

A Python Companion to ISLR

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1 Introduction

Figure 1 shows graphs of Wage versus three variables.

Figure 2 shows boxplots of previous days' percentage changes in S&P 500 grouped according to today's change Up or Down.

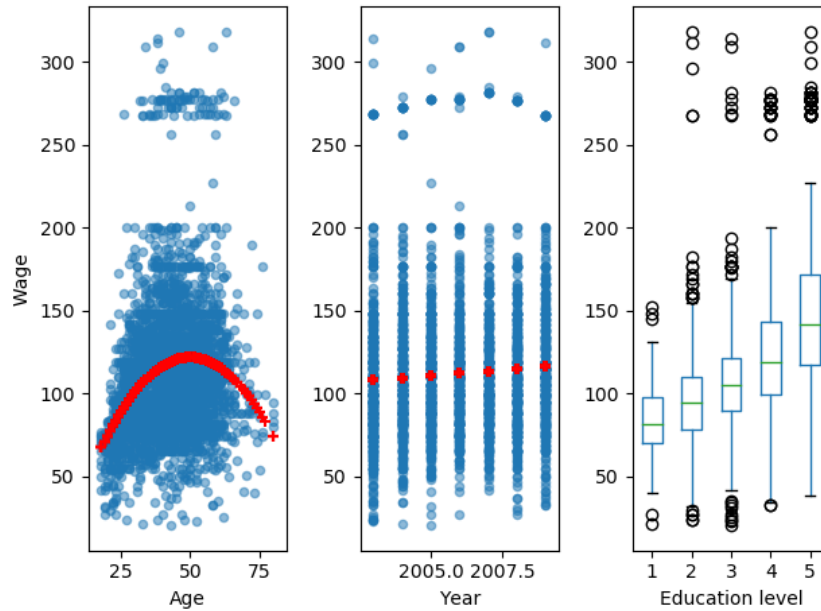


Figure 1: **Wage** data, which contains income survey information for males from the central Atlantic region of the United States. Left: **wage** as a function of **age**. On average, **wage** increases with **age** until about 60 years of age, at which point it begins to decline. Center: **wage** as a function of **year**. There is a slow but steady increase of approximately \$10,000 in the average **wage** between 2003 and 2009. Right: Boxplots displaying **wage** as a function of **education**, with 1 indicating the lowest level (no highschool diploma) and 5 the highest level (an advanced graduate degree). On average, **wage** increases with the level of **education**.



Figure 2: Left: Boxplots of the previous day's percentage change in the S&P 500 index for the days for which the market increased or decreased, obtained from the **Smarket** data. Center and Right: Same as left panel, but the percentage changes for two and three days previous are shown.

2 Statistical Learning

2.1 What is Statistical Learning?

Figure 3 shows scatter plots of `sales` versus `TV`, `radio`, and `newspaper` advertising. In each panel, the figure also includes an OLS regression line.



Figure 3: The Advertising data set. The plot displays `sales`, in thousands of units, as a function of `TV`, `radio`, and `newspaper` budgets, in thousands of dollars, for 200 different markets. In each plot we show the simple least squares fit of `sales` to that variable. In other words, each red line represents a simple model that can be used to predict `sales` using `TV`, `radio`, and `newspaper`, respectively.

Figure 4 is a plot of `Income` versus `Years of Education` from the Income data set. In the left panel, the “true” function (given by blue line) is actually my guess.

Figure 5 is a plot of `Income` versus `Years of Education` and `Seniority` from the Income data set. Since the book does not provide the true values of `Income`, “true” values shown in the plot are actually third order polynomial fit.

Figure 6 shows an example of the parametric approach applied to the



Figure 4: The `Income` data set. Left: The red dots are the observed values of `income` (in tens of thousands of dollars) and `years of education` for 30 individuals. Right: The blue curve represents the true underlying relationship between `income` and `years of education`, which is generally unknown (but is known in this case because the data are simulated). The vertical lines represent the error associated with each observation. Note that some of the errors are positive (when an observation lies above the blue curve) and some are negative (when an observation lies below the curve). Overall, these errors have approximately mean zero.

