Introduction to TensorFlow

Puteaux, Fall/Winter 2020-2021

```
###############################
##                           ##
##  Deep Learning in Python  ##
##                           ##
###############################
```

```
§2 Introduction to TensorFlow in Python
```

```
§2.1 Introduction to TensorFlow
```

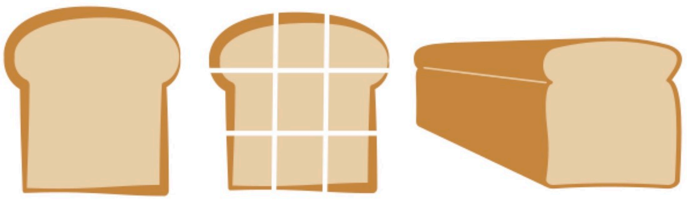
1 Constants and variables

1.1 What is TensorFlow?

- An open-source library for graph-based numerical computation:
  - developed by the Google Brain team
- Has both low and high-level APIs:
  - can be performed for addition, multiplication, differentiation
  - can be used to design and train machine learning models
- Important changes in TensorFlow 2.0:
  - eager execution is now available by default, which allows users to write simple and more intuitive code
  - model building is now centered around high-level APIs Keras and Estimators

1.2 What is a tensor?

- It is a generalization of vectors and matrices to potentially higher dimensions.
- It is a collection of numbers, which is arranged into a specific shape.



Source: Public Domain Vectors

1.3 Code of defining tensors in TensorFlow:

[1]:
```
import tensorflow as tf

# 0D Tensor
d0 = tf.ones((1, ))

d0
```

[1]:
```
<tf.Tensor: shape=(1,), dtype=float32, numpy=array([1.], dtype=float32)>
```

[2]:
```
# 1D Tensor
d1 = tf.ones((2, ))

d1
```

[2]:
```
<tf.Tensor: shape=(2,), dtype=float32, numpy=array([1., 1.], dtype=float32)>
```

[3]:
```
# 2D Tensor
d2 = tf.ones((2, 2))

d2
```

[3]:
```
<tf.Tensor: shape=(2, 2), dtype=float32, numpy=
array([[1., 1.],
       [1., 1.]], dtype=float32)>
```

[4]:
```
# 3D Tensor
d3 = tf.ones((2, 2, 2))

d3
```

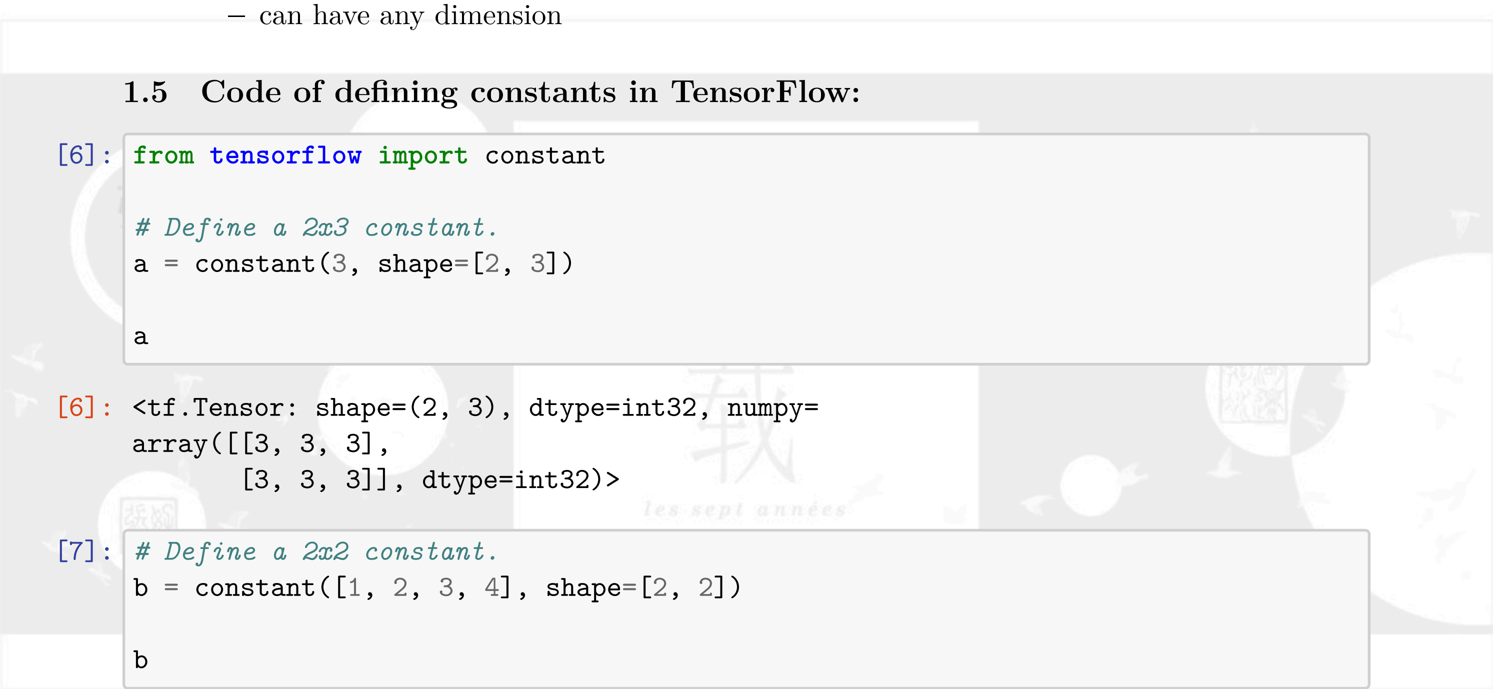
[4]:
```
<tf.Tensor: shape=(2, 2, 2), dtype=float32, numpy=
array([[[1., 1.],
        [1., 1.]],

       [[1., 1.],
        [1., 1.]]], dtype=float32)>
```

```
[5]: # Print the 3D tensor
     print(d3.numpy())
```

```
[[[1. 1.]
  [1. 1.]]

 [[1. 1.]
  [1. 1.]]]
```

