

# 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 <code>sigmoid</code> activation	Binary Cross-Entropy
Multi-class ( $c > 2$ )	$c$ neurons with <code>softmax</code> 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 <code>linear</code> activation	Binary Cross-Entropy ( <code>from_logits=True</code> )
Multi-class ( $c > 2$ )	$c$ neurons with <code>linear</code> activation	Categorical Cross-Entropy ( <code>from_logits=True</code> )



# 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

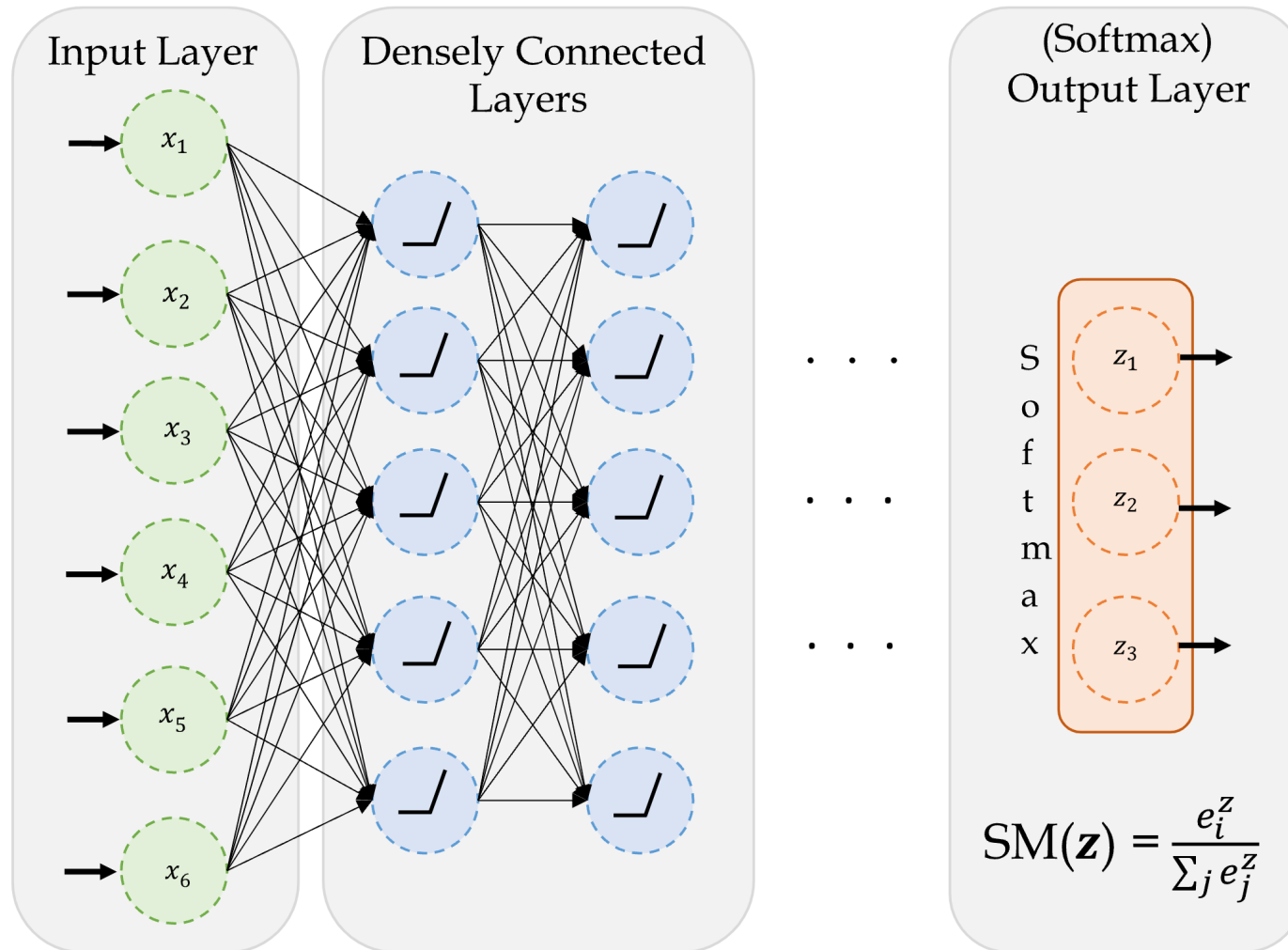
112 rows × 4 columns

```
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 - 1s - 196ms/step - loss: 1.3502

Epoch 2/5

4/4 - 0s - 52ms/step - loss: 1.2852

Epoch 3/5

4/4 - 0s - 21ms/step - loss: 1.2337

Epoch 4/5

4/4 - 0s - 31ms/step - loss: 1.1915

Epoch 5/5

4/4 - 0s - 21ms/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 - 1s - 232ms/step - accuracy: 0.2946 - loss: 1.3502

Epoch 2/5

4/4 - 0s - 31ms/step - accuracy: 0.3036 - loss: 1.2852

Epoch 3/5

4/4 - 0s - 22ms/step - accuracy: 0.3036 - loss: 1.2337

Epoch 4/5

4/4 - 0s - 28ms/step - accuracy: 0.3304 - loss: 1.1915

Epoch 5/5

4/4 - 0s - 15ms/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 20.6 s, sys: 2.43 s, total: 23.1 s  
Wall time: 1min 29s

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

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

