

This is a companion notebook for the book [Deep Learning with Python, Second Edition](#). For readability, it only contains runnable code blocks and section titles, and omits everything else in the book: text paragraphs, figures, and pseudocode.

If you want to be able to follow what's going on, I recommend reading the notebook side by side with your copy of the book.

This notebook was generated for TensorFlow 2.6.

▼ Working with Keras: A deep dive

A spectrum of workflows

▼ Different ways to build Keras models

▼ The Sequential model

The Sequential class

```
from tensorflow import keras
from tensorflow.keras import layers

model = keras.Sequential([
    layers.Dense(64, activation="relu"),
    layers.Dense(10, activation="softmax")
])
```

Incrementally building a Sequential model

```
model = keras.Sequential()
model.add(layers.Dense(64, activation="relu"))
model.add(layers.Dense(10, activation="softmax"))
```

Calling a model for the first time to build it

```
model.build(input_shape=(None, 3))
model.weights
```

The summary method

```
model.summary()
```

Naming models and layers with the `name` argument

```
model = keras.Sequential(name="my_example_model")
model.add(layers.Dense(64, activation="relu", name="my_first_layer"))
model.add(layers.Dense(10, activation="softmax", name="my_last_layer"))
model.build((None, 3))
model.summary()
```

Specifying the input shape of your model in advance

```
model = keras.Sequential()
model.add(keras.Input(shape=(3,)))
model.add(layers.Dense(64, activation="relu"))

model.summary()

model.add(layers.Dense(10, activation="softmax"))
model.summary()
```

▼ The Functional API

▼ A simple example

A simple Functional model with two Dense layers

```
inputs = keras.Input(shape=(3,), name="my_input")
features = layers.Dense(64, activation="relu")(inputs)
outputs = layers.Dense(10, activation="softmax")(features)
model = keras.Model(inputs=inputs, outputs=outputs)
```

```
inputs = keras.Input(shape=(3,), name="my_input")
```

```
inputs.shape
```

```
inputs.dtype
```

```
features = layers.Dense(64, activation="relu")(inputs)
```

```
features.shape
```

```

outputs = layers.Dense(10, activation="softmax")(features)
model = keras.Model(inputs=inputs, outputs=outputs)

model.summary()

```

▼ Multi-input, multi-output models

A multi-input, multi-output Functional model

```

vocabulary_size = 10000
num_tags = 100
num_departments = 4

title = keras.Input(shape=(vocabulary_size,), name="title")
text_body = keras.Input(shape=(vocabulary_size,), name="text_body")
tags = keras.Input(shape=(num_tags,), name="tags")

features = layers.Concatenate()([title, text_body, tags])
features = layers.Dense(64, activation="relu")(features)

priority = layers.Dense(1, activation="sigmoid", name="priority")(features)
department = layers.Dense(
    num_departments, activation="softmax", name="department")(features)

model = keras.Model(inputs=[title, text_body, tags], outputs=[priority, department])

```

▼ Training a multi-input, multi-output model

Training a model by providing lists of input & target arrays

```

import numpy as np

num_samples = 1280

title_data = np.random.randint(0, 2, size=(num_samples, vocabulary_size))
text_body_data = np.random.randint(0, 2, size=(num_samples, vocabulary_size))
tags_data = np.random.randint(0, 2, size=(num_samples, num_tags))

priority_data = np.random.random(size=(num_samples, 1))
department_data = np.random.randint(0, 2, size=(num_samples, num_departments))

model.compile(optimizer="rmsprop",
              loss=["mean_squared_error", "categorical_crossentropy"],
              metrics=[["mean_absolute_error"], ["accuracy"]])
model.fit([title_data, text_body_data, tags_data],
        [priority_data, department_data],
        epochs=1)

```

```
model.evaluate([title_data, text_body_data, tags_data],
               [priority_data, department_data])
priority_preds, department_preds = model.predict([title_data, text_body_data, tags_data])
```

Training a model by providing dicts of input & target arrays

```
model.compile(optimizer="rmsprop",
              loss={"priority": "mean_squared_error", "department": "categorical_crossentropy"},
              metrics={"priority": ["mean_absolute_error"], "department": ["accuracy"]})
model.fit({"title": title_data, "text_body": text_body_data, "tags": tags_data},
         {"priority": priority_data, "department": department_data},
         epochs=1)
model.evaluate({"title": title_data, "text_body": text_body_data, "tags": tags_data},
               {"priority": priority_data, "department": department_data})
priority_preds, department_preds = model.predict(
    {"title": title_data, "text_body": text_body_data, "tags": tags_data})
```

▼ The power of the Functional API: Access to layer connectivity

```
keras.utils.plot_model(model, "ticket_classifier.png")
```

```
keras.utils.plot_model(model, "ticket_classifier_with_shape_info.png", show_shapes=True)
```

