ADVANCED DEEP LEARNING WITH KERAS IN PYTHON

Keras input and dense layers

Zach Deane-Mayer
Data Scientist

Course outline

- Chapter 1: Introduction to the Keras functional API (Refresher)
- Chapter 2: Models with 2 inputs
- Chapter 3: Models with 3 inputs
- Chapter 4: Multiple outputs

Course Datasets: College basketball data, 1989-2017

Dataset 1: Regular season

- Team ID 1
- Team ID 2
- Home vs Away
- Score Difference (Team 1 - Team 2)
- Team 1 Score
- Team 2 Score
- Won vs Lost

Dataset 2: Tournament games

- Same as Dataset 1
- Also has difference in Seed

Course Datasets: College basketball data, 1989-2017

Inputs and outputs

Two fundamental parts:

- Input layer
- Output layer

Input Layer
Output Layer

Inputs

```
from keras.layers import Input
input_tensor = Input(shape=(1,))
```

Input Layer
Output Layer

Inputs

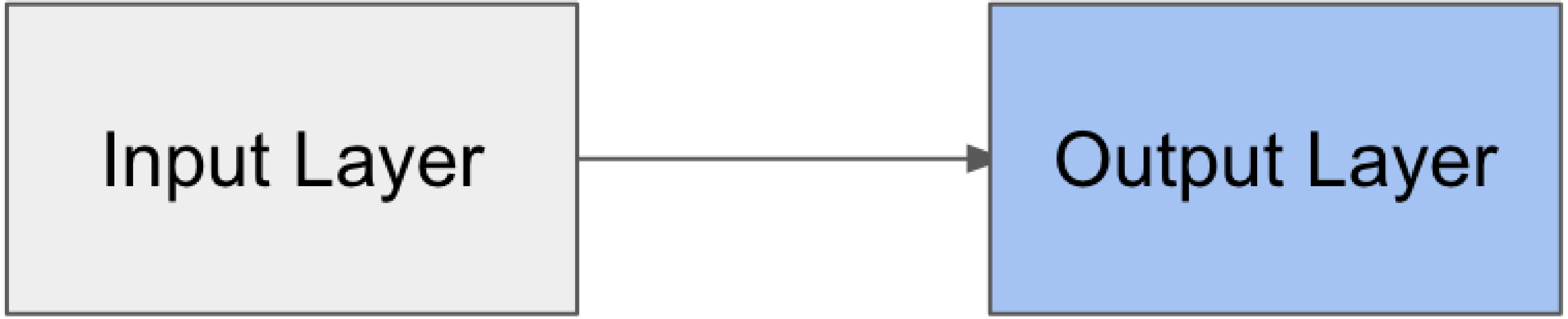
```
from keras.layers import Input
input_tensor = Input(shape=(1,))
print(input_tensor)

<tf.Tensor 'input_1:0' shape=(?, 1) dtype=float32>
```

Input Layer

Output Layer

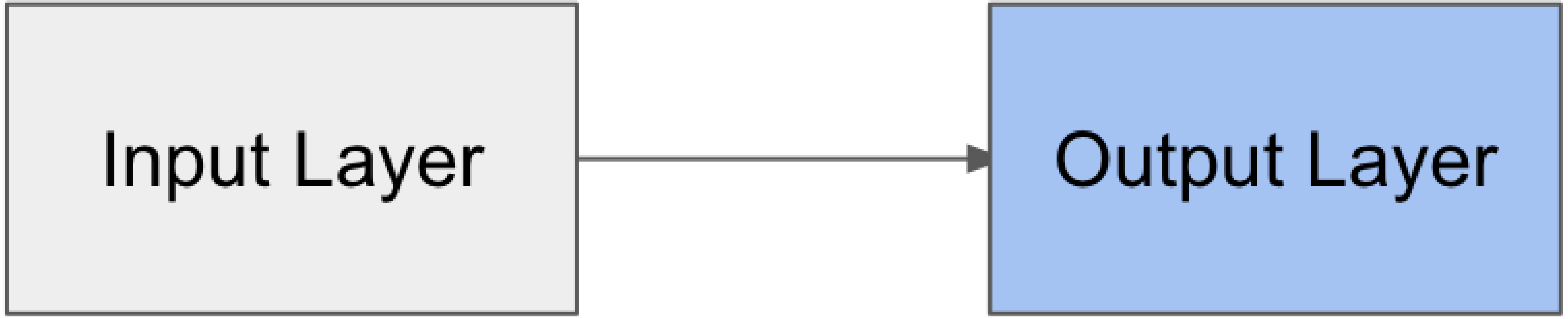
Outputs

```
from keras.layers import Dense
output_layer = Dense(1)
```



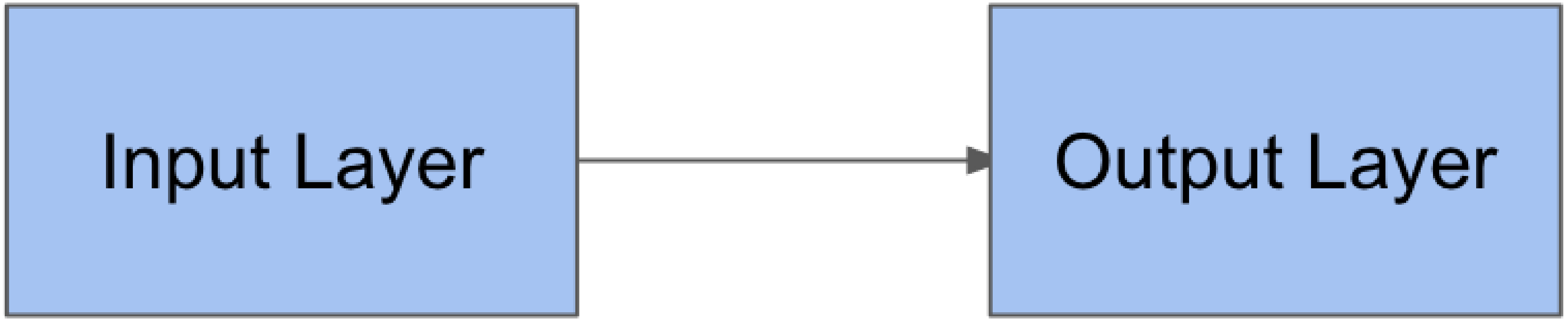
Outputs

```
from keras.layers import Dense
output_layer = Dense(1)
print(output_layer)

<keras.layers.core.Dense at 0x7f22e0295a58>
```



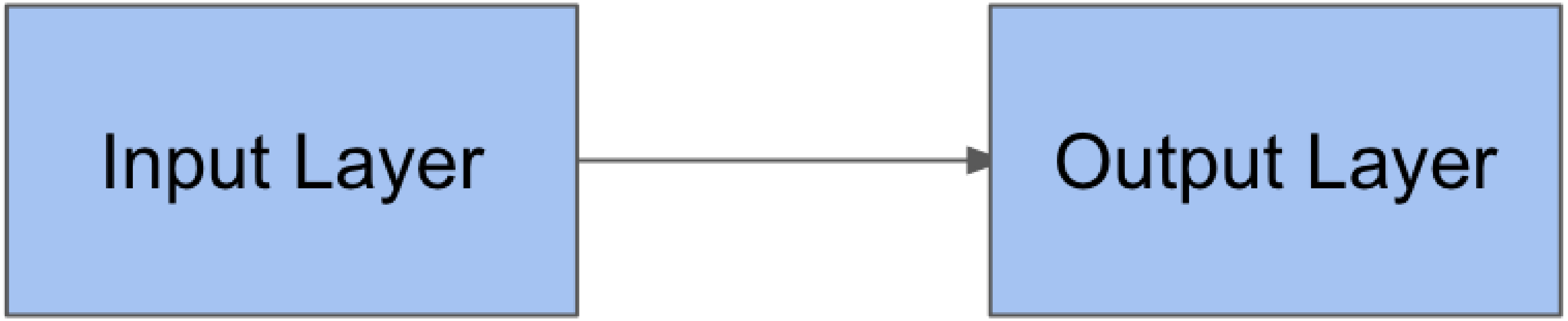
Connecting inputs to outputs

```
from keras.layers import Input, Dense
input_tensor = Input(shape=(1,))
output_layer = Dense(1)
output_tensor = output_layer(input_tensor)
```



Connecting inputs to outputs

```
print(output_tensor)

<tf.Tensor 'dense_1/BiasAdd:0' shape=(?, 1) dtype=float32>
```



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Let's practice!

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Keras models

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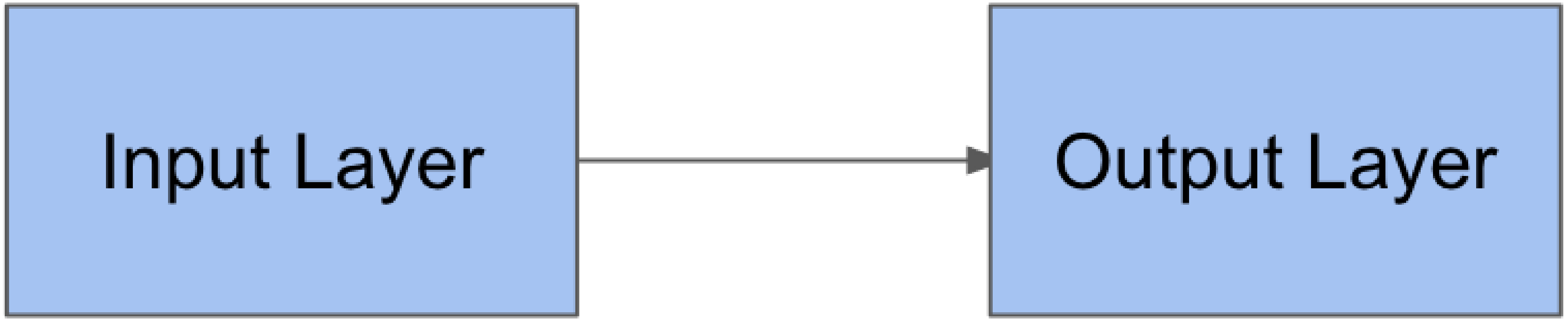
Data Scientist

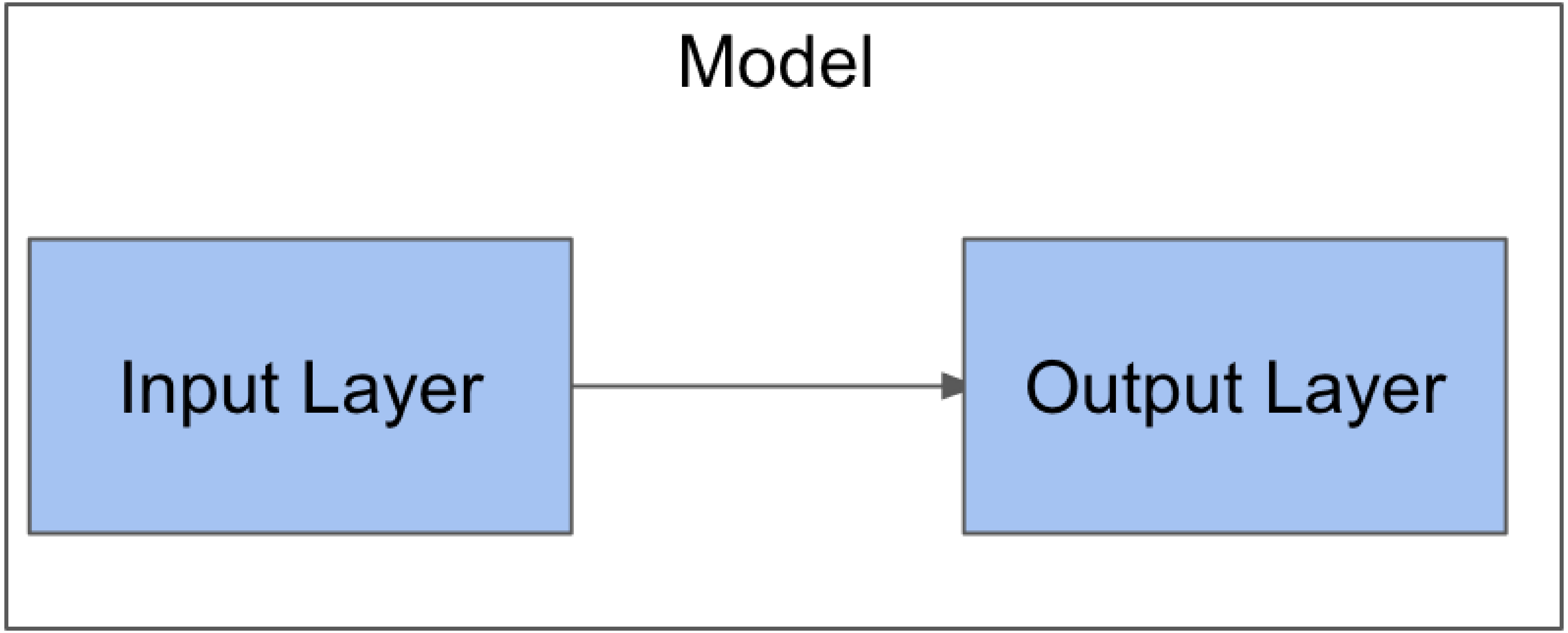
Keras models

```
from keras.layers import Input, Dense
input_tensor = Input(shape=(1,))
output_tensor = Dense(1)(input_tensor)
```



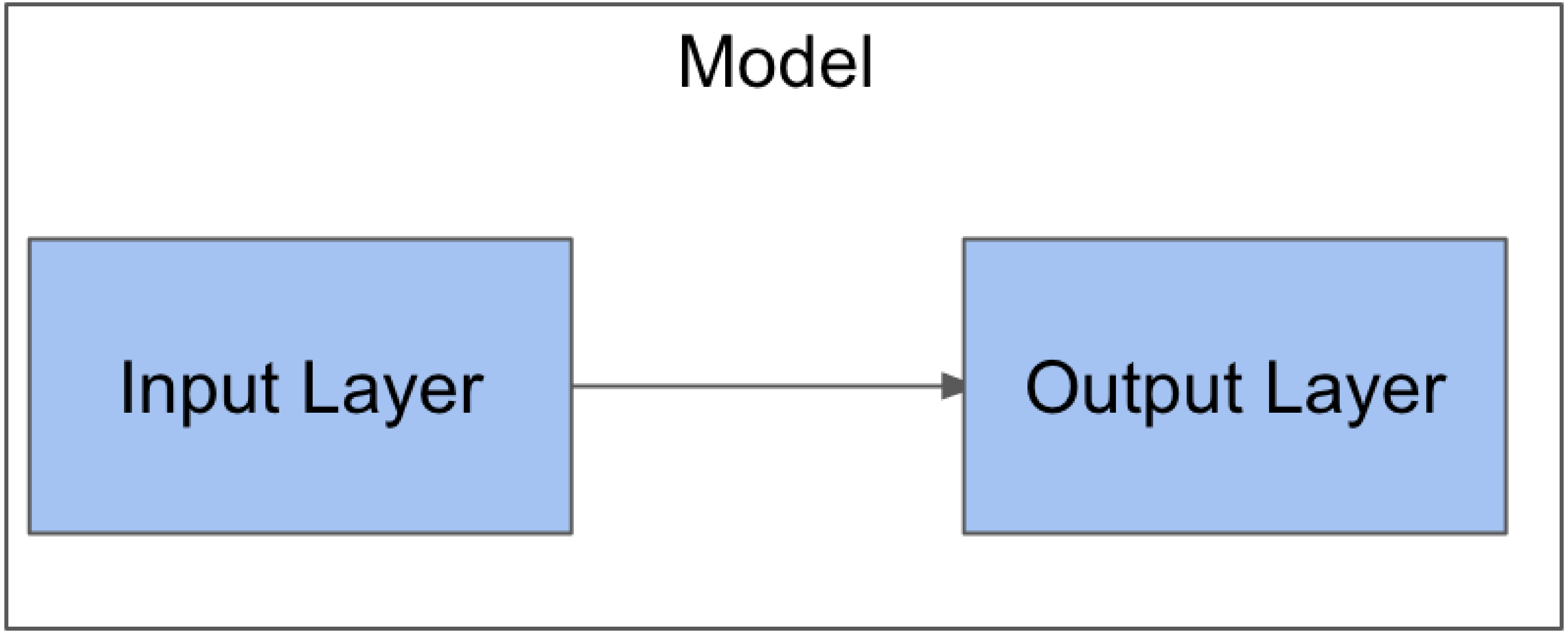
Keras models

```
from keras.models import Model
model = Model(input_tensor, output_tensor)
```