1.4 How to define constants in TensorFlow?

- A constant is the simplest category of tensor:
  - cannot be changed and not trainable
  - can have any dimension



1.5 Code of defining constants in TensorFlow:

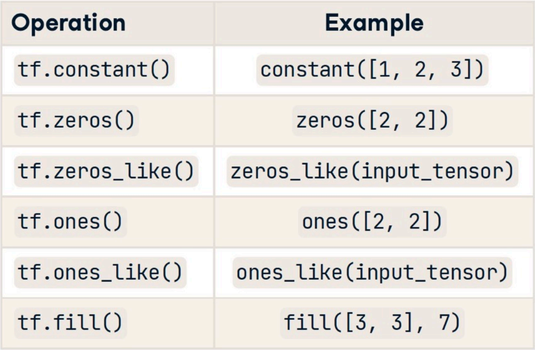
```
[6]: from tensorflow import constant

     # Define a 2x3 constant.
     a = constant(3, shape=[2, 3])

     a
```

```
[6]: <tf.Tensor: shape=(2, 3), dtype=int32, numpy=
     array([[3, 3, 3],
            [3, 3, 3]], dtype=int32)>
```

```
[7]: # Define a 2x2 constant.
     b = constant([1, 2, 3, 4], shape=[2, 2])

     b
```

```
[7]: <tf.Tensor: shape=(2, 2), dtype=int32, numpy=
     array([[1, 2],
            [3, 4]], dtype=int32)>
```

1.6 How to use convenience functions to define constants?



Operation	Example
tf.constant()	constant([1, 2, 3])
tf.zeros()	zeros([2, 2])
tf.zeros_like()	zeros_like(input_tensor)
tf.ones()	ones([2, 2])
tf.ones_like()	ones_like(input_tensor)
tf.fill()	fill([3, 3], 7)

1.7 Code of defining and initializing variables:

[8]:

```
import tensorflow as tf

# Define a variable
a0 = tf.Variable([1, 2, 3, 4, 5, 6], dtype=tf.float32)
a1 = tf.Variable([1, 2, 3, 4, 5, 6], dtype=tf.int16)

a0, a1
```

[8]:

```
(<tf.Variable 'Variable:0' shape=(6,) dtype=float32, numpy=array([1., 2., 3.,
4., 5., 6.], dtype=float32)>,
 <tf.Variable 'Variable:0' shape=(6,) dtype=int16, numpy=array([1, 2, 3, 4, 5,
6], dtype=int16)>)
```

[9]:

```
# Define a constant
b = tf.constant(2, tf.float32)

b
```

[9]:

```
<tf.Tensor: shape=(), dtype=float32, numpy=2.0>
```

[10]:

```
# Compute their product
c0 = tf.multiply(a0, b)
c1 = a0 * b

c0, c1
```

[10]:

```
(<tf.Tensor: shape=(6,), dtype=float32, numpy=array([ 2.,  4.,  6.,  8., 10.,
12.], dtype=float32)>,
 <tf.Tensor: shape=(6,), dtype=float32, numpy=array([ 2.,  4.,  6.,  8., 10.,
12.], dtype=float32)>)
```