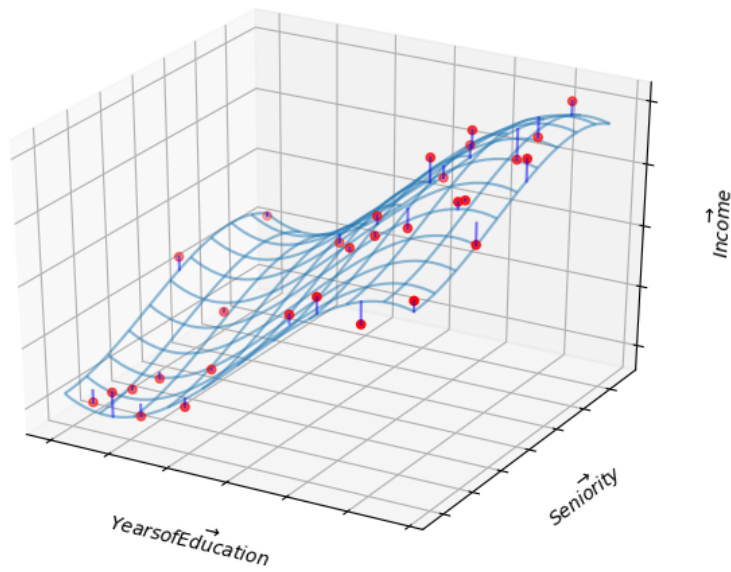


Figure 5: The plot displays `income` as a function of `years of education` and `seniority` in the `Income` data set. The blue surface represents the true underlying relationship between `income` and `years of education` and `seniority`, which is known since the data are simulated. The red dots indicate the observed values of these quantities for 30 individuals.

Income data from previous figure.

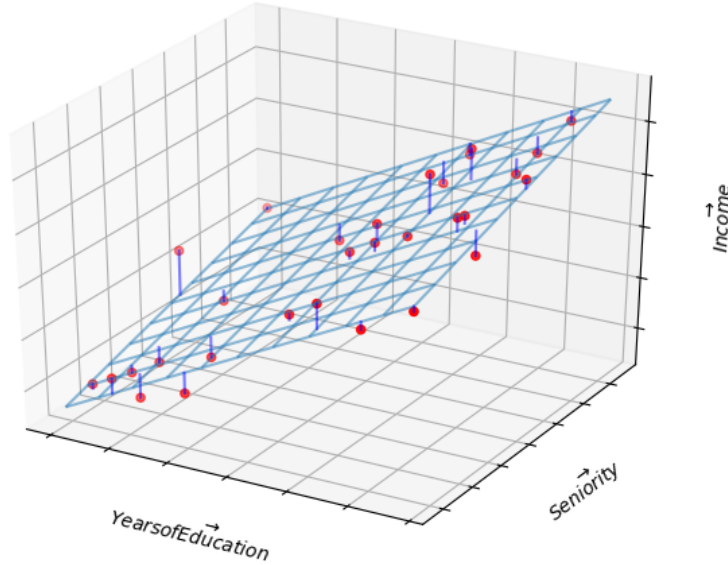


Figure 6: A linear model fit by least squares to the `Income` data from figure 5. The observations are shown in red, and the blue plane indicates the least squares fit to the data.

Figure 7 provides an illustration of the trade-off between flexibility and interpretability for some of the methods covered in this book.

Figure 8 provides a simple illustration of the clustering problem.

2.2 Assessing Model Accuracy

Figure 9 illustrates the tradeoff between training MSE and test MSE. We select a “true function” whose shape is similar to that shown in the book. In the left panel, the orange, blue, and green curves illustrate three possible estimates for f given by the black curve. The orange line is the linear regression fit, which is relatively inflexible. The blue and green curves were produced using *smoothing splines* from `UnivariateSpline` function in `scipy` package. We obtain different levels of flexibility by varying the parameter s , which affects the number of knots.