Compile a model

```
model.compile(optimizer='adam', loss='mae')
```



Summarize the model

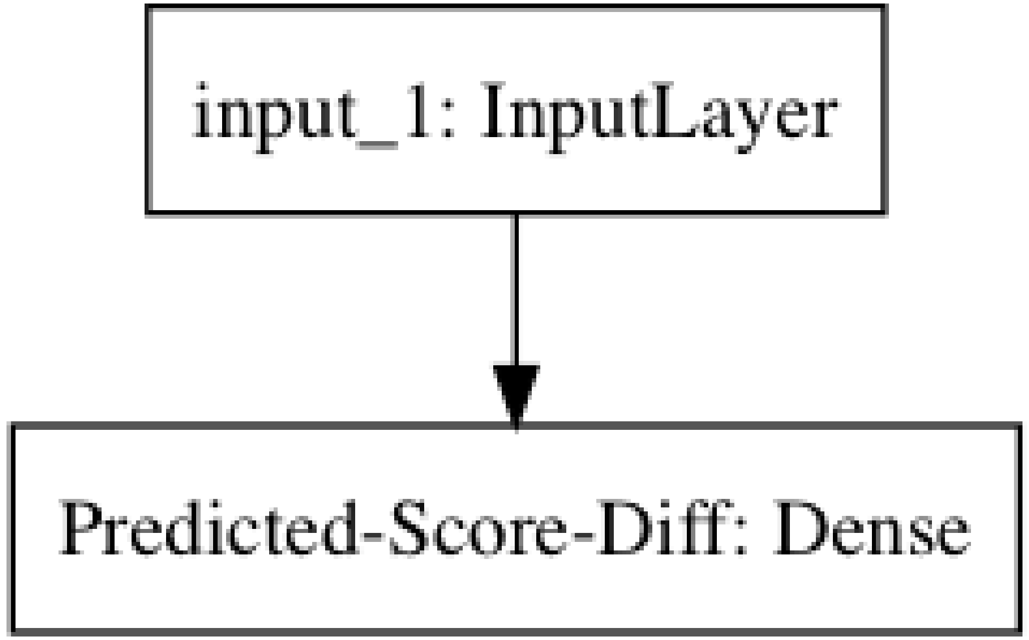
```
model.summary()


_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_1 (InputLayer)         (None, 1)                 0
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 2
=================================================================
Total params: 2
Trainable params: 2
Non-trainable params: 0
_________________________________________________________________
```

Plot model using keras

```
input_tensor = Input(shape=(1,))
output_layer = Dense(1, name='Predicted-Score-Diff')
output_tensor = output_layer(input_tensor)
model = Model(input_tensor, output_tensor)
plot_model(model, to_file ='model.png')

from matplotlib import pyplot as plt
img = plt.imread('model.png')
plt.imshow(img)
plt.show()
```



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Fit and evaluate a model

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Basketball Data

Goal: Predict tournament outcomes

Data Available: team ratings from the tournament organizers

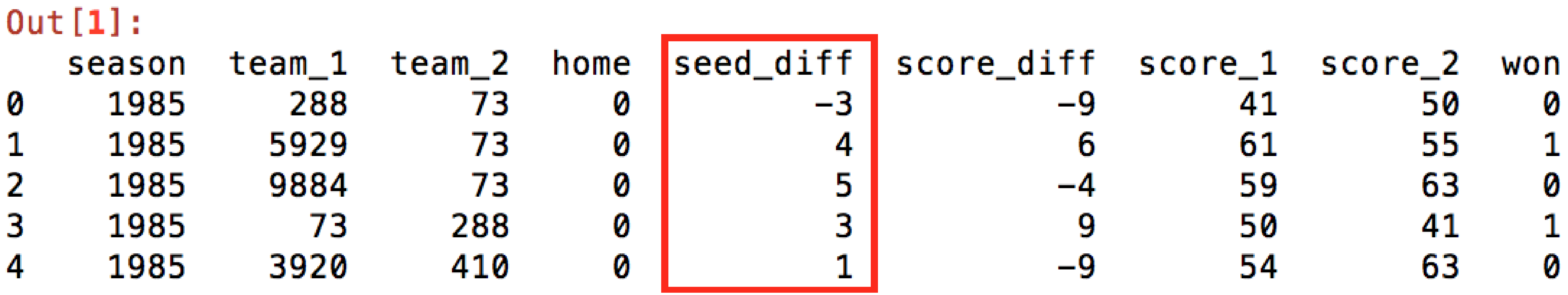
```
import pandas as pd
games_tourney = pd.read_csv('datasets/games_tourney.csv')
games_tourney.head()

Out[1]:
   season  team_1  team_2  home  seed_diff  score_diff  score_1  score_2  won
0    1985     288      73     0         -3          -9       41       50    0
1    1985    5929      73     0          4           6       61       55    1
2    1985    9884      73     0          5          -4       59       63    0
3    1985      73     288     0          3           9       50       41    1
4    1985    3920     410     0          1          -9       54       63    0
```

Basketball Data

Input: Seed difference

```
import pandas as pd
games_tourney = pd.read_csv('datasets/games_tourney.csv')
games_tourney.head()
```

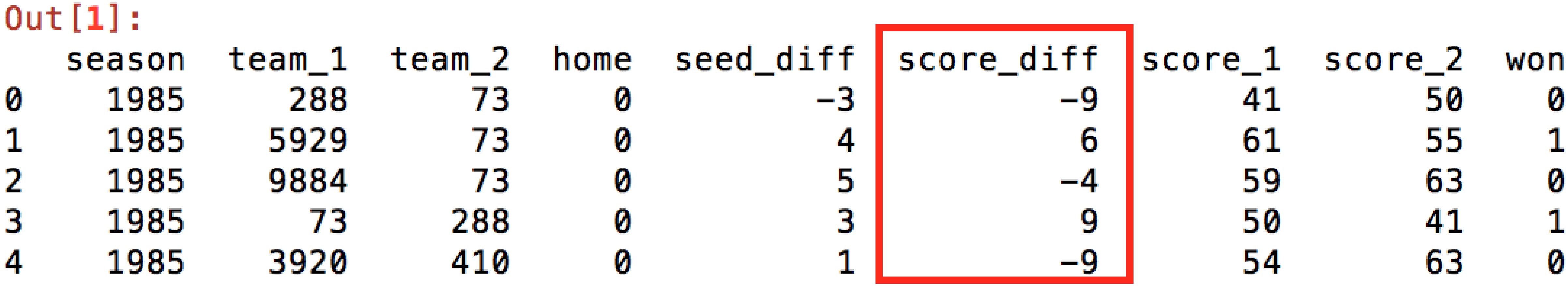


```
Out[1]:
    season  team_1  team_2  home  seed_diff  score_diff  score_1  score_2  won
0     1985     288      73     0         -3          -9       41       50    0
1     1985    5929      73     0          4           6       61       55    1
2     1985    9884      73     0          5          -4       59       63    0
3     1985      73     288     0          3           9       50       41    1
4     1985    3920     410     0          1          -9       54       63    0
```

Basketball Data

Output: Score difference

```python
import pandas as pd
games_tourney = pd.read_csv('datasets/games_tourney.csv')
games_tourney.head()
```



```
Out[1]:
   season  team_1  team_2  home  seed_diff  score_diff  score_1  score_2  won
0    1985     288      73     0         -3          -9       41       50    0
1    1985    5929      73     0          4           6       61       55    1
2    1985    9884      73     0          5          -4       59       63    0
3    1985      73     288     0          3           9       50       41    1
4    1985    3920     410     0          1          -9       54       63    0
```

Basketball Data

Input:

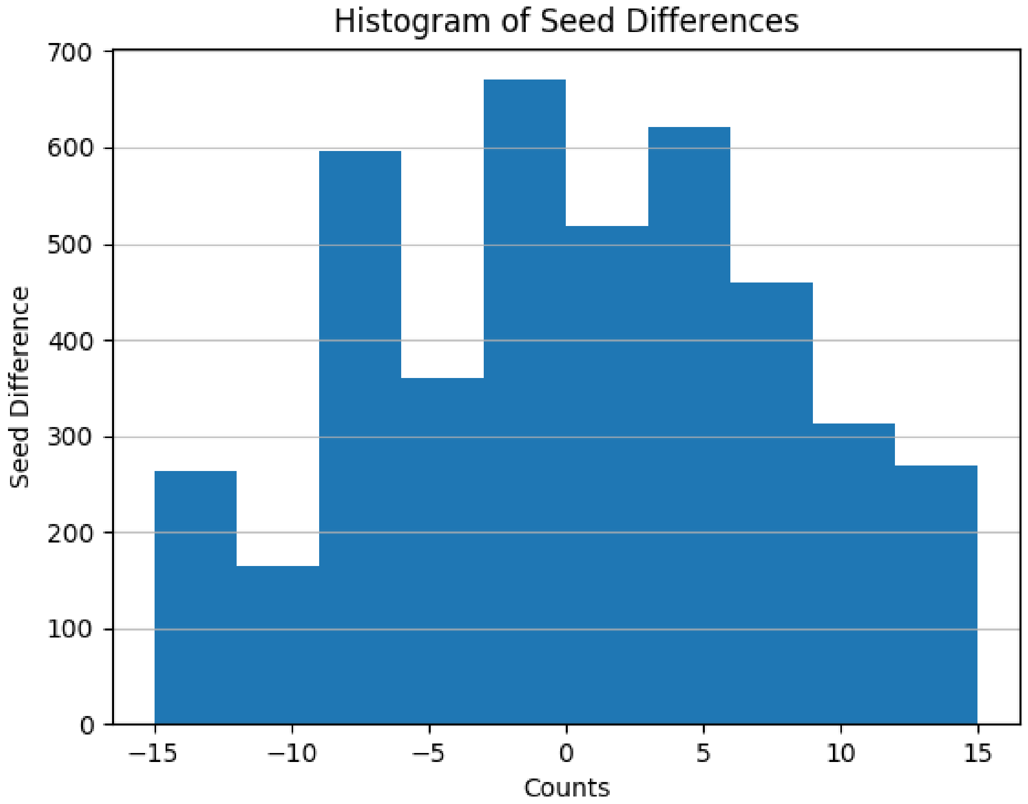
- Seed difference - one number: -15 to +15
- Seed range from 1-16
- Highest difference is 16-1 = +15
- Lowest difference is 1-16 = -15

Output:

- Score difference - one number: -50 to +50

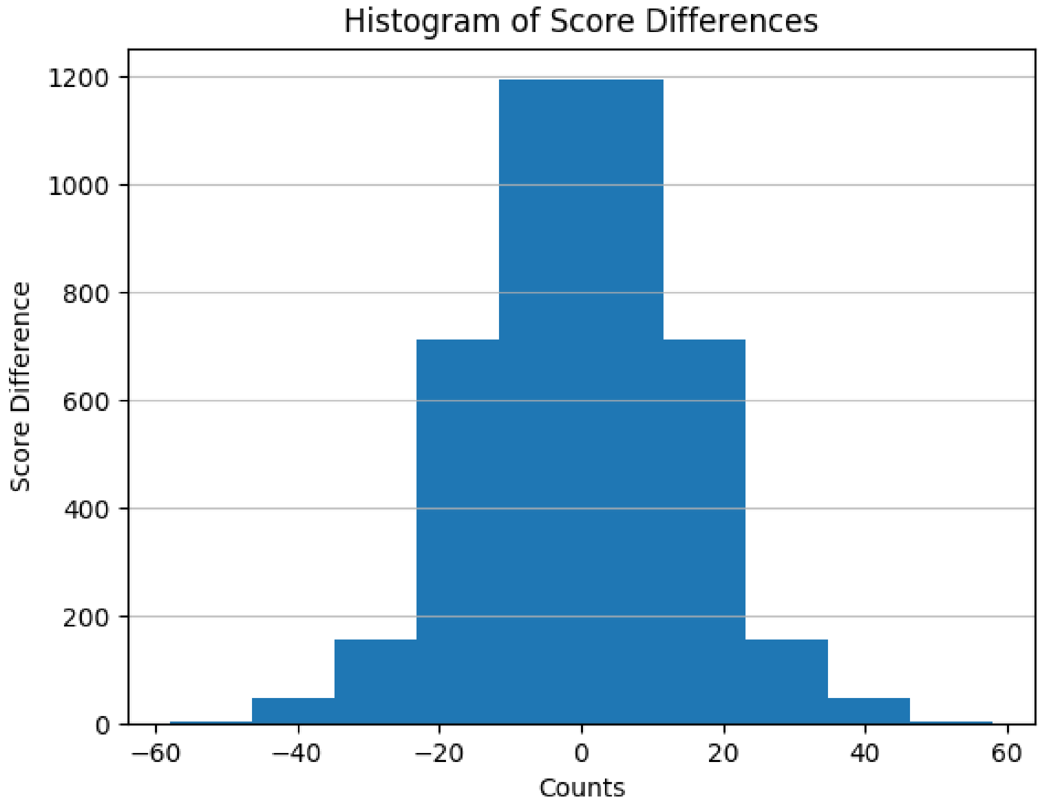
Basketball Data

- Seed difference: 15
  - Team 1: 16
  - Team 2: 1
- Seed difference: -15
  - Team 1: 1
  - Team 2: 16



Basketball Data

- Score difference: -9
  - Team 1: 41
  - Team 2: 50
- Score difference: 6
  - Team 1: 61
  - Team 2: 55



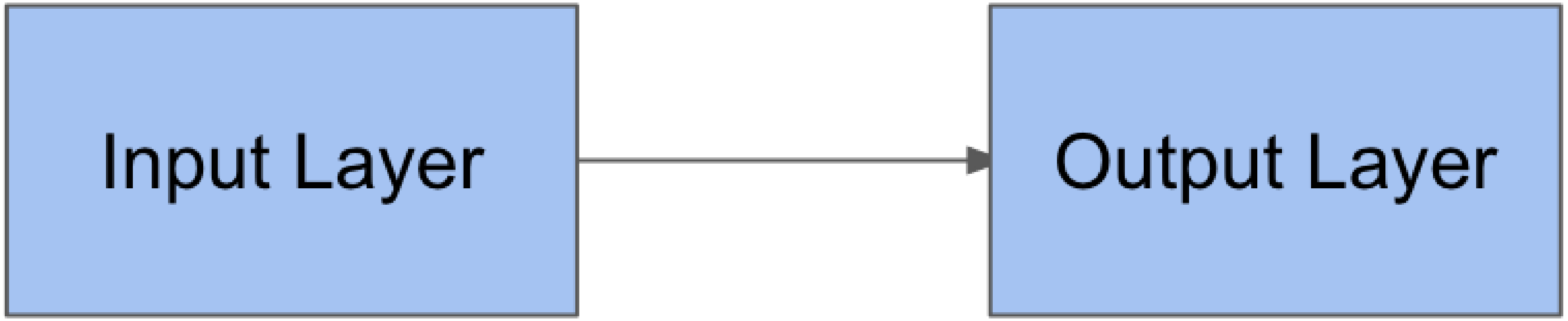
Basketball Data

```
import pandas as pd
games_tourney = pd.read_csv('datasets/games_tourney_samp.csv')
games_tourney.head()

Out[1]:
   season  team_1  team_2  home  seed_diff  score_diff  score_1  score_2  won
0    2017     320    6323     0         13          18      100       82    1
1    2017    6323     320     0        -13         -18       82      100    0
```