1.8 Practice exercises for constants and variables:

▶ **Package pre-loading:**

[11]:
```
import pandas as pd
import numpy as np
```

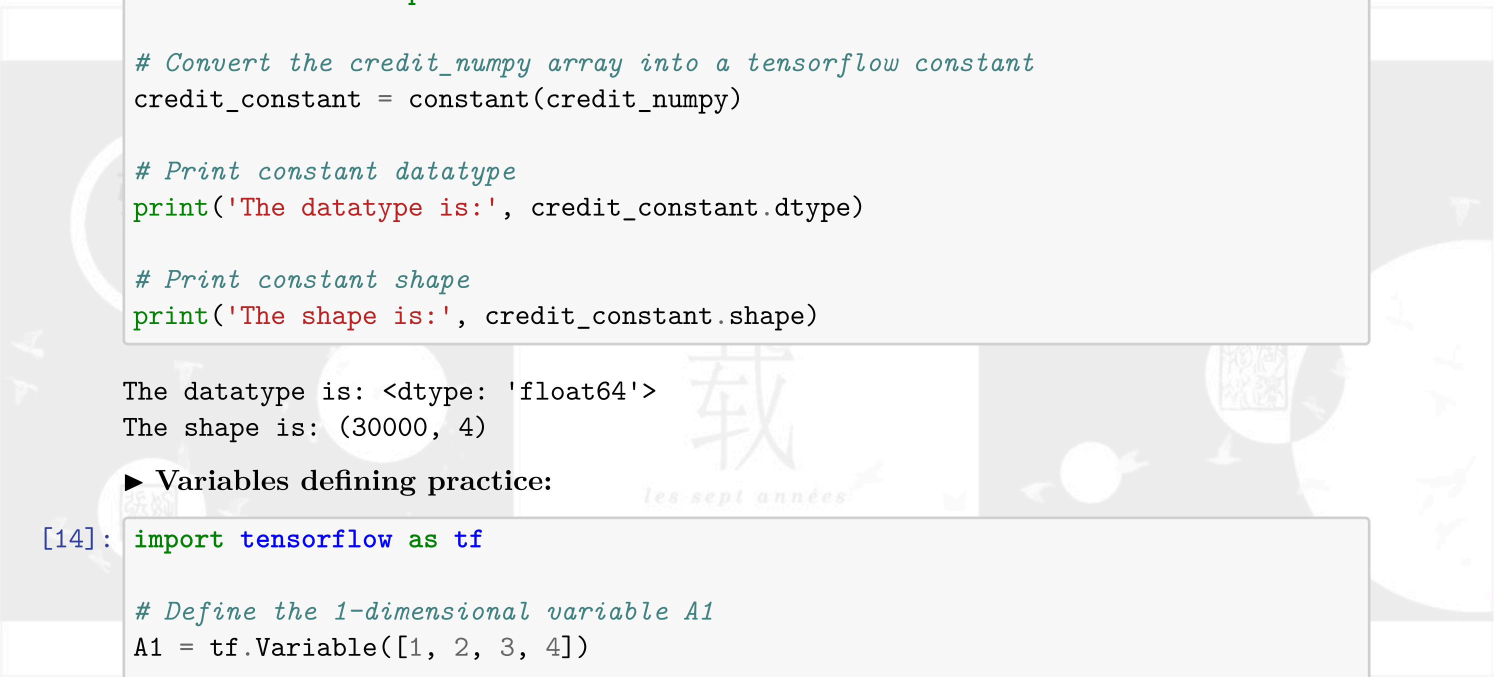
▶ **Data pre-loading:**

[12]:
```
df = pd.read_csv('ref3. UCI credit card.csv', dtype=np.float64)
credit_numpy = df[['EDUCATION', 'MARRIAGE', 'AGE', 'BILL_AMT1']].to_numpy()
```

▶ **Constants defining practice:**

[13]:
```
# Import constant from TensorFlow
from tensorflow import constant

# Convert the credit_numpy array into a tensorflow constant
credit_constant = constant(credit_numpy)

# Print constant datatype
print('The datatype is:', credit_constant.dtype)

# Print constant shape
print('The shape is:', credit_constant.shape)
```

```
The datatype is: <dtype: 'float64'>
The shape is: (30000, 4)
```



