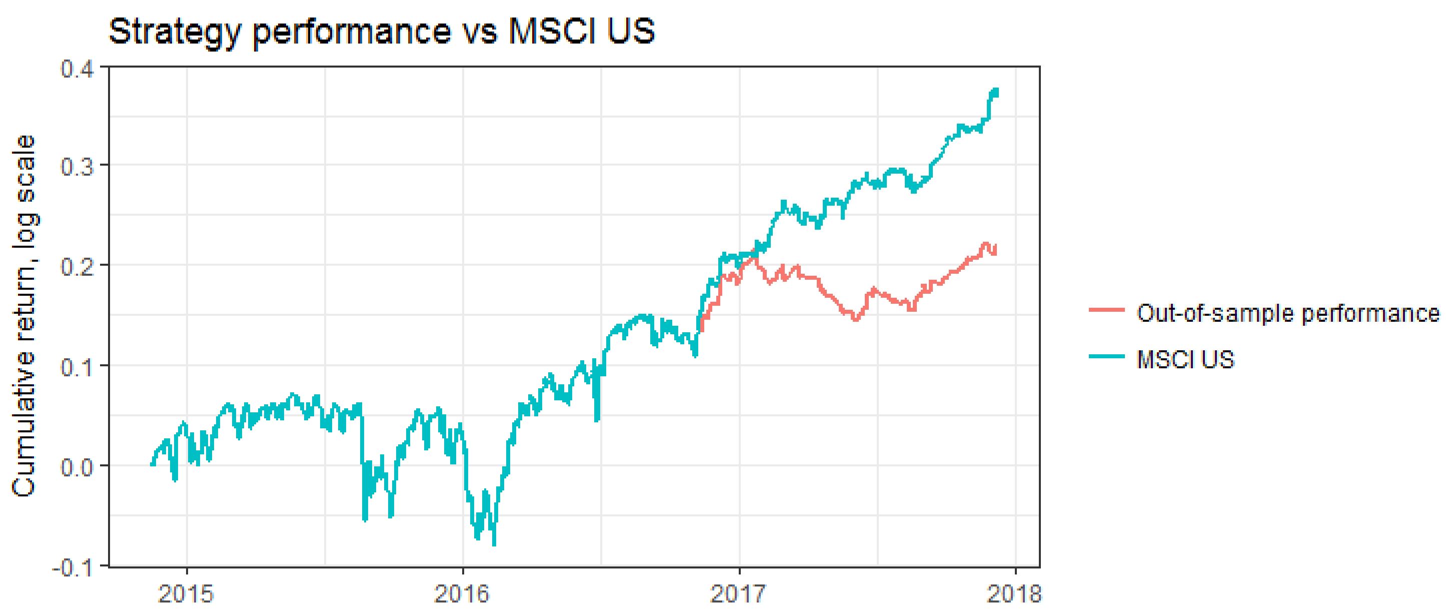
Out-of-sample performance

- As one would expect, the deep network predictor is very high variance
- Out-of-sample accuracy (based on 275 samples): **38%**
- Slightly outperforms a naïve logistic regression classifier (accuracy of 33%)



Source: UBS Quant, MSCI.

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Final words

- Very simplistic model, overfits the data
  - Regularisation (dropout)
  - More sophisticated architectures (convolutional, recurrent neural networks)
  - Increase the frequency

- What other packages for deep learning are there?
  - Torch/PyTorch
  - Theano
  - Caffe
  - Microsoft Cognitive Toolkit (CNTK)
  - Keras – High(er)-level API that works with TensorFlow, Theano and CNTK
  - ….

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Neutral	FSR is between -6% and 6% of the MRA.	39%	23%
Sell	FSR is > 6% below the MRA.	16%	11%
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Buy	Stock price expected to rise within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%
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