Build the model

```
from keras.models import Model
from keras.layers import Input, Dense
input_tensor = Input(shape=(1,))
output_tensor = Dense(1)(input_tensor)
model = Model(input_tensor, output_tensor)
model.compile(optimizer='adam', loss='mae')
```

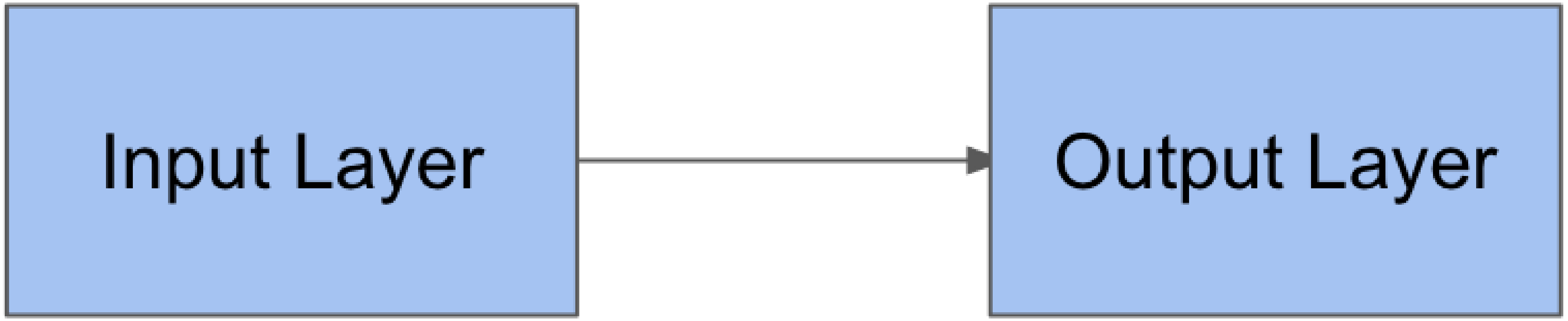


Input Layer

Output Layer

Fit the model

```python
from pandas import read_csv
games = read_csv('datasets/games_tourney.csv')
model.fit(games['seed_diff'],
          games['score_diff'],
          batch_size=64,
          validation_split=.20,
          verbose=True)
```



Evaluate the model

```
model.evaluate(games_test['seed_diff'],
               games_test['score_diff'])

1000/1000 [==============================] - 0s 26us/step
Out[1]: 9.742335235595704
```

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Category embeddings

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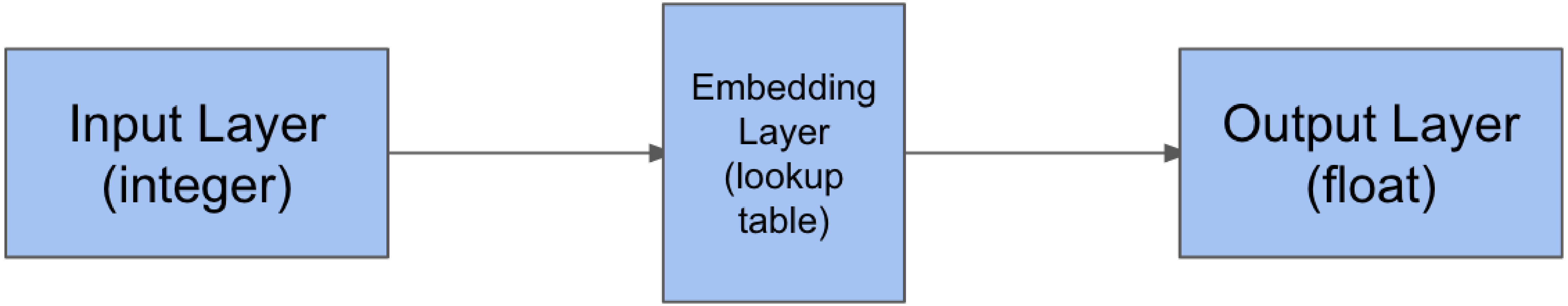
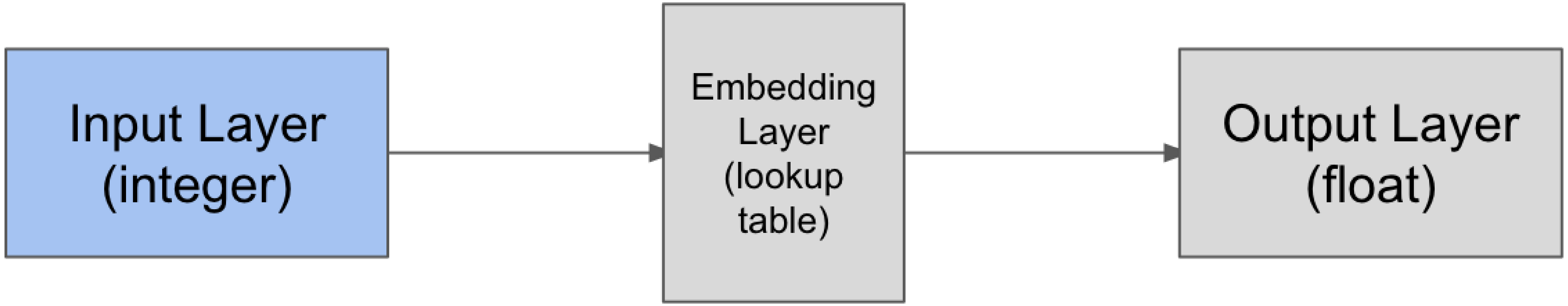
Category embeddings

- Input: integers
- Output: floats
- Note: Increased dimensionality: output layer flattens back to 2D



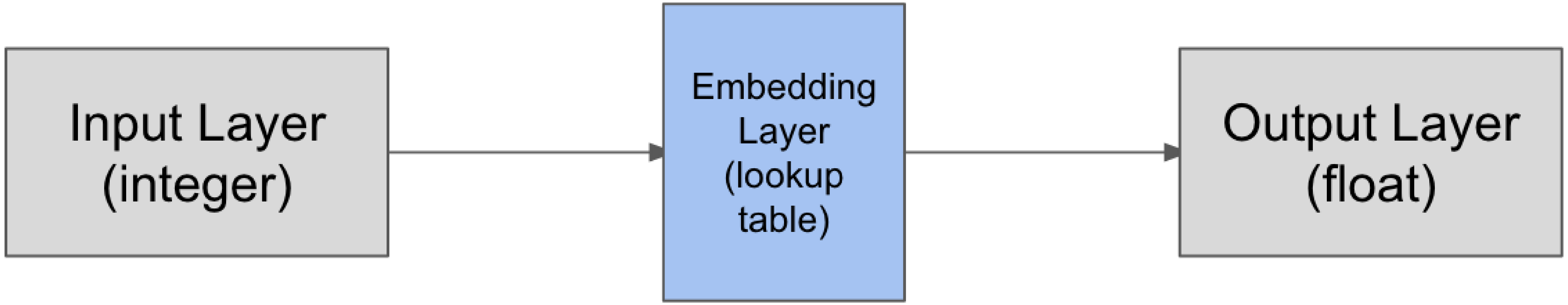
Inputs

```
input_tensor = Input(shape=(1,))
```



Embedding Layer

```
from keras.layers import Embedding
input_tensor = Input(shape=(1,))
n_teams = 10887
embed_layer = Embedding(input_dim=n_teams,
                        input_length=1,
                        output_dim=1,
                        name='Team-Strength-Lookup')
embed_tensor = embed_layer(input_tensor)
```



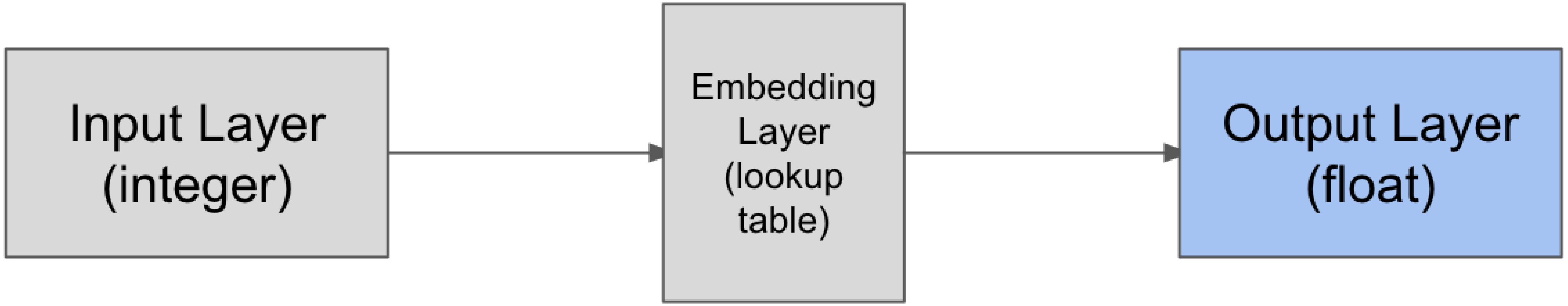
Input Layer (integer)

Embedding Layer (lookup table)

Output Layer (float)

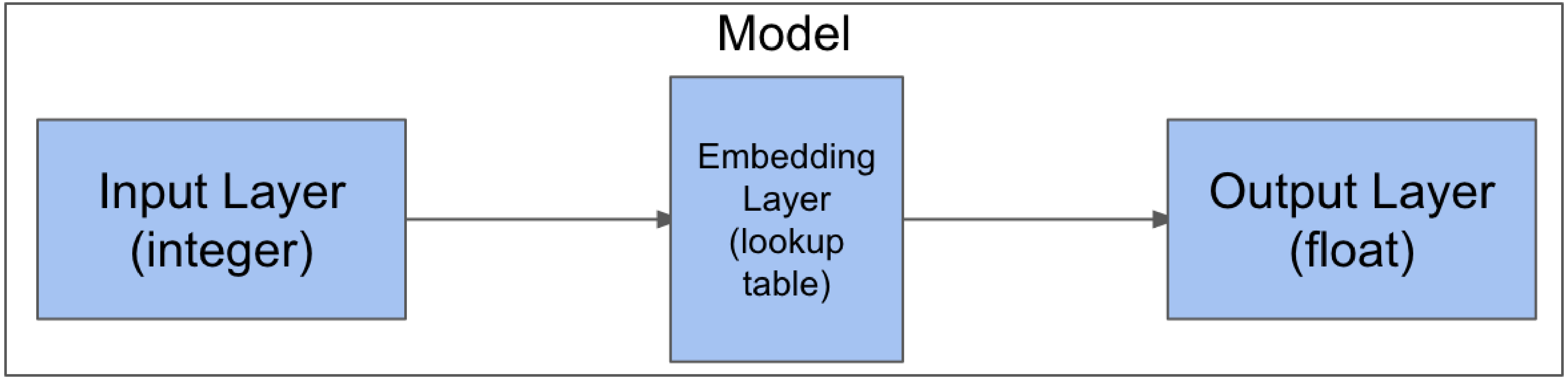
Flattening

```
from keras.layers import Flatten
flatten_tensor = Flatten()(embed_tensor)
```



Put it all together

```
input_tensor = Input(shape=(1,))
n_teams =  10887
embed_layer = Embedding(input_dim=n_teams,
                        input_length=1,
                        output_dim=1,
                        name='Team-Strength-Lookup')
embed_tensor = embed_layer(input_tensor)
flatten_tensor = Flatten()(embed_tensor)
model = Model(input_tensor, flatten_tensor)
```



Model

Input Layer (integer)

Embedding Layer (lookup table)

Output Layer (float)

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Shared layers

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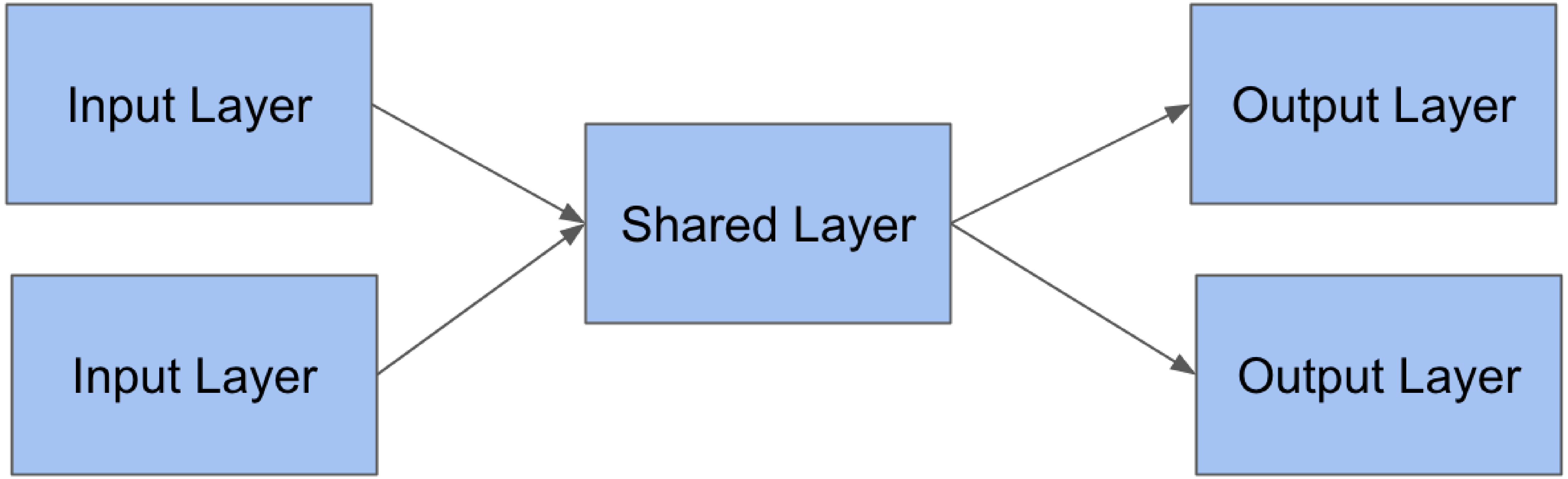
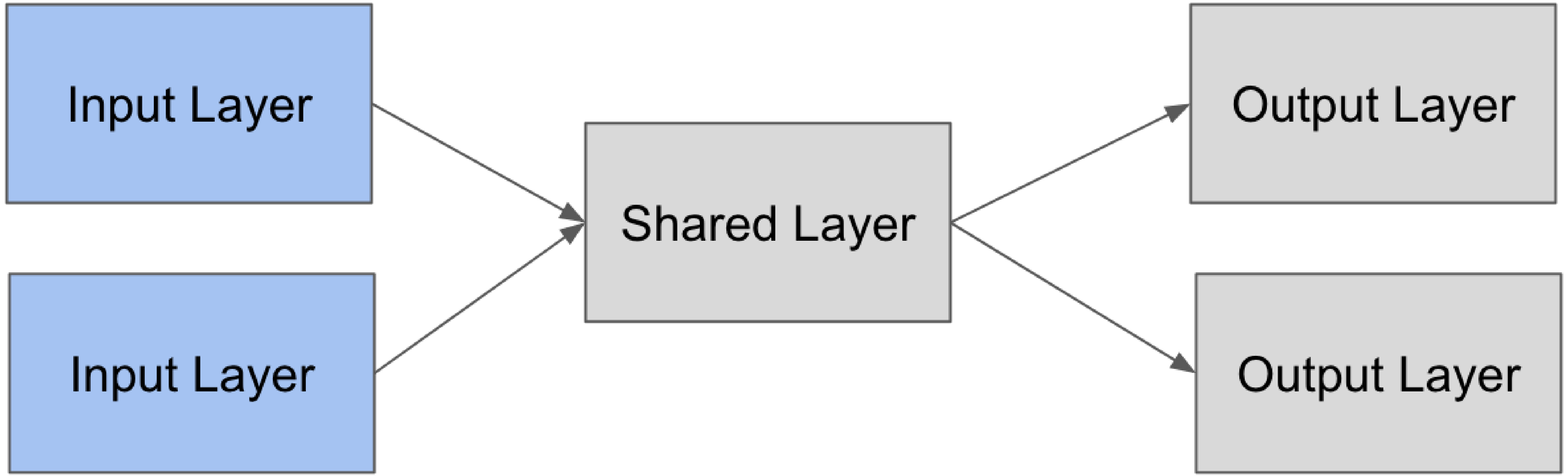
Shared layers