For the right panel, we have chosen polynomial fits. The degree of polynomial represents the level of flexibility. This is because the function



Figure 7: A representation of the tradeoff between flexibility and interpretability, using different statistical learning methods. In general, as the flexibility of a method increases, its interpretability decreases.

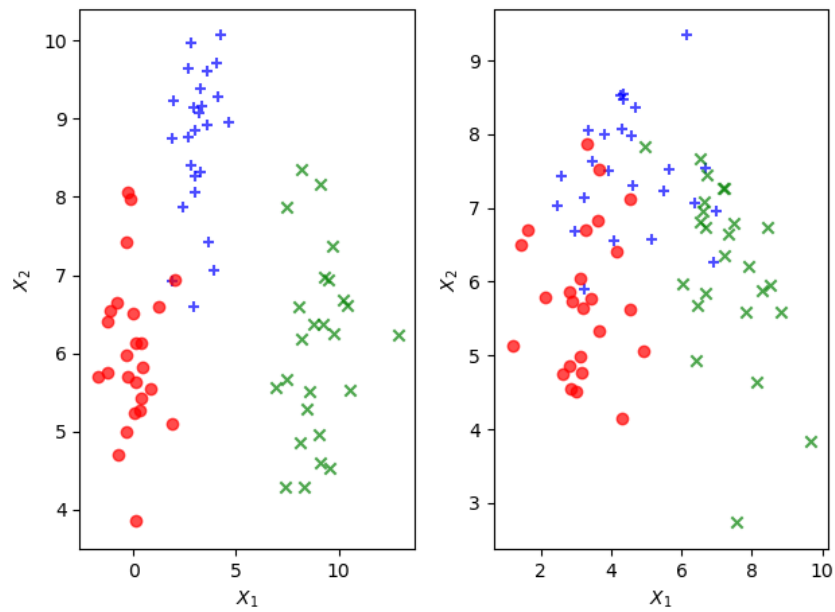


Figure 8: A clustering data set involving three groups. Each group is shown using a different colored symbol. Left: The three groups are well-separated. In this setting, a clustering approach should successfully identify the three groups. Right: There is some overlap among the groups. Now the clustering task is more challenging.

`UnivariateSpline` does not more than five degrees of freedom.

When we repeat the simulations for figure 9, we see considerable variation in the right panel MSE plots. But the overall conclusion remains the same.