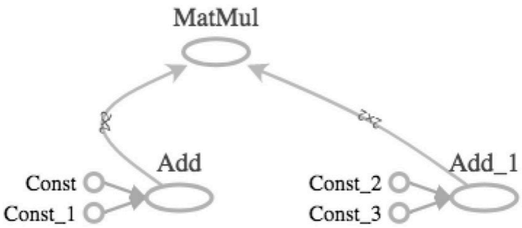
▶ **Variables defining practice:**

[14]:
```
import tensorflow as tf

# Define the 1-dimensional variable A1
A1 = tf.Variable([1, 2, 3, 4])

# Print the variable A1
print(A1)

# Convert A1 to a numpy array and assign it to B1
B1 = A1.numpy()

# Print B1
print(B1)
```

```
<tf.Variable 'Variable:0' shape=(4,) dtype=int32, numpy=array([1, 2, 3, 4],
dtype=int32)>
[1 2 3 4]
```

2 Basic operations

2.1 What is a TensorFlow operation?



2.2 Code of applying the addition operator:

[15]:
```
#Import constant and add from tensorflow
from tensorflow import constant, add

# Define 0-dimensional tensors
A0 = constant([1])
B0 = constant([2])

A0, B0
```

[15]:
```
(<tf.Tensor: shape=(1,), dtype=int32, numpy=array([1], dtype=int32)>,
 <tf.Tensor: shape=(1,), dtype=int32, numpy=array([2], dtype=int32)>)
```

[16]:
```
# Define 1-dimensional tensors
A1 = constant([1, 2])
B1 = constant([3, 4])

A1, B1
```

[16]:
```
(<tf.Tensor: shape=(2,), dtype=int32, numpy=array([1, 2], dtype=int32)>,
 <tf.Tensor: shape=(2,), dtype=int32, numpy=array([3, 4], dtype=int32)>)
```

[17]:
```
# Define 2-dimensional tensors
A2 = constant([[1, 2], [3, 4]])
B2 = constant([[5, 6], [7, 8]])

A2, B2
```

[17]:
```
(<tf.Tensor: shape=(2, 2), dtype=int32, numpy=
 array([[1, 2],
        [3, 4]], dtype=int32)>,
 <tf.Tensor: shape=(2, 2), dtype=int32, numpy=
 array([[5, 6],
        [7, 8]], dtype=int32)>)
```

[18]:
```python
# Perform tensor addition with add()
C0 = add(A0, B0)
C1 = add(A1, B1)
C2 = add(A2, B2)

C0, C1, C2
```

[18]:
```
(<tf.Tensor: shape=(1,), dtype=int32, numpy=array([3], dtype=int32)>,
 <tf.Tensor: shape=(2,), dtype=int32, numpy=array([4, 6], dtype=int32)>,
 <tf.Tensor: shape=(2, 2), dtype=int32, numpy=
 array([[ 6,  8],
        [10, 12]], dtype=int32)>)
```

2.3 How to perform tensor addition?

- The `add()` operation performs **element-wise addition** with two tensors.
- Element-wise addition requires both tensors to have the same shape:
  - scalar addition:

    $1 + 2 = 3$
  - vector addition:

    $[1, 2] + [3, 4] = [4, 6]$
  - matrix addition:

    $$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} + \begin{bmatrix} 5 & 6 \\ 7 & 8 \end{bmatrix} = \begin{bmatrix} 6 & 8 \\ 10 & 12 \end{bmatrix}$$
- The `add()` operator is overloaded.

2.4 How to perform multiplication in TensorFlow?

- **Element-wise multiplication** performed using `multiply()` operation.
- The tensors multiplied must have the same shape:
  - e.g., $[1, 2, 3]$ and $[3, 4, 5]$ or $[1, 2]$ and $[3, 4]$
- **Matrix multiplication** is performed with `matmul()` operator.
  - The `matmul(A, B)` operation multiplies `A` by `B`.
  - The number of columns of `A` must equal the number of rows of `B`.

2.5 Code of applying the multiplication operators:

[19]:
```python
# Import operators from tensorflow
from tensorflow import ones, matmul, multiply

# Define tensors
```

```
A0 = ones(1)
A31 = ones([3, 1])
A34 = ones([3, 4])
A43 = ones([4, 3])

A0, A31, A34, A43
```

[19]:

```
(<tf.Tensor: shape=(1,), dtype=float32, numpy=array([1.], dtype=float32)>,
 <tf.Tensor: shape=(3, 1), dtype=float32, numpy=
 array([[1.],
        [1.],
        [1.]], dtype=float32)>,
 <tf.Tensor: shape=(3, 4), dtype=float32, numpy=
 array([[1., 1., 1., 1.],
        [1., 1., 1., 1.],
        [1., 1., 1., 1.]], dtype=float32)>,
 <tf.Tensor: shape=(4, 3), dtype=float32, numpy=
 array([[1., 1., 1.],
        [1., 1., 1.],
        [1., 1., 1.],
        [1., 1., 1.]], dtype=float32)>)
```

