

Classification

ACTL3143 & ACTL5111 Deep Learning for Actuaries
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Lecture Outline

- **TLDR**
- Classification
- Stroke Prediction



Classification models in Keras

If the number of classes is c , then:

Target	Output Layer	Loss Function
Binary ($c = 2$)	1 neuron with sigmoid activation	Binary Cross-Entropy
Multi-class ($c > 2$)	c neurons with softmax activation	Categorical Cross-Entropy



Optionally output logits

If the number of classes is c , then:

Target	Output Layer	Loss Function
Binary ($c = 2$)	1 neuron with linear activation	Binary Cross-Entropy (from_logits=True)
Multi-class ($c > 2$)	c neurons with linear activation	Categorical Cross-Entropy (from_logits=True)



Code examples

Binary

```
1 model = Sequential([
2     # Skipping the earlier layers
3     Dense(1, activation="sigmoid")
4 ])
5 model.compile(loss="binary_crossentropy")
```

Binary (logits)

```
1 from keras.losses import BinaryCrossentropy
2 model = Sequential([
3     # Skipping the earlier layers
4     Dense(1, activation="linear")
5 ])
6 loss = BinaryCrossentropy(from_logits=True)
7 model.compile(loss=loss)
```

Multi-class

```
1 model = Sequential([
2     # Skipping the earlier layers
3     Dense(n_classes, activation="softmax")
4 ])
5 model.compile(loss="sparse_categorical_crossentropy")
```

Multi-class (logits)

```
1 from keras.losses import SparseCategoricalCrossentropy
2
3 model = Sequential([
4     # Skipping the earlier layers
5     Dense(n_classes, activation="linear")
6 ])
7 loss = SparseCategoricalCrossentropy(from_logits=True)
8 model.compile(loss=loss)
```



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Iris dataset

```

1 from sklearn.datasets import load_iris
2 iris = load_iris()
3 names = ["SepalLength", "SepalWidth", "PetalLength", "PetalWidth"]
4 features = pd.DataFrame(iris.data, columns=names)
5 features

```

	SepalLength	SepalWidth	PetalLength	PetalWidth
0	5.1	3.5	1.4	0.2
1	4.9	3.0	1.4	0.2
...
148	6.2	3.4	5.4	2.3
149	5.9	3.0	5.1	1.8

150 rows × 4 columns



Target variable

```
1 iris.target_names
```

```
array(['setosa', 'versicolor', 'virginica'],  
      dtype='<U10')
```

```
1 iris.target[:8]
```

```
array([0, 0, 0, 0, 0, 0, 0, 0])
```

```
1 target = iris.target  
2 target = target.reshape(-1, 1)  
3 target[:8]
```

```
array([[0],  
       [0],  
       [0],  
       [0],  
       [0],  
       [0],  
       [0],  
       [0]])
```

```
1 classes, counts = np.unique(  
2     target,  
3     return_counts=True  
4 )  
5 print(classes)  
6 print(counts)
```

```
[0 1 2]  
[50 50 50]
```

```
1 iris.target_names[  
2     target[[0, 30, 60]]  
3 ]
```

```
array(['setosa'],  
      ['setosa'],  
      ['versicolor']], dtype='<U10')
```



Split the data into train and test

```
1 X_train, X_test, y_train, y_test = train_test_split(features, target, random_state=24)
2 X_train
```

	SepalLength	SepalWidth	PetalLength	PetalWidth
53	5.5	2.3	4.0	1.3
58	6.6	2.9	4.6	1.3
95	5.7	3.0	4.2	1.2
...
145	6.7	3.0	5.2	2.3
87	6.3	2.3	4.4	1.3
131	7.9	3.8	6.4	2.0