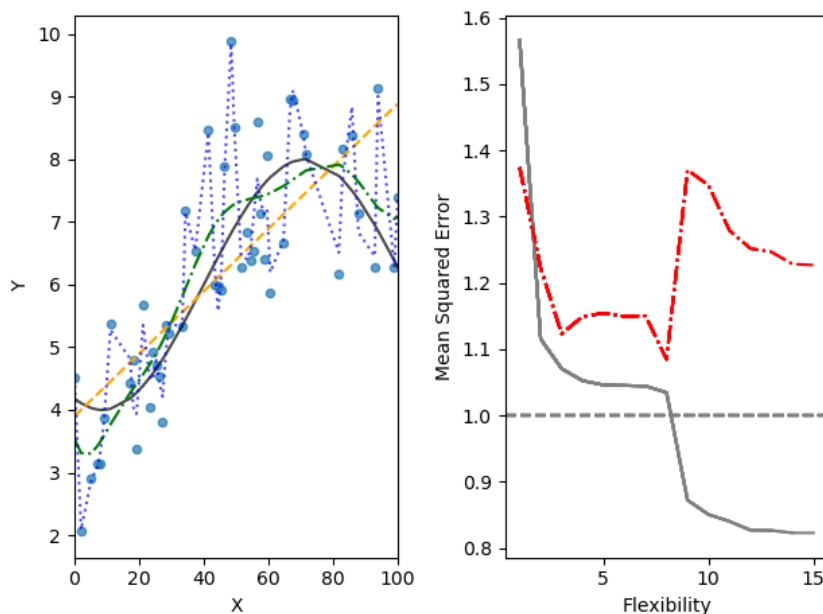


Figure 9: Left: Data simulated from f , shown in black. Three estimates of f are shown: the linear regression line (orange curve), and two smoothing spline fits (blue and green curves). Right: Training MSE (grey curve), test MSE (red curve), and minimum possible test MSE over all methods (dashed grey line).

Figure 10 provides another example in which the true f is approximately linear.

Figure 11 displays an example in which f is highly non-linear. The training and test MSE curves still exhibit the same general patterns.

Figure 12 displays the relationship between bias, variance, and test MSE. This relationship is referred to as *bias-variance trade-off*. When simulations are repeated, we see considerable variation in different graphs, especially for MSE lines. But overall shape remains the same.

Figure 13 provides an example using a simulated data set in two-dimensional space consisting of predictors X_1 and X_2 .

Figure 14 displays the KNN decision boundary, using $K = 10$, when



Figure 10: Details are as in figure 9 using a different true f that is much closer to linear. In this setting, linear regression provides a very good fit to the data.



Figure 11: Details are as in figure 9, using a different f that is far from linear. In this setting, linear regression provides a very poor fit to the data.



Figure 12: Squared bias (blue curve), variance (orange curve), $Var(\epsilon)$ (dashed line), and test MSE (red curve) for the three data sets in figures 9 - 11. The vertical dotted line indicates the flexibility level corresponding to the smallest test MSE.

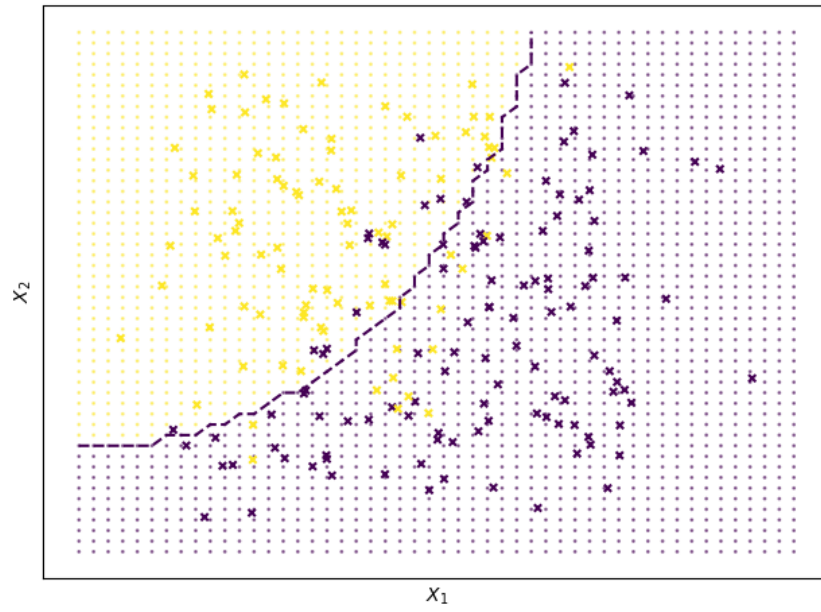


Figure 13: A simulated data set consisting of 200 observations in two groups, indicated in blue and orange. The dashed line represents the Bayes decision boundary. The orange background grid indicates the region in which a test observation will be assigned to the orange class, and blue background grid indicates the region in which a test observation will be assigned to the blue class.

applied to the simulated data set from figure 13. Even though the true distribution is not known by the KNN classifier, the KNN decision making boundary is very close to that of the Bayes classifier.