```
[0.09586217254400253, 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 3.15 s, sys: 377 ms, total: 3.53 s  
Wall time: 13.1 s  
Stopped after 68 epochs.

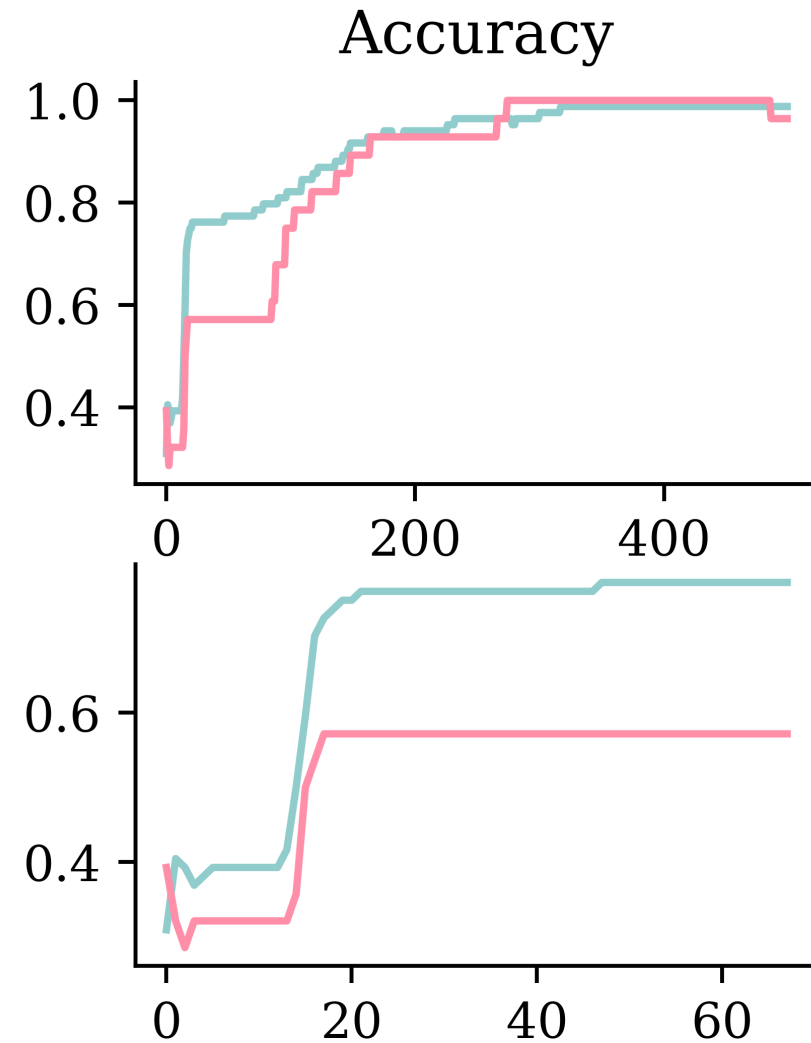
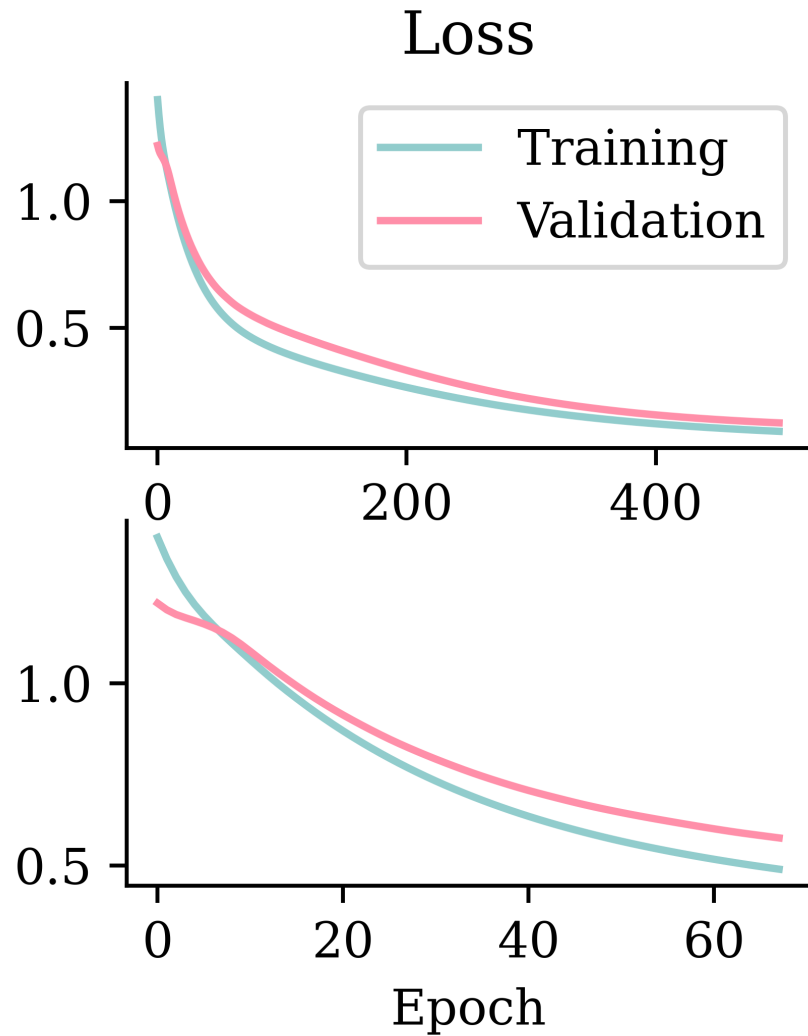
## Evaluation on test set:

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

```
[0.9856259226799011, 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([[0.13970962, 0.5175301 , 0.34276026],
       [0.24611066, 0.44371164, 0.3101777 ],
       [0.26309976, 0.43174297, 0.30515727],
       [0.259089   , 0.44883674, 0.2920743 ]], 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

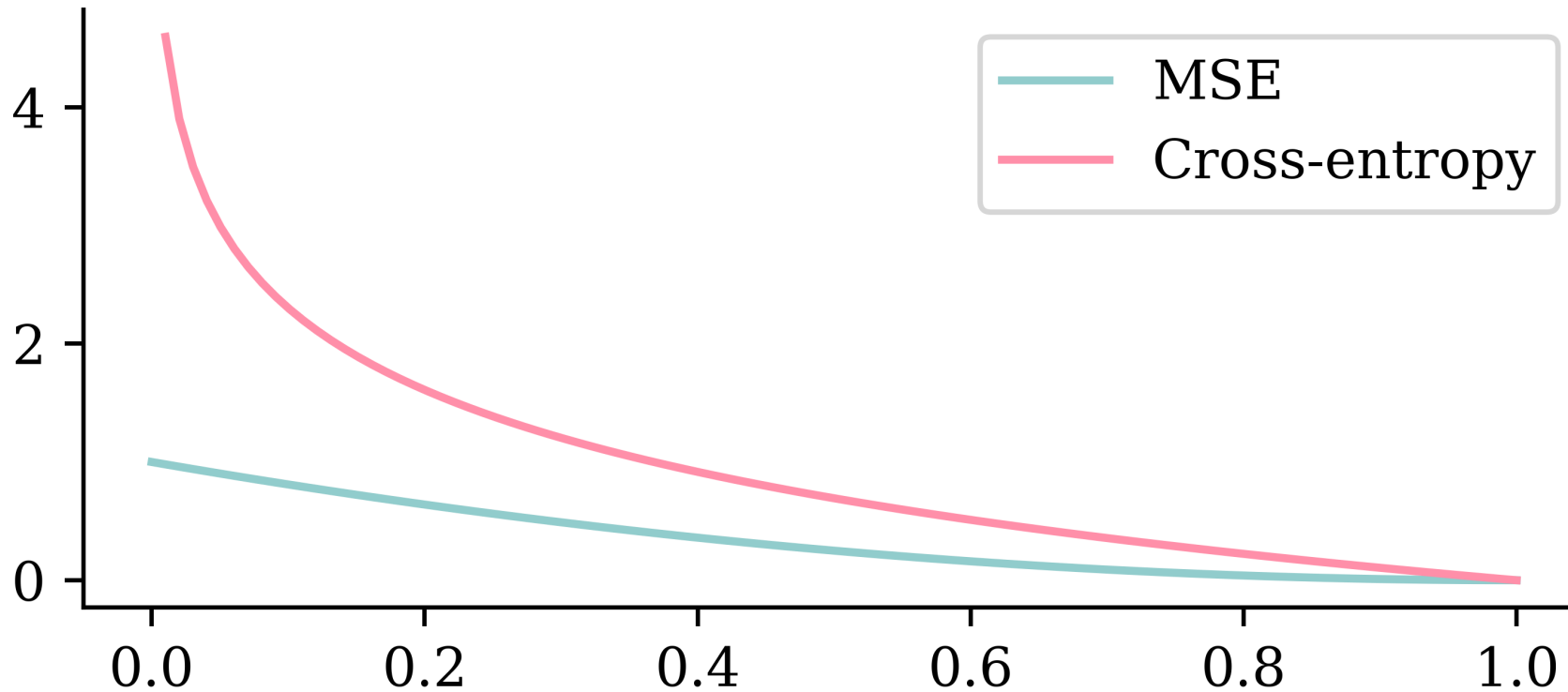
Neural Networks Part 6: Cross Entropy

Neural Networks Part 7: Cross Entropy Derivatives a



# 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]
```

	<b>XO_0</b>	<b>XO_1</b>	<b>XO_2</b>
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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# 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	Residenc
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_ct[["gender_Female",
2 gender_cols.iloc[ind-1:ind+3]]
```

	<b>gender</b>
4970	Male
3116	Other
4140	Male
2505	Female

	<b>gender_Female</b>	<b>gender_Male</b>
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,
0.812220573425293]
```