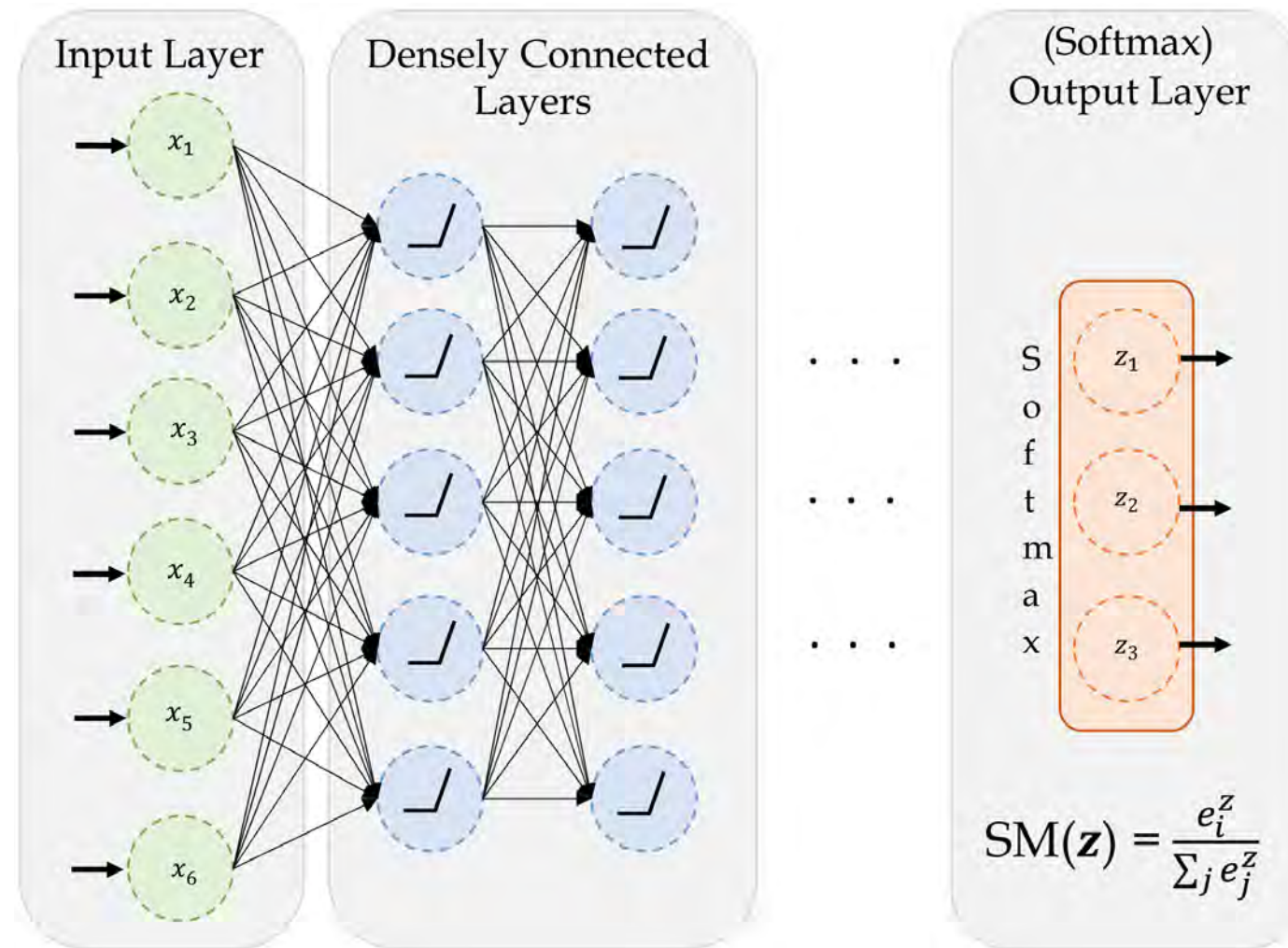
112 rows \times 4 columns

```
1 X_test.shape, y_test.shape
```

((38, 4), (38, 1))



A basic classifier network



A basic network for classifying into three categories.

Source: Marcus Lautier (2022).

Create a classifier model

```
1 NUM_FEATURES = len(features.columns)
2 NUM_CATS = len(np.unique(target))
3
4 print("Number of features:", NUM_FEATURES)
5 print("Number of categories:", NUM_CATS)
```

Number of features: 4

Number of categories: 3

Make a function to return a Keras model:

```
1 def build_model(seed=42):
2     random.seed(seed)
3     return Sequential([
4         Dense(30, activation="relu"),
5         Dense(NUM_CATS, activation="softmax")
6     ])
```



Fit the model

```
1 model = build_model()  
2 model.compile("adam", "sparse_categorical_crossentropy")  
3  
4 model.fit(X_train, y_train, epochs=5, verbose=2);
```

Epoch 1/5

4/4 - 0s - 105ms/step - loss: 1.3502

Epoch 2/5

4/4 - 0s - 3ms/step - loss: 1.2852

Epoch 3/5

4/4 - 0s - 3ms/step - loss: 1.2337

Epoch 4/5

4/4 - 0s - 3ms/step - loss: 1.1915

Epoch 5/5

4/4 - 0s - 5ms/step - loss: 1.1556



Track accuracy as the model trains

```
1 model = build_model()  
2 model.compile("adam", "sparse_categorical_crossentropy", metrics=["accuracy"])  
3 model.fit(X_train, y_train, epochs=5, verbose=2);
```

