

Deep Learning

We will demonstrate how to create deep neural nets with `keras`, which interfaces with `tensorflow`. This powerful tool is useful for applications such as automatic postal code recognition, a key feature in logistics systems for accurate deliveries.

```
library(keras)
```

```
## Warning: package 'keras' was built under R version 4.2.3
```

```
reticulate::use_condaenv(condaenv = "r-tensorflow")
```

A Multilayer Network on the MNIST Digit Data

The `keras` package includes various example datasets, such as the MNIST digit data. This dataset is frequently used for digit classification, which is essential for logistics tasks like reading postal codes.

```
mnist <- dataset_mnist()
x_train <- mnist$train$x
g_train <- mnist$train$y
x_test <- mnist$test$x
g_test <- mnist$test$y
dim(x_train)
```

```
## [1] 60000    28    28
```

```
dim(x_test)
```

```
## [1] 10000    28    28
```

The dataset includes 60,000 training images and 10,000 test images, each 28x28 pixels. These are stored in a 3D array, so we need to reshape them into a matrix format. Additionally, we need to “one-hot” encode the labels. Fortunately, `keras` provides convenient functions to handle this.

```
x_train <- array_reshape(x_train, c(nrow(x_train), 784))
x_test <- array_reshape(x_test, c(nrow(x_test), 784))
y_train <- to_categorical(g_train, 10)
y_test <- to_categorical(g_test, 10)
```

Neural networks are sensitive to input scaling. For example, digit values in postal codes (ranging from 0 to 255) must be rescaled to the $[0, 1]$ range for optimal performance.

```
x_train <- x_train / 255
x_test <- x_test / 255
```

Now, we are ready to define and fit our neural network model.

```

modelnn <- keras_model_sequential()
modelnn %>%
  layer_dense(input_shape = c(784), units = 256, activation = "relu") %>%
  layer_dropout(rate = 0.4) %>%
  layer_dense(units = 128, activation = "relu") %>%
  layer_dropout(rate = 0.3) %>%
  layer_dense(units = 10, activation = "softmax")

```

The first layer converts the 784 input units (from the reshaped images) to a hidden layer with 256 units using the ReLU activation. This structure is typical for tasks like postal code digit recognition in delivery systems.

```
summary(modelnn)
```

```

## Model: "sequential"
## -----
## Layer (type)                Output Shape          Param #
## =====
## dense_2 (Dense)              (None, 256)           200960
## dropout_1 (Dropout)          (None, 256)           0
## dense_1 (Dense)              (None, 128)           32896
## dropout (Dropout)            (None, 128)           0
## dense (Dense)                (None, 10)            1290
## =====
## Total params: 235146 (918.54 KB)
## Trainable params: 235146 (918.54 KB)
## Non-trainable params: 0 (0.00 Byte)
## -----

```

The model has 235,146 parameters, including a bias term in each layer. This is essential for fine-tuning the network to perform well on tasks like postal code classification.

Next, we define the fitting process, where we will minimize the cross-entropy loss function, commonly used in classification tasks.

```

modelnn %>% compile(loss = "categorical_crossentropy",
  optimizer = optimizer_rmsprop(), metrics = c("accuracy")
)

```

We are now ready to train the model using the prepared dataset. This step is crucial to teach the model to classify the digits.

```

system.time(
  history <- modelnn %>%
  #   fit(x_train, y_train, epochs = 30, batch_size = 128,
  #     fit(x_train, y_train, epochs = 15, batch_size = 128,
  #       validation_split = 0.2)
)

```

```

## Epoch 1/15
## 375/375 - 2s - loss: 0.4360 - accuracy: 0.8679 - val_loss: 0.1759 - val_accuracy: 0.9490 - 2s/epoch
## Epoch 2/15