[20]:

```
A0_A0 = multiply(A0, A0)
A31_A31 = multiply(A31, A31)
A34_A34 = multiply(A34, A34)

A0_A0, A31_A31, A34_A34
```

[20]:

```
(<tf.Tensor: shape=(1,), dtype=float32, numpy=array([1.], dtype=float32)>,
 <tf.Tensor: shape=(3, 1), dtype=float32, numpy=
 array([[1.],
        [1.],
        [1.]], dtype=float32)>,
 <tf.Tensor: shape=(3, 4), dtype=float32, numpy=
 array([[1., 1., 1., 1.],
        [1., 1., 1., 1.],
        [1., 1., 1., 1.]], dtype=float32)>)
```

[21]:

```
A43_A34 = matmul(A43, A34)

A43_A34
```

[21]:

```
<tf.Tensor: shape=(4, 4), dtype=float32, numpy=
array([[3., 3., 3., 3.],
       [3., 3., 3., 3.],
       [3., 3., 3., 3.],
       [3., 3., 3., 3.]], dtype=float32)>
```

2.6 How to sum over tensor dimensions?

- The `reduce_sum()` operator sums over the dimensions of a:
  - `tensorreduce_sum(A)` sums over all the dimensions of `A`
  - `reduce_sum(A, i)` sums over the dimension `i`

2.7 Code of summing over tensor dimensions:

```
[22]: # Import operations from tensorflow
      from tensorflow import ones, reduce_sum

      # Define a 2x3x4 tensor of ones
      A = ones([2, 3, 4])

      A
```

```
[22]: <tf.Tensor: shape=(2, 3, 4), dtype=float32, numpy=
      array([[[1., 1., 1., 1.],
              [1., 1., 1., 1.],
              [1., 1., 1., 1.]],

             [[1., 1., 1., 1.],
              [1., 1., 1., 1.],
              [1., 1., 1., 1.]]], dtype=float32)>
```

```
[23]: # Sum over all dimensions
      B = reduce_sum(A)

      B
```

```
[23]: <tf.Tensor: shape=(), dtype=float32, numpy=24.0>
```

```
[24]: # Sum over dimensions 0, 1, and 2
      B0 = reduce_sum(A, 0)
      B1 = reduce_sum(A, 1)
      B2 = reduce_sum(A, 2)

      B0, B1, B2
```

```
[24]: (<tf.Tensor: shape=(3, 4), dtype=float32, numpy=
       array([[2., 2., 2., 2.],
              [2., 2., 2., 2.],
              [2., 2., 2., 2.]], dtype=float32)>,
       <tf.Tensor: shape=(2, 4), dtype=float32, numpy=
       array([[3., 3., 3., 3.],
              [3., 3., 3., 3.]], dtype=float32)>,
       <tf.Tensor: shape=(2, 3), dtype=float32, numpy=
       array([[4., 4., 4.],
              [4., 4., 4.]], dtype=float32)>)
```