Figure 14: The firm line indicates the KNN decision boundary on the data from figure 13, using $K = 10$. The Bayes decision boundary is shown as a dashed line. The KNN and Bayes decision boundaries are very similar.

In figure 16 we have plotted the KNN test and training errors as a function of $\frac{1}{K}$. As $\frac{1}{K}$ increases, the method becomes more flexible. As in the regression setting, the training error rate consistently declines as the flexibility increases. However, the test error exhibits the characteristic U-shape, declining at first (with a minimum at approximately $K = 10$) before increasing again when the method becomes excessively flexible and overfits.



Figure 15: A comparison of the KNN decision boundaries (solid curves) obtained using $K = 1$ and $K = 100$ on the data from figure 13. With $K = 1$, the decision boundary is overly flexible, while with $K = 100$ it is not sufficiently flexible. The Bayes decision boundary is shown as dashed line.



Figure 16: The KNN training error rate (blue, 200 observations) and test error rate (orange, 5,000 observations) on the data from figure 13 as the level of flexibility (assessed using $\frac{1}{K}$) increases, or equivalently as the number of neighbors K decreases. The black dashed line indicates the Bayes error rate.

2.3 Lab: Introduction to Python

2.3.1 Basic Commands

In Python a list can be created by enclosing comma-separated elements by square brackets. Length of a list can be obtained using `len` function.

```
x = [1, 3, 2, 5]
print(len(x))
y = 3
z = 5
print(y + z)
```

```
4
8
```

To create an array of numbers, use `array` function in `numpy` library. `numpy` functions can be used to perform element-wise operations on arrays.

```
import numpy as np
x = np.array([[1, 2], [3, 4]])
y = np.array([6, 7, 8, 9]).reshape((2, 2))
print(x)
print(y)
print(x ** 2)
print(np.sqrt(y))
```

```
[[1 2]
 [3 4]]
[[6 7]
 [8 9]]
[[ 1  4]
 [ 9 16]]
[[2.44948974 2.64575131]
 [2.82842712 3.          ]]
```

`numpy.random` has a number of functions to generate random variables that follow a given distribution. Here we create two correlated sets of numbers, `x` and `y`, and use `numpy.corrcoef` to calculate correlation between them.

```

import numpy as np
np.random.seed(911)
x = np.random.normal(size=50)
y = x + np.random.normal(loc=50, scale=0.1, size=50)
print(np.corrcoef(x, y))
print(np.corrcoef(x, y)[0, 1])
print(np.mean(x))
print(np.var(y))
print(np.std(y) ** 2)

[[1.          0.99374931]
 [0.99374931 1.          ]]
0.9937493134584551
-0.020219724397254404
0.9330621750073689
0.9330621750073688

```

2.3.2 Graphics

matplotlib library has a number of functions to plot data in Python. It is possible to view graphs on screen or save them in file for inclusion in a document.

```

import numpy as np
import matplotlib          # only if we need to save figure in file
matplotlib.use('Agg')      # only to save figure in file
import matplotlib.pyplot as plt

x = np.random.normal(size=100)
y = np.random.normal(size=100)
plt.plot(x, y)
plt.xlabel('This is x-axis')
plt.ylabel('This is y-axis')
plt.title('Plot of X vs Y')

plt.savefig('xyPlot.png')  # only to save figure in a file

```

numpy function `linspace` can be used to create a sequence between a start and an end of a given length.

```

import numpy as np

```

```

import matplotlib.pyplot as plt

x = np.linspace(-np.pi, np.pi, num=50)
y = x
xx, yy = np.meshgrid(x, y)
zz = np.cos(yy) / (1 + xx ** 2)

plt.contour(xx, yy, zz)

fig, ax = plt.subplots()
zza = (zz - zz.T) / 2.0
CS = ax.contour(xx, yy, zza)
ax.clabel(CS, inline=1)