```

```

## 375/375 - 1s - loss: 0.2000 - accuracy: 0.9411 - val_loss: 0.1273 - val_accuracy: 0.9634 - 1s/epoch
## Epoch 3/15
## 375/375 - 1s - loss: 0.1539 - accuracy: 0.9534 - val_loss: 0.1032 - val_accuracy: 0.9696 - 1s/epoch
## Epoch 4/15
## 375/375 - 1s - loss: 0.1300 - accuracy: 0.9613 - val_loss: 0.0937 - val_accuracy: 0.9731 - 1s/epoch
## Epoch 5/15
## 375/375 - 1s - loss: 0.1108 - accuracy: 0.9664 - val_loss: 0.0929 - val_accuracy: 0.9722 - 1s/epoch
## Epoch 6/15
## 375/375 - 1s - loss: 0.1022 - accuracy: 0.9690 - val_loss: 0.0865 - val_accuracy: 0.9758 - 1s/epoch
## Epoch 7/15
## 375/375 - 1s - loss: 0.0926 - accuracy: 0.9723 - val_loss: 0.0832 - val_accuracy: 0.9768 - 1s/epoch
## Epoch 8/15
## 375/375 - 1s - loss: 0.0874 - accuracy: 0.9735 - val_loss: 0.0819 - val_accuracy: 0.9783 - 1s/epoch
## Epoch 9/15
## 375/375 - 1s - loss: 0.0823 - accuracy: 0.9754 - val_loss: 0.0843 - val_accuracy: 0.9768 - 1s/epoch
## Epoch 10/15
## 375/375 - 1s - loss: 0.0752 - accuracy: 0.9778 - val_loss: 0.0819 - val_accuracy: 0.9798 - 1s/epoch
## Epoch 11/15
## 375/375 - 1s - loss: 0.0746 - accuracy: 0.9773 - val_loss: 0.0854 - val_accuracy: 0.9776 - 1s/epoch
## Epoch 12/15
## 375/375 - 1s - loss: 0.0707 - accuracy: 0.9791 - val_loss: 0.0885 - val_accuracy: 0.9778 - 1s/epoch
## Epoch 13/15
## 375/375 - 1s - loss: 0.0661 - accuracy: 0.9804 - val_loss: 0.0885 - val_accuracy: 0.9796 - 1s/epoch
## Epoch 14/15
## 375/375 - 1s - loss: 0.0642 - accuracy: 0.9810 - val_loss: 0.0843 - val_accuracy: 0.9802 - 1s/epoch
## Epoch 15/15
## 375/375 - 1s - loss: 0.0614 - accuracy: 0.9811 - val_loss: 0.0861 - val_accuracy: 0.9799 - 1s/epoch

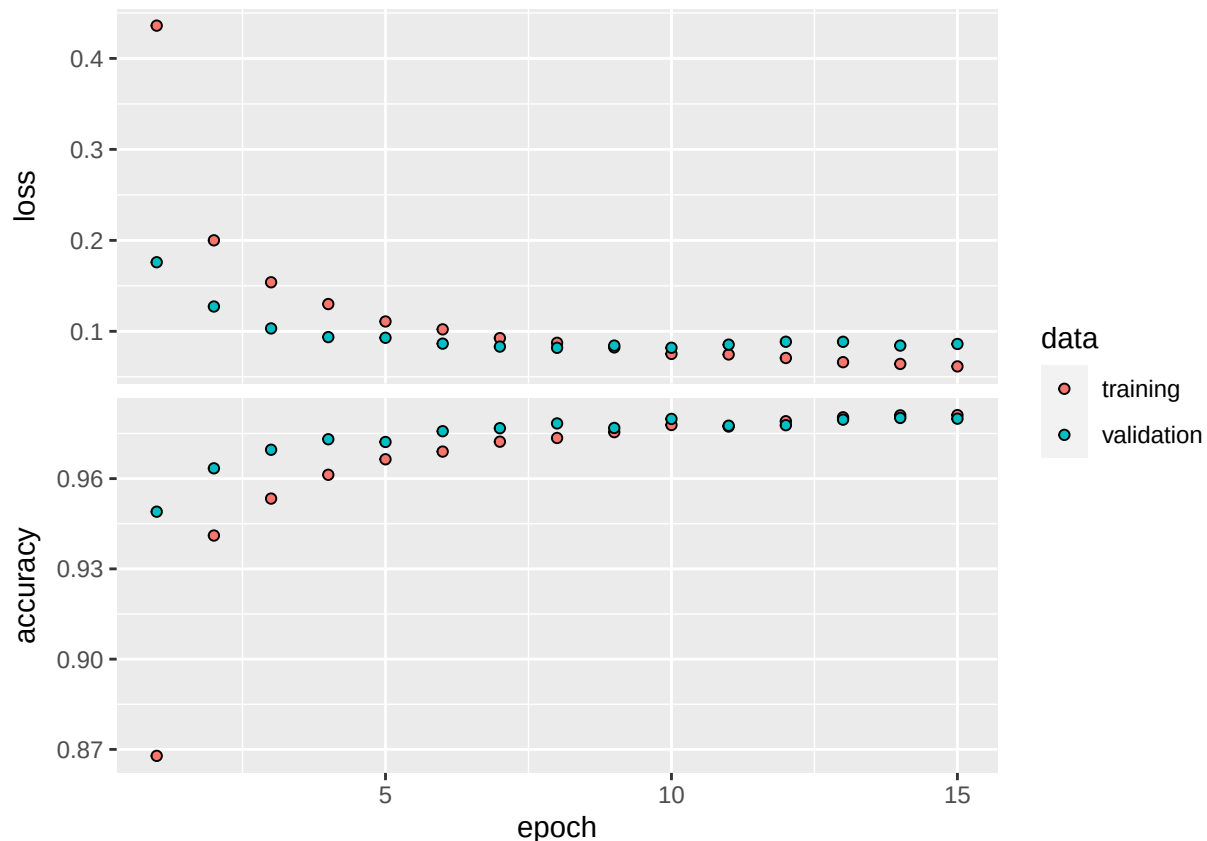
##      user  system elapsed
##  14.27    0.42   18.91

```

```

plot(history, smooth = FALSE)

```



The validation split of 20% means the model trains on 80% of the data. Training time is essential to ensure the model performs well when applied to logistics systems, especially for digit classification tasks like postal code reading.