Epoch 1/5

4/4 - 0s - 81ms/step - accuracy: 0.2946 - loss: 1.3502

Epoch 2/5

4/4 - 0s - 3ms/step - accuracy: 0.3036 - loss: 1.2852

Epoch 3/5

4/4 - 0s - 3ms/step - accuracy: 0.3036 - loss: 1.2337

Epoch 4/5

4/4 - 0s - 3ms/step - accuracy: 0.3304 - loss: 1.1915

Epoch 5/5

4/4 - 0s - 3ms/step - accuracy: 0.3393 - loss: 1.1556



Run a long fit

```
1 model = build_model()
2 model.compile("adam", "sparse_categorical_crossentropy", \
3               metrics=["accuracy"])
4 %time hist = model.fit(X_train, y_train, epochs=500, \
5                       validation_split=0.25, verbose=False)
```

CPU times: user 12.8 s, sys: 1.63 s, total: 14.5 s

Wall time: 12.1 s

Evaluation now returns both *loss* and *accuracy*.

```
1 model.evaluate(X_test, y_test, verbose=False)
```

[0.09586220979690552, 0.9736841917037964]



Add early stopping

```
1 model = build_model()
2 model.compile("adam", "sparse_categorical_crossentropy", \
3               metrics=["accuracy"])
4
5 es = EarlyStopping(restore_best_weights=True, patience=50,
6                   monitor="val_accuracy")
7 %time hist_es = model.fit(X_train, y_train, epochs=500, \
8                           validation_split=0.25, callbacks=[es], verbose=False);
9
10 print(f"Stopped after {len(hist_es.history['loss'])} epochs.")
```

CPU times: user 2.19 s, sys: 207 ms, total: 2.39 s
Wall time: 2.03 s
Stopped after 68 epochs.