```

2.3.3 Indexing Data

To access elements of an array, specify indexes inside square brackets. It is possible to access multiple rows and columns. `shape` method gives number of rows followed by number of columns.

```

import numpy as np

A = np.array(np.arange(1, 17))
A = A.reshape(4, 4, order='F')
print(A)
print(A[1, 2])
print(A[(0, 2), (1, 3)])          # does not work
print(A[range(0, 3), range(1, 4)]) # does not work
print(A[range(0, 2), :])
print(A[:, range(0, 2)])
print(A.shape)

[[ 1  5  9 13]
 [ 2  6 10 14]
 [ 3  7 11 15]
 [ 4  8 12 16]]
10
[ 5 15]
[ 5 10 15]
[[ 1  5  9 13]
 [ 2  6 10 14]]

```

```
[[1 5]
 [2 6]
 [3 7]
 [4 8]]
(4, 4)
```

2.3.4 Loading Data

pandas library provides `read_csv` function to read files with data in rectangular shape.

```
import pandas as pd
Auto = pd.read_csv('data/Auto.csv')
print(Auto.head())
print(Auto.shape)
print(Auto.columns)
```

	mpg	cylinders	displacement	...	year	origin	name
0	18.0	8	307.0	...	70	1	chevrolet chevelle malibu
1	15.0	8	350.0	...	70	1	buick skylark 320
2	18.0	8	318.0	...	70	1	plymouth satellite
3	16.0	8	304.0	...	70	1	amc rebel sst
4	17.0	8	302.0	...	70	1	ford torino

```
[5 rows x 9 columns]
```

```
(397, 9)
```

```
Index(['mpg', 'cylinders', 'displacement', 'horsepower', 'weight',
       'acceleration', 'year', 'origin', 'name'],
      dtype='object')
```

To load data from an R library, use `get_rdataset` function from `statsmodels`. This function seems to work only if the computer is connected to the internet.

```
from statsmodels import datasets
carseats = datasets.get_rdataset('Carseats', package='ISLR').data
print(carseats.shape)
print(carseats.columns)
```

```
(400, 11)
```

```
Index(['Sales', 'CompPrice', 'Income', 'Advertising', 'Population', 'Price',
       'ShelveLoc', 'Age', 'Education', 'Urban', 'US'],
      dtype='object')
```

2.3.5 Additional Graphical and Numerical Summaries

plot method can be directly applied to a pandas dataframe.

```
import pandas as pd
Auto = pd.read_csv('data/Auto.csv')
Auto.boxplot(column='mpg', by='cylinders', grid=False)
```

hist method can be applied to plot a histogram.

```
import pandas as pd
Auto = pd.read_csv('data/Auto.csv')
Auto.hist(column='mpg')
Auto.hist(column='mpg', color='red')
Auto.hist(column='mpg', color='red', bins=15)
```

For pairs plot, use scatter_matrix method in pandas.plotting.

```
import pandas as pd
from pandas import plotting
Auto = pd.read_csv('data/Auto.csv')
plotting.scatter_matrix(Auto[['mpg', 'displacement', 'horsepower', 'weight',
                             'acceleration']])
```

On pandas dataframes, describe method produces a summary of each variable.

```
import pandas as pd
Auto = pd.read_csv('data/Auto.csv')
print(Auto.describe())
```

	mpg	cylinders	...	year	origin
count	397.000000	397.000000	...	397.000000	397.000000
mean	23.515869	5.458438	...	75.994962	1.574307
std	7.825804	1.701577	...	3.690005	0.802549
min	9.000000	3.000000	...	70.000000	1.000000
25%	17.500000	4.000000	...	73.000000	1.000000
50%	23.000000	4.000000	...	76.000000	1.000000
75%	29.000000	8.000000	...	79.000000	2.000000
max	46.600000	8.000000	...	82.000000	3.000000

[8 rows x 7 columns]

3 Linear Regression

3.1 Simple Linear Regression

Figure 17 displays the simple linear regression fit to the **Advertising** data, where $\hat{\beta}_0 = 0.0475$ and $\hat{\beta}_1 = 7.0326$.