We then evaluate the model on the test set to see how well it generalizes.

```
accuracy <- function(pred, truth)
  mean(drop(as.numeric(pred)) == drop(truth))
modelnn %>% predict(x_test) %>% k_argmax() %>% accuracy(g_test)
```

```
## 313/313 - 0s - 332ms/epoch - 1ms/step
```

```
## [1] 0.9809
```

In logistics, it's important to visualize predictions, such as how well the model can classify postal codes.

```
modelnn %>% predict(x_test) %>% head() # Probability outputs, with one column showing a 100% probability
```

```
## 313/313 - 0s - 284ms/epoch - 908us/step
```

```
##           [,1]           [,2]           [,3]           [,4]           [,5]
## [1,] 1.222817e-14 3.812991e-14 8.086725e-10 9.864739e-08 6.428444e-16
## [2,] 8.493846e-14 1.514190e-07 9.999999e-01 2.035035e-09 2.322184e-19
## [3,] 1.530981e-09 9.999717e-01 8.296066e-07 1.519564e-07 2.105939e-06
## [4,] 9.999928e-01 1.493719e-10 5.035884e-06 3.127053e-08 2.041281e-08
```

```
## [5,] 2.644310e-08 1.262869e-09 1.987995e-07 2.162301e-09 9.976112e-01
## [6,] 8.531426e-11 9.999880e-01 3.060572e-08 7.009499e-09 3.991508e-07
##      [,6]      [,7]      [,8]      [,9]     [,10]
## [1,] 1.187227e-13 8.425289e-21 9.999999e-01 9.845001e-16 9.878964e-10
## [2,] 1.606945e-14 5.850592e-14 5.571261e-14 7.706228e-10 2.259606e-21
## [3,] 2.457005e-08 1.345594e-07 1.084966e-05 1.416526e-05 5.244272e-09
## [4,] 1.759811e-08 7.012583e-07 1.006028e-06 8.292285e-09 4.163659e-07
## [5,] 1.631197e-09 1.523727e-09 3.646911e-06 9.714764e-09 2.384996e-03
## [6,] 2.876477e-10 2.881492e-09 1.112503e-05 4.910660e-07 1.140373e-09
```

```
(prognose <- modelnn %>% predict(x_test) %>% k_argmax() %>% drop() %>% as.numeric())
```

```
## 313/313 - 0s - 273ms/epoch - 872us/step
```

```
##      [1] 7 2 1 0 4 1 4 9 5 9 0 6 9 0 1 5 9 7 3 4 9 6 6 5 4 0 7 4 0 1 3 1 3 4 7 2
##      [37] 7 1 2 1 1 7 4 2 3 5 1 2 4 4 6 3 5 5 6 0 4 1 9 5 7 8 9 3 7 4 6 4 3 0 7 0
##      [73] 2 9 1 7 3 2 9 7 7 6 2 7 8 4 7 3 6 1 3 6 9 3 1 4 1 7 6 9 6 0 5 4 9 9 2 1
##     [109] 9 4 8 7 3 9 7 4 4 4 9 2 5 4 7 6 7 9 0 5 8 5 6 6 5 7 8 1 0 1 6 4 6 7 3 1
##     [145] 7 1 8 2 0 3 9 9 5 5 1 5 6 0 3 4 4 6 5 4 6 5 4 5 1 4 4 7 2 3 2 7 1 8 1 8
##     [181] 1 8 5 0 8 9 2 5 0 1 1 1 0 9 0 3 1 6 4 2 3 6 1 1 1 3 9 5 2 9 4 5 9 3 9 0
##     [217] 3 6 5 5 7 2 2 7 1 2 8 4 1 7 3 3 8 8 7 9 2 2 4 1 5 9 8 7 2 3 0 2 4 2 4 1
##     [253] 9 5 7 7 2 8 2 0 