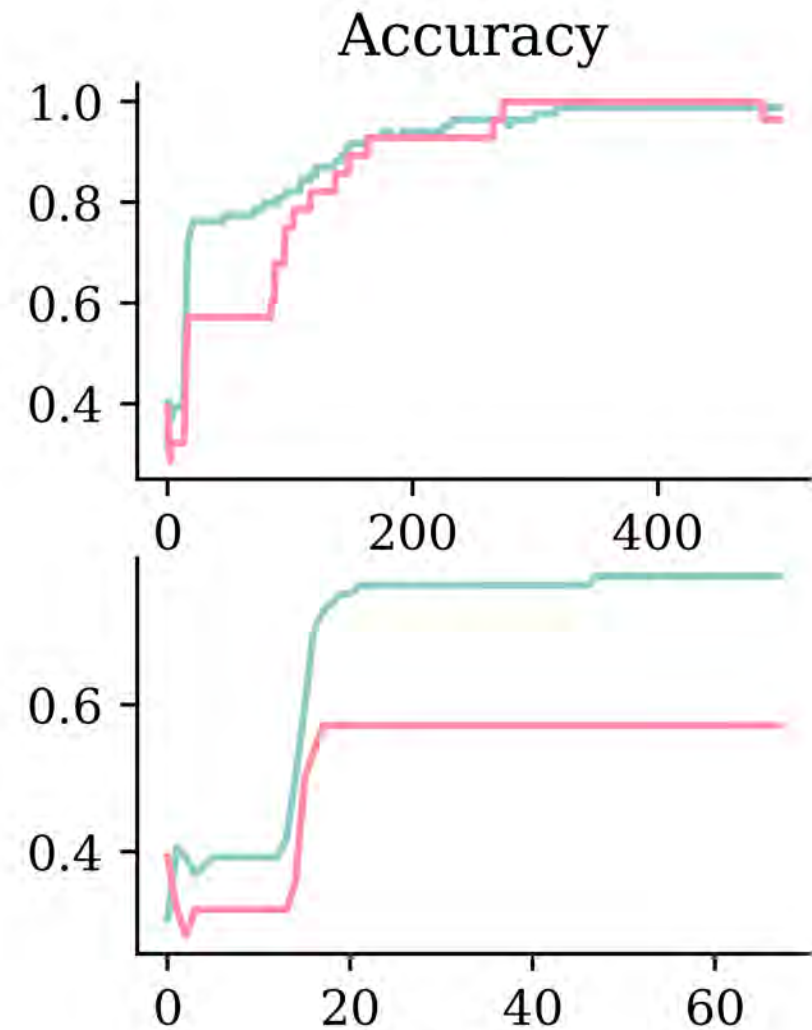
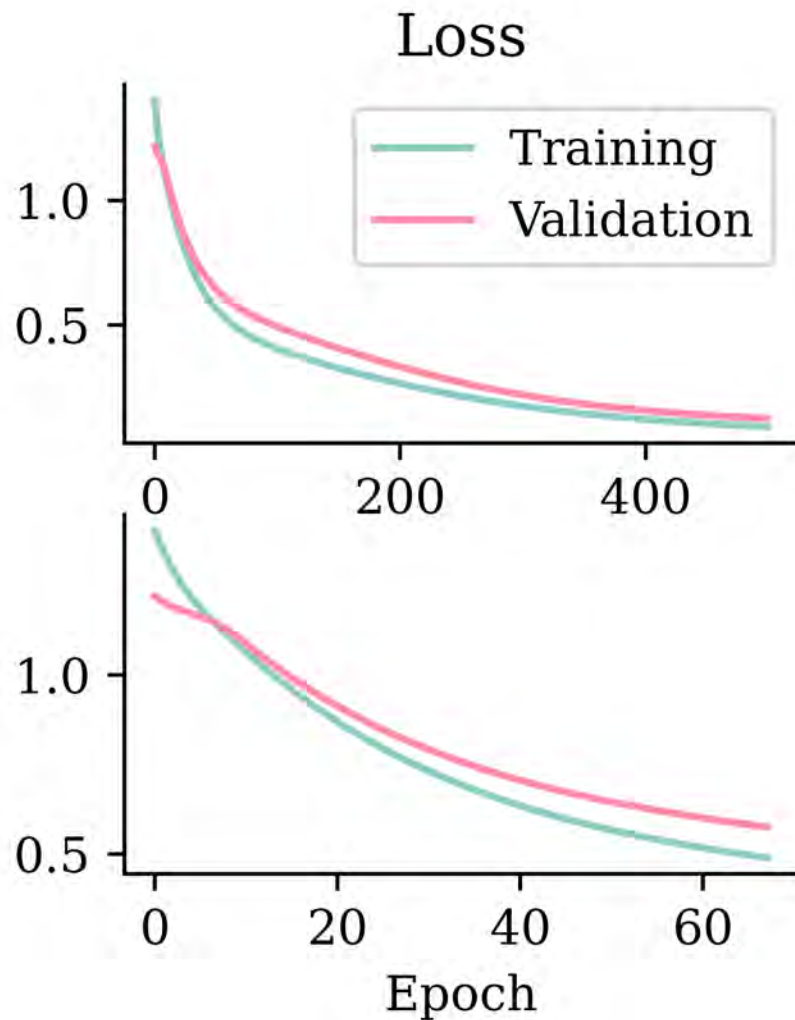
Evaluation on test set:

```
1 model.evaluate(X_test, y_test, verbose=False)
```

[0.9856260418891907, 0.5263158082962036]



Fitting metrics



What is the softmax activation?

It creates a “probability” vector: $\text{Softmax}(\mathbf{x}) = \frac{e_i^x}{\sum_j e_j^x}$.

In NumPy:

```
1 out = np.array([5, -1, 6])  
2 (np.exp(out) / np.exp(out).sum()).round(3)
```

```
array([0.269, 0.001, 0.731])
```

In Keras:

```
1 out = keras.ops.convert_to_tensor([[5.0, -1.0, 6.0]])  
2 keras.ops.round(keras.ops.softmax(out), 3)
```

```
<tf.Tensor: shape=(1, 3), dtype=float32, numpy=array([[0.269, 0.001, 0.731]], dtype=float32)>
```



Prediction using classifiers

```
1 y_test[:4]
```

```
array([[2],
       [2],
       [1],
       [1]])
```

```
1 y_pred = model.predict(X_test.head(4), verbose=0)
2 y_pred
```

```
array([[0.1397096 , 0.5175301 , 0.34276026],
       [0.24611065, 0.44371164, 0.3101777 ],
       [0.26309973, 0.43174297, 0.3051573 ],
       [0.259089  , 0.44883674, 0.29207426]], dtype=float32)
```

```
1 # Add 'keepdims=True' to get a column vector.
2 np.argmax(y_pred, axis=1)
```

```
array([1, 1, 1, 1])
```

```
1 iris.target_names[np.argmax(y_pred, axis=1)]
```

```
array(['versicolor', 'versicolor', 'versicolor', 'versicolor'],
      dtype='<U10')
```