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

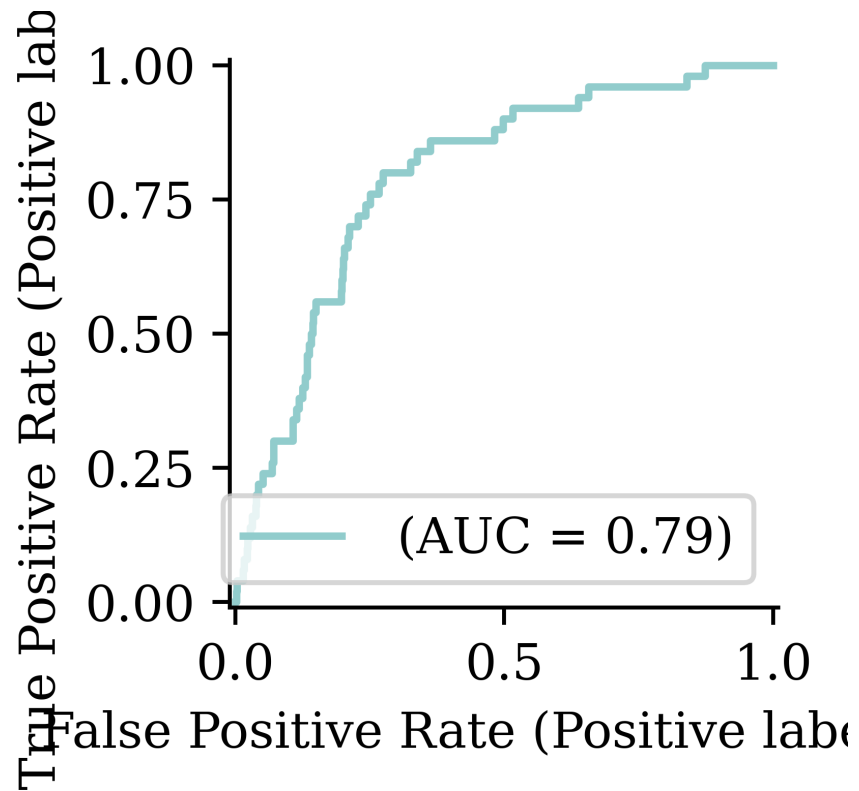
```
[0.3590189516544342, 0.1449822038412094,
0.8023483157157898, 0.791563868522644]
```



# Classification Metrics

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

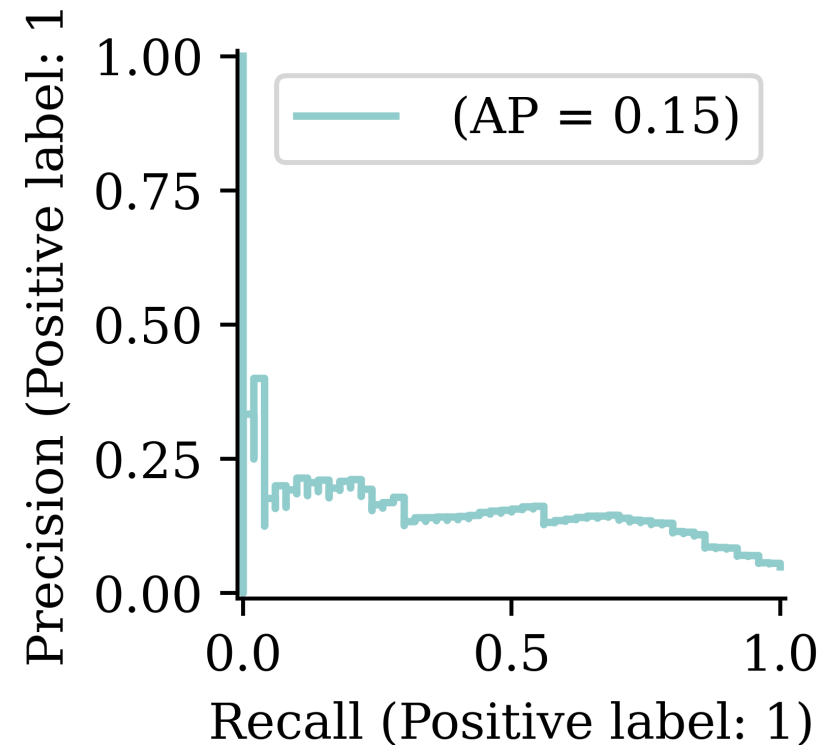
```
1 RocCurveDisplay.from_predictions(y_test, y_pred, name="");
```



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

```
array([[792, 180],
       [ 20,  37]])
```

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



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

```
array([[662, 310],
       [ 10,  17]])
```



# 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       : 3.11.11
IPython version      : 8.32.0
```

```
keras      : 3.8.0
matplotlib: 3.10.0
numpy      : 1.26.4
pandas     : 2.2.3
seaborn    : 0.13.2
scipy      : 1.13.1
torch      : 2.5.1
tensorflow: 2.18.0
tf_keras   : 2.18.0
```



# Glossary

- accuracy
- classification problem
- confusion matrix
- cross-entropy loss
- metrics
- sigmoid activation function
- softmax activation