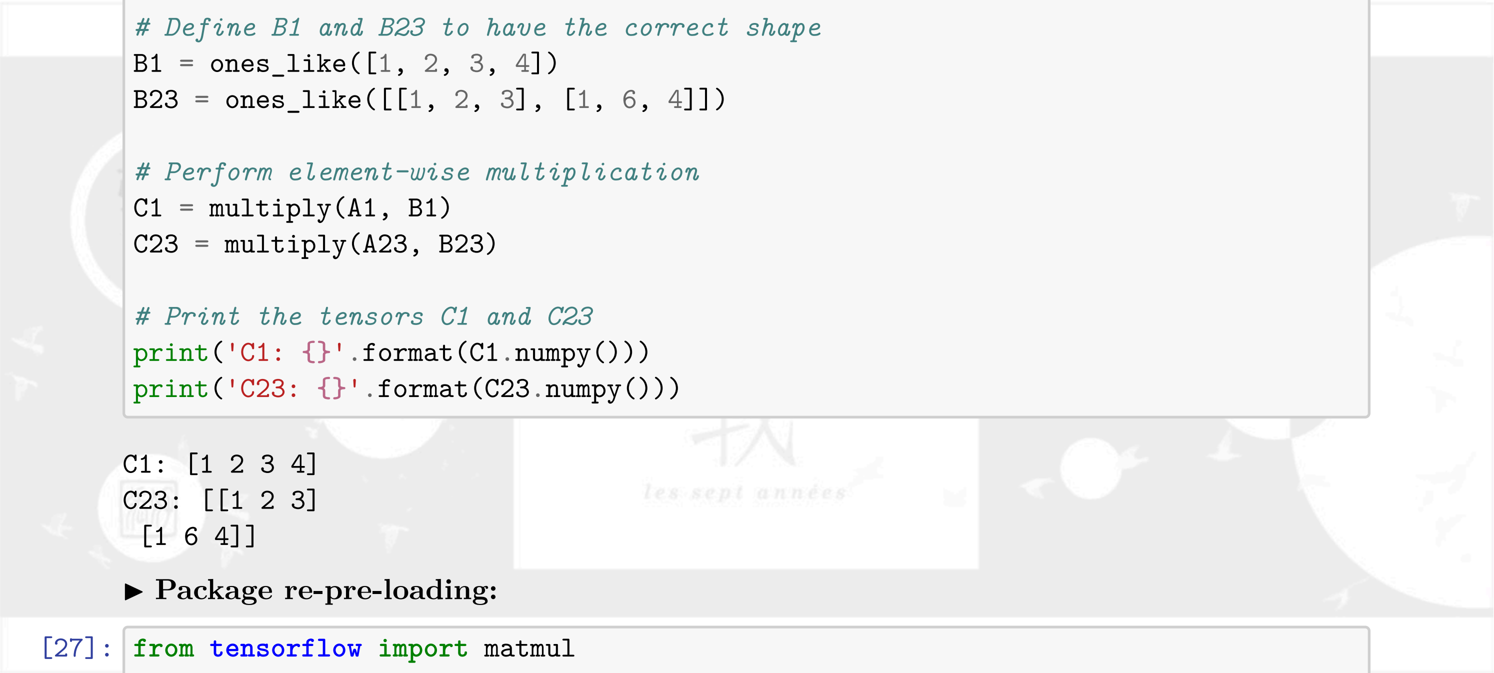
2.8 Practice exercises for basic operations:

▶ **Package pre-loading:**

[25]:
```
from tensorflow import constant, ones_like, multiply
```

▶ **Element-wise multiplication performing practice:**

[26]:
```
# Define tensors A1 and A23 as constants
A1 = constant([1, 2, 3, 4])
A23 = constant([[1, 2, 3], [1, 6, 4]])

# Define B1 and B23 to have the correct shape
B1 = ones_like([1, 2, 3, 4])
B23 = ones_like([[1, 2, 3], [1, 6, 4]])

# Perform element-wise multiplication
C1 = multiply(A1, B1)
C23 = multiply(A23, B23)

# Print the tensors C1 and C23
print('C1: {}'.format(C1.numpy()))
print('C23: {}'.format(C23.numpy()))
```



```
C1: [1 2 3 4]
C23: [[1 2 3]
 [1 6 4]]
```

▶ **Package re-pre-loading:**

[27]:
```
from tensorflow import matmul
```

▶ **Matrix multiplication predictions practice:**

[28]:
```
# Define features, params, and bill as constants
features = constant([[2, 24], [2, 26], [2, 57], [1, 37]])
params = constant([[1000], [150]])
bill = constant([[3913], [2682], [8617], [64400]])

# Compute billpred using features and params
billpred = matmul(features, params)

# Compute and print the error
error = bill - billpred
print(error.numpy())
```

```
[[-1687]
 [-3218]
 [-1933]
 [57850]]
```

2.9 Practice question for summing over tensor dimensions:

- There is a matrix, `wealth`. This contains the value of the bond and stock wealth for five individuals in thousands of dollars.
- `wealth` $= \begin{bmatrix} 11 & 50 \\ 7 & 2 \\ 4 & 60 \\ 3 & 0 \\ 25 & 10 \end{bmatrix}$
- The first column corresponds to bonds, and the second corresponds to stocks. Each row gives the bond and stock wealth for a single individual. Use `wealth`, `reduce_sum()`, and `.numpy()` to determine which statements are correct about `wealth`.

  ☐ The individual in the first row has the highest total wealth (i.e., stocks + bonds).

  ☐ Combined, the 5 individuals hold $50,000 in stocks.

  ☒ Combined, the 5 individuals hold $50,000 in bonds.

  ☐ The individual in the second row has the lowest total wealth (i.e., stocks + bonds).