8 5 7 7 9 1 8 1 8 0 3 0 1 9 9 4 1 8 2 1 2 9 7 5 9 2 6 4
##     [289] 1 5 8 2 9 2 0 4 0 0 2 8 4 7 1 2 4 0 2 7 4 3 3 0 0 3 1 9 6 5 2 5 9 7 9 3
##     [325] 0 4 2 0 7 1 1 2 1 5 3 3 9 7 8 6 3 6 1 3 8 1 0 5 1 3 1 5 5 6 1 8 5 1 7 9
##     [361] 4 6 2 2 5 0 6 5 6 3 7 2 0 8 8 5 4 1 1 4 0 3 3 7 6 1 6 2 1 9 2 8 6 1 9 5
##     [397] 2 5 4 4 2 8 3 8 2 4 5 0 3 1 7 7 5 7 9 7 1 9 2 1 4 2 9 2 0 4 9 1 4 8 1 8
##     [433] 4 5 9 8 8 3 7 6 0 0 3 0 2 0 6 9 9 3 3 3 2 3 9 1 2 6 8 0 5 6 6 6 3 8 8 2
##     [469] 7 5 8 9 6 1 8 4 1 2 5 9 1 9 7 5 4 0 8 9 9 1 0 5 2 3 7 2 9 4 0 6 3 9 5 2
##     [505] 1 3 1 3 6 5 7 4 2 2 6 3 2 6 5 4 8 9 7 1 3 0 3 8 3 1 9 3 4 4 6 4 2 1 8 2
##     [541] 5 4 8 8 4 0 0 2 3 2 7 7 0 8 7 4 4 7 9 6 9 0 9 8 0 4 6 0 6 3 5 4 8 3 3 9
##     [577] 3 3 3 7 8 0 2 2 1 7 0 6 5 4 3 8 0 9 6 3 8 0 9 9 6 8 6 8 5 7 8 6 0 2 4 0
##     [613] 2 2 3 1 9 7 5 8 0 8 4 6 2 6 7 9 3 2 9 8 2 2 9 2 7 3 5 9 1 8 0 2 0 5 2 1
##     [649] 3 7 6 7 1 2 5 8 0 3 7 1 4 0 9 1 8 6 7 7 4 3 4 9 1 9 5 1 7 3 9 7 6 9 1 3
##     [685] 3 8 3 3 6 7 2 4 5 8 5 1 1 4 4 3 1 0 7 7 0 7 9 4 4 8 5 5 4 0 8 2 1 6 8 4
##     [721] 8 0 4 0 6 1 7 3 2 6 7 2 6 9 3 1 4 6 2 5 9 2 0 6 2 1 7 3 4 1 0 5 4 3 1 1
##     [757] 7 4 9 9 4 8 4 0 2 4 5 1 1 6 4 7 1 9 4 2 4 1 5 5 3 8 3 1 4 5 6 8 9 4 1 5
##     [793] 3 8 0 3 2 5 1 2 8 3 4 4 0 8 8 3 3 1 7 3 5 9 6 3 2 6 1 3 6 0 7 2 1 7 1 4
##     [829] 2 4 2 1 7 9 6 1 1 2 4 8 1 7 7 4 8 0 7 3 1 3 1 0 7 7 0 3 5 5 2 7 6 6 9 2
##     [865] 8 3 5 2 2 5 6 0 8 2 9 2 8 8 8 8 7 4 9 3 0 6 6 3 2 1 3 2 2 9 3 0 0 5 7 8
##     [901] 3 4 4 6 0 2 9 1 4 7 4 7 3 9 8 8 4 7 1 2 1 2 2 3 2 3 2 3 9 1 7 4 0 3 5 5
##     [937] 8 6 3 2 6 7 6 6 3 2 7 9 1 1 7 5 6 4 9 5 2 3 3 4 7 8 9 1 1 0 9 1 4 4 5 4
##     [973] 0 6 2 2 3 1 5 1 2 0 3 8 1 2 6 7 1 6 2 3 9 0 1 2 2 0 8 9 9 0 2 5 1 9 7 8
##    [1009] 1 0 4 1 7 9 5 4 2 6 8 1 3 7 5 4 4 1 8 1 3 8 1 2 5 8 0 6 2 1 1 7 1 5 3 4
##    [1045] 8 9 5 0 9 2 2 4 8 2 1 7 2 4 9 4 4 0 3 9 2 2 3 3 8 3 5 7 3 5 8 1 2 4 4 6
##    [1081] 4 9 5 1 0 6 9 5 9 5 9 7 3 8 0 3 7 1 3 6 7 8 5 9 7 9 6 9 6 3 7 4 6 5 3 5
##    [1117] 4 7 8 7 8 0 7 6 8 8 7 3 3 1 9 5 2 7 3 5 1 1 2 1 4 7 4 7 5 4 5 4 0 8 3 6
##    [1153] 9 6 0 2 7 4 4 4 4 6 6 4 7 9 3 4 5 5 8 7 3 7 2 7 0 2 4 1 1 6 8 9 2 8 7 2
##    [1189] 0 1 5 0 9 1 7 0 6 0 8 6 8 1 8 0 3 3 7 2 3 6 2 1 6 1 1 3 7 9 0 8 0 5 4 0
##    [1225] 4 8 2 2 9 8 4 0 9 5 8 5 1 2 1 3 1 7 9 5 7 2 0 3 8 8 6 2 5 4 1 9 2 1 5 8
##    [1261] 7 0 2 4 4 3 6 8 8 2 4 0 5 0 4 4 7 9 3 4 1 5 9 7 3 5 8 8 0 9 3 3 6 6 0 1
##    [1297] 6 0 3 7 4 4 1 2 9 1 4 6 9 9 3 9 8 4 4 3 1 3 1 3 8 7 9 4 8 8 7 9 9 1 4 5
##    [1333] 6 0 5 2 2 2 1 5 5 2 4 9 6 2 7 7 2 2 1 1 2 8 3 7 2 4 1 7 1 7 6 7 8 2 7 3
##    [1369] 1 7 5 8 2 6 2 2 5 6 5 0 9 2 4 3 3 9 7 6 6 8 0 4 1 3 8 2 9 1 8 0 6 7 2 1
```