- Require the functional API
- Very flexible



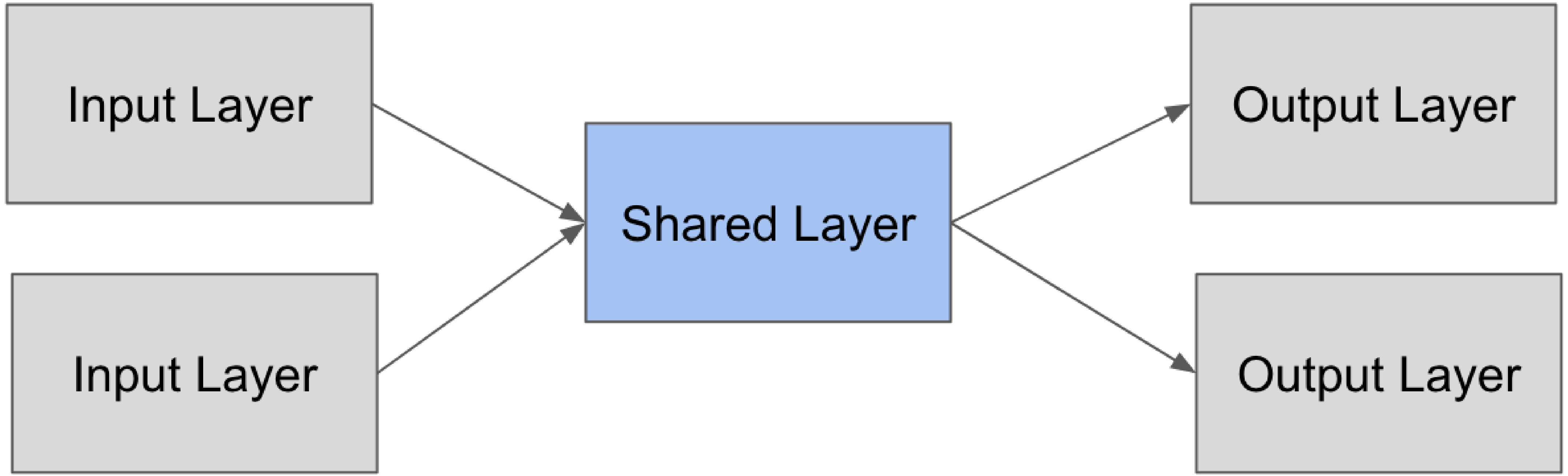
Shared layers

```
input_tensor_1 = Input((1,))
input_tensor_2 = Input((1,))
```



Shared layers

```
shared_layer = Dense(1)
output_tensor_1 = shared_layer(input_tensor_1)
output_tensor_2 = shared_layer(input_tensor_2)
```

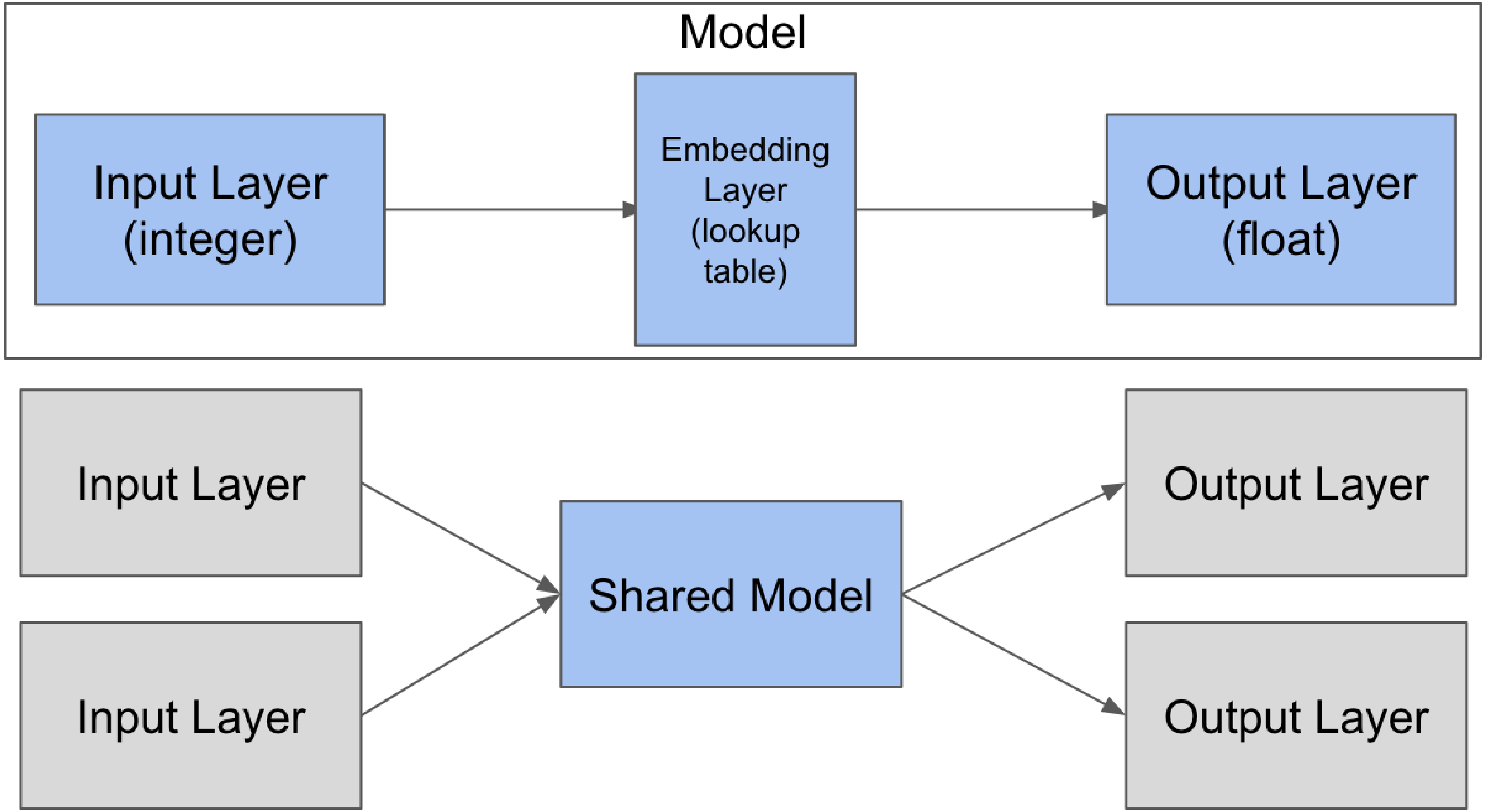


Sharing multiple layers as a model

```
input_tensor = Input(shape=(1,))
n_teams = 10887
embed_layer = Embedding(input_dim=n_teams,
                        input_length=1,
                        output_dim=1,
                        name='Team-Strength-Lookup')
embed_tensor = embed_layer(input_tensor)
flatten_tensor = Flatten()(embed_tensor)
model = Model(input_tensor, flatten_tensor)
```

```
input_tensor_1 = Input((1,))
input_tensor_2 = Input((1,))
output_tensor_1 = model(input_tensor_1)
output_tensor_2 = model(input_tensor_2)
```

Sharing multiple layers as a model



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Merge layers

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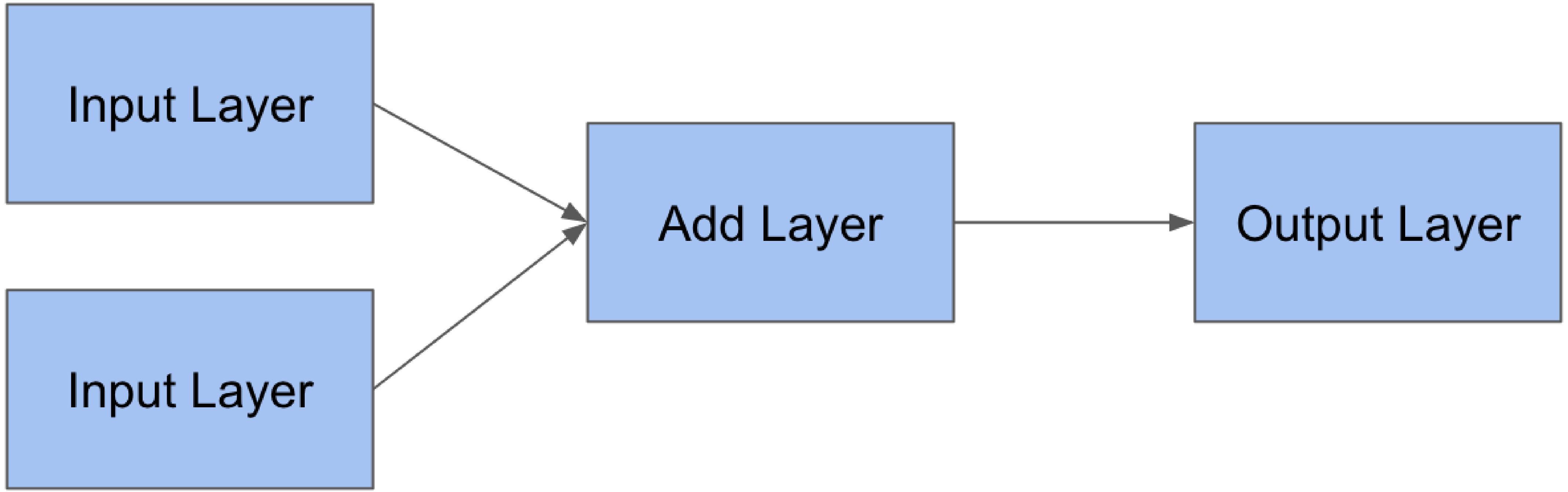
Merge layers

- Add
- Subtract
- Multiply
- Concatenate

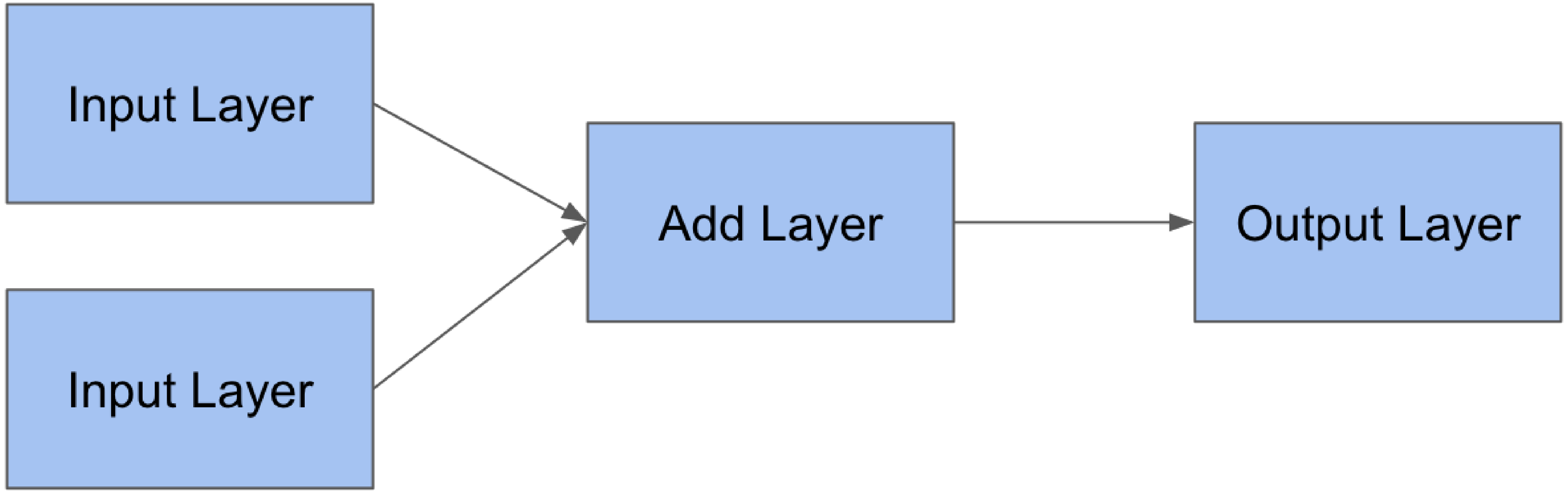
Merge layers

```
from keras.layers import Input, Add
in_tensor_1 = Input((1,))
in_tensor_2 = Input((1,))
out_tensor = Add()([in_tensor_1, in_tensor_2])
```



Merge layers

```
in_tensor_3 = Input((1,))
out_tensor = Add()([in_tensor_1, in_tensor_2, in_tensor_3]
```