Figure 17: For the **Advertising** data, the least squares fit for the regression of **sales** onto **TV** is shown. The fit is found by minimizing the sum of squared errors. Each grey line represents an error, and the fit makes a compromise by averaging their squares. In this case a linear fit captures the essence of the relationship, although it is somewhat deficient in the left of the plot.

In figure 18, we have computed RSS for a number of values of β_0 and β_1 , using the advertising data with **sales** as the response and **TV** as the predictor.

The left-hand panel of figure 19 displays *population regression line* and *least squares line* for a simple simulated example. The red line in the left-hand panel displays the *true* relationship, $f(X) = 2 + 3X$, while the blue line is the least squares estimate based on observed data. In the right-hand panel of figure 19 we have generated five different data sets from the model $Y = 2 + 3X + \epsilon$ and plotted the corresponding five least squares lines.

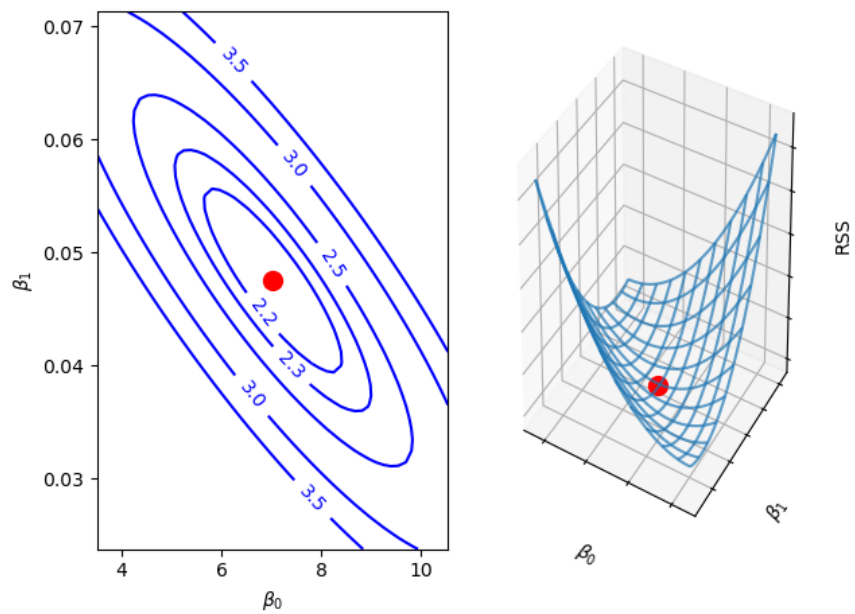


Figure 18: Contour and three-dimensional plots of the RSS on the **Advertising** data, using **sales** as the response and **TV** as the predictor. The red dots correspond to the least squares estimates $\hat{\beta}_0$ and $\hat{\beta}_1$.



Figure 19: A simulated data set. Left: The red line represents the true relationship, $f(X) = 2 + 3X$, which is known as the population regression line. The blue line is the least squares line; it is the least squares estimate for $f(X)$ based on the observed data, shown in grey circles. Right: The population regression line is again shown in red, and the least squares line in blue. In cyan, five least squares lines are shown, each computed on the basis of a separate random set of observations. Each least squares line is different, but on average, the least squares lines are quite close to the population regression line.

For **Advertising** data, this table provides details of the least squares model for the regression of number of units sold on TV advertising budget.

	Coef.	Std.Err.	t	P> t
Intercept	7.0326	0.4578	15.3603	0.0
TV	0.0475	0.0027	17.6676	0.0

In the next table 1, we report more information about the least squares model.

Table 1: For the **Advertising** data, more information about the least squares model for the regression of number of units sold on TV advertising budget.

Residual standard error	3.259
R^2	0.612
F-statistic	312.145

3.2 Multiple Linear Regression