```

## [1405] 0 5 5 2 0 2 2 0 2 4 7 8 0 9 9 4 6 5 4 9 1 8 3 4 9 9 1 2 2 8 1 9 6 4 0 9
## [1441] 4 8 3 8 6 0 2 5 1 9 6 2 9 4 0 9 6 0 6 2 5 4 2 3 8 4 5 5 0 3 8 5 3 5 8 6
## [1477] 5 7 6 3 3 9 6 1 1 2 9 0 4 3 3 6 9 5 7 3 7 7 7 8 3 9 8 3 0 7 2 7 9 4 5 4
## [1513] 9 3 2 1 4 0 2 3 7 5 9 8 8 5 0 5 1 4 7 3 9 0 0 0 6 6 2 3 7 8 4 7 7 9 2 4
## [1549] 1 6 5 2 4 9 9 1 8 4 0 9 8 4 8 7 7 0 7 8 8 6 0 4 8 8 2 4 7 6 6 6 4 7 1 8
## [1585] 8 2 3 6 3 0 0 3 7 6 9 7 9 9 5 4 3 3 6 1 2 3 7 3 3 2 0 3 3 8 4 3 6 3 5 0
## [1621] 2 0 9 0 7 4 6 9 3 5 1 9 6 1 4 5 4 5 0 5 9 5 2 1 2 9 1 9 9 4 0 8 4 5 2 9
## [1657] 2 1 2 1 7 3 6 8 8 4 9 1 9 8 5 7 5 1 1 8 6 5 2 4 4 7 2 3 5 6 8 8 6 2 3 1
## [1693] 0 5 8 9 2 9 6 7 0 4 8 7 1 7 4 1 0 3 7 2 0 0 9 1 7 8 7 8 4 7 2 0 4 6 0 3
## [1729] 1 1 3 3 9 6 7 4 1 5 3 0 8 7 3 9 6 9 3 5 0 2 7 2 5 1 2 5 8 0 8 8 1 5 0 3
## [1765] 0 3 1 4 0 3 7 2 7 1 8 0 7 0 4 3 1 9 8 7 7 1 4 9 9 3 7 1 7 9 0 2 0 3 3 7
## [1801] 6 9 2 3 3 7 7 0 0 7 5 2 9 8 7 4 4 2 6 6 1 9 6 8 2 9 0 8 3 1 1 6 3 5 1 1
## [1837] 1 3 1 2 3 0 2 0 1 3 5 5 7 4 9 9 6 9 6 8 3 6 6 8 5 1 4 2 4 4 5 1 1 9 0 2
## [1873] 4 9 5 7 1 8 3 5 6 9 8 7 1 1 6 7 6 3 2 2 0 8 9 2 5 1 0 8 1 4 5 7 9 6 9 0
## [1909] 6 1 5 5 8 3 8 2 6 5 0 7 4 6 1 3 4 7 3 2 3 4 2 5 2 7 1 7 2 6 4 1 5 7 8 6
## [1945] 0 1 8 2 5 7 7 6 9 3 5 8 4 2 4 0 8 8 3 4 9 2 7 5 8 6 5 6 0 8 6 7 3 6 4 9
## [1981] 4 6 6 3 2 4 1 0 1 4 6 2 9 1 1 0 6 3 9 5 6 5 6 5 9 4 6 4 3 9 1 3 4 1 9 1
## [2017] 2 1 1 9 3 5 4 0 9 3 6 1 7 5 5 3 3 0 1 5 7 5 8 6 5 1 0 8 2 3 4 6 7 9 8 1
## [2053] 8 9 9 2 8 6 2 7 0 0 6 7 5 8 6 0 9 3 7 1 3 5 4 3 3 5 5 6 3 0 2 3 4 2 3 0
## [2089] 9 9 4 7 2 8 4 7 0 6 0 8 5 2 8 5 7 3 0 8 2 7 2 8 2 5 5 7 6 4 6 8 4 8 2 7
## [2125] 4 5 2 0 3 9 9 6 7 2 5 1 1 1 2 3 6 7 8 7 6 4 8 9 4 8 6 3 8 3 1 0 6 2 2 5
## [2161] 6 9 8 8 1 4 1 7 8 4 6 1 8 4 3 1 2 8 0 8 5 9 2 4 2 0 2 7 0 1 0 2 5 7 6 7
## [2197] 9 4 2 6 2 4 4 8 0 4 4 5 8 0 6 8 9 8 5 6 9 0 4 8 7 1 3 4 5 8 0 9 1 3 3 6
## [2233] 9 8 7 1 0 5 7 1 7 5 2 7 9 1 8 5 2 4 9 4 7 2 2 3 4 9 1 9 2 1 7 9 4 4 1 6
## [2269] 7 2 7 8 8 1 9 7 1 1 7 5 3 3 5 1 3 7 6 1 3 8 7 3 9 6 0 0 2 8 8 2 3 7 1 3