Input Layer

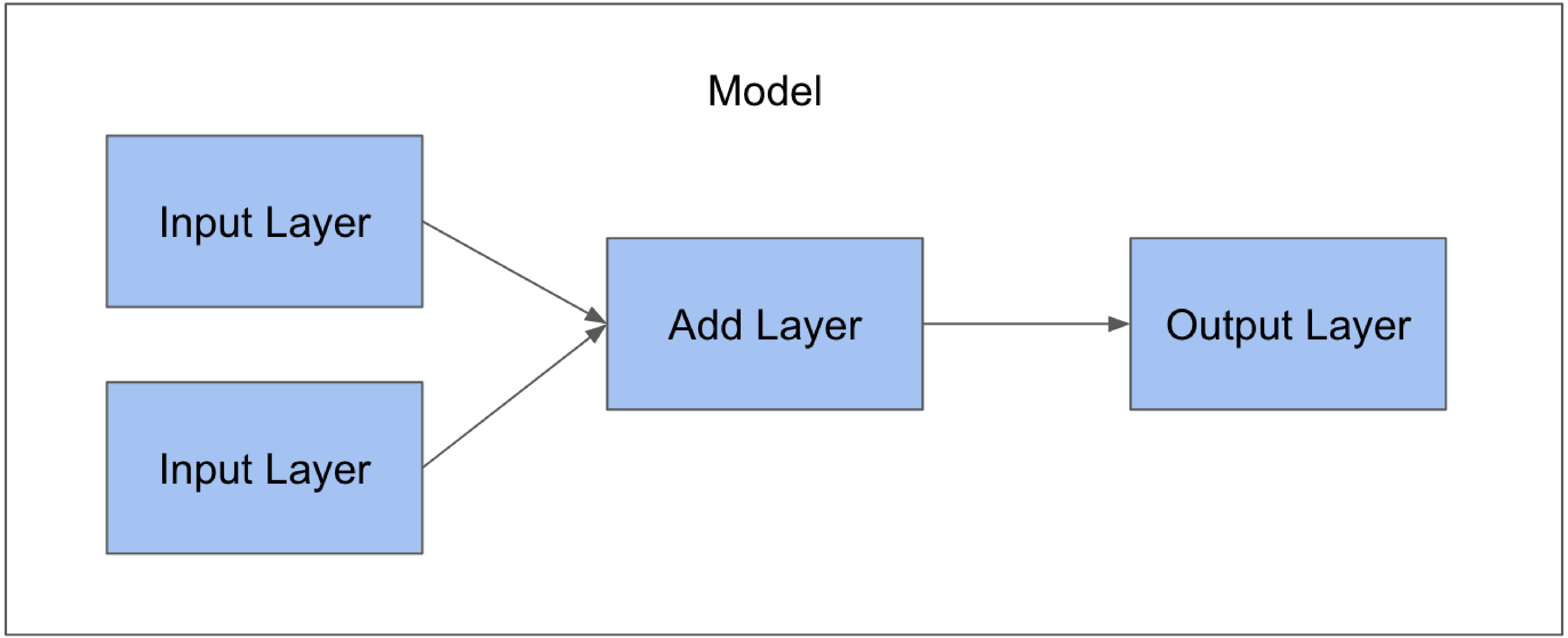
Input Layer

Add Layer

Output Layer

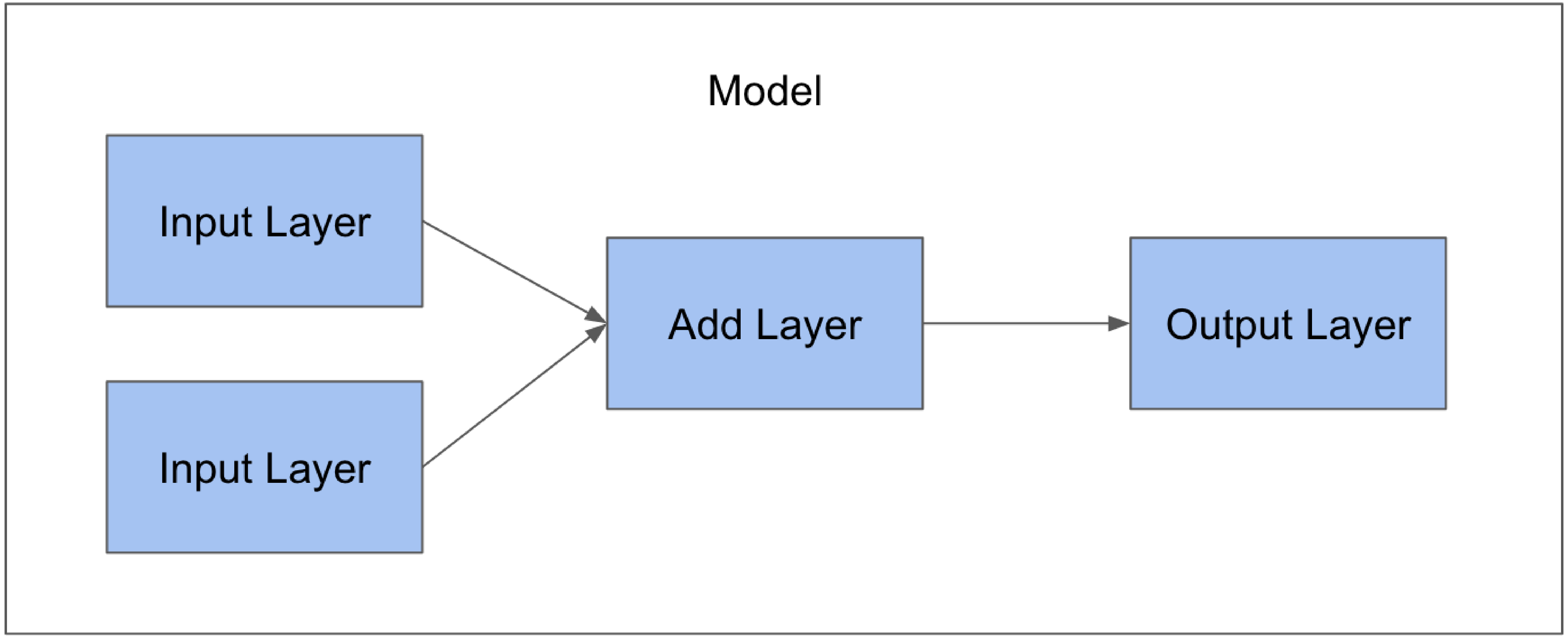
Create the model

```
from keras.models import Model
model = Model([in_tensor_1, in_tensor_2], out_tensor)
```



Compile the model

```
model.compile(optimizer='adam', loss='mean_absolute_error')
```



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Let's practice!

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Fitting and Predicting with multiple inputs

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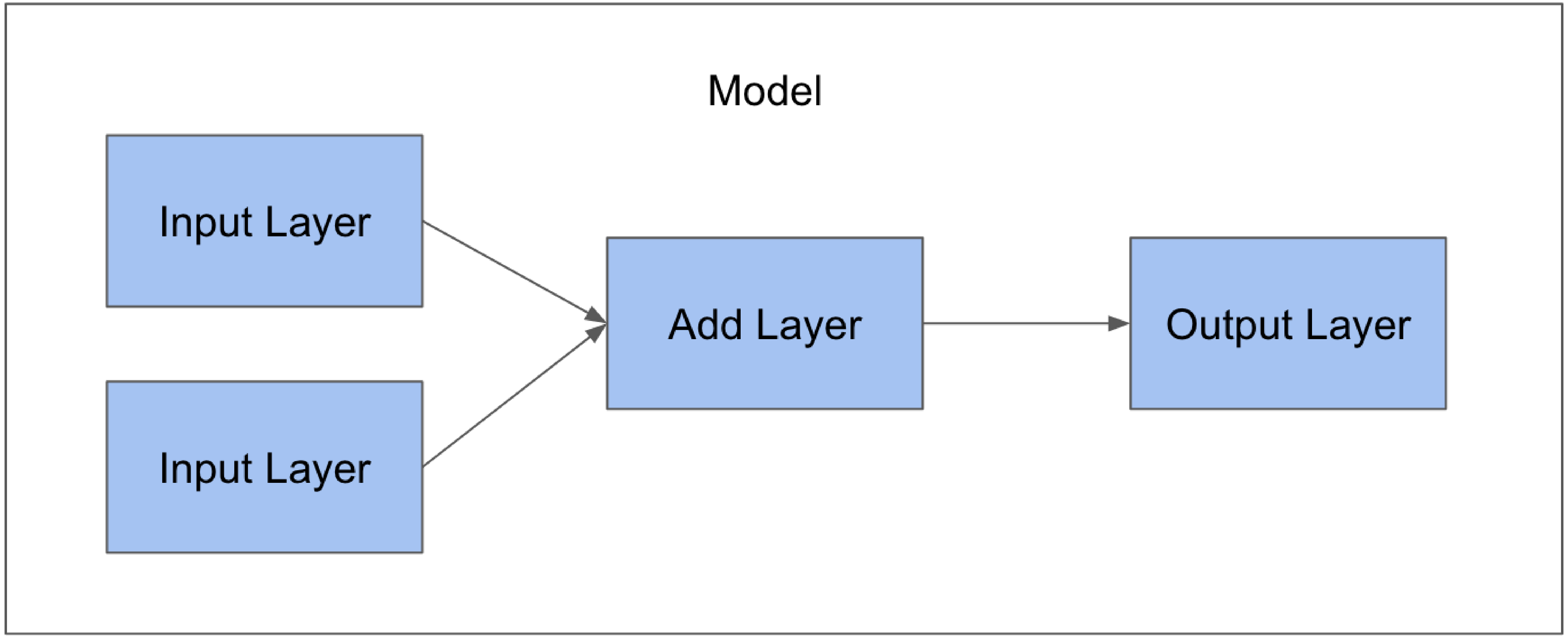
Fit with multiple inputs

```
model.fit([data_1, data_2], target)
```



Predict with multiple inputs

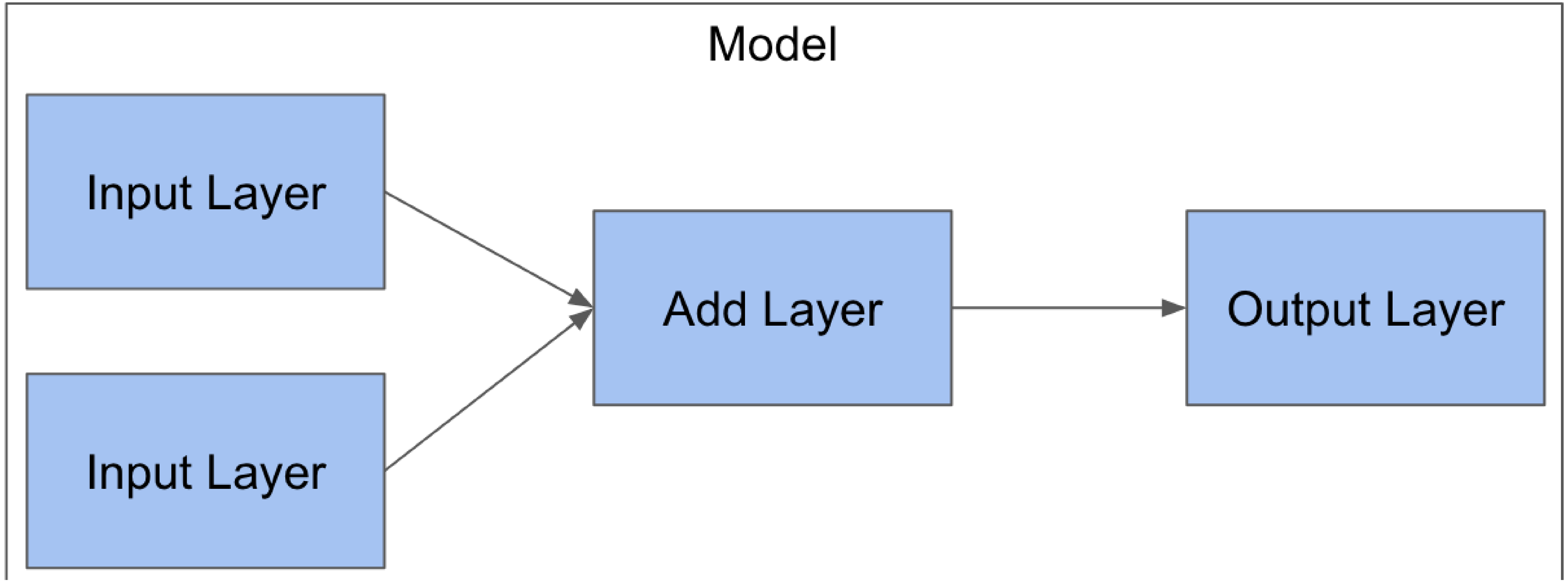
```
model.predict([np.array([[1]]), np.array([[2]])])
array([[3.]], dtype=float32)
```

```
model.predict([np.array([[42]]), np.array([[119]])])
array([[161.]], dtype=float32)
```

Evaluate with multiple inputs

```
model.evaluate([np.array([[-1]]), np.array([[-2]])], np.ar
```

```
1/1 [==============================] - 0s 801us/step
Out[21]: 0.0
```



Model

Input Layer

Input Layer

Add Layer

Output Layer

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Three-input models

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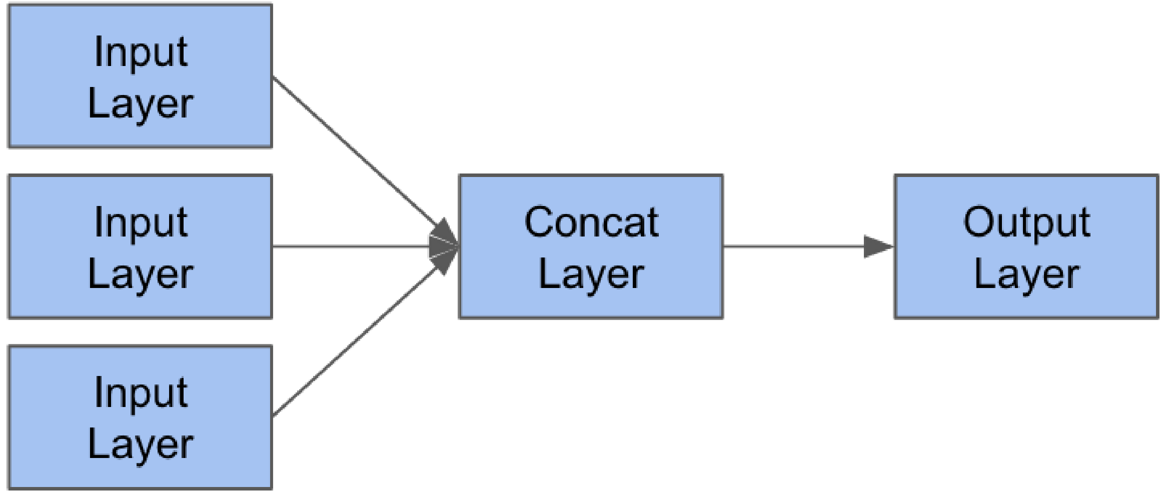
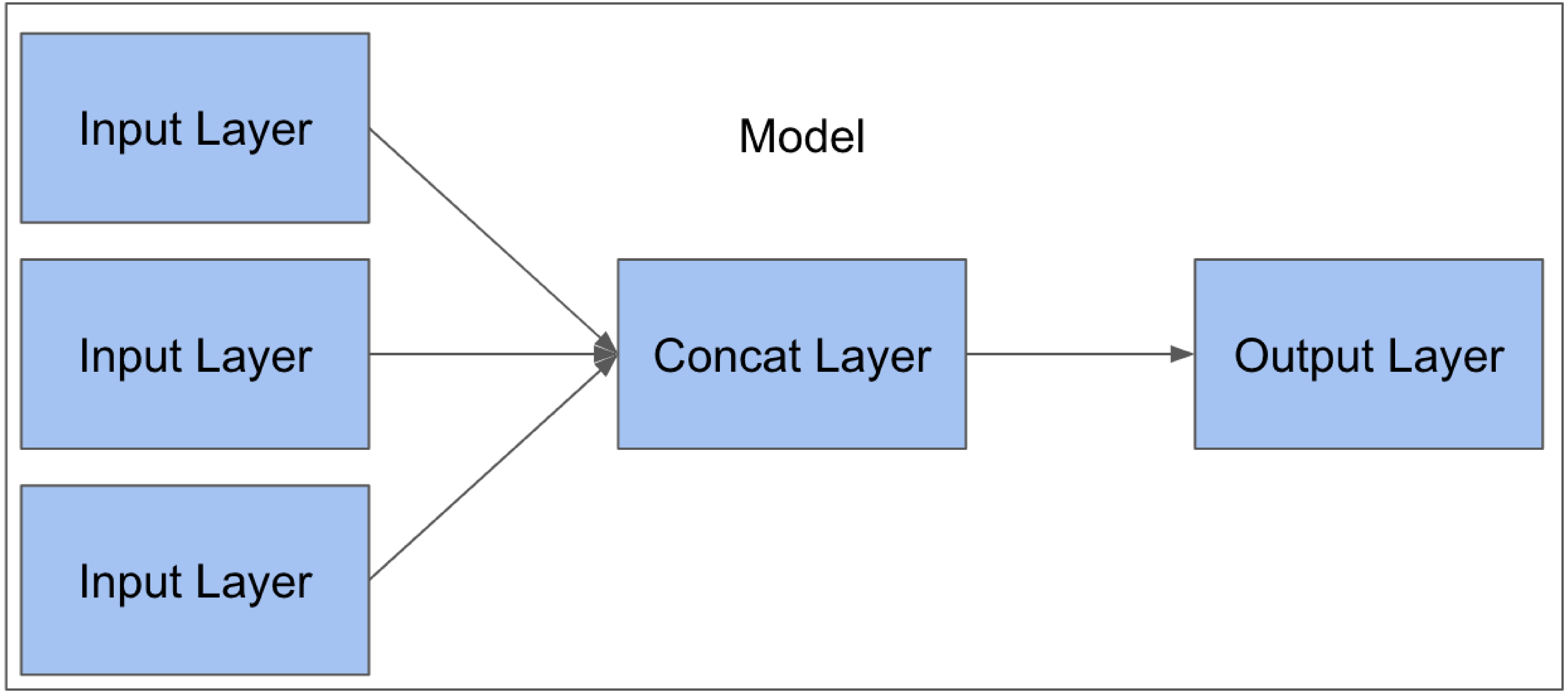
Simple model with 3 inputs

```
from keras.layers import Input, Concatenate, Dense
in_tensor_1 = Input(shape=(1,))
in_tensor_2 = Input(shape=(1,))
in_tensor_3 = Input(shape=(1,))
out_tensor = Concatenate()([in_tensor_1, in_tensor_2, in_tensor_3])
output_tensor = Dense(1)(out_tensor)
```