Cross-entropy loss: ELI5

Neural Networks Part 6: Cross Entropy

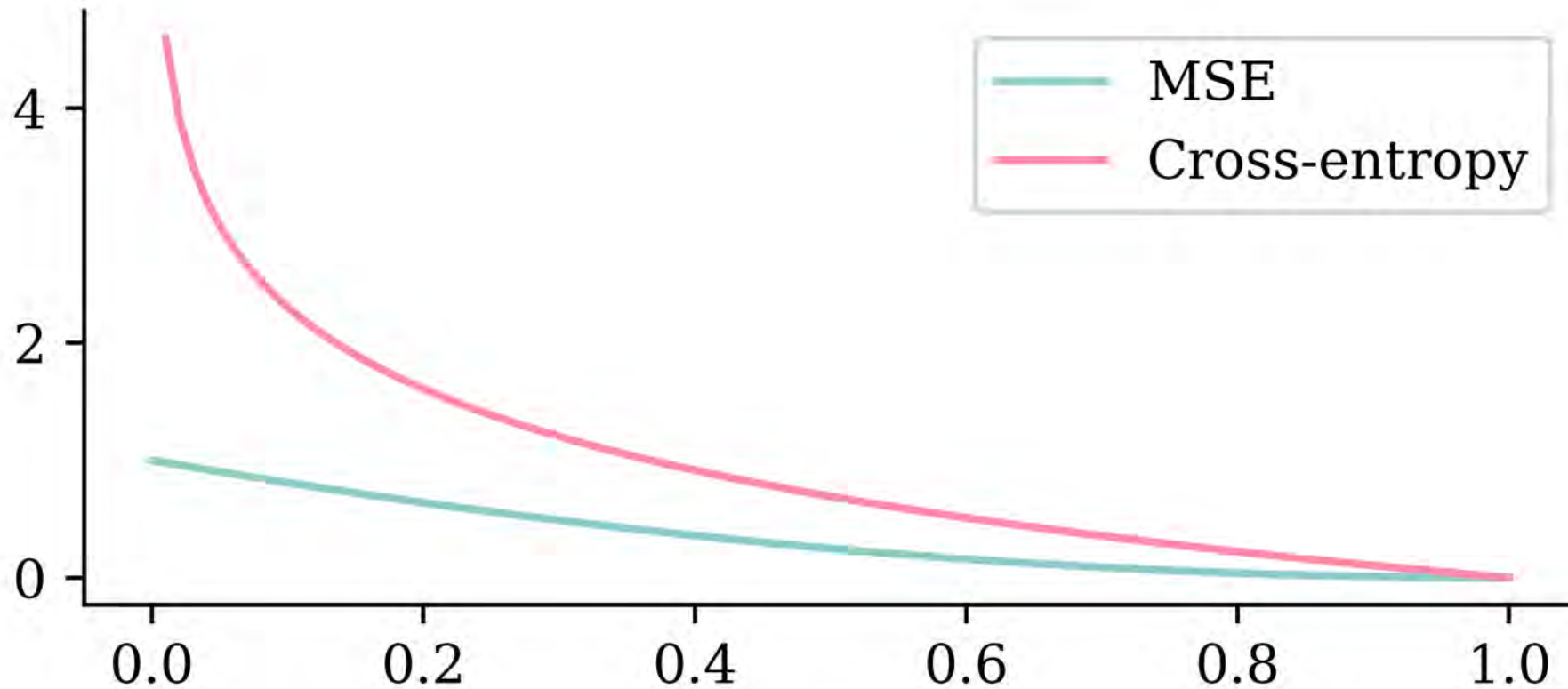


Neural Networks Part 7: Cross Entropy Derivativ...



Why use cross-entropy loss?

```
1 p = np.linspace(0, 1, 100)
2 plt.plot(p, (1 - p) ** 2)
3 plt.plot(p, -np.log(p))
4 plt.legend(["MSE", "Cross-entropy"]);
```



One-hot encoding

```
1 from sklearn.preprocessing import OneHotEncoder
2
3 enc = OneHotEncoder(sparse_output=False)
4
5 y_train_oh = enc.fit_transform(y_train)
6 y_test_oh = enc.transform(y_test)
```

```
1 y_train[:5]
```

```
array([[1],
       [1],
       [1],
       [0],
       [0]])
```

```
1 y_train_oh[:5]
```

	x0_0	x0_1	x0_2
0	0.0	1.0	0.0
1	0.0	1.0	0.0
2	0.0	1.0	0.0
3	1.0	0.0	0.0
4	1.0	0.0	0.0



Classifier given one-hot outputs

Create the model (*new loss function*):

```
1 model = build_model()  
2 model.compile("adam", "categorical_crossentropy", \  
3     metrics=["accuracy"])
```