## [2305] 0 3 4 4 3 8 9 2 3 9 7 1 1 7 0 4 9 6 5 9 1 3 0 2 0 0 4 6 7 0 7 1 4 6 4 5
## [2341] 4 9 9 1 7 9 5 3 3 8 2 3 6 2 2 1 1 1 1 1 6 9 8 4 3 7 1 6 4 8 0 9 7 4 2 4
## [2377] 0 7 0 1 9 8 8 6 0 0 4 1 6 8 2 2 3 8 4 8 2 2 1 7 5 4 4 0 4 3 1 7 3 1 0 1
## [2413] 2 5 9 2 1 0 1 8 9 1 4 8 3 8 9 3 6 2 8 3 2 2 1 0 4 2 9 2 4 3 7 9 1 5 2 9
## [2449] 9 0 3 8 5 3 5 0 9 4 6 2 5 0 2 7 4 6 6 8 6 6 8 6 9 1 7 2 5 9 9 0 7 2 7 6
## [2485] 7 0 6 5 4 4 7 2 0 9 9 2 2 9 4 4 2 3 3 2 1 7 0 7 6 4 1 3 8 7 9 5 9 2 5 1
## [2521] 8 7 3 7 1 5 5 0 9 1 4 0 6 3 3 6 0 4 9 7 5 1 6 8 9 5 5 7 9 3 8 3 8 1 5 3
## [2557] 5 0 5 5 3 8 6 7 7 7 3 7 0 5 9 0 2 5 5 3 1 7 7 8 6 5 9 3 8 9 5 3 7 9 1 7
## [2593] 0 0 3 7 2 3 8 1 8 6 2 9 5 7 5 1 8 6 2 5 1 4 8 4 5 8 3 0 6 2 7 3 3 2 1 0
## [2629] 7 3 4 0 3 9 3 2 8 9 0 3 8 0 7 6 5 4 7 3 0 0 8 6 2 5 1 1 0 0 4 4 0 1 2 3
## [2665] 2 7 7 8 5 2 5 7 6 9 1 4 1 6 4 2 4 3 5 4 3 9 5 0 1 5 3 8 9 1 9 7 9 5 5 2
## [2701] 7 4 6 0 1 1 1 0 4 4 7 6 3 0 0 4 3 0 6 1 9 6 1 3 8 1 2 5 6 2 7 3 6 0 1 9
## [2737] 7 6 6 8 9 2 9 5 8 3 1 0 0 7 6 6 2 1 6 9 3 1 8 6 9 0 6 0 0 0 6 3 5 9 3 4
## [2773] 5 5 8 5 3 0 4 0 2 9 6 8 2 3 1 2 1 1 5 6 9 8 0 6 6 5 5 3 8 6 2 1 4 5 4 3
## [2809] 7 8 3 0 9 3 5 1 1 0 4 4 7 0 1 7 0 1 6 1 4 5 6 6 5 7 8 4 4 7 2 5 3 7 0 7
## [2845] 7 9 6 4 2 8 5 7 8 3 9 5 8 9 9 8 6 2 8 9 2 3 6 1 1 8 9 3 4 0 7 9 6 7 1 4
## [2881] 1 3 4 9 3 1 4 7 7 4 7 2 9 3 0 8 8 8 4 0 4 4 1 5 2 8 3 4 9 5 2 8 1 5 3 7
## [2917] 9 4 2 5 6 2 5 9 3 5 9 2 1 9 5 3 0 6 9 8 4 0 4 7 2 9 0 1 0 3 1 6 5 8 1 5
## [2953] 3 5 0 3 5 5 9 2 8 7 0 4 9 1 9 7 7 5 3 2 0 9 1 8 6 2 3 9 6 2 1 9 1 3 5 5
## [2989] 0 3 8 3 3 7 6 6 0 1 4 0 6 9 8 1 2 9 9 5 9 7 3 7 8 0 1 3 0 4 6 1 0 2 5 8
## [3025] 4 4 1 1 5 4 8 6 0 6 9 2 6 2 7 1 7 9 4 0 0 3 8 2 2 3 1 6 0 5 7 7 9 2 6 7
## [3061] 7 7 8 6 8 8 4 6 8 4 1 2 8 2 3 9 4 0 3 7 3 2 3 3 7 3 4 0 6 2 0 8 1 5 3 5
## [3097] 4 1 7 1 5 7 5 7 3 2 2 7 3 7 3 7 8 5 4 5 2 9 6 5 3 6 7 4 1 7 1 5 2 3 6 3
## [3133] 1 4 2 6 7 4 3 8 0 6 2 1 6 5 3 9 1 9 3 2 1 8 4 4 6 5 8 6 9 7 7 8 6 9 7 3
## [3169] 9 4 0 5 4 6 4 1 2 3 0 0 2 6 6 5 7 0 8 6 4 7 9 0 7 3 4 2 1 8 8 5 9 2 7 1
## [3205] 8 8 8 2 7 6 0 1 2 7 1 0 8 3 6 0 5 3 6 2 8 7 0 1 4 2 1 1 4 4 4 4 7 1 6 2
## [3241] 9 9 0 0 1 8 8 4 3 4 2 0 6 1 6 1 2 2 2 1 2 3 7 8 1 0 0 2 1 6 6 0 1 6 2 5
## [3277] 1 7 4 8 2 1 4 3 8 3 9 9 4 9 3 4 7 2 7 5 7 0 4 3 3 2 6 7 6 0 0 6 7 7 0 5
## [3313] 5 8 1 0 7 0 2 8 1 5 0 8 8 0 3 2 7 7 2 6 4 7 5 5 9 2 9 2 8 4 6 8 6 5 0 0