Retrieving the inputs or outputs of a layer in a Functional model

```
model.layers
```

```
model.layers[3].input
```

```
model.layers[3].output
```

Creating a new model by reusing intermediate layer outputs

```
features = model.layers[4].output
difficulty = layers.Dense(3, activation="softmax", name="difficulty")(features)
```

```
new_model = keras.Model(
    inputs=[title, text_body, tags],
    outputs=[priority, department, difficulty])
```

```
keras.utils.plot_model(new_model, "updated_ticket_classifier.png", show_shapes=True)
```

▼ Subclassing the Model class

▼ Rewriting our previous example as a subclassed model

A simple subclassed model

```
class CustomerTicketModel(keras.Model):

    def __init__(self, num_departments):
        super().__init__()
        self.concat_layer = layers.Concatenate()
        self.mixing_layer = layers.Dense(64, activation="relu")
        self.priority_scorer = layers.Dense(1, activation="sigmoid")
        self.department_classifier = layers.Dense(
            num_departments, activation="softmax")

    def call(self, inputs):
        title = inputs["title"]
        text_body = inputs["text_body"]
        tags = inputs["tags"]

        features = self.concat_layer([title, text_body, tags])
        features = self.mixing_layer(features)
        priority = self.priority_scorer(features)
        department = self.department_classifier(features)
        return priority, department

model = CustomerTicketModel(num_departments=4)

priority, department = model(
    {"title": title_data, "text_body": text_body_data, "tags": tags_data})

model.compile(optimizer="rmsprop",
              loss=["mean_squared_error", "categorical_crossentropy"],
              metrics=[["mean_absolute_error"], ["accuracy"]])
model.fit({"title": title_data,
          "text_body": text_body_data,
          "tags": tags_data},
        [priority_data, department_data],
        epochs=1)
model.evaluate({"title": title_data,
               "text_body": text_body_data,
               "tags": tags_data},
              [priority_data, department_data])
priority_preds, department_preds = model.predict({"title": title_data,
                                                  "text_body": text_body_data,
                                                  "tags": tags_data})
```

Beware: What subclassed models don't support

▼ Mixing and matching different components

Creating a Functional model that includes a subclassed model

```
class Classifier(keras.Model):

    def __init__(self, num_classes=2):
        super().__init__()
        if num_classes == 2:
            num_units = 1
            activation = "sigmoid"
        else:
            num_units = num_classes
            activation = "softmax"
        self.dense = layers.Dense(num_units, activation=activation)

    def call(self, inputs):
        return self.dense(inputs)

inputs = keras.Input(shape=(3,))
features = layers.Dense(64, activation="relu")(inputs)
outputs = Classifier(num_classes=10)(features)
model = keras.Model(inputs=inputs, outputs=outputs)
```

Creating a subclassed model that includes a Functional model

```
inputs = keras.Input(shape=(64,))
outputs = layers.Dense(1, activation="sigmoid")(inputs)
binary_classifier = keras.Model(inputs=inputs, outputs=outputs)

class MyModel(keras.Model):

    def __init__(self, num_classes=2):
        super().__init__()
        self.dense = layers.Dense(64, activation="relu")
        self.classifier = binary_classifier

    def call(self, inputs):
        features = self.dense(inputs)
        return self.classifier(features)

model = MyModel()
```

Remember: Use the right tool for the job

▼ Using built-in training and evaluation loops

The standard workflow: `compile()`, `fit()`, `evaluate()`, `predict()`

```
from tensorflow.keras.datasets import mnist

def get_mnist_model():
    inputs = keras.Input(shape=(28 * 28,))
    features = layers.Dense(512, activation="relu")(inputs)
    features = layers.Dropout(0.5)(features)
    outputs = layers.Dense(10, activation="softmax")(features)
    model = keras.Model(inputs, outputs)
    return model

(images, labels), (test_images, test_labels) = mnist.load_data()
images = images.reshape((60000, 28 * 28)).astype("float32") / 255
test_images = test_images.reshape((10000, 28 * 28)).astype("float32") / 255
train_images, val_images = images[10000:], images[:10000]
train_labels, val_labels = labels[10000:], labels[:10000]

model = get_mnist_model()
model.compile(optimizer="rmsprop",
              loss="sparse_categorical_crossentropy",
              metrics=["accuracy"])
model.fit(train_images, train_labels,
          epochs=3,
          validation_data=(val_images, val_labels))
test_metrics = model.evaluate(test_images, test_labels)
predictions = model.predict(test_images)
```