Simple model with 3 inputs

```
from keras.models import Model
model = Model([in_tensor_1, in_tensor_2, in_tensor_3], out_tensor)
```

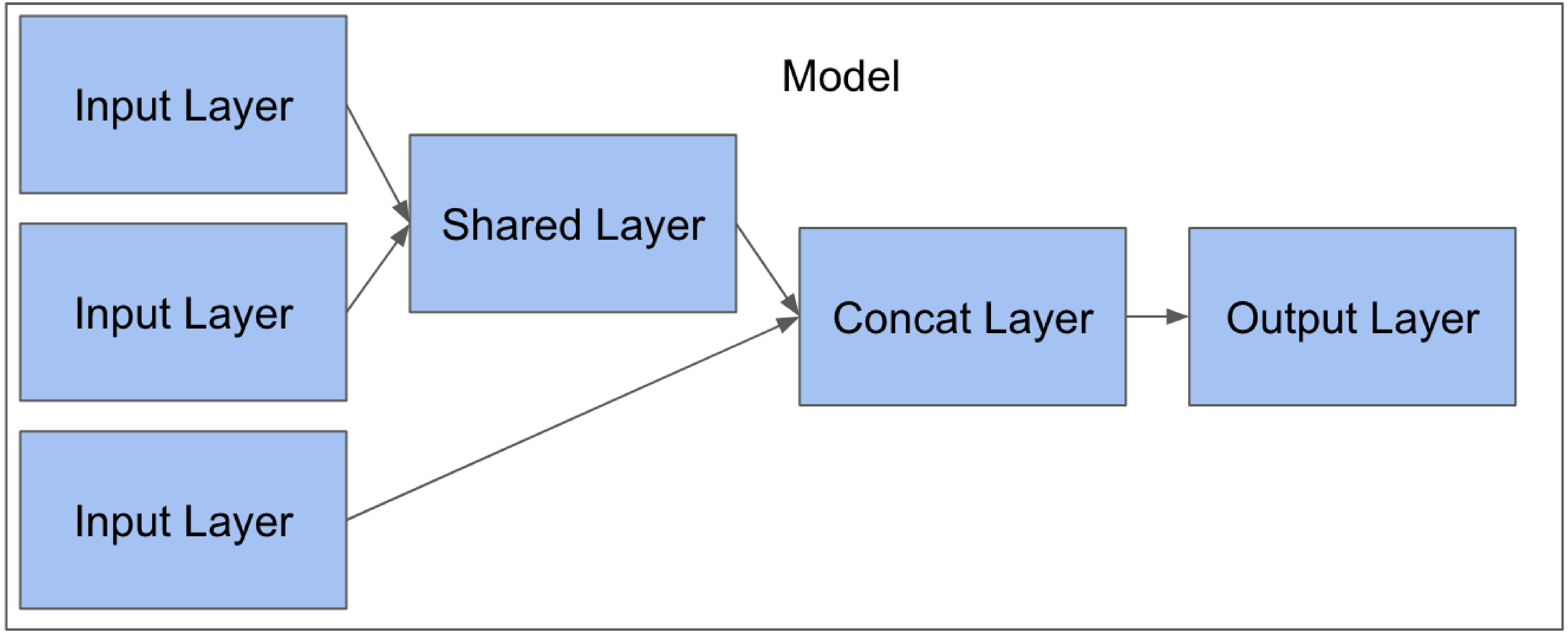


Shared layers with 3 inputs

```
shared_layer = Dense(1)
shared_tensor_1 = shared_layer(in_tensor_1)
shared_tensor_2 = shared_layer(in_tensor_1)
out_tensor = Concatenate()([shared_tensor_1, shared_tensor_2, in_tensor_3])
out_tensor = Dense(1)(out_tensor)
```

Shared layers with 3 inputs

```
from keras.models import Model
model = Model([in_tensor_1, in_tensor_2, in_tensor_3], out_tensor)
```



Fitting a 3 input model

```
from keras.models import Model
model = Model([in_tensor_1, in_tensor_2, in_tensor_3], out_tensor)
model.compile(loss='mae', optimizer='adam')
```

```
model.fit([[train['col1'], train['col2'], train['col3']],
          train_data['target'])
```

```
model.evaluate([[test['col1'], test['col2'], test['col3']],
               test['target'])
```

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Summarizing and plotting models

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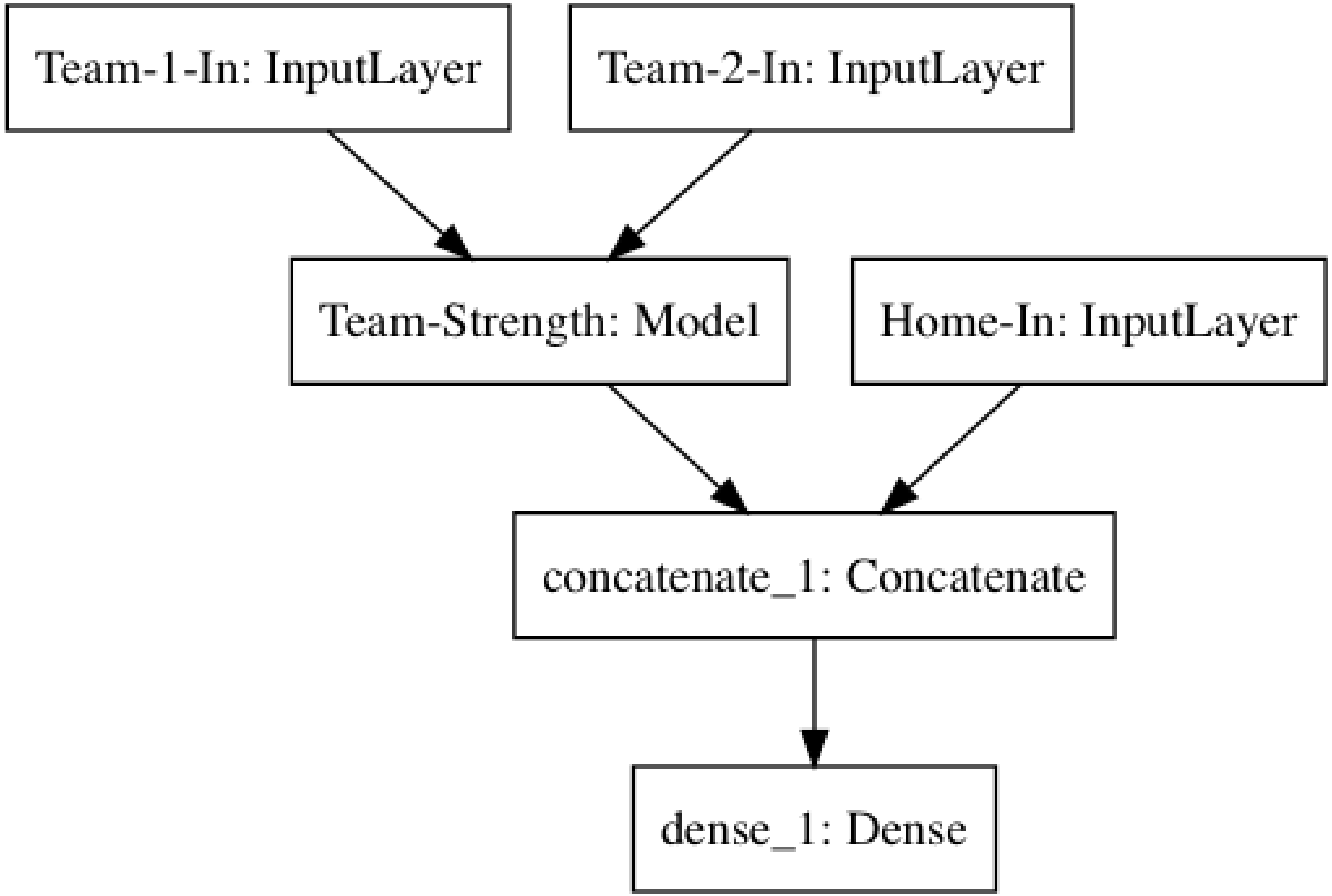
Understanding a model summary

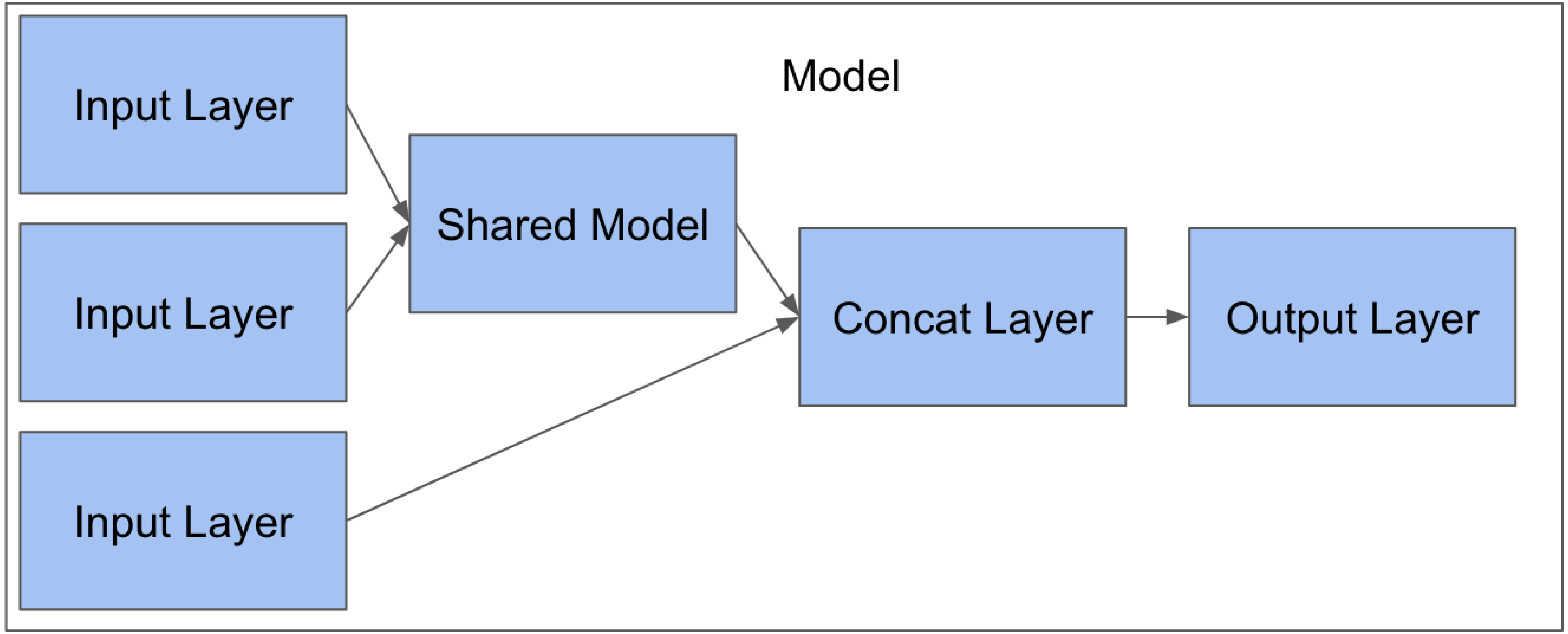
```
________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
input_1 (InputLayer)            (None, 1)            0
________________________________________________________________________________
input_2 (InputLayer)            (None, 1)            0
________________________________________________________________________________
input_3 (InputLayer)            (None, 1)            0
________________________________________________________________________________
concatenate_1 (Concatenate)     (None, 3)            0           input_1[0][0]
                                                                 input_2[0][0]
                                                                 input_3[0][0]
________________________________________________________________________________
dense_1 (Dense)                 (None, 1)            4           concatenate_1[0
================================================================================
Total params: 4
Trainable params: 4
Non-trainable params: 0
________________________________________________________________________________
```

Understanding a model summary

```
__________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================
input_1 (InputLayer)            (None, 1)            0
__________________________________________________________________________________
embedding_1 (Embedding)         (None, 1, 1)         10887       input_1[0][0]
__________________________________________________________________________________
flatten_1 (Flatten)             (None, 1)            0           embedding_1[0][
__________________________________________________________________________________
input_2 (InputLayer)            (None, 1)            0
__________________________________________________________________________________
input_3 (InputLayer)            (None, 1)            0
__________________________________________________________________________________
concatenate_1 (Concatenate)     (None, 3)            0           flatten_1[0][0]
                                                                 input_2[0][0]
                                                                 input_3[0][0]
__________________________________________________________________________________
dense_1 (Dense)                 (None, 1)            4           concatenate_1[0
==================================================================================
Total params: 10,891
Trainable params: 10,891
Non-trainable params: 0

__________________________________________________________________________________
```


Team-1-In: InputLayer
Team-2-In: InputLayer
Team-Strength: Model
Home-In: InputLayer
concatenate_1: Concatenate
dense_1: Dense

Understanding a model plot!