Fit the model (*new target variables*):

```
1 model.fit(X_train, y_train_oh, epochs=100, verbose=False);
```

Evaluate the model (*new target variables*):

```
1 model.evaluate(X_test, y_test_oh, verbose=False)
```

```
[0.347093790769577, 0.9473684430122375]
```



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- **Stroke Prediction**



The data

Dataset source: [Kaggle Stroke Prediction Dataset](#).

```
1 data = pd.read_csv("stroke.csv")
2 data.head()
```

	id	gender	age	hypertension	heart_disease	ever_married	work_type	Residence
0	9046	Male	67.0	0	1	Yes	Private	Urban
1	51676	Female	61.0	0	0	Yes	Self-employed	Rural
2	31112	Male	80.0	0	1	Yes	Private	Rural
3	60182	Female	49.0	0	0	Yes	Private	Urban
4	1665	Female	79.0	1	0	Yes	Self-employed	Rural



Data description

1. **id**: unique identifier
2. **gender**: “Male”, “Female” or “Other”
3. **age**: age of the patient
4. **hypertension**: 0 or 1 if the patient has hypertension
5. **heart_disease**: 0 or 1 if the patient has any heart disease
6. **ever_married**: “No” or “Yes”
7. **work_type**: “children”, “Govt_jov”, “Never_worked”, “Private” or “Self-employed”
8. **Residence_type**: “Rural” or “Urban”
9. **avg_glucose_level**: average glucose level in blood
10. **bmi**: body mass index
11. **smoking_status**: “formerly smoked”, “never smoked”, “smokes” or “Unknown”
12. **stroke**: 0 or 1 if the patient had a stroke

Source: Kaggle, **Stroke Prediction Dataset**.



Split the data

First, look for missing values.

```
1 number_missing = data.isna().sum()  
2 number_missing[number_missing > 0]
```

```
bmi      201  
dtype: int64
```

```
1 features = data.drop(["id", "stroke"], axis=1)  
2 target = data["stroke"]  
3  
4 X_main, X_test, y_main, y_test = train_test_split(  
5     features, target, test_size=0.2, random_state=7)  
6 X_train, X_val, y_train, y_val = train_test_split(  
7     X_main, y_main, test_size=0.25, random_state=12)  
8  
9 X_train.shape, X_val.shape, X_test.shape
```

```
((3066, 10), (1022, 10), (1022, 10))
```



What values do we see in the data?

```
1 X_train["gender"].value_counts()
```

```
gender
Female    1802
Male      1264
Name: count, dtype: int64
```

```
1 X_train["ever_married"].value_counts()
```

```
ever_married
Yes      2007
No       1059
Name: count, dtype: int64
```

```
1 X_train["Residence_type"].value_counts()
```

```
Residence_type
Urban    1536
Rural    1530
Name: count, dtype: int64
```

```
1 X_train["work_type"].value_counts()
```

```
work_type
Private      1754
Self-employed  490
children      419
Govt_job      390
Never_worked   13
Name: count, dtype: int64
```

```
1 X_train["smoking_status"].value_counts()
```

```
smoking_status
never smoked  1130
Unknown       944
formerly smoked  522
smokes        470
Name: count, dtype: int64
```



Preprocess columns individually

1. Take categorical columns \hookrightarrow one-hot vectors
2. binary columns \hookrightarrow do nothing
3. continuous columns \hookrightarrow impute NaNs & standardise.



Scikit-learn column transformer

```

1  from sklearn.pipeline import make_pipeline
2
3  cat_vars = ["gender", "ever_married", "Residence_type",
4             "work_type", "smoking_status"]
5
6  ct = make_column_transformer(
7      (OneHotEncoder(sparse_output=False, handle_unknown="ignore"), cat_vars),
8      ("passthrough", ["hypertension", "heart_disease"]),
9      remainder=make_pipeline(SimpleImputer(), StandardScaler()),
10     verbose_feature_names_out=False
11 )
12
13 X_train_ct = ct.fit_transform(X_train)
14 X_val_ct = ct.transform(X_val)
15 X_test_ct = ct.transform(X_test)
16
17 for name, X in zip(("train", "val", "test"), (X_train_ct, X_val_ct, X_test_ct)):
18     num_na = X.isna().sum().sum()
19     print(f"The {name} set has shape {X.shape} & with {num_na} NAs.")

```

The train set has shape (3066, 20) & with 0 NAs.

The val set has shape (1022, 20) & with 0 NAs.

The test set has shape (1022, 20) & with 0 NAs.