```

```

## [3349] 8 7 6 1 7 1 1 2 7 4 0 0 7 7 6 3 8 6 4 2 0 9 4 0 5 7 8 2 7 4 7 1 1 3 6 6
## [3385] 6 9 1 9 4 8 3 6 9 5 9 6 2 4 6 7 7 0 6 6 9 4 8 3 5 3 4 9 0 0 5 2 5 0 7 1
## [3421] 1 1 6 7 6 7 9 6 6 4 1 4 3 1 1 2 2 4 1 0 8 2 6 3 4 0 0 6 3 3 0 7 1 7 1 1
## [3457] 3 1 0 9 9 7 5 4 1 4 8 9 5 3 5 1 9 8 2 7 3 9 9 0 1 0 2 9 3 9 3 3 6 2 9 9
## [3493] 8 3 7 4 0 4 7 8 4 9 8 1 9 7 5 9 2 8 2 2 0 2 2 3 8 4 6 8 4 8 2 4 6 7 9 3
## [3529] 3 9 4 3 1 9 4 7 0 5 9 6 0 4 4 4 4 6 1 2 3 2 6 4 5 9 6 8 5 6 0 8 6 4 1 8
## [3565] 6 5 2 8 4 5 5 4 7 7 0 7 8 2 2 3 7 0 1 8 0 7 1 9 8 7 5 5 9 1 7 5 4 3 1 2
## [3601] 2 1 6 6 7 1 1 4 0 7 4 2 4 0 6 4 7 6 9 5 3 4 6 5 0 1 8 8 2 8 3 5 7 8 0 8
## [3637] 5 7 1 1 0 1 3 7 8 5 0 7 1 1 0 1 1 4 5 2 7 6 2 3 0 2 8 5 9 6 9 7 2 1 3 6
## [3673] 4 1 8 2 4 0 5 1 0 2 2 6 4 4 3 9 6 1 6 5 7 9 2 0 2 6 0 1 4 3 5 2 8 8 0 8
## [3709] 8 9 0 9 6 7 6 3 9 3 9 7 7 7 4 9 0 6 4 4 4 2 7 2 8 1 0 0 7 8 3 3 3 1 3 7
## [3745] 6 1 3 1 6 6 5 7 4 7 5 9 5 8 4 9 9 1 6 5 0 1 3 7 0 3 4 8 2 2 0 2 8 1 5 1
## [3781] 6 8 8 9 1 2 1 3 5 1 0 9 4 4 8 3 8 5 9 7 6 6 2 0 0 0 5 8 8 1 5 3 3 8 5 1
## [3817] 8 2 4 4 9 9 6 2 3 3 5 6 4 8 0 9 2 8 3 6 7 5 1 2 9 4 9 1 2 8 6 0 7 0 9 1
## [3853] 1 6 7 5 9 9 1 9 5 9 2 5 0 4 1 0 8 9 0 8 9 8 9 4 2 5 7 9 8 9 8 0 9 9 6 8
## [3889] 9 9 5 9 8 5 1 0 3 3 5 2 1 6 5 0 2 8 2 5 6 2 3 0 2 2 6 4 3 5 5 1 7 2 1 6
## [3925] 9 1 9 9 5 5 1 6 2 2 8 6 7 1 4 6 0 6 0 5 3 2 2 3 6 8 9 8 5 3 8 5 4 5 2 0
## [3961] 5 6 3 2 8 3 9 9 5 7 9 4 6 7 1 3 7 3 6 6 0 9 0 1 9 9 2 8 8 0 1 6 9 7 5 3
## [3997] 4 7 4 9 9 4 3 6 3 1 1 7 6 9 1 8 4 1 1 9 9 4 3 6 8 1 6 0 4 1 3 7 7 4 9 5
## [4033] 1 0 0 1 1 6 2 1 9 8 4 0 3 6 4 9 0 7 1 6 5 7 5 2 5 1 8 5 4 7 0 6 7 9 2 5
## [4069] 8 1 0 4 5 7 1 8 5 1 3 0 0 6 0 7 3 1 8 3 9 7 0 0 8 9 5 9 8 3 2 7 2 9 7 2
## [4105] 1 1 3 7 5 3 1 9 8 2 2 2 8 8 5 7 3 8 9 8 8 6 8 2 3 9 7 5 6 2 9 2 8 8 1 6
## [4141] 2 8 7 9 1 8 0 1 7 2 0 7 5 1 9 0 2 0 9 8 6 2 3 0 3 8 0 2 1 1 1 1 4 2 9 7
## [4177] 7 5 1 1 2 1 9 9 9 1 0 2 0 2 1 1 4 6 4 1 5 4 9 9 7 7 5 6 2 2 2 8 0 6 9 6
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Comparing the predicted labels with the true labels helps assess how well the model is classifying postal codes.

prognose

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## [9973] 4 9 4 3 6 4 1 7 2 6 5 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6