▼ Writing your own metrics

Implementing a custom metric by subclassing the `Metric` class

```
import tensorflow as tf

class RootMeanSquaredError(keras.metrics.Metric):

    def __init__(self, name="rmse", **kwargs):
        super().__init__(name=name, **kwargs)
        self.mse_sum = self.add_weight(name="mse_sum", initializer="zeros")
        self.total_samples = self.add_weight(
            name="total_samples", initializer="zeros", dtype="int32")

    def update_state(self, y_true, y_pred, sample_weight=None):
        y_true = tf.one_hot(y_true, depth=tf.shape(y_pred)[1])
        mse = tf.reduce_sum(tf.square(y_true - y_pred))
        self.mse_sum.assign_add(mse)
        num_samples = tf.shape(y_pred)[0]
        self.total_samples.assign_add(num_samples)
```

```

def result(self):
    return tf.sqrt(self.mse_sum / tf.cast(self.total_samples, tf.float32))

def reset_state(self):
    self.mse_sum.assign(0.)
    self.total_samples.assign(0)

model = get_mnist_model()
model.compile(optimizer="rmsprop",
              loss="sparse_categorical_crossentropy",
              metrics=["accuracy", RootMeanSquaredError()])
model.fit(train_images, train_labels,
          epochs=3,
          validation_data=(val_images, val_labels))
test_metrics = model.evaluate(test_images, test_labels)

```

▼ Using callbacks

▼ The EarlyStopping and ModelCheckpoint callbacks

Using the `callbacks` argument in the `fit()` method

```

callbacks_list = [
    keras.callbacks.EarlyStopping(
        monitor="val_accuracy",
        patience=2,
    ),
    keras.callbacks.ModelCheckpoint(
        filepath="checkpoint_path.keras",
        monitor="val_loss",
        save_best_only=True,
    )
]
model = get_mnist_model()
model.compile(optimizer="rmsprop",
              loss="sparse_categorical_crossentropy",
              metrics=["accuracy"])
model.fit(train_images, train_labels,
          epochs=10,
          callbacks=callbacks_list,
          validation_data=(val_images, val_labels))

model = keras.models.load_model("checkpoint_path.keras")

```

▼ Writing your own callbacks

Creating a custom callback by subclassing the `Callback` class


```

from matplotlib import pyplot as plt

class LossHistory(keras.callbacks.Callback):
    def on_train_begin(self, logs):
        self.per_batch_losses = []

    def on_batch_end(self, batch, logs):
        self.per_batch_losses.append(logs.get("loss"))

    def on_epoch_end(self, epoch, logs):
        plt.clf()
        plt.plot(range(len(self.per_batch_losses)), self.per_batch_losses,
                  label="Training loss for each batch")
        plt.xlabel(f"Batch (epoch {epoch})")
        plt.ylabel("Loss")
        plt.legend()
        plt.savefig(f"plot_at_epoch_{epoch}")
        self.per_batch_losses = []

model = get_mnist_model()
model.compile(optimizer="rmsprop",
              loss="sparse_categorical_crossentropy",
              metrics=["accuracy"])
model.fit(train_images, train_labels,
          epochs=10,
          callbacks=[LossHistory()],
          validation_data=(val_images, val_labels))

```

▼ Monitoring and visualization with TensorBoard

```

model = get_mnist_model()
model.compile(optimizer="rmsprop",
              loss="sparse_categorical_crossentropy",
              metrics=["accuracy"])

tensorboard = keras.callbacks.TensorBoard(
    log_dir="/full_path_to_your_log_dir",
)
model.fit(train_images, train_labels,
          epochs=10,
          validation_data=(val_images, val_labels),
          callbacks=[tensorboard])

%load_ext tensorboard
%tensorboard --logdir /full_path_to_your_log_dir

```

▼ Writing your own training and evaluation loops

Training versus inference

▼ Low-level usage of metrics

```
metric = keras.metrics.SparseCategoricalAccuracy()
targets = [0, 1, 2]
predictions = [[1, 0, 0], [0, 1, 0], [0, 0, 1]]
metric.update_state(targets, predictions)
current_result = metric.result()
print(f"result: {current_result:.2f}")

values = [0, 1, 2, 3, 4]
mean_tracker = keras.metrics.Mean()
for value in values:
    mean_tracker.update_state(value)
print(f"Mean of values: {mean_tracker.result():.2f}")
```

▼ A complete training and evaluation loop

Writing a step-by-step training loop: the training step function

```
model = get_mnist_model()

loss_fn = keras.losses.SparseCategoricalCrossentropy()
optimizer = keras.optimizers.RMSprop()
metrics = [keras.metrics.SparseCategoricalAccuracy()]
loss_tracking_metric = keras.metrics.Mean()

def train_step(inputs, targets):
    with tf.GradientTape() as tape:
        predictions = model(inputs, training=True)
        loss = loss_fn(targets, predictions)
        gradients = tape.gradient(loss, model.trainable_weights)
        optimizer.apply_gradients(zip(gradients, model.trainable_weights))

    logs = {}
    for metric in metrics:
        metric.update_state(targets, predictions)
        logs[metric.name] = metric.result()

    loss_tracking_metric.update_state(loss)
    logs["loss"] = loss_tracking_metric.result()
    return logs
```