Handling unseen categories

```
1 X_train["gender"].value_counts()
```

```
gender
Female    1802
Male      1264
Name: count, dtype: int64
```

```
1 X_val["gender"].value_counts()
```

```
gender
Female    615
Male      406
Other       1
Name: count, dtype: int64
```

```
1 ind = np.argmax(X_val["gender"] == "Other")
2 X_val.iloc[ind-1:ind+3][["gender"]]
```

```
1 gender_cols = X_val.columns[X_val.columns == "gender_Female"]
2 gender_cols.iloc[ind-1:ind+3]
```

	gender
4970	Male
3116	Other
4140	Male
2505	Female

	gender_Female	gender_Male
4970	0.0	1.0
3116	0.0	0.0
4140	0.0	1.0
2505	1.0	0.0

Setup a binary classification model

```

1 def create_model(seed=42):
2     random.seed(seed)
3     model = Sequential()
4     model.add(Input(X_train_ct.shape[1:]))
5     model.add(Dense(32, "leaky_relu"))
6     model.add(Dense(16, "leaky_relu"))
7     model.add(Dense(1, "sigmoid"))
8     return model

```

```

1 model = create_model()
2 model.summary()

```

Model: "sequential_5"

Layer (type)	Output Shape	Param #
dense_10 (Dense)	(None, 32)	672
dense_11 (Dense)	(None, 16)	528
dense_12 (Dense)	(None, 1)	17

Total params: 1,217 (4.75 KB)

Trainable params: 1,217 (4.75 KB)

Non-trainable params: 0 (0.00 B)



Add metrics, compile, and fit

```

1 model = create_model()
2
3 pr_auc = keras.metrics.AUC(curve="PR", name="pr_auc")
4 model.compile(optimizer="adam", loss="binary_crossentropy",
5               metrics=[pr_auc, "accuracy", "auc"])
6
7 es = EarlyStopping(patience=50, restore_best_weights=True,
8                   monitor="val_pr_auc", verbose=1)
9 model.fit(X_train_ct, y_train, callbacks=[es], epochs=1_000, verbose=0,
10         validation_data=(X_val_ct, y_val));

```

Epoch 65: early stopping

Restoring model weights from the end of the best epoch: 15.

```

1 model.evaluate(X_val_ct, y_val, verbose

```

```

[0.14444081485271454,
 0.13122102618217468,
 0.9589040875434875,
 0.8215014934539795]

```



Overweight the minority class

```

1 model = create_model()
2
3 pr_auc = keras.metrics.AUC(curve="PR", name="pr_auc")
4 model.compile(optimizer="adam", loss="binary_crossentropy",
5               metrics=[pr_auc, "accuracy", "auc"])
6
7 es = EarlyStopping(patience=50, restore_best_weights=True,
8                   monitor="val_pr_auc", verbose=1)
9 model.fit(X_train_ct, y_train.to_numpy(), callbacks=[es], epochs=1_000, verbose=0,
10         validation_data=(X_val_ct, y_val), class_weight={0: 1, 1: 10});

```

Epoch 74: early stopping

Restoring model weights from the end of the best epoch: 24.

```
1 model.evaluate(X_val_ct, y_val, verbose
```

```

[0.3345569670200348,
 0.13615098595619202,
 0.8062622547149658,
 0.8122206330299377]

```

```
1 model.evaluate(X_test_ct, y_test, verbo
```

```

[0.3590189516544342,
 0.1449822038412094,
 0.8023483157157898,
 0.7915638089179993]

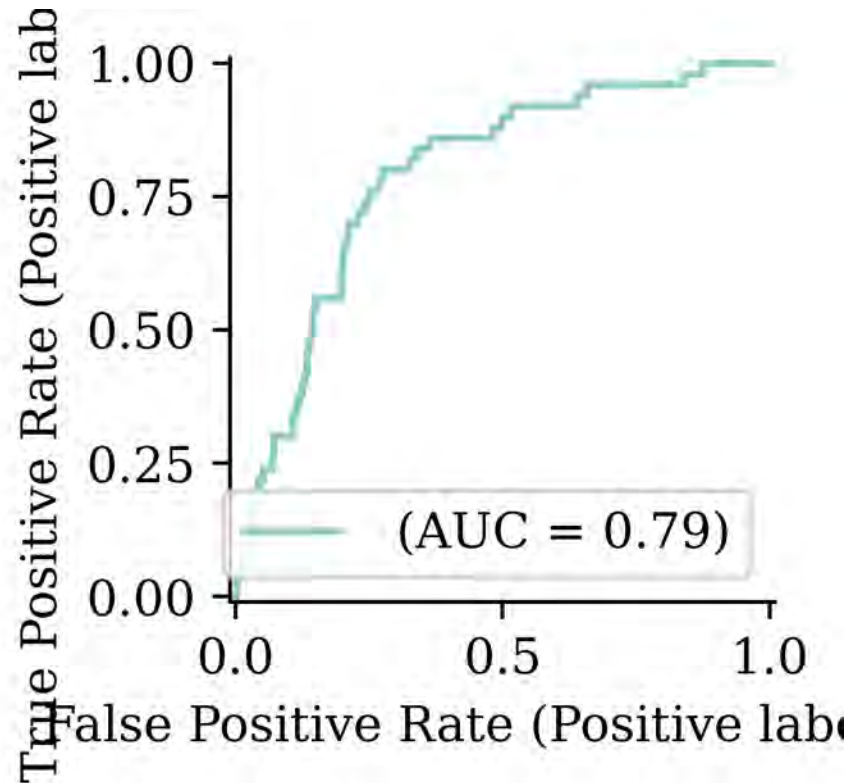
```