```

```
cor(prognose,g_test)
```

```
## [1] 0.9782303
```

In logistics, accurate digit classification (e.g., postal codes) is crucial for optimizing delivery processes and

ensuring correct package routing.

For simpler tasks, we can use a multiclass logistic regression model, which is faster but less complex than the previous neural network.

```
modellr <- keras_model_sequential() %>%  
  layer_dense(input_shape = 784, units = 10,  
              activation = "softmax")  
summary(modellr)
```

```
## Model: "sequential_1"  
##  
## -----  
## Layer (type)                Output Shape          Param #  
## -----  
## dense_3 (Dense)             (None, 10)            7850  
## -----  
## Total params: 7850 (30.66 KB)  
## Trainable params: 7850 (30.66 KB)  
## Non-trainable params: 0 (0.00 Byte)  
## -----
```

The training process is similar, but the architecture is simpler, making it faster for less demanding tasks.

```
modellr %>% compile(loss = "categorical_crossentropy",  
                  optimizer = optimizer_rmsprop(), metrics = c("accuracy"))  
modellr %>% fit(x_train, y_train, epochs = 30,  
              batch_size = 128, validation_split = 0.2)
```

```
## Epoch 1/30  
## 375/375 - 1s - loss: 0.6763 - accuracy: 0.8314 - val_loss: 0.3610 - val_accuracy: 0.9039 - 831ms/epoch  
## Epoch 2/30  
## 375/375 - 0s - loss: 0.3542 - accuracy: 0.9019 - val_loss: 0.3104 - val_accuracy: 0.9162 - 493ms/epoch  
## Epoch 3/30  
## 375/375 - 1s - loss: 0.3182 - accuracy: 0.9113 - val_loss: 0.2978 - val_accuracy: 0.9168 - 559ms/epoch  
## Epoch 4/30  
## 375/375 - 0s - loss: 0.3020 - accuracy: 0.9151 - val_loss: 0.2839 - val_accuracy: 0.9232 - 493ms/epoch  
## Epoch 5/30  
## 375/375 - 1s - loss: 0.2921 - accuracy: 0.9178 - val_loss: 0.2812 - val_accuracy: 0.9214 - 541ms/epoch  
## Epoch 6/30  
## 375/375 - 0s - loss: 0.2857 - accuracy: 0.9198 - val_loss: 0.2747 - val_accuracy: 0.9246 - 487ms/epoch  
## Epoch 7/30  
## 375/375 - 0s - loss: 0.2806 - accuracy: 0.9213 - val_loss: 0.2723 - val_accuracy: 0.9261 - 485ms/epoch  
## Epoch 8/30  
## 375/375 - 0s - loss: 0.2767 - accuracy: 0.9228 - val_loss: 0.2704 - val_accuracy: 0.9247 - 486ms/epoch  
## Epoch 9/30  
## 375/375 - 0s - loss: 0.2733 - accuracy: 0.9240 - val_loss: 0.2697 - val_accuracy: 0.9260 - 478ms/epoch  
## Epoch 10/30  
## 375/375 - 0s - loss: 0.2705 - accuracy: 0.9251 - val_loss: 0.2697 - val_accuracy: 0.9258 - 486ms/epoch  
## Epoch 11/30  
## 375/375 - 0s - loss: 0.2682 - accuracy: 0.9254 - val_loss: 0.2664 - val_accuracy: 0.9275 - 484ms/epoch  
## Epoch 12/30  
## 375/375 - 1s - loss: 0.2664 - accuracy: 0.9262 - val_loss: 0.2662 - val_accuracy: 0.9277 - 526ms/epoch  
## Epoch 13/30
```

```

## 375/375 - 0s - loss: 0.2648 - accuracy: 0.9266 - val_loss: 0.2664 - val_accuracy: 0.9275 - 482ms/epoch
## Epoch 14/30
## 375/375 - 0s - loss: 0.2631 - accuracy: 0.9275 - val_loss: 0.2665 - val_accuracy: 0.9273 - 479ms/epoch
## Epoch 15/30
## 375/375 - 0s - loss: 0.2615 - accuracy: 0.9279 - val_loss: 0.2653 - val_accuracy: 0.9275 - 485ms/epoch
## Epoch 16/30
## 375/375 - 0s - loss: 0.2603 - accuracy: 0.9278 - val_loss: 0.2649 - val_accuracy: 0.9287 - 477ms/epoch
## Epoch 17/30
## 375/375 - 0s - loss: 0.2593 - accuracy: 0.9287 - val_loss: 0.2630 - val_accuracy: 0.9289 - 476ms/epoch
## Epoch 18/30
## 375/375 - 0s - loss: 0.2583 - accuracy: 0.9292 - val_loss: 0.2630 - val_accuracy: 0.9287 - 481ms/epoch
## Epoch 19/30
## 375/375 - 0s - loss: 0.2572 - accuracy: 0.9292 - val_loss: 0.2644 - val_accuracy: 0.9288 - 480ms/epoch
## Epoch 20/30
## 375/375 - 0s - loss: 0.2560 - accuracy: 0.9298 - val_loss: 0.2637 - val_accuracy: 0.9281 - 478ms/epoch
## Epoch 21/30
## 375/375 - 0s - loss: 0.2553 - accuracy: 0.9300 - val_loss: 0.2628 - val_accuracy: 0.9297 - 478ms/epoch
## Epoch 22/30
## 375/375 - 0s - loss: 0.2545 - accuracy: 0.9303 - val_loss: 0.2634 - val_accuracy: 0.9293 - 481ms/epoch
## Epoch 23/30
## 375/375 - 0s - loss: 0.2537 - accuracy: 0.9303 - val_loss: 0.2620 - val_accuracy: 0.9301 - 484ms/epoch
## Epoch 24/30
## 375/375 - 0s - loss: 0.2532 - accuracy: 0.9305 - val_loss: 0.2634 - val_accuracy: 0.9296 - 480ms/epoch
## Epoch 25/30
## 375/375 - 0s - loss: 0.2524 - accuracy: 0.9306 - val_loss: 0.2625 - val_accuracy: 0.9297 - 485ms/epoch
## Epoch 26/30
## 375/375 - 0s - loss: 0.2517 - accuracy: 0.9308 - val_loss: 0.2645 - val_accuracy: 0.9283 - 481ms/epoch
## Epoch 27/30
## 375/375 - 0s - loss: 0.2510 - accuracy: 0.9316 - val_loss: 0.2635 - val_accuracy: 0.9293 - 486ms/epoch
## Epoch 28/30
## 375/375 - 0s - loss: 0.2505 - accuracy: 0.9318 - val_loss: 0.2633 - val_accuracy: 0.9302 - 475ms/epoch
## Epoch 29/30
## 375/375 - 0s - loss: 0.2499 - accuracy: 0.9317 - val_loss: 0.2621 - val_accuracy: 0.9298 - 481ms/epoch
## Epoch 30/30
## 375/375 - 0s - loss: 0.2494 - accuracy: 0.9317 - val_loss: 0.2620 - val_accuracy: 0.9312 - 481ms/epoch

```

```

modellr %>% predict(x_test) %>% k_argmax() %>% accuracy(g_test)

```

```

## 313/313 - 0s - 219ms/epoch - 700us/step

```

```

## [1] 0.9276

```

While this approach is faster, it may not be as effective on complex datasets like MNIST. However, it can still be useful for logistics applications where digit recognition is less complex but still necessary.