ADVANCED DEEP LEARNING WITH KERAS IN PYTHON

Let's Practice

ADVANCED DEEP LEARNING WITH KERAS IN PYTHON

Stacking models

Zach Deane Mayer
Data Scientist

Stacking models requires 2 datasets

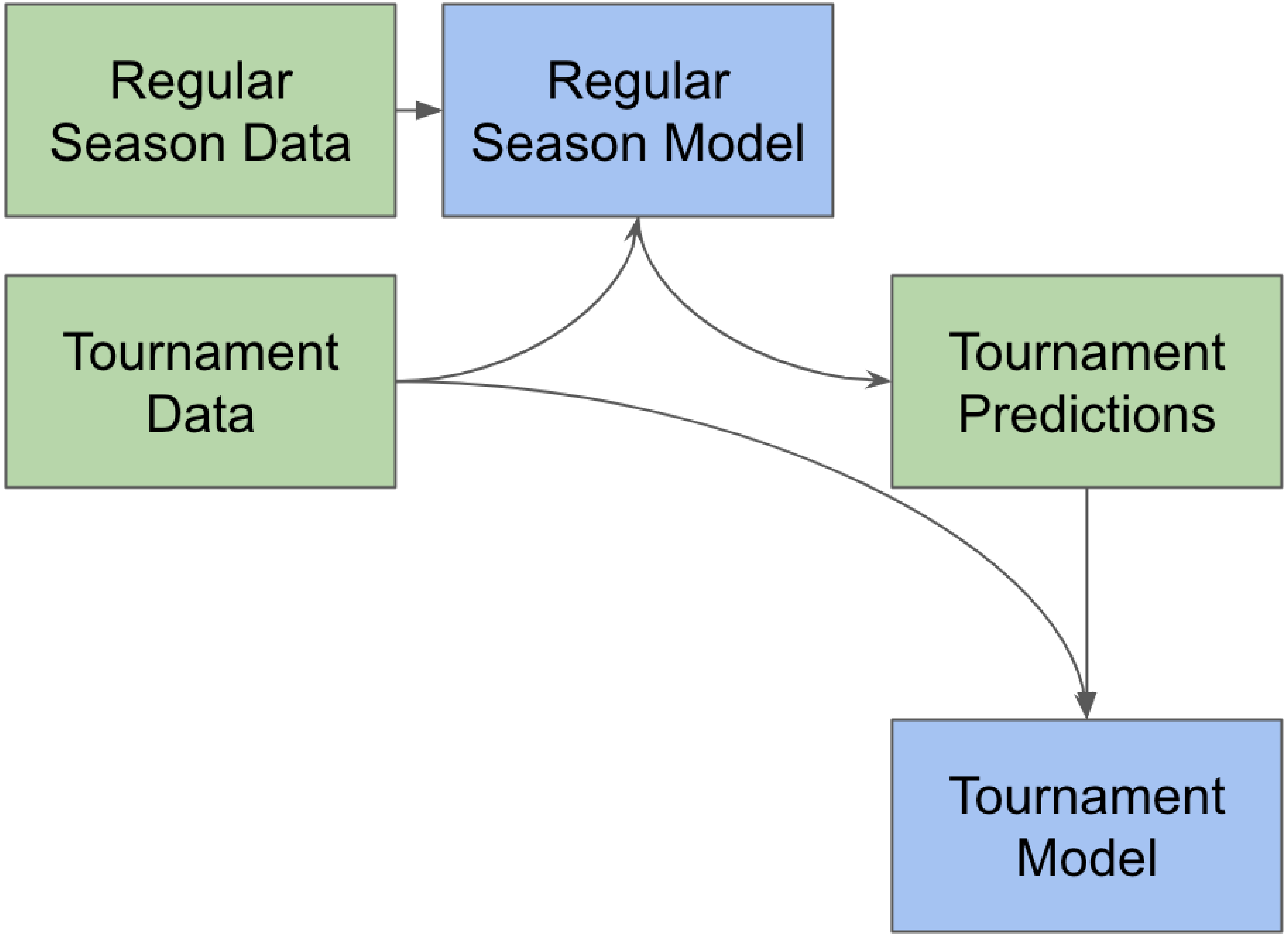
```
from pandas import read_csv
games_season = read_csv('datasets/games_season.csv')
games_season.head()

   team_1  team_2  home  score_diff
0    3745    6664     0          17
1     126    7493     1           7
2     288    3593     1           7
3    1846    9881     1          16
4    2675   10298     1          12
```

```
games_tourney = read_csv('datasets/games_tourney.csv')
games_tourney.head()

   team_1  team_2  home  seed_diff  score_diff
0     288      73     0         -3          -9
1    5929      73     0          4           6
2    9884      73     0          5          -4
3      73     288     0          3           9
4    3920     410     0          1          -9
```

Enrich the tournament data

```
in_data_1 = games_tourney['team_1']
in_data_2 = games_tourney['team_2']
in_data_3 = games_tourney['home']
pred = regular_season_model.predict([in_data_1, in_data_2, in_data_3])
```

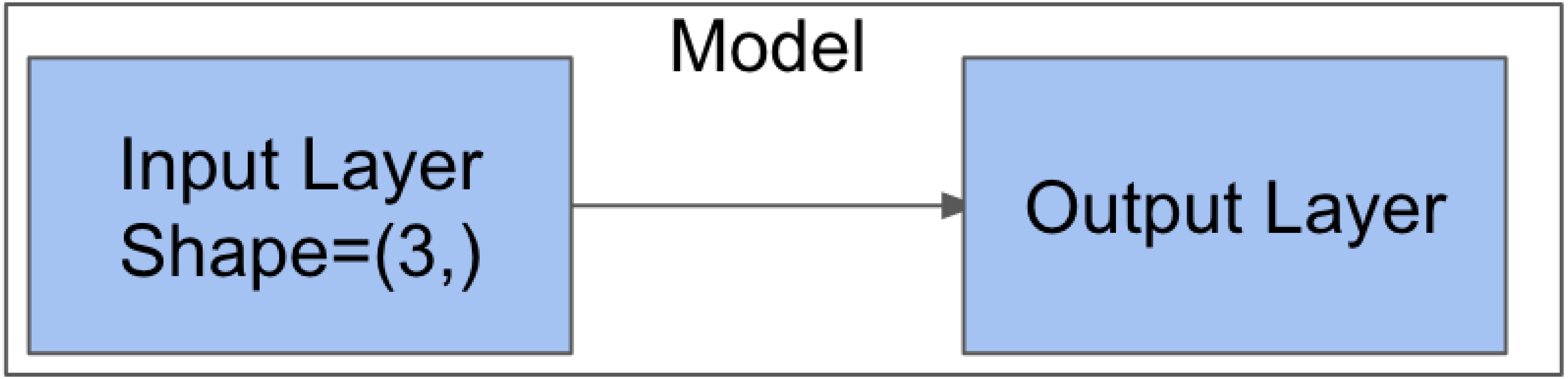
```
games_tourney['pred'] = pred
games_tourney.head()

   team_1  team_2  home  seed_diff      pred  score_diff
0     288      73     0         -3  0.582556          -9
1    5929      73     0          4  0.707279           6
2    9884      73     0          5  1.364844          -4
3      73     288     0          3  0.699145           9
4    3920     410     0          1  0.833066          -9
```


Regular Season Data
Regular Season Model
Tournament Data
Tournament Predictions
Tournament Model

3 input model with pure numeric data

```
games_tourney[['home','seed_diff','pred']].head()

   home  seed_diff      pred
0     0         -3  0.582556
1     0          4  0.707279
2     0          5  1.364844
3     0          3  0.699145
4     0          1  0.833066
```

3 input model with pure numeric data



3 input model with pure numeric data

```
from keras.layers import Input, Dense
in_tensor = Input(shape=(3,))
out_tensor = Dense(1)(in_tensor)
```

```
from keras.models import Model
model = Model(in_tensor, out_tensor)
model.compile(optimizer='adam', loss='mae')
train_X = train_data[['home','seed_diff','pred']]
train_y = train_data['score_diff']
model.fit(train_X,train_y, epochs=10, validation_split=.10)
```

```
test_X = test_data[['home','seed_diff','pred']]
test_y = test_data['score_diff']
model.evaluate(test_X, test_y)
1066/1066 [==============================] - 0s 14us/step
9.11321775461451
```

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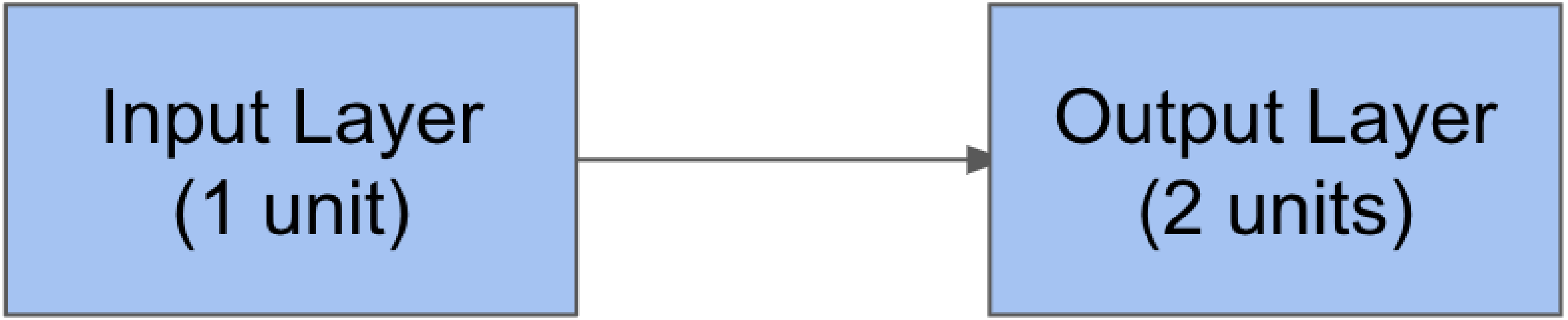
Two-output models

Zach Deane-Mayer
Data Scientist

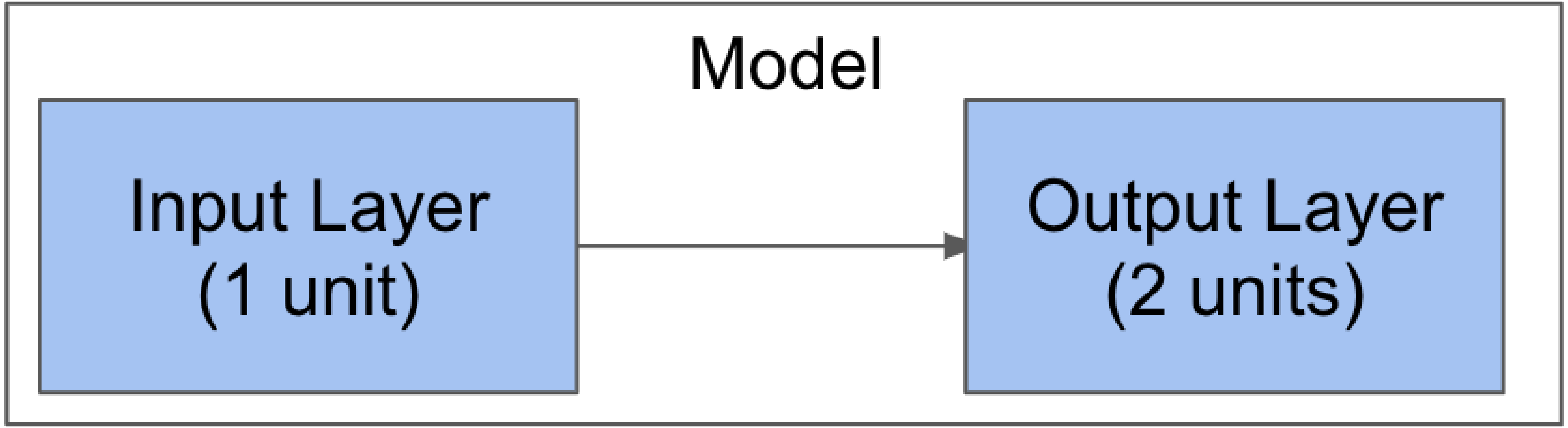
Simple model with 2 outputs

```
from keras.layers import Input, Concatenate, Dense
input_tensor = Input(shape=(1,))
output_tensor = Dense(2)(input_tensor)
```



Simple model with 2 outputs

```
from keras.models import Model
model = Model(input_tensor, output_tensor)
model.compile(optimizer='adam', loss='mean_absolute_error')
```



Fitting a model with 2 outputs

```
games_tourney_train[['seed_diff', 'score_1', 'score_2']].head()
```

```
   seed_diff  score_1  score_2
0         -3       41       50
1          4       61       55
2          5       59       63
3          3       50       41
4          1       54       63
```

```
X = games_tourney_train[['seed_diff']]
y = games_tourney_train[['score_1', 'score_2']]
model.fit(X, y, epochs=500)
```

Inspecting a 2 output model

```
model.get_weights()
```

```
[array([[ 0.60714734, -0.5988793 ]], dtype=float32),
 array([70.39491, 70.39306], dtype=float32)]
```

Evaluating a model with 2 outputs

```
X = games_tourney_test[['seed_diff']]
y = games_tourney_test[['score_1', 'score_2']]
model.evaluate(X, y)
```

```
11.528035634635021
```

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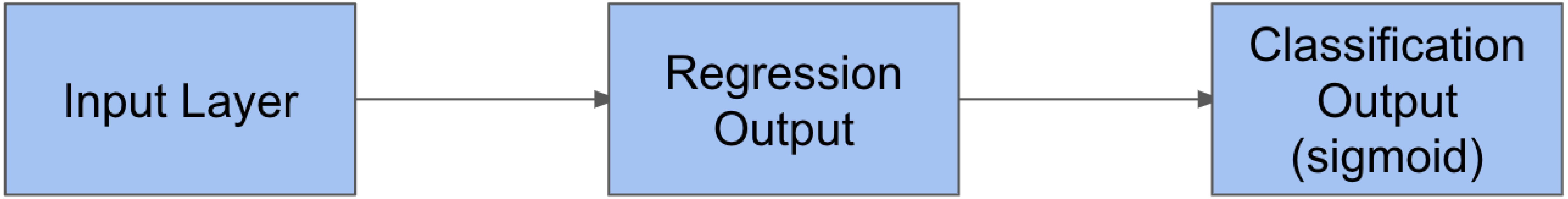
Single model for classification and regression

Zach Deane-Mayer
Data Scientist

Build a simple regressor/classifier

```
from keras.layers import Input, Dense
input_tensor = Input(shape=(1,))
output_tensor_reg = Dense(1)(input_tensor)
output_tensor_class = Dense(1, activation='sigmoid')(output_tensor_reg)
```



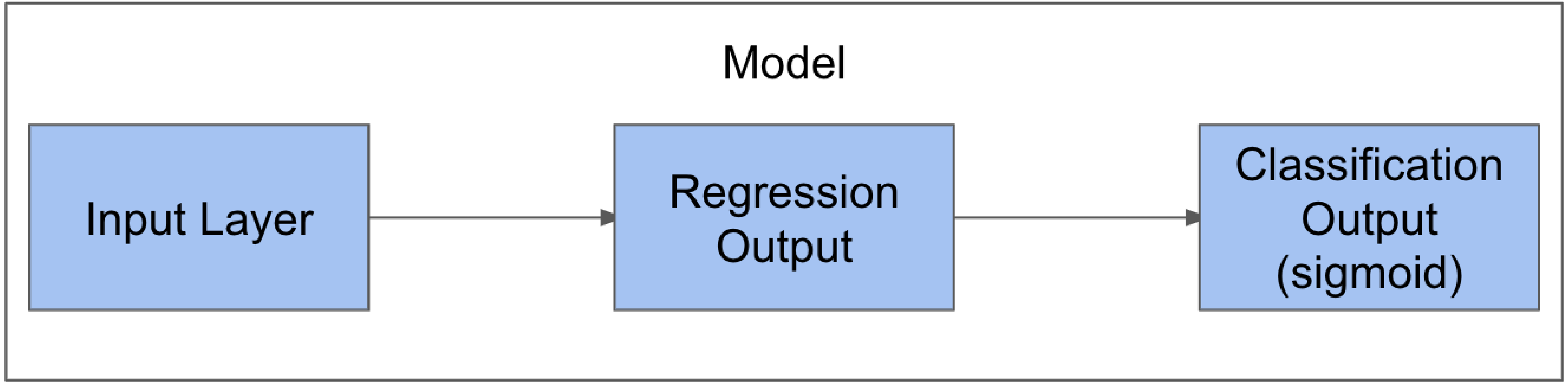
Input Layer

Regression Output

Classification Output (sigmoid)