Writing a step-by-step training loop: resetting the metrics

```
def reset_metrics():
    for metric in metrics:
        metric.reset_state()
    loss_tracking_metric.reset_state()
```

Writing a step-by-step training loop: the loop itself

```
training_dataset = tf.data.Dataset.from_tensor_slices((train_images, train_labels))
training_dataset = training_dataset.batch(32)
epochs = 3
for epoch in range(epochs):
    reset_metrics()
    for inputs_batch, targets_batch in training_dataset:
        logs = train_step(inputs_batch, targets_batch)
    print(f"Results at the end of epoch {epoch}")
    for key, value in logs.items():
        print(f"...{key}: {value:.4f}")
```

Writing a step-by-step evaluation loop

```
def test_step(inputs, targets):
    predictions = model(inputs, training=False)
    loss = loss_fn(targets, predictions)

    logs = {}
    for metric in metrics:
        metric.update_state(targets, predictions)
        logs["val_" + metric.name] = metric.result()

    loss_tracking_metric.update_state(loss)
    logs["val_loss"] = loss_tracking_metric.result()
    return logs

val_dataset = tf.data.Dataset.from_tensor_slices((val_images, val_labels))
val_dataset = val_dataset.batch(32)
reset_metrics()
for inputs_batch, targets_batch in val_dataset:
    logs = test_step(inputs_batch, targets_batch)
print("Evaluation results:")
for key, value in logs.items():
    print(f"...{key}: {value:.4f}")
```

▼ Make it fast with tf.function

Adding a tf.function decorator to our evaluation-step function

```
@tf.function
def test_step(inputs, targets):
```

```

predictions = model(inputs, training=False)
loss = loss_fn(targets, predictions)

logs = {}
for metric in metrics:
    metric.update_state(targets, predictions)
    logs["val_" + metric.name] = metric.result()

loss_tracking_metric.update_state(loss)
logs["val_loss"] = loss_tracking_metric.result()
return logs

val_dataset = tf.data.Dataset.from_tensor_slices((val_images, val_labels))
val_dataset = val_dataset.batch(32)
reset_metrics()
for inputs_batch, targets_batch in val_dataset:
    logs = test_step(inputs_batch, targets_batch)
print("Evaluation results:")
for key, value in logs.items():
    print(f"...{key}: {value:.4f}")

```

▼ Leveraging fit() with a custom training loop

Implementing a custom training step to use with fit()

```

loss_fn = keras.losses.SparseCategoricalCrossentropy()
loss_tracker = keras.metrics.Mean(name="loss")

class CustomModel(keras.Model):
    def train_step(self, data):
        inputs, targets = data
        with tf.GradientTape() as tape:
            predictions = self(inputs, training=True)
            loss = loss_fn(targets, predictions)
            gradients = tape.gradient(loss, model.trainable_weights)
            optimizer.apply_gradients(zip(gradients, model.trainable_weights))

        loss_tracker.update_state(loss)
        return {"loss": loss_tracker.result()}

@property
def metrics(self):
    return [loss_tracker]

inputs = keras.Input(shape=(28 * 28,))
features = layers.Dense(512, activation="relu")(inputs)
features = layers.Dropout(0.5)(features)
outputs = layers.Dense(10, activation="softmax")(features)
model = CustomModel(inputs, outputs)

```

```
model.compile(optimizer=keras.optimizers.RMSprop())
model.fit(train_images, train_labels, epochs=3)

class CustomModel(keras.Model):
    def train_step(self, data):
        inputs, targets = data
        with tf.GradientTape() as tape:
            predictions = self(inputs, training=True)
            loss = self.compiled_loss(targets, predictions)
            gradients = tape.gradient(loss, model.trainable_weights)
            optimizer.apply_gradients(zip(gradients, model.trainable_weights))
            self.compiled_metrics.update_state(targets, predictions)
        return {m.name: m.result() for m in self.metrics}

inputs = keras.Input(shape=(28 * 28,))
features = layers.Dense(512, activation="relu")(inputs)
features = layers.Dropout(0.5)(features)
outputs = layers.Dense(10, activation="softmax")(features)
model = CustomModel(inputs, outputs)

model.compile(optimizer=keras.optimizers.RMSprop(),
              loss=keras.losses.SparseCategoricalCrossentropy(),
              metrics=[keras.metrics.SparseCategoricalAccuracy()])
model.fit(train_images, train_labels, epochs=3)
```

Summary