▶ **Package pre-loading:**

[29]:
```
from tensorflow import constant, reduce_sum
```

▶ **Data pre-loading:**

[30]:
```
wealth = constant([[11, 50], [7, 2], [4, 60], [3, 0], [25, 10]])
```

▶ **Question-solving method:**

[31]:
```
wealth
```

[31]:
```
<tf.Tensor: shape=(5, 2), dtype=int32, numpy=
array([[11, 50],
       [ 7,  2],
       [ 4, 60],
       [ 3,  0],
       [25, 10]], dtype=int32)>
```

[32]:
```
wealth.numpy()
```

[32]:
```
array([[11, 50],
       [ 7,  2],
       [ 4, 60],
       [ 3,  0],
       [25, 10]], dtype=int32)
```

```
[33]: reduce_sum(wealth)
```

```
[33]: <tf.Tensor: shape=(), dtype=int32, numpy=172>
```

```
[34]: reduce_sum(wealth, 0)
```

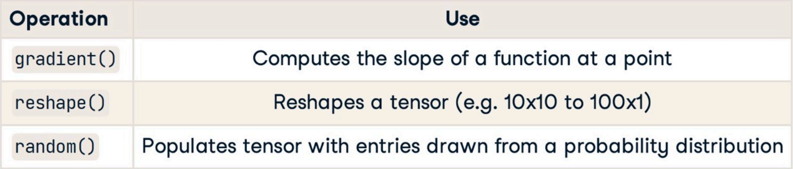
```
[34]: <tf.Tensor: shape=(2,), dtype=int32, numpy=array([ 50, 122], dtype=int32)>
```

```
[35]: reduce_sum(wealth, 1)
```

```
[35]: <tf.Tensor: shape=(5,), dtype=int32, numpy=array([61,  9, 64,  3, 35],
      dtype=int32)>
```

3 Advanced operations

3.1 What are the advanced operations?

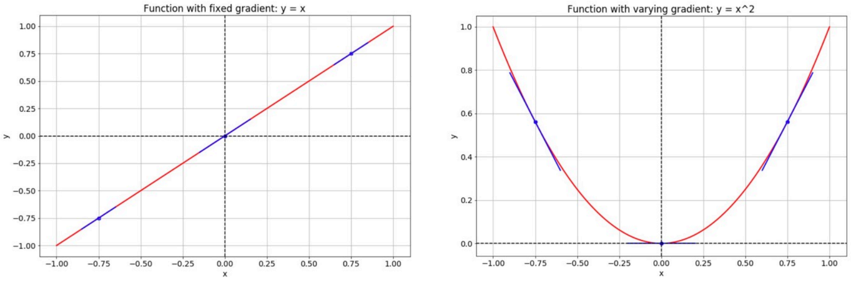


Operation	Use
`gradient()`	Computes the slope of a function at a point
`reshape()`	Reshapes a tensor (e.g. 10x10 to 100x1)
`random()`	Populates tensor with entries drawn from a probability distribution

3.2 How to find the optimum?

- In many problems, it is in need to find the optimum of a function:
  - **Minimum**: the lowest value of a loss function
  - **Maximum**: the highest value of the objective function
- It is possible to do this by using the `gradient()` operation:
  - **Optimum**: find a point where $gradient = 0$
  - **Minimum**: change in $gradient > 0$
  - **Maximum**: change in $gradient < 0$

3.3 How to calculate the gradient?



3.4 Code of gradients in TensorFlow:

[36]:
```
# Import tensorflow under the alias tf
import tensorflow as tf

# Define x
x = tf.Variable(-1.0)

x
```

[36]:
```
<tf.Variable 'Variable:0' shape=() dtype=float32, numpy=-1.0>
```

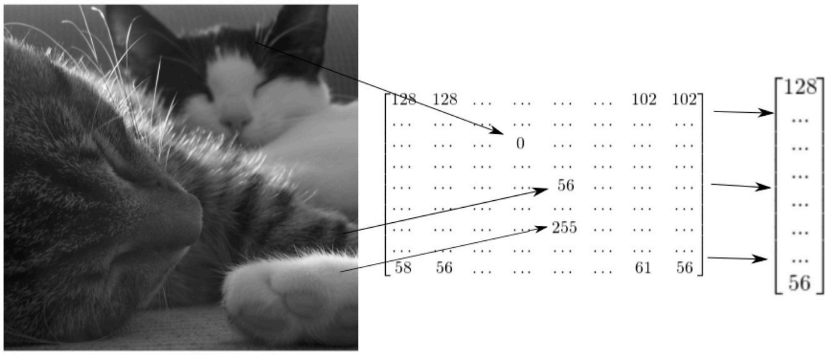
[37]:
```
# Define y within instance of GradientTape
with tf.GradientTape() as tape:
    tape.watch(x)
    y = tf.multiply(x, x)

y
```

[37]:
```
<tf.Tensor: shape=(), dtype=float32, numpy=1.0>
```

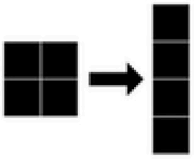
[38]:
```
# Evaluate the gradient of y at x = -1
g = tape.gradient(y, x)
print(g.numpy())
```

```
-2.0
```