Classification Metrics

```
1 from sklearn.metrics import confusion_matrix, RocCurveDisplay, PrecisionRecallDisplay
2 y_pred = model.predict(X_test_ct, verbose=0)
```

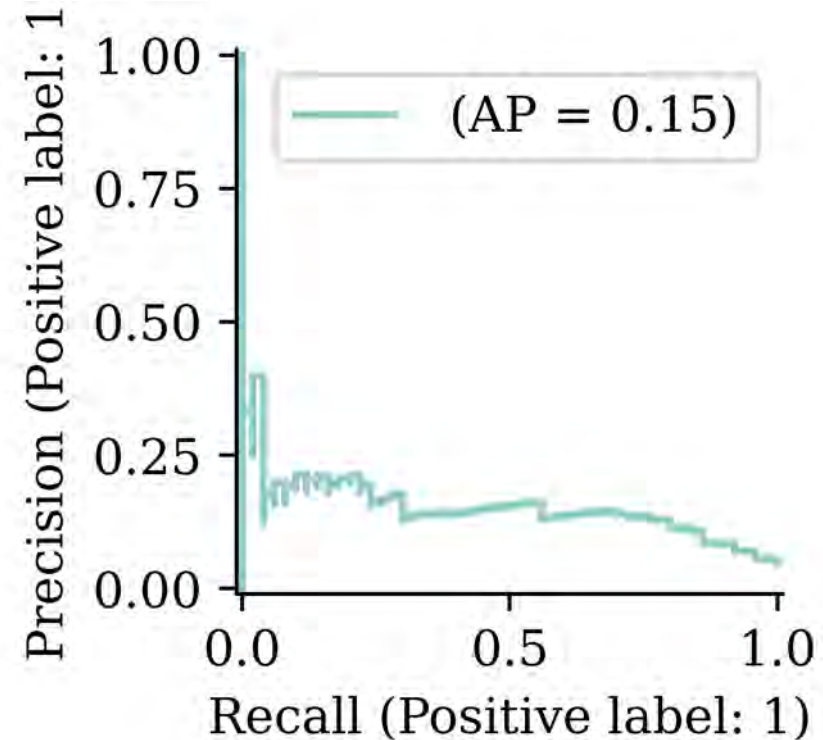
```
1 RocCurveDisplay.from_predictions(y_test, y_pred, name="");
```



```
1 y_pred_stroke = y_pred > 0.5
2 confusion_matrix(y_test, y_pred_stroke)
```

```
array([[792, 180],
       [ 22, 281]])
```

```
1 PrecisionRecallDisplay.from_predictions(y_test, y_pred, na
```



```
1 y_pred_stroke = y_pred > 0.3
2 confusion_matrix(y_test, y_pred_stroke)
```

```
array([[662, 310],
       [ 10, 401]])
```



Package Versions

```
1 from watermark import watermark
2 print(watermark(python=True, packages="keras,matplotlib,numpy,pandas,seaborn,scipy,torch
```

```
Python implementation: CPython
Python version       : 3.11.9
IPython version      : 8.24.0
```

```
keras      : 3.3.3
matplotlib: 3.9.0
numpy      : 1.26.4
pandas     : 2.2.2
seaborn    : 0.13.2
scipy      : 1.11.0
torch      : 2.3.1
tensorflow: 2.16.1
tf_keras   : 2.16.0
```



Glossary

- classification problem
- confusion matrix
- cross-entropy loss
- sigmoid activation function