Make a regressor/classifier model

```
from keras.models import Model
model = Model(input_tensor, [output_tensor_reg, output_tensor_class])
model.compile(loss=['mean_absolute_error', 'binary_crossentropy'],
              optimizer='adam')
```



Model

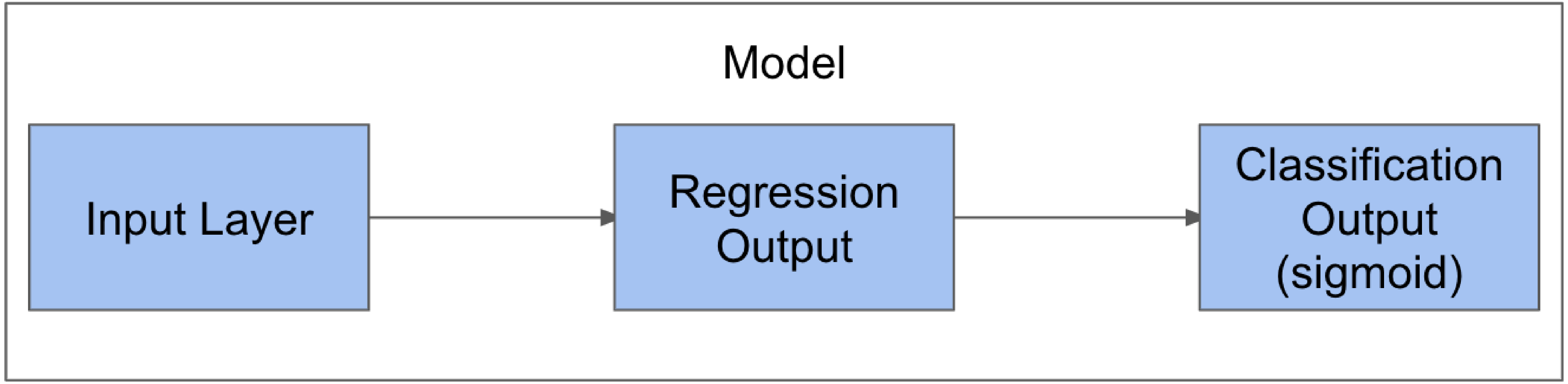
Input Layer

Regression Output

Classification Output (sigmoid)

Fit the combination classifier/regressor

```
X = games_tourney_train[['seed_diff']]
y_reg = games_tourney_train[['score_diff']]
y_class = games_tourney_train[['won']]
model.fit(X, [y_reg, y_class], epochs=100)
```



Model

Input Layer

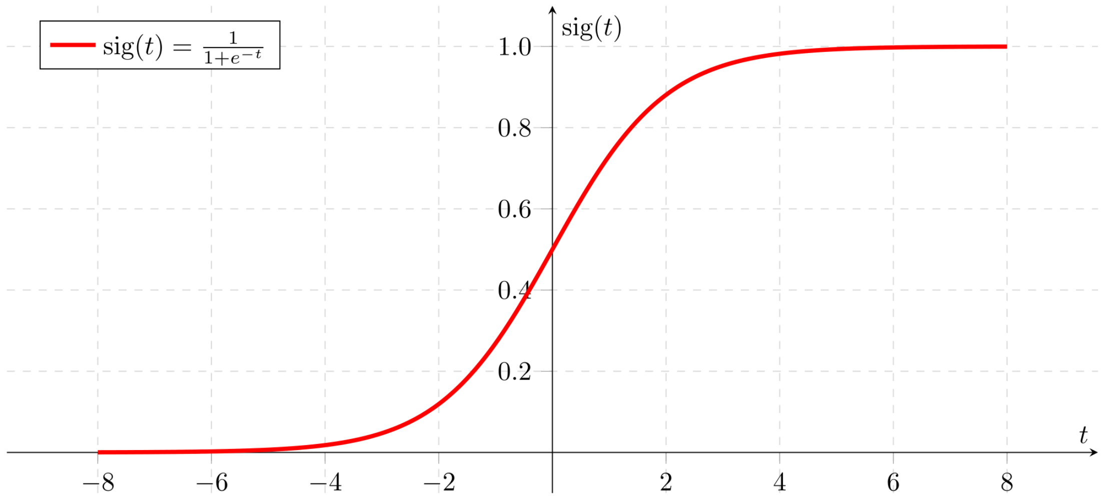
Regression Output

Classification Output (sigmoid)

Look at the model's weights

```
model.get_weights()

[array([[1.2371823]], dtype=float32),
 array([-0.05451894], dtype=float32),
 array([[0.13870609]], dtype=float32),
 array([0.00734114], dtype=float32)]
```



Look at the model's weights

```
model.get_weights()

[array([[1.2371823]], dtype=float32),
 array([-0.05451894], dtype=float32),
 array([[0.13870609]], dtype=float32),
 array([0.00734114], dtype=float32)]
```

```
from scipy.special import expit as sigmoid
print(sigmoid(1 * 0.13870609 + 0.00734114))
```

```
0.5364470465211318
```

Evaluate the model on new data

```
X = games_tourney_test[['seed_diff']]
y_reg = games_tourney_test[['score_diff']]
y_class = games_tourney_test[['won']]
model.evaluate(X, [y_reg, y_class])
```

```
[9.866300069455413, 9.281179495657208, 0.585120575627864]
```

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Now you try!

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Wrap-up

Zach Deane-Mayer
Data Scientist

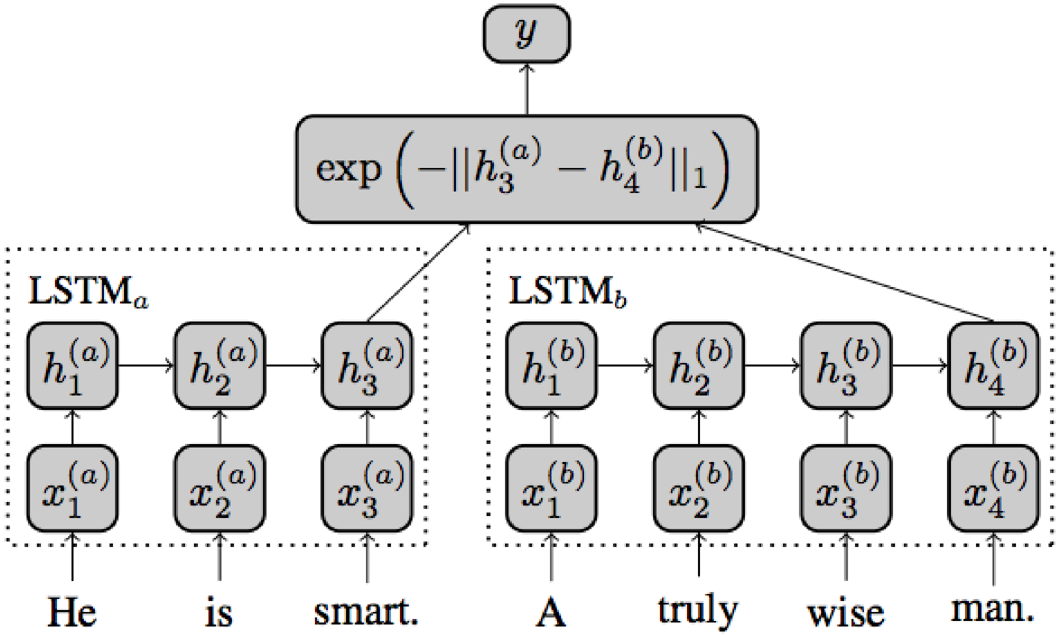
So far...

- Functional API
- Shared layers
- Categorical embeddings
- Multiple inputs
- Multiple outputs
- Regression / Classification in one model

Shared layers

Useful for making comparisons

- Basketball teams
- Image similarity / retrieval
- Document similarity

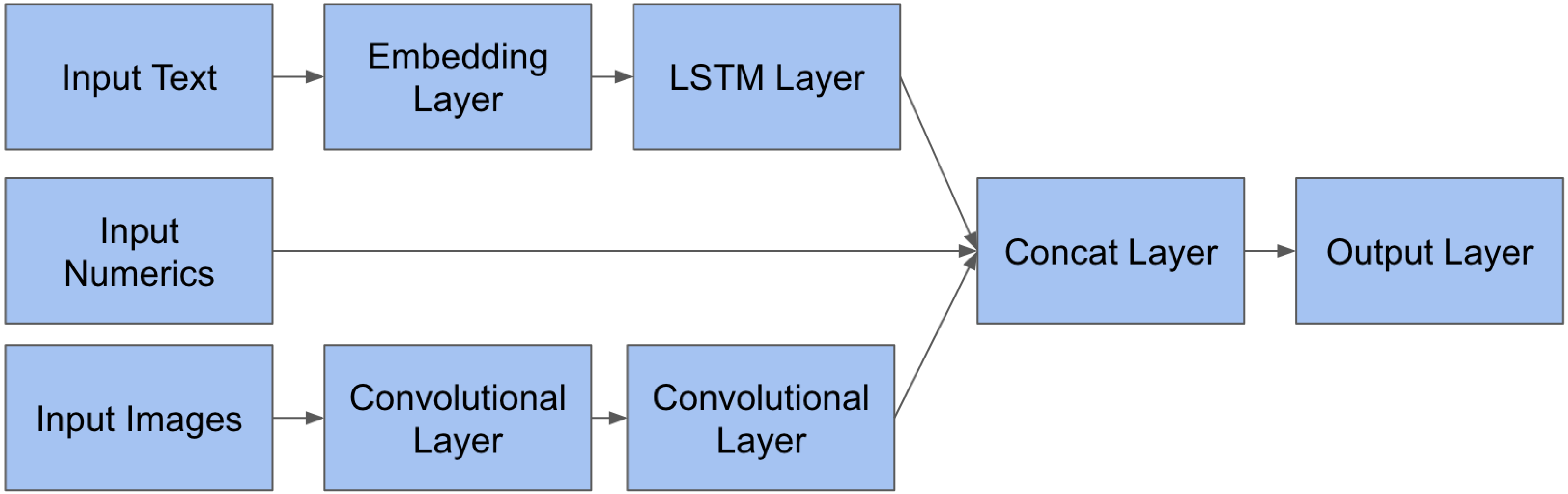


y
$\exp\left(-\|h_3^{(a)} - h_4^{(b)}\|_1\right)$
LSTM$_a$
$h_1^{(a)}$ $h_2^{(a)}$ $h_3^{(a)}$
$x_1^{(a)}$ $x_2^{(a)}$ $x_3^{(a)}$
LSTM$_b$
$h_1^{(b)}$ $h_2^{(b)}$ $h_3^{(b)}$ $h_4^{(b)}$
$x_1^{(b)}$ $x_2^{(b)}$ $x_3^{(b)}$ $x_4^{(b)}$
He is smart.
A truly wise man.

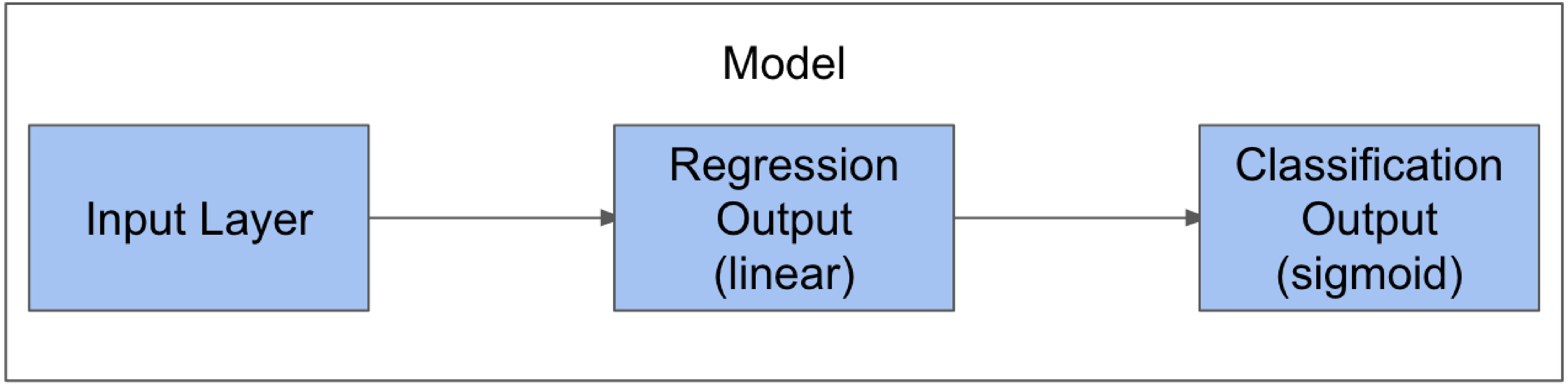
Known in the academic literature as Siamese networks

- Link to blog post
- Link to academic paper

Multiple inputs



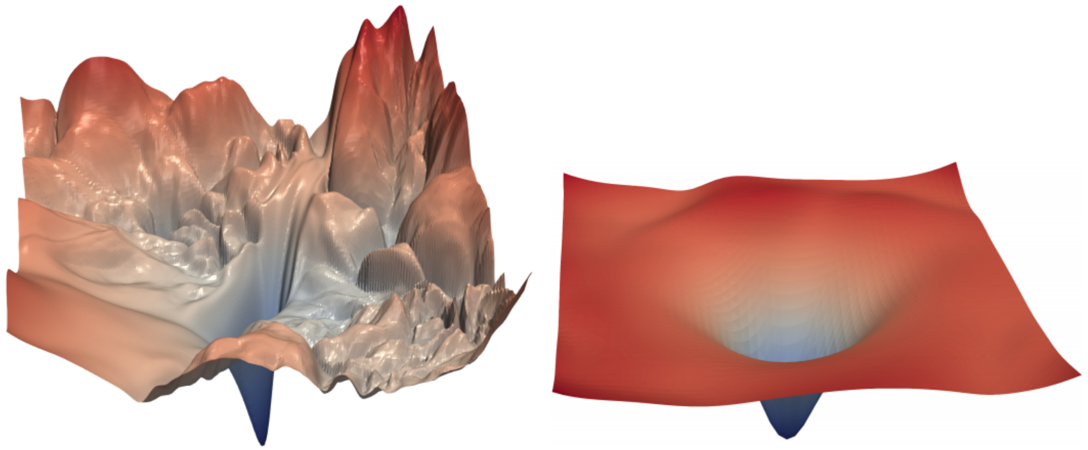
Multiple outputs



Skip connections

```
input_tensor = Input((100,))
hidden_tensor = Dense(256, activation='relu')(input_tensor)
hidden_tensor = Dense(256, activation='relu')(hidden_tensor)
hidden_tensor = Dense(256, activation='relu')(hidden_tensor)
output_tensor = Concatenate()([input_tensor, hidden_tensor])
output_tensor = Dense(256, activation='relu')(output_tensor)
```

Visualizing the Loss Landscape of Neural Nets



(a) without skip connections (b) with skip connections

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Best of luck!