3.5 How to deal with images as tensors?



3.6 How to reshape a grayscale image?



3.7 Code of reshaping a grayscale image:

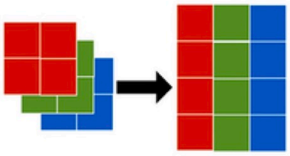
[39]:
```
# Import tensorflow as alias tf
import tensorflow as tf

# Generate grayscale image
gray = tf.random.uniform([2, 2], maxval=255, dtype='int32')

gray
```

[39]:
```
<tf.Tensor: shape=(2, 2), dtype=int32, numpy=
array([[ 89,  10],
       [232, 243]], dtype=int32)>
```

[40]:
```
# Reshape grayscale image
gray = tf.reshape(gray, [2 * 2, 1])

gray
```

[40]:
```
<tf.Tensor: shape=(4, 1), dtype=int32, numpy=
array([[ 89],
       [ 10],
       [232],
       [243]], dtype=int32)>
```

3.8 How to reshape a color image?



3.9 Code of reshaping a color image:

```
[41]: # Import tensorflow as alias tf
      import tensorflow as tf

      # Generate color image
      color = tf.random.uniform([2, 2, 3], maxval=255, dtype='int32')

      color
```

```
[41]: <tf.Tensor: shape=(2, 2, 3), dtype=int32, numpy=
      array([[[ 38,  26,  24],
              [133, 252,  83]],

             [[206, 156,  82],
              [173, 115,  93]]], dtype=int32)>
```

```
[42]: # Reshape color image
      color = tf.reshape(color, [2 * 2, 3])

      color
```

```
[42]: <tf.Tensor: shape=(4, 3), dtype=int32, numpy=
      array([[ 38,  26,  24],
             [133, 252,  83],
             [206, 156,  82],
             [173, 115,  93]], dtype=int32)>
```

3.10 Practice exercises for advanced operations:

▶ **Diagram of images for reshaping:**

▶ **Package pre-loading:**

[43]:

```
import numpy as np
from tensorflow import reshape
```

▶ **Data pre-loading:**

[44]:

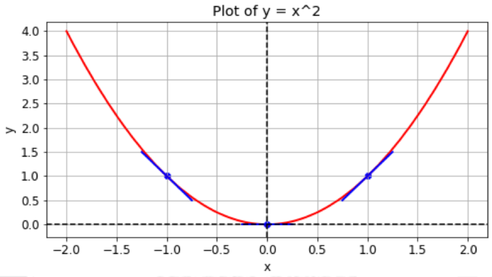
```
gray_tensor = np.loadtxt("ref11. Gray tensor.csv", delimiter=',')

color_tensor = np.loadtxt("ref12. Color tensor.csv", delimiter=',')
color_tensor = color_tensor.reshape(color_tensor.shape[0],
                                    color_tensor.shape[1] // 3, 3)
```

▶ **Tensor reshaping practice:**

[45]:

```
# Reshape the grayscale image tensor into a vector
gray_vector = reshape(gray_tensor, (-1, 1))

# Reshape the color image tensor into a vector
color_vector = reshape(color_tensor, (-1, 1))
```

▶ **Diagram of gradient descent:**



▶ **Package re-pre-loading:**

[46]:

```
from tensorflow import Variable, GradientTape, multiply
```

▶ **Gradients optimization practice:**

[47]:

```
def compute_gradient(x0):
    # Define x as a variable with an initial value of x0
    x = Variable(x0)
    with GradientTape() as tape:
        tape.watch(x)
        # Define y using the multiply operation
        y = multiply(x, x)
    # Return the gradient of y with respect to x
    return tape.gradient(y, x).numpy()


# Compute and print gradients at x = -1, 1, and 0
```

```
print(compute_gradient(-1.0))
print(compute_gradient(1.0))
print(compute_gradient(0.0))
```

```
-2.0
2.0
0.0
```

▶ **Package re-pre-loading:**

[48]:
```
from tensorflow import matmul, reduce_sum
```

▶ **Data re-pre-loading:**

[49]:
```
letter = np.array([[1., 0., 1.], [1., 1., 0.], [1., 0., 1.]])

model = np.array([[1., 0., -1.]])
```

▶ **Image data working practice:**

[50]:
```
# Reshape model from a 1x3 to a 3x1 tensor
model = reshape(model, (3, 1))

# Multiply letter by model
output = matmul(letter, model)

# Sum over output and print prediction using the numpy method
prediction = reduce_sum(output)
print(prediction.numpy())
```

```
1.0
```